# Physical, Earth, and Space Science Skill and Practice Worksheets

## Chapter 1: Measurement

### 1.1 Measurement
- Lab Safety
- Using Your Textbook
- SI Units
- Scientific Notation

### 1.2 Time and Distance
- Measuring Length
- Averaging
- SQ3R Reading and Study Method
- Stopwatch Math
- Understanding Light Years
- Indirect Measurement

### 1.3 Converting Units
- Dimensional Analysis
- Fractions Review
- Significant Digits
- Study Notes
- Science Vocabulary
- SI Unit Conversion
- Extra Practice
- SI-English Conversions

### 1.4 Graphing
- Creating Scatterplots
- What’s the Scale?
- Interpreting Graphs
- Recognizing Patterns on Graphs

## Chapter 2: The Scientific Process

### 2.1 Inquiry and the Scientific Method
- Scientific Processes
- What’s Your Hypothesis?

### 2.2 Experiments and Variables
- Recording Observations in the Lab
- Using a Spreadsheet
- Identifying Control and Experimental Variables

### 2.3 The Nature of Science and Technology

## Chapter 3: Mapping

### 3.1 Maps
- Position on the Coordinate Plane
- Latitude and Longitude
- Map Scales
- Vectors on a Map

### 3.2 Topographic Maps
- Topographic Maps

### 3.3 Bathymetric Maps
- Bathymetric Maps
- Tanya Atwater

## Chapter 4: Motion

### 4.1 Speed and Velocity
- Solving Equations With One Variable
- Problem Solving Boxes
- Problem Solving with Rates
- Percent Error
- Speed
- Velocity

### 4.2 Graphs of Motion
- Calculating Slope From a Graph
- Analyzing Graphs of Motion With Numbers
- Analyzing Graphs of Motion Without Numbers

### 4.3 Acceleration
- Acceleration
- Acceleration and Speed-Time Graphs
- Acceleration Due to Gravity
### Chapter 5: Force

<table>
<thead>
<tr>
<th>Section</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 Forces</td>
<td>• Ratios and Proportions • Internet Research • Bibliographies • Mass vs. Weight • Mass, Weight, and Gravity • Gravity Problems • Universal Gravitation</td>
</tr>
<tr>
<td>5.2 Friction</td>
<td>• Friction</td>
</tr>
<tr>
<td>5.3 Forces in Equilibrium</td>
<td>• Equilibrium</td>
</tr>
</tbody>
</table>

### Chapter 6: Laws of Motion

<table>
<thead>
<tr>
<th>Section</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 Newton's First Law</td>
<td>• Net Force and Newton's First Law • Isaac Newton</td>
</tr>
<tr>
<td>6.2 Newton's Second Law</td>
<td>• Newton's Second Law</td>
</tr>
<tr>
<td>6.3 Newton’s Third Law and Momentum</td>
<td>• Applying Newton’s Laws • Momentum • Momentum Conservation • Collisions and Conservation of Momentum • Rate of Change of Momentum</td>
</tr>
</tbody>
</table>
## Chapter 7: Work and Energy

### 7.1 Force, Work, and Machines
- Mechanical Advantage
- Mechanical Advantage of Simple Machines
- Work
- Types of Levers

### 7.2 Energy and the Conservation of Energy
- Potential and Kinetic Energy
- Identifying Energy Transformations
- Energy Transformations Extra Practice
- Conservation of Energy

### 7.3 Efficiency and Power
- Efficiency
- Power

## Chapter 8: Matter and Temperature

### 8.1 The Nature of Matter

### 8.2 Temperature
- Measuring Temperature
- Temperature Scales

### 8.3 Phases of Matter
- Reading a Heating/Cooling Curve
<table>
<thead>
<tr>
<th>Chapter and Section</th>
<th>MATH</th>
<th>READING</th>
<th>CONTENT</th>
<th>BIOGRAPHY</th>
<th>CHALLENGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chapter 9: Heat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.1 Heat and Thermal Energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Specific Heat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Using the Heat Equation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.2 Heat Transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Heat Transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chapter 10: Properties of Matter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.1 Density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Measuring Mass with a Triple Beam Balance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Measuring Volume</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>• Calculating Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.2 Properties of Solids</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• Density</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.3 Properties of Fluids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Pressure in fluids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Boyle’s Law</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.4 Buoyancy</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>• Buoyancy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Charles’ Law</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Pressure-Temperature Relationship</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Archimedes</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>• Narcis Monturiol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Archimedes’ Principle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Chapter 11: Weather and Climate

11.1 Earth’s Atmosphere
- Layers of the Atmosphere

11.2 Weather Variables
- Gaspard-Gustave Coriolis
- Degree Days

11.3 Weather Patterns
- Joanne Simpson
- Weather Maps
- Tracking A Hurricane

### Chapter 12: Atoms and the Periodic Table

12.1 Atomic Structure
- Structure of the Atom
- Atoms and Isotopes
- Ernest Rutherford

12.2 Electrons
- Electrons and Energy Levels
- Neils Bohr

12.3 The Periodic Table of the Elements
- The Periodic Table

12.4 Properties of the Elements

### Chapter 13: Compounds

13.1 Chemical Bonds and Electrons
- Dot Diagrams

13.2 Chemical Formulas
- Finding the Least Common Multiple
- Chemical Formulas
- Naming Compounds
- Families of Compounds

13.3 Molecules and Carbon Compounds
## Chapter 14: Changes in Matter

<table>
<thead>
<tr>
<th>Section</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.1 Chemical Reactions</td>
<td>Chemical Equations, The Avogadro Number, Formula Mass</td>
</tr>
<tr>
<td>14.2 Types of Reactions</td>
<td>Classifying Reactions, Predicting Chemical Equations, Percent Yield</td>
</tr>
<tr>
<td>14.3 Energy in Chemical Reactions</td>
<td></td>
</tr>
<tr>
<td>14.4 Nuclear Reactions</td>
<td>Lise Meitner, Marie and Pierre Curie, Rosalyn Yalow, Chien-Shiung Wu, Radioactivity</td>
</tr>
</tbody>
</table>

## Chapter 15: Matter and Earth's Resources

<table>
<thead>
<tr>
<th>Section</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.1 Chemical Cycles</td>
<td></td>
</tr>
<tr>
<td>15.2 Global Climate Change</td>
<td>Svante Arrhenius</td>
</tr>
</tbody>
</table>
# Chapter 16: Electricity

## 16.1 Charge and Electric Circuits
- Open and Closed Circuits
- Benjamin Franklin

## 16.2 Current and Voltage
- Using an Electric Meter

## 16.3 Resistance and Ohm's Laws
- Voltage, Current, and Resistance
- Ohm's law

## 16.4 Types of Circuits
- Series Circuits
- Parallel Circuits
- Thomas Edison
- George Westinghouse
- Lewis Latimer

# Chapter 17: Magnetism

## 17.1 Properties of Magnets
- Magnetic Earth

## 17.2 Electromagnets
- Maglev Train Model Project

## 17.3 Electric Motors and Generators

## 17.4 Generating Electricity
- Michael Faraday
- Transformers
- Electrical Power
### Chapter 18: Earth’s History and Rocks

<table>
<thead>
<tr>
<th>Section</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1 Geologic Time</td>
<td>• Andrew Douglass</td>
</tr>
<tr>
<td>18.2 Relative Dating</td>
<td>• Relative Dating • Nicolas Steno</td>
</tr>
<tr>
<td>18.3 The Rock Cycle</td>
<td>• The Rock Cycle</td>
</tr>
</tbody>
</table>

### Chapter 19: Matter and Earth

<table>
<thead>
<tr>
<th>Section</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.1 Inside Earth</td>
<td>• Earth’s Interior • Charles Richter • Jules Verne</td>
</tr>
<tr>
<td>19.2 Plate Tectonics</td>
<td>• Alfred Wegener • Harry Hess • John Tuzo Wilson</td>
</tr>
<tr>
<td>19.3 Plate Boundaries</td>
<td>• Earth’s Largest Plates</td>
</tr>
<tr>
<td>19.4 Metamorphic Rocks</td>
<td>• Continental U.S. Geology</td>
</tr>
</tbody>
</table>

### Chapter 20: Earthquakes and Volcanoes

<table>
<thead>
<tr>
<th>Section</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.1 Earthquakes</td>
<td>• Averaging • Finding an Earthquake Epicenter</td>
</tr>
<tr>
<td>20.2 Volcanoes</td>
<td>• Volcano Parts</td>
</tr>
<tr>
<td>20.3 Igneous Rocks</td>
<td>• Basalt and Granite</td>
</tr>
</tbody>
</table>
### Chapter 21: Water and Solutions

21.1 Water

21.2 Solutions

- Concentration of Solutions
- Solubility
- Salinity and Concentration Problems

21.3 Acids, Bases, and pH

- Calculating pH

### Chapter 22: Earth’s Water Systems

22.1 Water on Earth’s Surface

- Groundwater and Wells Project

22.2 The Water Cycle

- The Water Cycle

22.3 Oceans

### Chapter 23: How Water Shapes the Land

23.1 Weathering and Erosion

23.2 Rivers, Streams, and Sedimentation

23.3 Glaciers

23.4 Sedimentary Rocks
### Chapter 24: Waves and Sound

#### 24.1 Harmonic Motion
- Period and Frequency
- Harmonic Motion Graphs

#### 24.2 Properties of Waves
- Waves
- Wave Interference

#### 24.3 Sound
- Decibel Scale
- The Human Ear
- Standing Waves
- Waves and Energy
- Palm Pipes Project

### Chapter 25: Light and the Electromagnetic Spectrum

#### 25.1 Properties of Light
- The Electromagnetic Spectrum

#### 25.2 Color and Vision
- Color Mixing
- The Human Eye

#### 25.3 Optics
- Measuring Angles
- Using Ray Diagrams
- Reflection
- Refraction
- Drawing Ray Diagrams
<table>
<thead>
<tr>
<th>Chapter and Section</th>
<th>Lab Skills</th>
<th>Math</th>
<th>Reading</th>
<th>Content</th>
<th>Biography</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chapter 26: The Solar System</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26.1 Motion in the Solar System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Astronomical Units</td>
<td>• Nicolaus Copernicus</td>
<td>• Measuring the Moon’s Diameter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Gravity Problems</td>
<td>• Galileo Galilei</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Universal Gravitation</td>
<td>• Johannes Kepler</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26.2 Motion and Astronomical Cycles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Benjamin Banneker</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26.3 Objects in the Solar System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Touring the Solar System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chapter 27: Stars</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27.1 The Sun</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• The Sun: A Cross-Section</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Arthur Walker</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27.2 Stars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Inverse Square Law</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27.3 Life Cycles of Stars</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chapter 28: Exploring the Universe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.1 Tools of Astronomers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Scientific Notation</td>
<td>• Understanding Light Years</td>
<td>• Edwin Hubble</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Parsecs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.2 Galaxies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Light Intensity</td>
<td>• Henrietta Leavitt</td>
<td>• Calculating Luminosity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.3 Theories About the Universe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Doppler Shift</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.1 Lab Safety

What can I do to protect myself and others in the lab?

Science equipment and supplies are fun to use. However, these materials must always be used with care. Here you will learn how to be safe in a science lab.

Follow these basic safety guidelines

Your teacher will divide the class into groups. Each group should create a poster-sized display of one of the following guidelines. Hang the posters in the lab. Review these safety guidelines before each investigation.

1. **Prepare** for each investigation.
   a. Read the investigation sheets carefully.
   b. Take special note of safety instructions.

2. **Listen** to your teacher’s instructions before, during, and after the investigation. Take notes to help you remember what your teacher has said.

3. **Get ready to work**: Roll long sleeves above the wrist. Tie back long hair. Remove dangling jewelry and any loose, bulky outer layers of clothing. Wear shoes that cover the toes.

4. **Gather** protective clothing (goggles, apron, gloves) at the beginning of the investigation.

5. **Emphasize teamwork**. Help each other. Watch out for one another’s safety.

6. **Clean up** spills immediately. Clean up all materials and supplies after an investigation.

Know what to do when...

7. **working with heat**:
   a. Always handle hot items with a hot pad. Never use your bare hands.
   b. Move carefully when you are near hot items. Sudden movements could cause burns if you touch or spill something hot.
   c. Inform others if they are near hot items or liquids.

8. **working with electricity**:
   a. Always keep electric cords away from water.
   b. Extension cords must not be placed where they may cause someone to trip or fall.
   c. If an electrical appliance isn’t working, feels hot, or smells hot, tell a teacher right away.

9. **disposing of materials and supplies**:
   a. Generally, liquid household chemicals can be poured into a sink. Completely wash the chemical down the drain with plenty of water.
   b. Generally, solid household chemicals can be placed in a trash can.
c. Any liquids or solids that **should not** be poured down the sink or placed in the trash have special disposal guidelines. Follow your teacher’s instructions.

d. If glass breaks, do not use your bare hands to pick up the pieces. Use a dustpan and a brush to clean up. “Sharps” trash (trash that has pieces of glass) should be well labeled. The best way to throw away broken glass is to seal it in a labeled cardboard box.

10. **you are concerned about your safety or the safety of others:**

a. Talk to your teacher immediately. Here are some examples:
   - You smell chemical or gas fumes. This might indicate a chemical or gas leak.
   - You smell something burning.
   - You injure yourself or see someone else who is injured.
   - You are having trouble using your equipment.
   - You do not understand the instructions for the investigation.

b. Listen carefully to your teacher’s instructions.

c. Follow your teacher’s instructions exactly.
Safety quiz

1. Draw a diagram of your science lab in the space below. Include in your diagram the following items. Include notes that explain how to use these important safety items.

   - Exit/entrance ways
   - Fire extinguisher(s)
   - Fire blanket
   - Eye wash and shower
   - First aid kit
   - Location of eye goggles and lab aprons
   - Sink
   - Trash cans
   - Fire blanket
   - Location of special safety instructions

2. How many fire extinguishers are in your science lab? Explain how to use them.

   ____________________________________________________________

   ____________________________________________________________

3. List the steps that your teacher and your class would take to safely exit the science lab and the building in case of a fire or other emergency.

   ____________________________________________________________

   ____________________________________________________________

   ____________________________________________________________

   ____________________________________________________________
4. Before beginning certain investigations, why should you first put on protective goggles and clothing?

5. Why is teamwork important when you are working in a science lab?

6. Why should you clean up after every investigation?

7. List at least three things you should do if you sense danger or see an emergency in your classroom or lab.

8. Five lab situations are described below. What would you do in each situation?
   
   a. You accidentally knock over a glass container and it breaks on the floor.

   b. You accidentally spill a large amount of water on the floor.
c. You suddenly begin to smell a “chemical” odor that gives you a headache.

d. You hear the fire alarm while you are working in the lab. You are wearing your goggles and lab apron.

e. While your lab partner has her lab goggles off, she gets some liquid from the experiment in her eye.

f. A fire starts in the lab.

Safety in the science lab is everyone’s responsibility!
Safety contract

Keep this contract in your notebook at all times.

By signing it, you agree to follow all the steps necessary to be safe in your science class and lab.

I, ____________________,   (Your name)

- Have learned about the use and location of the following:
  - Aprons and gloves
  - Eye protection
  - Eyewash fountain
  - Fire extinguisher and fire blanket
  - First aid kit
  - Heat sources (burners, hot plate, etc) and how to use them safely
  - Waste-disposal containers for glass, chemicals, matches, paper, and wood
- Understand the safety information presented.
- Will ask questions when I do not understand safety instructions.
- Pledge to follow all of the safety guidelines that are presented on the Safety Skill Sheet at all times.
- Pledge to follow all of the safety guidelines that are presented on investigation sheets.
- Will always follow the safety instructions that my teacher provides.

Additionally, I pledge to be careful about my own safety and to help others be safe. I understand that I am responsible for helping to create a safe environment in the classroom and lab.

Signed and dated,

____________________________________________________    _________________________________
Signature of Parent or Guardian                                                         Date

Parent’s or Guardian’s statement:

I have read the Safety Skills sheet and give my consent for the student who has signed the preceding statement to engage in laboratory activities using a variety of equipment and materials, including those described. I pledge my cooperation in urging that she or he observe the safety regulations prescribed.

____________________________________________________    _________________________________
Signature of Parent or Guardian                                                         Date
1.1 Using Your Textbook

Your textbook is a tool to help you understand and enjoy science. Colors, shapes, and symbols are used in the book to help you find information quickly. Take a few minutes to get familiar with these features—it will help you get the most out of your book all year long.

Part 1: Organizing features of the student text

Spend a few minutes answering the questions below. You will learn to recognize visual clues that organize the reading and help you find information quickly.

1. What color is used to identify Unit four?
2. List four important vocabulary words for section 3.2.
3. What color are the boxes in which you found these vocabulary words?
4. What is the main idea of the last paragraph on page 37?
5. Where do you find section review questions?
6. What is the first key question for Chapter 9?
7. What are the four numbered parts (or steps) shown in each sample problem in the text?
8. List the four sections of questions in each Chapter Assessment.

Part 2: The Table of Contents

The Table of Contents is found after the introduction pages. Use it to answer the following questions.

1. How many units are in the textbook? List their titles.
2. Which unit will be the most interesting to you? Why?
3. Where do you find the glossary and index? How are they different?

Part 3: Glossary and Index

The glossary and index can help you quickly find information in your textbook. Use these tools to answer the following questions.

1. What is the definition of velocity?
2. On what pages will you find information about the layer of Earth’s atmosphere known as the troposphere?
3. On what page will you find a short biography of agricultural scientist George Washington Carver?
1.1 SI Units

In the late 1700's, as scientists began to develop the ideas of physics and chemistry, they needed better units of measurement to communicate scientific data. Scientists needed to prove their ideas with data based on measurements that other scientists could reproduce. A decimal system of units based on the meter as a standard length, the kilogram as a standard mass, and the liter as a standard volume was developed by the French. Today this system is known as the SI system, or metric system.

The equations below show how the meter is related to other units in this system of measurements.

\[
1 \text{ meter} = 100 \text{ centimeters} \\
1 \text{ cubic centimeter} = 1 \text{ cm}^3 = 1 \text{ milliliter} \\
1000 \text{ milliliters} = 1 \text{ liter}
\]

The SI system is easy to use because all the units are based on factors of 10. In the English system, there are 12 inches in a foot, 3 feet in a yard, and 5,280 feet in a mile. In the SI system, there are 10 millimeters in a centimeter, 100 centimeters in a meter, and 1,000 meters in a kilometer.

**Question:** Using the graphic at right, state how many kilometers it is from the North Pole to the equator.

**Answer:** You need to convert 10,000,000 meters to kilometers.

Since 1 meter = 0.001 kilometers, 0.001 is the multiplication factor. To solve, multiply 10,000,000 \(0.001 \text{ km} = 10,000 \text{ km}\). So, it is 10,000 kilometers from the North Pole to the equator.

These are the standard units of measurement that you will use in your scientific studies. The prefixes on the following page are used with the base units when measuring very large or very small quantities.

<table>
<thead>
<tr>
<th>When you are measuring:</th>
<th>Use this standard unit:</th>
<th>Symbol of unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>length</td>
<td>meter</td>
<td>m</td>
</tr>
<tr>
<td>volume</td>
<td>liter</td>
<td>l</td>
</tr>
<tr>
<td>force</td>
<td>newton</td>
<td>N</td>
</tr>
<tr>
<td>temperature</td>
<td>degree Celsius</td>
<td>°C</td>
</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
</tr>
</tbody>
</table>

You may wonder why the kilogram, rather than the gram, is called the standard unit for mass. This is because the mass of an object is based on how much matter it contains as compared to the standard kilogram made from platinum and iridium and kept in Paris. The gram is such a small amount of matter that if it had been used as a standard, small errors in reproducing that standard would be multiplied into very large errors when large quantities of mass were measured.
The following prefixes in the SI system indicate the multiplication factor to be used with the basic unit. For example, the prefix kilo- is a factor of 1,000. A kilometer is equal to 1,000 meters, and a kilogram is equal to 1,000 grams.

<table>
<thead>
<tr>
<th>Prefix</th>
<th>kilo</th>
<th>hecto</th>
<th>deka</th>
<th>Basic unit (no prefix)</th>
<th>deci</th>
<th>centi</th>
<th>milli</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>k</td>
<td>h</td>
<td>da</td>
<td>m, l, g</td>
<td>d</td>
<td>c</td>
<td>m</td>
</tr>
<tr>
<td>Multiplication Factor or Place-Value</td>
<td>1,000</td>
<td>100</td>
<td>10</td>
<td>1</td>
<td>0.1</td>
<td>0.01</td>
<td>0.001</td>
</tr>
</tbody>
</table>

**EXAMPLES**

1. How many centigrams are there in 24 grams?
   a. Restate the question: 24 grams = __________ centigrams
   b. Use the place value chart to determine the multiplication factor, and solve:

   
   Since we want to convert grams (ones place) to centigrams (hundredths place), count the number of places on the chart it takes to move from the ones place to get to the hundredths place. Since it takes 2 moves to the right, the multiplication factor is 100.

   **Solution:** multiply $24 \times 100 = 2,400$.

   **Answer:** There are 2,400 centigrams in 24 grams.

2. How many liters are there in 5,000 deciliters?
   a. Restate the question: 5,000 deciliters (dl) = __________ liters (l)?
   b. Use the place value chart to determine the multiplication factor, and solve:

   Since we want to convert deciliters (tenths place) to liters (ones place), count the number of places on the chart it takes to move from the ones place to get to the hundredths place. Since it takes 1 move to the left, the multiplication factor is 0.1.

   **Solution:** multiply $5,000 \times 0.1 = 500$.

   **Answer:** There are 500 liters in 5,000 deciliters.

3. How many decimeters are in a dekameter?
   a. Restate the question: 1 dam = __________ dm.
   b. Use the place value chart to determine the multiplication factor, and solve:
Since we want to convert dekameters to decimeters, count the number of places on the chart it takes to move from the tens place (deka) to the tenths place (deci). It takes 2 moves to the right, so the multiplication factor is 100.

Solution: multiply $1 \times 100 = 100$.

Answer: There are 100 decimeters in one dekameter.

4. How many kilograms are equivalent to 520,000 centigrams?
   (1) Restate the question: 520,000 centigrams = __________ kilograms.
   (2) Determine the multiplication factor, and solve:
   Moving from the hundredths place (centi) to the thousands place (kilo) requires moving 5 places to the left, so the multiplication factor is 0.00001.
   Solution: Multiply $520,000 \times 0.00001 = 5.2$
   Answer: 5.2 kilograms are equivalent to 520,000 centigrams.

Practice

1. How many grams are in a dekagram?
2. How many millimeters are there in one meter?
3. How many millimeters are in 6 decimeters?
4. Convert 4,200 decigrams to grams.
5. How many liters are equivalent to 500 centiliters?
6. Convert 100 millimeters to meters.
7. How many milligrams are equivalent to 150 dekagrams?
8. How many liters are equivalent to 0.3 kiloliters?
9. How many centimeters are in 65 kilometers?
10. Twelve dekagrams are equivalent to how many milligrams?
11. Seven hundred twenty centiliters is how many liters?
12. A fountain can hold 53,000 deciliters of water. How many kiloliters is this?
13. What is the name of a length that is 100 times larger than a millimeter?
14. How many times larger than a centigram is a dekagram?
15. Name the distance that is 10 times smaller than a centimeter.
1.1 Scientific Notation

A number like 43,200,000,000,000,000,000 (43 quintillion, 200 quadrillion) can take a long time to write, and an even longer time to read. Because scientists frequently encounter very large numbers like this one (and also very small numbers, such as 0.000000012, or twelve trillionths), they developed a shorthand method for writing these types of numbers. This method is called scientific notation. A number is written in scientific notation when it is written as the product of two factors, where the first factor is a number that is greater than or equal to 1, but less than 10, and the second factor is an integer power of 10. Some examples of numbers written in scientific notation are given in the table below:

<table>
<thead>
<tr>
<th>Scientific Notation</th>
<th>Standard Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.32 \times 10^{19}</td>
<td>43,200,000,000,000,000</td>
</tr>
<tr>
<td>1.2 \times 10^{-8}</td>
<td>0.000000012</td>
</tr>
<tr>
<td>5.2777 \times 10^{7}</td>
<td>52,777,000</td>
</tr>
<tr>
<td>6.99 \times 10^{-5}</td>
<td>0.0000699</td>
</tr>
</tbody>
</table>

Rewrite numbers given in scientific notation in standard form.

- Express $4.25 \times 10^6$ in standard form: $4.25 \times 10^6 = 4,250,000$
  Move the decimal point (in 4.25) six places to the right. The exponent of the “10” is 6, giving us the number of places to move the decimal. We know to move it to the right since the exponent is a positive number.

- Express $4.033 \times 10^{-3}$ in standard form: $4.033 \times 10^{-3} = 0.004033$
  Move the decimal point (in 4.033) three places to the left. The exponent of the “10” is negative 3, giving the number of places to move the decimal. We know to move it to the left since the exponent is negative.

Rewrite numbers given in standard form in scientific notation.

- Express 26,040,000,000 in scientific notation: $26,040,000,000 = 2.604 \times 10^{10}$
  Place the decimal point in 2604 so that the number is greater than or equal to one (but less than ten). This gives the first factor (2.604). To get from 2.604 to 26,040,000,000 the decimal point has to move 10 places to the right, so the power of ten is positive 10.

- Express 0.0001009 in scientific notation: $0.0001009 = 1.009 \times 10^{-4}$
  Place the decimal point in 1009 so that the number is greater than or equal to one (but less than ten). This gives the first factor (1.009). To get from 1.009 to 0.0001009 the decimal point has to move four places to the left, so the power of ten is negative 4.
1. Fill in the missing numbers. Some will require converting scientific notation to standard form, while others will require converting standard form to scientific notation.

<table>
<thead>
<tr>
<th>Scientific Notation</th>
<th>Standard Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $6.03 \times 10^{-2}$</td>
<td></td>
</tr>
<tr>
<td>b. $9.11 \times 10^5$</td>
<td></td>
</tr>
<tr>
<td>c. $5.570 \times 10^{-7}$</td>
<td></td>
</tr>
<tr>
<td>d.</td>
<td>999.0</td>
</tr>
<tr>
<td>e.</td>
<td>264,000</td>
</tr>
<tr>
<td>f.</td>
<td>761,000,000</td>
</tr>
<tr>
<td>g. $7.13 \times 10^7$</td>
<td></td>
</tr>
<tr>
<td>h.</td>
<td>0.00320</td>
</tr>
<tr>
<td>i.</td>
<td>0.000040</td>
</tr>
<tr>
<td>j. $1.2 \times 10^{-12}$</td>
<td></td>
</tr>
<tr>
<td>k.</td>
<td>$42,000,000,000,000$</td>
</tr>
<tr>
<td>l.</td>
<td>12,004,000,000</td>
</tr>
<tr>
<td>m. $9.906 \times 10^{-2}$</td>
<td></td>
</tr>
</tbody>
</table>

2. Explain why the numbers below are not written in scientific notation, then give the correct way to write the number in scientific notation.

Example: $0.06 \times 10^5$ is not written in scientific notation because the first factor (0.06) is not greater than or equal to 1. The correct way to write this number in scientific notation is $6.0 \times 10^3$.

a. $2.004 \times 1^{11}$
b. $56 \times 10^{-4}$
c. $2 \times 100^2$
d. $10 \times 10^{-6}$
3. Write the numbers in the following statements in scientific notation:
   a. The national debt in 2005 was about $7,935,000,000,000.
   b. In 2005, the U.S. population was about 297,000,000.
   c. Earth's crust contains approximately 120 trillion (120,000,000,000,000) metric tons of gold.
   d. The mass of an electron is 0.000 000 000 000 000 000 000 000 000 000 91 kilograms.
   e. The usual growth of hair is 0.00033 meters per day.
   f. The population of Iraq in 2005 was approximately 26,000,000.
   g. The population of California in 2005 was approximately 33,900,000.
   h. The approximate area of California is 164,000 square miles.
   i. The approximate area of Iraq in 2005 was 169,000 square miles.
   j. In 2005, one right-fielder made a salary of $12,500,000 playing professional baseball.
1.2 Measuring Length

How do you find the length of an object?

Size matters! When you describe the length of an object, or the distance between two objects, you are describing something very important about the object. Is it as small as a bacteria (2 micrometers)? Is it a light year away (9.46 \times 10^{15} \text{ meters})? By using the metric system you can quickly see the difference in size between objects.

Reading the meter scale correctly

Look at the ruler in the picture above. Each small line on the top of the ruler represents one millimeter. Larger lines stand for 5 millimeter and 10 millimeter intervals. When the object you are measuring falls between the lines, read the number to the nearest 0.5 millimeter. Practice measuring several objects with your own metric ruler. Compare your results with a lab partner.

Stop and think

a. You may have seen a ruler like this marked in centimeter units. How many millimeters are in one centimeter?

b. Notice that the ruler also has markings for reading the English system. Give an example of when it would be better to measure with the English system than the metric system. Give a different example of when it would be better to use the metric system.

Materials
- Metric ruler
- Pencil
- Paper
- Small objects
- Calculator
Example 1: Measuring objects correctly

Look at the picture above. How long is the building block?

1. Report the length of the building block to the nearest 0.5 millimeters.
2. Convert your answer to centimeters.
3. Convert your answer to meters.

Example 2: Measuring objects correctly

Look at the picture above. How long is the pencil?

1. Report the length of the pencil to the nearest 0.5 millimeters.
2. Challenge: How many building blocks in example 1 will it take to equal the length of the pencil?
3. Challenge: Convert the length of the pencil to inches by dividing your answer by 25.4 millimeters per inch.
Example 3: Measuring objects correctly

Look at the picture above. How long is the domino?

1. Report the length of the domino to the nearest 0.5 millimeters.
2. Challenge: How many dominoes will fit end to end on the 30 cm ruler?

Practice converting units for length

By completing the examples above you show that you are familiar with some of the prefixes used in the metric system like milli- and centi-. The table on the following page gives other prefixes you may be less familiar with. Try converting the length of the domino from millimeters into all the other units given in the table.

Refer to the multiplication factor this way:

- 1 kilometer equals 1000 meters.
- 1000 millimeters equals 1 meter.

1. How many millimeters are in a kilometer?

2. Fill in the table with your multiplication factor by converting millimeters to the unit given. The first one is done for you.

3. Divide the domino’s length in millimeters by the number in your multiplication factor column. This is the answer you will put in the last column.
4. .

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Multiplication factor</th>
<th>Scientific notation in meters</th>
<th>Your multiplication factor</th>
<th>Your domino length in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>pico-</td>
<td>p</td>
<td>0.0000000000001</td>
<td>$10^{-12}$</td>
<td>$10^{-9}$</td>
<td>$42.5 \times 10^9$ pm</td>
</tr>
<tr>
<td>nano-</td>
<td>n</td>
<td>0.000000001</td>
<td>$10^{-9}$</td>
<td></td>
<td>nm</td>
</tr>
<tr>
<td>micro-</td>
<td>μ</td>
<td>0.000001</td>
<td>$10^{-6}$</td>
<td></td>
<td>μm</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>0.001</td>
<td>$10^{-3}$</td>
<td></td>
<td>mm</td>
</tr>
<tr>
<td>centi-</td>
<td>c</td>
<td>0.01</td>
<td>$10^{-2}$</td>
<td></td>
<td>cm</td>
</tr>
<tr>
<td>deci-</td>
<td>d</td>
<td>0.1</td>
<td>$10^{-1}$</td>
<td></td>
<td>dm</td>
</tr>
<tr>
<td>deka-</td>
<td>da</td>
<td>10</td>
<td>$10^1$</td>
<td></td>
<td>dam</td>
</tr>
<tr>
<td>hecto-</td>
<td>h</td>
<td>100</td>
<td>$10^2$</td>
<td></td>
<td>hm</td>
</tr>
<tr>
<td>kilo-</td>
<td>k</td>
<td>1000</td>
<td>$10^3$</td>
<td></td>
<td>km</td>
</tr>
</tbody>
</table>
1.2 Averaging

The most common type of average is called the mean. Usually when someone (who’s not your math teacher) asks you to find the average of something, it is the mean that they want. To find the mean, just sum (add) all the data, then divide the total by the number of items in the data set. This type of average is used daily by many people. Teachers and students use it to average grades. Meteorologists use it to average normal high and low temperatures for a certain date. Sports statisticians use it to calculate batting averages and many other things.

**Example**

- William has had three tests so far in his English class. His grades are 80%, 75%, and 90%. What is his average test grade?

**Solution:**

a. Find the sum of the data: $80 + 75 + 90 = 245$

b. Divide the sum (245) by the number of items in the data set (3): $245 \div 3 \approx 82\%$

William’s average (mean) test grade in English (so far) is about 82%.

**Practice**

1. The families on Carvel Street were cleaning out their basements and garages to prepare for their annual garage sale. At 202 Carvel Street, they found seven old baseball gloves. At 208, they found two baseball gloves. At 214, they found four gloves, and at 221 they found two gloves. If these are the only houses on the street, what is the average number of old baseball gloves found at a house on Carvel Street?

2. During a holiday gift exchange, the members of the winter play cast set a limit of $10 per gift. The actual prices of each gift purchased were: $8.50, $10.29, $4.45, $12.79, $6.99, $9.29, $5.97, and $8.33. What was the average price of the gifts?

3. During weekend babysitting jobs, each sitter charged a different hourly rate. Rachel charged $4.00, Juanita charged $3.50, Michael charged $4.25, Rosa charged $5.00, and Smith charged $3.00.

   a. What was the average hourly rate charged among these babysitters?

   b. If they each worked a total of eight hours, what was their average pay for the weekend?

4. The boys on the ninth grade basketball team at Fillmore High School scored 22 points, 12 points, 8 points, 4 points, 4 points, 3 points, 2 points, 2 points, and 1 point in Thursday’s game. What was the average number of points scored by each player in the game?

5. Jerry and his friends were eating pizza together on a Friday night. Jerry ate a whole pizza (12 slices) by himself! Pat ate three slices, Jack ate seven slices, Don and Dave ate four slices each, and Teri ate just two slices. What was the average number of slices of pizza eaten by one of these friends that night?
1.2 Reading Strategies (SQ3R)

Students often read a science textbook as if they were watching a movie—they just sit there and expect to take it all in. Actually, reading a science book is more like playing a video game. You have to interact with it! This skill builder will teach you active strategies that will improve your reading and study skills. Remember—just like in video game playing—the more you practice these strategies, the more skilled you will become.

The SQ3R active reading method was developed in 1941 by Francis Robinson to help his students get the most out of their textbooks. Using the SQ3R method will help you interact with your text, so that you understand and remember what you read. “SQ3R” stands for:

Survey
Question
Read
Recite
Review

Your student text has many features to help you organize your reading. These features are highlighted in Chapter 1: Measurement, found on pages 3–32 of your student text. Open your text to those pages so that you can see the features for yourself.

Survey the chapter first.

- Skim the introduction on the first page of every chapter. Notice the key questions. The key questions are thought-provoking and designed to spark your interest in the chapter. See if you can answer these questions after you have read the entire chapter.
- You will find vocabulary words with their definitions in blue boxes on the right side of each page. Vocabulary words will be scattered throughout the chapter. Write down any vocabulary words that are unfamiliar to you to help you recognize them later.
- Next, skim the chapter to get an overview. Notice the section numbers and titles. These divide the chapter into major topics. The subheadings in each section outline important points. Vocabulary words are highlighted in bold blue type. Solving Problems pages provide step-by-step examples to help you learn to use mathematical formulas. Tables, charts, and figures summarize important information.
- Read the section review questions at the end of each section. The questions help you identify what you are expected to know when you finish your reading. You will also find Challenge, Solve It, Study Skills, Journal, Science Fact, and/or Technology boxes scattered throughout each section. These boxes provide you with an interesting way to learn more about information in the section.
- Carefully read the Chapter Assessment at the end of the chapter to see what kinds of questions you will need to be able to answer. Notice that it is divided into four subtitles: Vocabulary, Concepts, Problems, and Applying Your Knowledge. Each set is listed by chapter section.
Question what you see. Turn headings into questions.

- Look at each of the section headings and subheadings, found at the tops of pages in your text. Change each heading to a question by using words such as who, what, when, where, why, and how. For example, Section 1.1: Measurements could become What measurements will I need to make in physical science? The subheading Two common measurement systems could become What are two common measurement systems? Write down each question and try to answer it. Doing this will help you pinpoint what you already know and what you need to learn as you read.

Read and look for answers to the questions you wrote.

- Pay special attention to the sidenotes in the left margin of each page. For example, under the Section 1.3 subheading Converting between English and SI units, the sidenotes are: The problem of multiple units and Comparing English and SI units. These phrases and short sentences are designed to guide you to the main idea of each paragraph. Also, note the sidebars and illustrations on the right side of the page with additional explanations and concepts. For example, the target diagrams in Figure 1.4 will help you understand the terms accuracy, precision, and resolution.

- Slow your reading pace when you come to a difficult paragraph. Read difficult paragraphs out loud. Copy a confusing sentence onto paper. These methods force you to slow down and allow you time to think about what the author is saying.

Recite concepts out loud.

- This step may seem strange at first, because you are asked to talk to yourself! But studies show that saying concepts out loud can actually help you to record them in your long-term memory.

- At the end of each section, stop reading. Ask yourself each of the questions you wrote in step two on the previous page. Answer each question out loud, in your own words. Imagine that you are explaining the concept to someone who hasn’t read the text.

- You may find it helpful to write down your answers. By using your senses of seeing, hearing, and touch (when you write), you create more memory paths in your brain.

Review it all.

- Once you have finished the entire chapter, go back and answer all of the questions that you wrote for each section. If you can’t remember the answer, go back and reread that portion of the text. Recite and write the answer again.

- Next, reread the key questions at the beginning of the chapter. Can you answer these?

- Complete the section reviews and the chapter assessment. Use the glossary and index at the back of the book to help you locate specific definitions.

The SQ3R method may seem time-consuming, but it works! With practice, you will learn to recognize the important concepts quickly.

Active reading helps you learn and remember what you have read, so you will have less to re-learn as you study for quizzes and tests.
1.2 Stopwatch Math

What do horse racing, competitive swimming, stock car racing, speed skating, many track and field events, and some scientific experiments have in common? The need for some sort of stopwatch, and people to interpret the data. For competitive athletes in speed-related sports, finishing times (and split times taken at various intervals of a race) are important to help the athletes gauge progress and identify weaknesses so they can adjust their training and improve their performance.

Example:

- Three girls ran the following times for one mile in their gym class: Julie ran 9:33.2 (9 minutes, 33.2 seconds), Maggie ran 9:44.24 (9 minutes, 44.24 seconds), and Mel ran 9:33.27 (9 minutes, 33.27 seconds). In what order did they finish?

Solution:

The girl who came in first is the one with the fastest (smallest) time. Compare each time digit by digit, starting with the largest place-value. Here, that would be the minutes place:

There is a “9” in the minutes’ place of each time, so next, compare the seconds’ place. Since Maggie’s time has larger numbers in the seconds’ place (44) than Julie or Mel (33), her time is larger (slower) than the other two. We know Maggie finished third out of the three girls. Now, comparing Julie’s time (9:33.2) to Mel’s (9:33.27), it is helpful to rewrite Julie’s time (9:33.2) so that it has the same number of places as Mel’s. Julie’s time needs one more digit, so adding a zero onto the end of her time, it becomes 9:33.20. Notice that Mel’s time is larger (slower) than Julie’s (27 > 20). This means that Julie’s time was fastest (smallest), so she finished first, followed by Mel, and Maggie’s time was the slowest (largest).

Practice:

1. Put each set of times in order from fastest to slowest.

   a. 5.5  5.05  5  5.2  5.15

   | Fastest | | | | | Slowest |
   |---------|---|---|---|---|
   |         |   |   |   |   |
   |         |   |   |   |   |

   b. 6:06.04  6:06  6:06.4  6:06.004

   | Fastest | | | | | Slowest |
   |---------|---|---|---|---|
   |         |   |   |   |   |
   |         |   |   |   |   |
   |         |   |   |   |   |
2. The table below gives the winners and their times from eight USA track and field championship races in the men’s 100 meter run. Rewrite the table so that the times are in order from fastest to slowest. Include the times and the years. Please note that the “w” that occurs next to some times indicates that the time was wind aided.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>10.08</td>
<td>9.91</td>
<td>10.11</td>
<td>9.88w</td>
<td>9.95w</td>
<td>10.01</td>
<td>9.97w</td>
<td>9.88w</td>
</tr>
<tr>
<td>Name</td>
<td>Justin Gatlin</td>
<td>Maurice Greene</td>
<td>Bernard Williams</td>
<td>Maurice Greene</td>
<td>Tim Montgomery</td>
<td>Maurice Greene</td>
<td>Dennis Mitchell</td>
<td>Tim Harden</td>
</tr>
</tbody>
</table>

3. The following times were recorded during an experiment with battery-powered cars. Put them in order from fastest to slowest.

<table>
<thead>
<tr>
<th>Fastest</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th>Slowest</th>
</tr>
</thead>
</table>


<table>
<thead>
<tr>
<th>Fastest</th>
<th></th>
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<th>Slowest</th>
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<table>
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<tr>
<th>Fastest</th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th>Slowest</th>
</tr>
</thead>
</table>

4. Write a set of five times (in order from fastest to slowest) that are all between 26:15.2 and 26:15.24. Do not include the given numbers in your set.
1.2 Understanding Light Years

How far is it from Los Angeles to New York? Pretty far, but it can still be measured in miles or kilometers. How far is it from Earth to the Sun? It’s about one hundred forty-nine million, six hundred thousand kilometers (149,600,000, or $1.496 \times 10^8$ km). Because this number is so large, and many other distances in space are even larger, scientists developed bigger units in order to measure them. An Astronomical Unit (AU) is $1.496 \times 10^8$ km (the distance from Earth to the sun). This unit is usually used to measure distances within our solar system. To measure longer distances (like the distance between Earth and stars and other galaxies), the light year (ly) is used. A light year is the distance that light travels through space in one year, or $9.468 \times 10^{12}$ km.

**EXAMPLES**

1. **Converting light years (ly) to kilometers (km)**
   
   Earth’s closest star (Proxima Centauri) is about 4.22 light years away. How far is this in kilometers?

   **Explanation/Answer:** Multiply the number of kilometers in one light year ($9.468 \times 10^{12}$ km/ly) by the number of light years given (in this case, 4.22 ly).

   \[
   \left(9.468 \times 10^{12}\right) \text{ km} \quad \times \quad 4.22 \text{ ly} \approx 3.995 \times 10^{13} \text{ km}
   \]

2. **Converting kilometers to light years**

   Polaris (the North Star) is about $4.07124 \times 10^{15}$ km from the earth. How far is this in light years?

   **Explanation/Answer:** Divide the number of kilometers (in this case, $4.07124 \times 10^{15}$ km) by the number of kilometers in one light year ($9.468 \times 10^{12}$ km/ly).

   \[
   \frac{4.07124 \times 10^{15}}{9.468 \times 10^{12}} \times 1 \text{ ly} \approx 430 \text{ light years}
   \]

**PRACTICE**

Convert each number of light years to kilometers.

1. 6 light years
2. $4.5 \times 10^6$ light years
3. $4 \times 10^{-3}$ light years

Convert each number of kilometers to light years.

4. $5.06 \times 10^{16}$ km
5. 11 km
6. 11,003,000,000,000 km
1.2

Solve each problem using what you have learned.

7. The second brightest star in the sky (after Sirius) is Canopus. This yellow-white supergiant is about $1.13616 \times 10^{16}$ kilometers away. How far away is it in light years?

8. Regulus (one of the stars in the constellation Leo the Lion) is about 350 times brighter than the sun. It is 85 light years away from the earth. How far is this in kilometers?

9. The distance from earth to Pluto is about 28.61 AU from the earth. Remember that an AU = $1.496 \times 10^8$ km. How many kilometers is it from Pluto to the earth?

10. If you were to travel in a straight line from Los Angeles to New York City, you would travel 3,940 kilometers. How far is this in AU’s?

11. Challenge: How many AU’s are equivalent to one light year?
1.2 Indirect Measurement

Have you ever wondered how scientists and engineers measure large quantities like the mass of an iceberg, the volume of a lake, or the distance across a river? Obviously, balances, graduated cylinders, and measuring tapes could not do the job! Very large (or very small) quantities are calculated through a process called indirect measurement. This skill sheet will give you an opportunity to try indirect measurement for yourself.

**EXAMPLE**

- The length of a tree’s shadow is 4.25 meters and the length of a meter stick’s shadow is 1.25 meters. Using these two values and the length of the meter stick, how tall is the tree?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>The height of a tree.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Given</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree’s shadow = 4.25 m</td>
<td>1.00 m = height of tree</td>
</tr>
<tr>
<td>Meter’s stick’s shadow = 1.25 m</td>
<td>1.25 m = 4.25 m</td>
</tr>
<tr>
<td>Height of meter stick = 1 m</td>
<td>4.25 m × 1.00 m = height of tree</td>
</tr>
<tr>
<td></td>
<td>1.25 m = 4.25 m</td>
</tr>
<tr>
<td></td>
<td>3.40 m = height of tree</td>
</tr>
</tbody>
</table>

Relationships

There is a direct relationship between the height of objects and the length of their shadows.

\[
\frac{\text{height of meter stick}}{\text{length of meter stick shadow}} = \frac{\text{height of object}}{\text{length of object shadow}}
\]

- At the science museum, 12 first graders stand on a giant scale to measure their mass. The combined mass of the 12 first graders is 262 kilograms. What is the average mass of a first grader in this group?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>The average mass of a first grader.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Given</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mass of 12 first graders = 262 kilograms</td>
<td>262 kilograms (/ 12) = 21.8 kilograms</td>
</tr>
</tbody>
</table>

Relationships

To get the average mass of one first grader, divide the total mass by 12.

\[
\frac{262 \text{ kilograms}}{12} = 21.8 \text{ kilograms}
\]

The average mass of a first grader in this group is 21.8 kilograms.

**PRACTICE**

1. You go to another forest and measure the shadow of a tree to be 6 meters long. The shadow of your meter stick is 2 meters long. How tall is the tree?

2. The height of a flagpole is 8.50 meters. If the length of the meter stick shadow is 1.50 meters, what is the length of the flagpole’s shadow?
3. While touring a city, you see a skyscraper and wonder how tall it is. You see that it is clearly divided into floors. You estimate that each floor is 20 feet high. You count that the skyscraper has 112 floors.
   a. Approximately how tall is this skyscraper in feet?
   b. Approximately how tall is the skyscraper in meters? (One foot is about 0.3 meter.)

4. There are 10 apples in a one-kilogram bag of apples. What is the average mass of each apple in the bag? Give your answer in units of kilograms and grams.

5. If you place one staple on an electronic balance, the balance still reads 0.00 grams. However, if you place 210 staples on the balance, it reads 6.80 grams. What is the mass of one staple?

6. A stack of 55 business cards is 1.85 cm tall. Use this information to determine the thickness of one business card.

7. A stack of eight compact disks is 1.0 centimeter high. What is the thickness of one compact disk (CD) in centimeters? What is the thickness of one CD in millimeters?

8. A quarter is 2.4 millimeters thick. How tall are the following stacks of quarters?
   a. A stack worth 50 cents
   b. A stack worth $1
   c. A stack worth $5
   d. A stack worth $1,000
   (Give your answer in millimeters and meters.)

9. Yvonne has gained a reputation for her delicious cheesecakes. She takes orders for 10 cheesecakes and spends 8.5 hours on one Saturday baking them all. She earns $120 from selling these cheesecakes.
   a. What is the average length of time to make one cheesecake? Give your answer in minutes.
   b. What does Yvonne charge for each cheesecake?
   c. How much money is Yvonne earning per hour for her work?

10. A sculptor wants to create a statue. She goes to a quarry to buy a block of marble. She finds a chip of marble on the ground. The volume of the chip is 15.3 cm³. The mass of the chip is 41.3 grams. The sculptor purchases a block of marble 30.0-by-40.0-by-100.0 cm. Use a proportion to find the mass of her block of marble.

11. The instructions on a bottle of eye drops say to place three drops in each eye, using the dropper. How could you find the volume of one of these drops? Write a procedure for finding the volume of a drop that includes using a glass of water, a 10.0-mL graduated cylinder, and the dropper.

12. A student wants to use indirect measurement to find the thickness of a sheet of newspaper. In a 50-centimeter tall recycling bin, she finds 50 sheets of newspaper. Each sheet in the bin is folded in fourths. Design a procedure for the student to use that would allow her to measure the thickness of one sheet of newspaper with little experimental error. The student has a meter stick and a calculator.
Dimensional analysis is a way to find the correct label (also called units or dimensions) for the solution to a problem. In dimensional analysis, we treat the units the same way that we treat the numbers. For example, this problem shows how can you can “cancel” the sevens and then perform the multiplication:

\[
\frac{3 \cdot 7}{7 \cdot 8} = \frac{3}{8}
\]

In some problems, there are no numerical cancellations to make, but you need to pay close attention to the units (or dimensions):

- If there are 16 ounces in one pound, how many ounces are in four pounds?

\[
\frac{16 \text{ oz}}{1 \text{ lb}} \cdot 4 \text{ lb} = \frac{16 \cdot 4 \text{ oz} \cdot \text{lb}}{1 \text{ lb}} = \frac{64 \text{ oz}}{1} = 64 \text{ oz}
\]

The “lbs” may be cancelled either before or after the multiplication.

The goal of dimensional analysis is to simplify a problem by focusing on the units of measurement (dimensions).

Dimensional analysis is very useful when converting between units (like converting inches to yards, or converting between the English and SI systems of measurement).

**Example**

- The ninth grade class is having a reward lunch for collecting the most food for a canned food drive. They have decided to order pizza. They are figuring two slices of pizza per student. Each pizza that will be ordered will have 12 slices. There are 220 students total in the ninth grade. How many pizzas should they order?

**Solution:**

1. Determine what we want to find out: here, it is the number or whole pizzas needed to feed 220 ninth graders. It’s important to remember that if the solution is to have the label “pizzas,” “pizzas” should be kept in the numerator as the problem is set up.

2. Determine what we know. We know that they’re planning 2 slices of pizza per student, that there are 12 slices in each pizza, and that there are 220 ninth graders.

3. Write what you know as fractions with units. Here, we have: \(\frac{2 \text{ slices}}{\text{student}} \cdot \frac{12 \text{ slices}}{\text{pizza}}\) and 220 students.

Notice that in the fraction, \(\frac{12 \text{ slices}}{\text{pizza}}\), “pizza” is in the denominator.

Recall that (from step #1, above) “pizza” should be kept in the numerator, as it will be the label of the final solution. To correct this problem, just switch the numerator and denominator: \(\frac{1 \text{ pizza}}{12 \text{ slices}}\).
4. Set up the problem by focusing on the units. Just writing the information as a multiplication problem, we have:

\[
\frac{1 \text{ pizza}}{12 \text{ slices}} \cdot \frac{2 \text{ slices}}{\text{student}} \cdot \frac{220 \text{ students}}{1} = \frac{110 \text{ pizza \cdot slices \cdot students}}{3 \text{ slices \cdot students}} = 36 \frac{2}{3} \text{ pizzas}
\]

Therefore, 37 pizzas will need to be ordered.

Notice that canceling the units can be done either before or after the multiplication.

6. Check your solution for reasonableness: Since there are 12 slices in each pizza, and we’re figuring that each student will eat 2 slices, one pizza will feed 6 students. It is expected that a little less than 40 pizzas would be needed. It does seem reasonable that 37 pizzas would feed 220 students.

**Practice**

1. Multiply. Be sure to label your answers.
   
   a. \(\frac{12.00}{1 \text{ hr}} \cdot \frac{6 \text{ hr}}{1 \text{ day}}\)
   
   b. \(\frac{2 \text{ lbs}}{1 \text{ person}} \cdot \frac{7 \text{ days}}{1 \text{ week}} \cdot \frac{15 \text{ people}}{1 \text{ day}}\)

2. Use dimensional analysis to convert each. You may need to use a reference to find some conversion factors. Show all of your work.
   
   a. 11.0 quarts to some number of gallons
   
   b. 220. centimeters to some number of meters
   
   c. 6000. inches to some number of miles
   
   d. How many cups are there in 4.0 gallons?

3. Use dimensional analysis to find each solution. You may need to use a reference to find some conversion factors. Show all of your work.
   
   a. Frank just graduated from eighth grade. Assuming exactly four years from now he will graduate from high school, how many seconds does he have until his high school graduation?
   
   b. In 2005, Christian Cantwell won the US outdoor track and field championship shot put competition with a throw of 21.64 meters. How far is this in feet?
   
   c. A recipe for caramel oatmeal cookies calls for 1.5 cups of milk. Sam is helping to make the cookies for the soccer and football teams plus the cheerleaders and marching band, and needs to multiply the recipe by twelve. How much milk (in quarts) will he need altogether?
   
   d. How many football fields (including the 10 yards in each end zone) would it take to make a mile?
   
   e. Corey’s sister’s car gets 30. miles on each gallon of gas. How many kilometers per gallon is this?
   
   f. Convert your answer from (e) to kilometers per liter.
   
   g. A car is traveling at a rate of 65 miles per hour. How many feet per second is this?
1.3 Fractions Review

In physical science classes, you will solve problems that involve fractions. Understanding the rules for addition, subtraction, multiplication, and division of fractions helps you solve these problems. The diagram below shows the parts of a fraction. This skill sheet guides you through a review of the rules for working with fractions. You will see how the rules are used in both simple and complex fractions.

### Addition and subtraction of fractions

To add or subtract fractions you must first have a common denominator. For example, if you wanted to add or subtract $\frac{5}{8}$ and $\frac{6}{4}$, you must first convert both denominators to the same number.

**Addition:**

\[
\frac{5}{8} + \frac{6}{4} = \frac{5}{8} + \left(\frac{2 \times 6}{2 \times 4}\right) = \frac{5}{8} + \frac{12}{8} = \frac{17}{8}
\]

**Subtraction:**

\[
\frac{5}{8} - \frac{6}{4} = \frac{5}{8} - \left(\frac{2 \times 6}{2 \times 4}\right) = \frac{5}{8} - \frac{12}{8} = -\frac{7}{8}
\]

As you can see, the rules for adding and subtracting positive and negative numbers also apply to fractions.

### Multiplication of fractions

To multiply fractions, first multiply the numerators and then multiply the denominators. For example:

\[
\frac{5}{8} \times \frac{6}{4} = \frac{30}{32}
\]

Fractions are commonly expressed in their lowest terms so that they are easier to recognize. To find a fraction’s lowest terms, you need to divide the numerator and the denominator by any common factors. The fraction in the example above can be rewritten like this:

\[
\frac{30}{32} = \frac{3 \times 2 \times 5}{2 \times 2 \times 2 \times 2}
\]
This form is called the **prime factorization** because all of the factors are prime numbers (this means they can’t be divided by any whole number except 1 to get a whole number answer). Notice that there’s a 2 in both the numerator and the denominator. Cross out any factor that appears in both places. Multiply out the remaining factors. The simplified fraction is:

\[
\frac{3 \times 5}{2 \times 2 \times 2 \times 2} = \frac{15}{32}
\]

At other times you may be asked to change the fraction to a decimal. This is very easy! Simply divide the numerator by the denominator. Remember that the divisor line between the numerator and the denominator in a fraction means “divide by” and is the same as a division sign (÷).

\[
\frac{30}{32} = 30 ÷ 32 = 0.9375
\]

**Division of fractions**

To divide fractions you first invert (turn upside down) the second fraction and then multiply. Follow the rules for multiplying fractions. When necessary, reduce the fraction to its lowest terms. For example:

\[
\frac{5}{8} ÷ \frac{6}{4} = \frac{5 \times 4}{8 \times 6} = \frac{20}{48}
\]

\[
= \frac{2 \times 2 \times 5}{2 \times 2 \times 2 \times 3} = \frac{5}{2 \times 2 \times 3} = \frac{5}{12}
\]

**Division of complex fractions**

An example of a complex fraction is shown below. A complex fraction is a fraction of fractions. You can divide complex fractions using the rules you already know for dividing fractions. For example:

\[
\frac{5}{8} ÷ \frac{\left(\frac{5}{8} ÷ \frac{6}{4}\right)}{4} = \frac{5 \times 4}{8 \times 6} = \frac{20}{48}
\]

Reduce:

\[
\frac{20}{48} = \frac{2 \times 2 \times 5}{2 \times 2 \times 2 \times 3} = \frac{5}{12}
\]

As you can see, the last two examples yielded the same answer. Can you see why? The two examples are the same, but written differently. The line between the two fractions, \(\frac{5}{8}\) and \(\frac{6}{4}\), acts the same as a division (÷) sign.
Solving fraction problems

Now it’s your turn to solve some problems. Be sure to show your work. Reduce your answers to lowest terms.

Addition of fractions:

1. \( \frac{4}{12} + \frac{3}{4} \)

2. \( \frac{7}{8} + \frac{5}{7} \)

3. \( \frac{3}{4} + \frac{6}{8} + \frac{5}{3} \)

4. Express the above fractions in decimal form.

Subtraction of fractions:

1. \( \frac{4}{12} - \frac{3}{4} \)

2. \( \frac{7}{8} - \frac{5}{7} \)

3. \( \frac{3}{4} - \frac{6}{8} - \frac{5}{3} \)

4. Express the above fractions in decimal form.

Multiplication of fractions:

1. \( \frac{4}{12} \times \frac{3}{4} \)

2. \( \frac{7}{8} \times \frac{5}{7} \)

3. \( \frac{3}{4} \times \frac{6}{8} \times \frac{5}{3} \)

4. Express the above fractions in decimal form.
Division of fractions:
1. \( \frac{4}{12} \div \frac{3}{4} \)
2. \( \frac{7}{8} \div \frac{5}{7} \)
3. \( \frac{10}{15} \div \frac{1}{3} \)
4. \( \frac{8}{18} \div \frac{2}{3} \)
5. Express the above fractions in decimal form.

Division of complex fractions:
1. \( \frac{3}{4} \div \frac{6}{8} \)
2. \( \frac{3}{4} \div \frac{5}{3} \times \frac{7}{6} \)
3. \( \frac{5}{3} \div \frac{10}{4} \times \frac{2}{3} \)
4. \( \frac{25}{10} \div \frac{15}{3} \div \frac{5}{3} \)
5. Express the above fractions in decimal form.
1.3 Significant Digits

Francisco is training for a 10-kilometer run. Each morning, he runs a loop around his neighborhood. To find out exactly how far he’s running, he asks his older sister to drive the loop in her car. Using the car’s trip odometer, they find that the route is 7.2 miles long.

To find the distance in kilometers, Francisco looks in the reference section of his science text and finds that 1.000 mile = 1.609 kilometers. He multiplies 7.2 miles by 1.609 km/mile. The answer, according to his calculator, is 11.5848 kilometers.

Francisco wonders what all those numbers after the decimal point really mean. Can a car odometer measure distances as small as 0.0008 kilometer? That’s a distance less than one meter!

This skill sheet will help you answer Francisco’s question. It will also help you figure out which digits in your own calculations are significant.

What are significant digits?

Significant digits are the *meaningful* digits in a measured quantity. Scientists have agreed upon a number of rules to determine which numbers in a measurement are significant. The rules are:

1. **Non-zero digits in a measurement are always significant.** This means that the distance measured by the car odometer, 7.2 miles, has two significant digits.

2. **Zeros between two significant digits in a measurement are significant.** This means that the measurement of kilometers per mile, 1.609 kilometers, has four significant digits.

3. **All final zeros to the right of a decimal point in a measurement are significant.** This means that the measurement 1.000 miles has four significant digits.

4. **If there is no decimal point, final zeros in a measurement are NOT significant.** This means that the number 20 in the phrase “20-liter water cooler” has one significant digit. The water cooler isn’t marked off in 1-liter increments, so no measurement decision was made regarding the ones place.

5. **A decimal point is used after a whole number ending in zero to indicate that a final zero IS significant.** If you measure 100 grams of lemonade powder to the nearest whole gram, write the number as 100. grams. This shows that your measurement has three significant digits.

6. **In a measurement, zeros that exist only to put the decimal point in the right place are NOT significant.** This means that the number 0.0008 in the phrase “0.0008 kilometer” has one significant digit.

7. **A number that is found by counting rather than measuring is said to have an infinite number of significant digits.** For example, the race officials count 386 runners at the starting line. The number 386, in this case, has an infinite number of significant digits.
Find the number of significant digits

### Table 1: Number of Significant Digits

<table>
<thead>
<tr>
<th>Value</th>
<th>How many significant digits does each value have?</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 36.33 minutes</td>
<td></td>
</tr>
<tr>
<td>b. 100 miles</td>
<td></td>
</tr>
<tr>
<td>c. 120.2 milliliters</td>
<td></td>
</tr>
<tr>
<td>d. 0.0074 kilometers</td>
<td></td>
</tr>
<tr>
<td>e. 0.010 kilograms</td>
<td></td>
</tr>
<tr>
<td>f. 300. grams</td>
<td></td>
</tr>
<tr>
<td>g. 42 students</td>
<td></td>
</tr>
</tbody>
</table>

Using significant digits in calculations

Taking measurements and recording data are often a part of science classes. When you use the data in calculations, keep in mind this important principle:

**When using data in a calculation, your answer can’t be more precise than the least precise measurement.**

**Example**

You are using a ruler to measure the length of each side of a rectangle. The ruler is marked in tenths of a centimeter. This means that you can estimate the distance between two 0.1 cm marks and make measurements that are to two places after the decimal.

You measure the two short sides of the triangle and find that they each have a length of 12.25 cm. The long sides each have a length of 20.75 cm.

The rectangle’s perimeter (distance around) is $12.25 \text{ cm} + 20.75 \text{ cm} + 12.25 \text{ cm} + 20.75 \text{ cm}$, or 66.00 cm. The two zeros to the right of the decimal point show that you measured with a precision of 0.01 cm.

The area of the rectangle is found by multiplying the length of the short side by the length of the long side.

$$12.25 \text{ cm} \times 20.75 \text{ cm} = 254.1875 \text{ cm}^2$$

The answer you get from you calculator has seven significant digits. This incorrectly implies that your ruler can measure to one ten-thousandth of a centimeter. Your ruler can’t measure distances that small!
Follow these steps for determining the right answer for your calculation:

- When multiplying or dividing measurements, find the measurement in the calculation with the least number of significant digits. After doing your calculation, round the answer to that number of significant digits.
  
  In the rectangle example on the previous page, each measurement has 4 significant digits. When you multiply the measurements to find the area, your answer should be rounded to four significant digits. The area should be reported as 254.2 cm².

- When adding or subtracting measurements, the answer must not contain more decimal places than your least accurate measurement.
  
  In the rectangle example, the perimeter is reported to two decimal places to show that your ruler measures length to the nearest 0.01 centimeter.
  
  It is important to note that when adding or subtracting, you are not concerned with the number of significant digits to the left of the decimal point. When adding 1.25 cm + 1,000.50 cm + 2,000,000.75 cm, the answer is 2,001,002.50 cm. It is okay to have an answer with nine significant digits, because only TWO of them are to the right of the decimal point.

- When you are finding the average of several measurements, remember that numbers found by counting have an infinite number of significant digits.
  
  For example, a student measures the distance between two magnets when their attractive force is first felt. He repeats the experiment three times. His results are: 23.25 cm, 23.30 cm, 23.20 cm.
  
  To find the average distance, He adds the three times and divides the sum by three. “Three” is the number of times the experiment is repeated.

  \[
  \frac{23.25 \text{ cm} + 23.30 \text{ cm} + 23.20 \text{ cm}}{3} = 23.25 \text{ cm}
  \]

  In this equation, the number 3 is found by counting the number of times the experiment is repeated, not by measuring something. Therefore it is said to have an infinite number of significant digits. That’s why the answer has four significant digits, not just one.

**Report your answers with significant digits**

Have you ever participated in a road race? The following problems are all related to a road race event. Can you come up with some other problems that you might have to solve if you were running in or volunteering for a road race?

1. The banner over the finish line of a running race is 400. centimeters long and 85 centimeters high. What is the area of the banner?
2. Heidi stops at three water stations during the running race. She drinks 0.25 liters of water at the first stop, 0.3 liters at the second stop, and 0.37 liters at the third stop. How much water does she consume throughout the race?

3. The race officials want to set up portable bleachers near the finish line. Each set of bleachers is 4.50 meters long and 2.85 meters wide. How many square meters of open ground space do they need for each set?

4. The race has been held annually for ten years. The high temperatures for the race dates (in degrees Celsius) are listed in the table below. What is the average high temperature for the race day based on the temperatures for the past ten years? Write your answer in the bottom row in the table.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Race</th>
<th>Race Day Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>18.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>28.9</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>20.6</td>
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</tr>
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<td>6</td>
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</tr>
<tr>
<td>7</td>
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<td></td>
</tr>
<tr>
<td>8</td>
<td>23.9</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>26.7</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>27.8</td>
<td></td>
</tr>
</tbody>
</table>

Average Temperature

5. **Challenge!** Ji-Sun has participated in the race for the past four years. His times, reported in minutes:seconds, were

40:30
43:40
39:06
38:52

What is his average time to complete the race? (Hint: Convert all times to seconds before averaging!)

6. Come up with one more problem that uses information that is related to a road race. Write your problem in the space below and come up with the answer. Be sure to write your answer with the correct number of significant digits.
1.3 Study Notes

This skill builder will help you take notes while you read. Each paragraph in the text has a sidenote. Fill in the table as you read each section of your textbook. Use the information to study for tests!

- First, write in the number of the section that you are reading. For example, the first section of the text is 1.1. This is the first section in chapter 1 of the text.
- For each paragraph that you read, write the sidenote. Then write a question based on this sidenote. As you read the paragraph, answer your own question!
- When you study, fold this paper so that the answers are hidden. Use separate paper to write answers to each of your questions. Then unfold this paper and check your work.

**EXAMPLE**

Section number: 1.1

<table>
<thead>
<tr>
<th>Page number</th>
<th>Sidenote text</th>
<th>Question based on sidenote</th>
<th>Answer to question</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Accuracy</td>
<td>What is the science definition of accuracy?</td>
<td>In science, accuracy means how close a measurement is to an accepted or true value.</td>
</tr>
</tbody>
</table>

**PRACTICE**

Section number: _________

<table>
<thead>
<tr>
<th>Page number</th>
<th>Sidenote text</th>
<th>Question based on sidenote</th>
<th>Answer to question</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Answer to question</td>
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</tbody>
</table>
1.3 Science Vocabulary

One stumbling block for many science students is the number of new vocabulary words they encounter. Each field of science has its own body of terms, and there are many additional terms that are used in all the fields of science. However, few people are likely to run across these terms in their daily lives until they enter science classes in school. How do students master this new language? The same way they master any vocabulary—by looking to the roots!

Prefixes and suffixes play an important role in word structure. Prefixes are word parts that begin a word, and suffixes are word parts that end a word. These parts, also called roots, often have special meanings due to their use in other languages.

Prefixes and suffixes of words (and entire words themselves) in the English language are derived from other languages. Some of these languages like French are used in the world culture today and some languages belong to cultures long past. Latin and Greek are the two most common languages from which we derive pieces and parts of our words.

The study of languages provides tremendous benefit to understanding the meanings of words. Other languages provide us with greater understanding of our own language since the roots of many of the words come from these languages. For example, English, French, Italian, and Spanish all have Latin as a common ancestral language. Therefore, studying French, Italian, or Spanish increases the size of your vocabulary toolbox. Studying Latin (or Greek) is also a tremendous aid for mastery and comprehension of the English vocabulary.

When you encounter a new word and are unsure of its meaning, find and isolate the prefix and suffix of the word. It may help to write the word on a separate sheet of paper and circle or underline these parts. The remaining, uncircled parts of the word may also have a special meaning. Now, study each part of the word and work towards understanding its meaning.

Consider the word blueberry. There are two pieces to this word—the prefix blue and the suffix berry. Each of these word parts has its own meaning which, when combined with the other word part, gives the whole word its own, unique meaning. Blue denotes a color with which you are familiar. A berry is a small fruit that birds (and humans!) like to eat. Put them together, and you understand that blueberry probably means a small fruit that is colored blue. From your past experiences, you realize that this is a pretty good description of blueberries. Science words can be broken apart and analyzed in the same way to get an understanding of their meanings.

Below are some words you may encounter in a science class. For each word, circle the prefix and put a box around the suffix:

- thermometer
- electrolyte
- monoatomic
- volumetric
- endothermic
- spectroscopic
- prototype
- convex
- supersaturated
The table below lists some prefixes and suffixes that are found in scientific vocabulary along with their respective meanings. Use this table to write a definition for the following terms.

<table>
<thead>
<tr>
<th>Prefixes</th>
<th>Suffixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>homo – same, equal</td>
<td>-escence – to exist</td>
</tr>
<tr>
<td>poly – many</td>
<td>-meter – measure</td>
</tr>
<tr>
<td>hydro – water</td>
<td>-ology – the study of</td>
</tr>
<tr>
<td>lumen – light</td>
<td>-mer – unit</td>
</tr>
<tr>
<td>spectro – a continuous range or full extent</td>
<td>-geneous – kind or type</td>
</tr>
<tr>
<td>hetero – different</td>
<td></td>
</tr>
</tbody>
</table>

1. hydrology _______________________________________
2. polymer _________________________________________
3. homogeneous _____________________________________
4. heterogeneous _____________________________________
5. luminescence _____________________________________
6. spectrometer _____________________________________

Now, using a dictionary, look up the words for which you provided your own definition, and write the formal definitions in the spaces below:

1. hydrology _______________________________________
2. polymer _________________________________________
3. homogeneous _____________________________________
4. heterogeneous _____________________________________
5. luminescence _____________________________________
6. spectrometer _____________________________________
Using the table of prefixes and suffixes provided below, write a word that corresponds to each of the following definitions:

<table>
<thead>
<tr>
<th>Prefixes</th>
<th>Suffixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>thermo – heat</td>
<td>-scope – to view</td>
</tr>
<tr>
<td>mono – one</td>
<td>-meter – measure</td>
</tr>
<tr>
<td>tele – far</td>
<td>-atomic – indivisible unit</td>
</tr>
<tr>
<td>sono – sound, tone</td>
<td>-graph, -gram – something written</td>
</tr>
</tbody>
</table>

1. A device to measure heat or temperature: ________________________________
2. A graph showing the loudness and frequencies of sounds: __________________
3. Having only one type of “indivisible” unit: ______________________________
4. A device used to view distant objects: _________________________________

Look up the words you created in the dictionary. Write your words and the accepted definitions in the space below:

<table>
<thead>
<tr>
<th>Word Dictionary Definition</th>
</tr>
</thead>
</table>

How closely did your definitions match the accepted ones found in the dictionary? Your definitions based on your understanding of the roots for the prefixes and suffixes likely provided you with good results. A thorough knowledge of prefixes and suffixes will be a tremendous help to you as you proceed through your science education and will enable you to better understand the written and spoken language you encounter in your daily life.
1.3 SI Unit Conversion—Extra Practice

Science is about exploring and understanding the universe, from the tiniest subatomic particles to the mind-boggling expanses of interstellar space. We gain understanding by asking questions, observing, measuring, and sharing results with others. You will use SI (metric) measuring tools for this purpose throughout the year. This skill sheet will help you become familiar with the SI prefixes you will use to measure length, mass, and volume.

Here are the prefixes you will use to report measurements:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>kilo-</th>
<th>hecto-</th>
<th>deka-</th>
<th>Basic unit (no prefix)</th>
<th>deci-</th>
<th>centi-</th>
<th>milli-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>k</td>
<td>h</td>
<td>da</td>
<td>m, g, l</td>
<td>d</td>
<td>c</td>
<td>m</td>
</tr>
<tr>
<td>Multiplication Factor or Place-Value</td>
<td>1,000</td>
<td>100</td>
<td>10</td>
<td>1</td>
<td>0.1</td>
<td>0.01</td>
<td>0.001</td>
</tr>
</tbody>
</table>

**EXAMPLE**

1. How many centimeters are there in 24 meters?
   a. Restate the question: 24 meters = __________ centimeters.
   b. Use the place value chart above to determine the multiplication factor, and solve.
   Count the number of places on the chart it takes to move from meters (the ones place) to centimeters (the hundredths place). Since it takes 2 moves to the right, the multiplication factor is 100. Move the decimal two places to the right.

   Solution: multiply $24 \times 100 = 2,400$.

   Answer: There are 2,400 centimeters in 24 meters.

**PRACTICE**

Use the chart above to help you answer the following questions.

**Part A: Distance conversions**

1. Earth’s diameter is 12,756 kilometers. How many meters is this?
2. The diameter of Earth’s moon is 3,476 kilometers. Express this distance in centimeters.
3. The average distance between Earth and its moon is 384,000,000 meters. Express this distance in kilometers.
4. A billion years ago, Earth and its moon were just 200,000 kilometers apart. Express this distance in meters.
5. Earth’s moon is covered with impact craters. These craters form when an asteroid, comet, or meteorite crashes into the moon’s surface. The largest impact crater, called Clavius, is 160 kilometers across. How many centimeters is this?

6. A crater known as Aristarchus is 3.6 kilometers deep. What is this distance in millimeters?

7. Another feature of the moon’s surface is long, narrow valleys called Rilles. The Hadley Rille is 125 kilometers long, 0.4 kilometers deep, and 1.5 kilometers wide at its widest point. Express these distances in meters.

8. To escape Earth’s gravitational pull, an object must reach a speed of 11,180 meters per second. How fast is this in kilometers per second?

Part B: Mass conversions

9. The largest land mammal is the African Elephant. The average adult has a mass of 5,400 kilograms. Express this mass in grams.

10. One of the smallest mammals is the bumblebee bat, with a mass of about 0.002 kilograms. Express this mass in grams.

11. A pygmy shrew is another tiny mammal, with a mass ranging from 1.2 grams to 2.7 grams. Express these measurements in milligrams.

12. The largest mammal ever found on Earth was a female blue whale with a mass of more than 158,000,000 grams. Express this mass in kilograms.

13. A blue whale’s heart is so large that a person could crawl through its largest blood vessel (the aorta). The heart has a mass of about 450 kg. Express this mass in milligrams.

14. A baby blue whale will drink between 23 and 90 kilograms of milk each day. Express these masses in grams.

Part C: Volume conversions

15. A mature sugar maple tree produces about 40 liters of sap each season. How many milliliters is this?

16. After the sap is collected, extra water in it must be boiled off. Forty liters of sap is boiled down to produce one liter of maple syrup. How many milliliters of syrup are in one liter?

17. Canada is the world’s largest commercial producer of maple syrup. In 2005, Canada produced about 26,600,000 liters of maple syrup. How many kiloliters is this?

18. Vermont is the United States’ largest commercial producer of maple syrup. Vermont produced about 1,558 kiloliters of maple syrup in 2005. How many liters is this?

19. One serving of maple syrup is 1/4 cup, or 0.06 liters. How many milliliters of syrup is this?

1.3 SI-English Conversions

Even though the United States adopted the SI system in the 1800’s, most Americans still use the English system (feet, pounds, gallons, etc.) in their daily lives. Because almost all other countries in the world, and many professions (medicine, science, photography, and auto mechanics among them) use the SI system, it is often necessary to convert between the two systems.

It is useful to be familiar with examples of measurements in both systems. Most people in the United States are very familiar with English system units because they are used in everyday tasks. Some examples of SI system measurements are:

One kilometer (1 km) is about two and a half times around a standard running track.

One centimeter (1 cm) is about the width of your little finger.

One kilogram (1 kg) is about the mass of a full one-liter bottle of drinking water.

One gram (1 g) is about the mass of a paper clip.

One liter (1 l) is a common size of a bottle of drinking water.

One milliliter (1 mL) is about one droplet of liquid.
When precise conversions between SI and English systems are necessary, you will need to know the conversion factors given in the table below.

### Table 1: English - SI measurement equivalents

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length:</strong></td>
<td>1 inch = 2.54 centimeters</td>
</tr>
<tr>
<td></td>
<td>1 kilometer ≈ 0.62 mile</td>
</tr>
<tr>
<td><strong>Volume:</strong></td>
<td>1 liter ≈ 1.06 quart</td>
</tr>
<tr>
<td><strong>Mass: Weight (on Earth)</strong></td>
<td>1 kilogram ≈ 2.2 pounds</td>
</tr>
<tr>
<td></td>
<td>1 ounce ≈ 28 grams</td>
</tr>
</tbody>
</table>

#### EXAMPLES

1. If we need to know the mass of a 50.-pound bag of dog food in kilograms, we take the following steps:

   (1) Restate the question: 50. lb ≈ _________ kg
   
   (2) Find the conversion factor from the table: 1 kg ≈ 2.2 lb
   
   (3) Multiply the ratios making sure that the unwanted units cancel, leaving only the desired units (kilograms) in the answer:

   \[
   \frac{50 \text{ lb}}{1} \cdot \frac{1 \text{ kg}}{2.2 \text{ lb}} \approx \frac{50 \text{ kg}}{2.2} \approx 22.7272 \text{ kg} \quad \approx 23 \text{ kg}
   \]

2. How many inches are equivalent to 99 centimeters?

   (1) Restate the question: 99 centimeters = _________ inches
   
   (2) Find the conversion factor from the table: 1 inch = 2.54 centimeters.
   
   (3) Multiply the ratios. Make sure the units cancel correctly to produce the desired unit in the answer.

   \[
   \frac{99 \text{ cm}}{1} \cdot \frac{1 \text{ in}}{2.54 \text{ cm}} = \frac{99 \text{ in}}{2.54} \approx 38.97638 \text{ in} \approx 39 \text{ inches}
   \]

3. An eighth grader is 5 feet 10. inches tall. We want to know how many centimeters that is without measuring.

   (1) Restate the question: 5 feet 10. inches = _________ centimeters
   
   (2) Convert units within one system if necessary: 5 feet 10. inches needs to be rewritten as either feet or inches. Since our conversion factor (from the table) is given as 1 inch = 2.54 centimeters, it makes sense to rewrite the quantity 5 feet 10. inches as some number of inches. First convert the number of feet (5) to inches, then add 10. inches. Since there are 12 inches in 1 foot, use that as your conversion factor to calculate:

   \[
   \frac{5 \text{ ft}}{1} \cdot \frac{12 \text{ in}}{1 \text{ ft}} = \frac{60 \text{ in}}{1} = 60 \text{ inches}
   \]
Now add: 60. inches + 10. inches = 70. inches. 5 feet 10. inches = 70. inches. We now need to convert 70. inches to centimeters.

(3) Restate the question: 70. inches = __________ centimeters.

(4) Choose the correct conversion factor from the table. Here, we want to convert inches to centimeters, so use 1 inch = 2.54 centimeters.

(5) Multiply the ratios. Make sure the units cancel correctly to produce the desired type of unit in the answer.

\[
\frac{70\text{ in}}{1} \cdot \frac{2.54\text{ cm}}{\text{in}} = \frac{177.8\text{ cm}}{1} = 180\text{ cm}
\]

### Practice

1. 7.0 km ≈ __________ mi
2. 115 g ≈ __________ oz
3. 2,000. lb. ≈ __________ kg
4. A 2.0-liter bottle of soda is about how many quarts?
5. A pumpkin weighs 5.4 pounds. What is its mass in grams? (Hint: There are 16 ounces in one pound).
6. Felipe biked 54 kilometers on Sunday. How many miles is this?
7. How many inches are in 72.0 meters? How many yards is this?
8. In a track meet, Julian runs the 800. meter dash, the 1600. meter run, and the opening leg of the 4 × 400. meter relay. How many miles is this altogether?
9. How many liters are equivalent to 1.0 gallon? (There are exactly four quarts in a gallon.)
10. The mass of a large order of french fries is about 170. grams. What is its approximate weight in pounds?
1.4 Creating Scatterplots

Scatterplots allow you to present data in a form that shows a cause and effect relationship between two variables. The parts of a scatterplot include:

1. **Data pairs:** Scatterplots are made using pairs of numbers. Each pair of numbers represents one data point on a graph. The first number in the pair represents the independent variable and is plotted on the x-axis. The second number represents the dependent variable and is plotted on the y-axis.

2. **Axis labels:** The label on the x-axis is the name of the independent variable. The label on the y-axis is the name of the dependent variable. Be sure to write the units of each variable in parentheses after its label.

3. **Scale:** The scale is the quantity represented per line on the graph. The scale of the graph depends on the number of lines available on your graph paper and the range of the data. Divide the range by the number of lines. To make the calculated scale easy-to-use, round the value to a whole number.

4. **Title:** The format for the title of a graph is: “Dependent variable name versus independent variable name.”

**Practice**

1. For each data pair in the table, identify the independent and dependent variable. Then, rewrite the data pair according to the headings in the next two columns of the table. The first two data pairs are done for you.

<table>
<thead>
<tr>
<th>Data pair (not necessarily in order)</th>
<th>Independent (x-axis)</th>
<th>Dependent (y-axis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Temperature Hours of heating</td>
<td>Hours of heating</td>
<td>Temperature</td>
</tr>
<tr>
<td>2 Stopping distance Speed of a car</td>
<td>Speed of a car</td>
<td>Stopping distance</td>
</tr>
<tr>
<td>3 Number of people in a family Cost per week for groceries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Stream flow rate Amount of rainfall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Tree age Average tree height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Test score Number of hours studying for a test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Population of a city Number of schools needed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Using the variable range and number of lines, calculate the scale for an axis. The first two are done for you.

<table>
<thead>
<tr>
<th>Variable range</th>
<th>Number of lines</th>
<th>Range ≥ Number of lines</th>
<th>Calculated scale</th>
<th>Adjusted scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>24</td>
<td>13 ≥ 24 = 0.54</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>43</td>
<td>83 ≥ 43 = 1.9</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>33</td>
<td></td>
<td></td>
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<tr>
<td>300</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>900</td>
<td>15</td>
<td></td>
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</tr>
</tbody>
</table>
3. Here is a data set to use to create a scatterplot. Follow these steps to make the graph.
   a. Place this data set in the table below. Each data point is given in the format of \((x, y)\). The \(x\)-values represent time in minutes. The \(y\)-values represent distance in kilometers.

\((0, 5.0), (10, 9.5), (20, 14.0), (30, 18.5), (40, 23.0), (50, 27.5), (60, 32.0)\).

<table>
<thead>
<tr>
<th>Independent variable (x-axis)</th>
<th>Dependent variable (y-axis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

b. What is the range for the independent variable?

c. What is the range for the dependent variable?

d. Make your graph using the blank graph below. Each axis has twenty lines (boxes). Use this information to determine the adjusted scale for the \(x\)-axis and the \(y\)-axis.

e. Label your scatterplot. Add a label for the \(x\)-axis, \(y\)-axis, and provide a title.

f. Draw a smooth line through the data points.
g. What is the position value after 45 minutes? Use your scatterplot to answer this question.
1.4 What’s the Scale?

Graphs allow you to present data in a form that is easy to understand. With a graph, you can see whether your data shows a pattern and you can picture the relationship between your variables.

The **scale** on a graph is the quantity represented per line on the graph. Your graph’s scales will depend on the type of data you are plotting. Each of your graph’s axes has its own separate scale. You need to be consistent with your scales. If one line on a graph represents 1 cm on the \(x\)-axis, it has to stay that way for the entire \(x\)-axis.

When figuring out the scale for your graph, you first need to know the **range**. When you want your axis to start at zero, your range is equal to your highest data value. Once you have the range, you can calculate the scale. Count the number of lines you have available on your graph paper. Now, divide the range by the number of lines. This number is your scale. Then you adjust your scale by rounding up to a whole number.

Calculate the scales for the data set listed in the table below. Your graph paper is 20 boxes by 20 boxes.

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Amount of rainfall (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>25</td>
<td>37</td>
</tr>
<tr>
<td>30</td>
<td>59</td>
</tr>
</tbody>
</table>

**Identify the variables.**

1. Which is the independent variable?  **Time** is your independent variable; it goes on the \(x\)-axis.
2. Which is the dependent variable?  **Amount of rainfall** is your dependent variable; it goes on the \(y\)-axis.

**Find the ranges.**

2. What is the range of data for the \(x\)-axis?  **30 hours**
3. What is the range of data for the \(y\)-axis?  **59 mL**

**Calculate the scales.**

3. What is the scale for your \(x\)-axis?  
   
   \[\frac{30 \text{ hrs}}{20 \text{ boxes}} = 1.5 \text{ hrs/box} \]
   
   Each line on the graph is equal to 2 hours.
   
   The \(x\)-axis will start at zero and go up to 40 hours, with each line counting as 2 hours.

   What is the scale for your \(y\)-axis?  
   
   \[\frac{59 \text{ mL}}{20 \text{ boxes}} = 2.95 \text{ mL/box} \]
   
   Each line on the graph is equal to 3 mL.
   
   The \(y\)-axis will start at zero and go up to 60 mL, with each line counting as 3 mL.
1. Given the variable range and the number of lines, calculate the scale for an axis. Often the calculated scale is not an easy-to-use value. To make the calculated scale easy-to-use, round the value and write this number in the column with the heading “Adjusted scale.” The first two are done for you.

<table>
<thead>
<tr>
<th>Range from 0</th>
<th>Number of Lines</th>
<th>Range ≥ Number of Lines</th>
<th>Calculated scale</th>
<th>Adjusted scale (whole number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>10</td>
<td>14 ≥ 10 =</td>
<td>1.4</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>8 ≥ 5 =</td>
<td>1.6</td>
<td>2</td>
</tr>
<tr>
<td>1000</td>
<td>20</td>
<td>1000 ≥ 20 =</td>
<td></td>
<td></td>
</tr>
<tr>
<td>547</td>
<td>15</td>
<td>547 ≥ 15 =</td>
<td></td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>30</td>
<td>99 ≥ 30 =</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>12</td>
<td>35 ≥ 12 =</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Calculate the range and the scale for the x-axis starting at zero, given the following data pairs and a 30 box by 30 box piece of graph paper. Each data point is given in the format of (x, y): (1, 27), (30, 32), (20, 19), (6, 80), (15, 21).

3. Calculate the range and the scale for the y-axis starting at zero, given the following data pairs and a 10 box by 10 box piece of graph paper. Each data point is given in the format of (x, y): (1, 5), (2, 10), (3, 15), (4, 20), (5, 25).

4. Calculate the scale for both the x-axis and the y-axis of a graph using the data set in the table below. Your graph paper is 20 boxes by 20 boxes. Start both the x- and y-axis at zero.
   a. Which is the independent variable? Which is the dependent variable?
   b. What is the range of data for the x-axis? What is the range of data for the y-axis?
   c. What is the scale for your x-axis? What is the scale for your y-axis?

<table>
<thead>
<tr>
<th>Day</th>
<th>Average Daily Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67</td>
</tr>
<tr>
<td>3</td>
<td>68</td>
</tr>
<tr>
<td>5</td>
<td>73</td>
</tr>
<tr>
<td>7</td>
<td>66</td>
</tr>
<tr>
<td>9</td>
<td>70</td>
</tr>
<tr>
<td>11</td>
<td>64</td>
</tr>
</tbody>
</table>
1.4 Interpreting Graphs

The four main kinds of graphs are scatterplots, bar graphs, pie graphs, and line graphs.

To learn how to interpret graphs, we will start with an example of a scatterplot. The data presented on the scatterplot below is the amount of money in a cash box during a car wash that lasted for five hours. Use this graph to follow the steps and answer the questions below.

Step 1: Read the labels on the graph.

1. What is the title of the graph?

2. Read the labels for the $x$-axis and the $y$-axis. What two variables are represented on the graph?

   Step 2: Read the units used for the variable on the $x$-axis and the variable on the $y$-axis.

3. What unit is used for the variable on the $x$-axis?

4. What unit is used for the variable on the $y$-axis?
Step 3: Look at the range of values on the x- and y-axes. Do the range of values make sense? What would the data look like if the range of values on the axes was spread out more or less?

5. What is the range of values for the x-axis?

6. The range of values for the y-axis is 0 to $120. What would the graph look like if the range of values was 0 to $500? Where would the data appear on the graph if this were the case?

Step 4: After looking at the parts of the graph, pay attention to the data that is plotted. Is there a relationship between the two variables?

7. Is there a relationship between the variables that are represented on the graph?

Step 5: Write a sentence that describes the information presented on the graph. For example, you may say, “As the values for the variable on the x-axis increase, the values for the variable on the y-axis decrease.”

8. Write your own description of the graph.

9. The theater club at your school needs to raise $1000 for a trip that they want to take. They will be taking the trip next fall. It is now April. Based on the graph, would you recommend that the group wash cars to raise money? Write out a detailed response to this question. Be sure to provide evidence to support your reasons for your recommendation.

Now, apply what you know about interpreting graphs to a bar graph. Use the steps from part one to help you answer the questions.

1. What is the title of this graph?

2. What variables are represented on the graph? (Hint: there are three variables.) Describe each variable in terms of the categories or the range of values used.

3. Write a sentence that describes how the percentage of teenagers employed compares from city to city. Do not state any conclusions about the data in your sentence.

4. Write a sentence that describes how the percentage of boys employed compares to the percentage of girls employed. Do not state any conclusions about the data in your sentence.

5. Based on the data represented in the graph, come up with a hypothesis for why the percentage of teenagers employed differs from city to city.

6. Based on the data represented in the graph, come up with a hypothesis to explain the employment differences between boys and girls in these cities.
Now, apply what you know about interpreting graphs to a pie graph. Use the steps from part one to help you answer the questions.

1. What is the title of this graph?

2. What variables are represented on the graph? (Hint: there are two variables.)

3. Are any units used in this graph? Explain your answer.

4. If you were going to report on this data, what would you say? Write two to three sentences that describe this graph. Do not state any conclusions about the data in your sentence.

5. Come up with a hypothesis based on the data in this graph. Briefly describe how you would test your hypothesis.

6. Do you have a job? If so, in which category does your job fit? Do you think this pie graph accurately represents the working teenager population in your area? Explain your response.

Finally, apply what you know about interpreting graphs to a line graph. Use the steps from part one to help you answer the questions.

1. What is the title of this graph?

2. What variables are represented on the graph? (Hint: there are two variables.)

3. What is the range of values for each variable?

4. Write a sentence that describes the change in student population at Springfield High School from 1970 to 1985. Do not state any conclusions about the data in your sentence.


   b. If this were your high school, how could you find out if your explanation is correct?

6. Explain why this graph is a line graph, not a scatterplot.
1.4 Recognizing Patterns on Graphs

In physical science class, you will do laboratory experiments to answer questions such as: If I change this, what will happen to that? For example, you might ask: If I change the mass of a toy car by adding some cargo, what will happen to its acceleration down a ramp? Or, you might ask: If I change the temperature of some water in a beaker by heating it on a burner, what will happen to the amount of sugar that I can dissolve in it?

Making a scatterplot graph of your results can help you recognize patterns in your data. In order to share your results with others, it is helpful to understand the vocabulary that scientists use to describe patterns seen on scatterplot graphs. In this skill sheet, you will practice describing some of these patterns.

Example

Take a look at these two graphs:

<table>
<thead>
<tr>
<th>Direct relationship between variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Graph 1] (Mass of coins vs. Volume of coins)</td>
</tr>
</tbody>
</table>

In each case, the line or curve slopes up from left to right. This tells you there is a **direct relationship** between the x- and y-variables. If you increase the x-value, the y-value will also increase.

Here are two more graphs:

<table>
<thead>
<tr>
<th>Inverse relationship between variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Graph 3] (Cash spent vs. Cash in wallet)</td>
</tr>
</tbody>
</table>
In each case, the line or curve slopes down from left to right. This tells you there is an **inverse relationship** between the x- and y-variables. If you increase the x-value, the y-value will decrease.

Sometimes your graphs will be a straight line. This tells you there is a **linear relationship** between variables.

If the graph is a curve, we say that the relationship is **non-linear**.

Scatterplots can also help us describe the strength of the relationship between two variables. The following graphs show the number of grams of three different substances that will dissolve in 100 ml of water at different temperatures.

<table>
<thead>
<tr>
<th></th>
<th>No relationship</th>
<th>Weak relationship</th>
<th>Strong relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Substance 1</strong></td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
</tr>
<tr>
<td><strong>Substance 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Substance 3</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Substance A: The amount that will dissolve is not related to temperature. **No relationship.**
Substance B: The amount that will dissolve increases slightly with temperature. **This is a weak relationship.**
Substance C: The amount that will dissolve increases a lot with temperature. **This is a strong relationship.**
Answer the following questions about graphs A–F, below.

<table>
<thead>
<tr>
<th>Graph</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Mass of water vs. Volume of water</td>
</tr>
<tr>
<td>B</td>
<td>Liters of gas in tank vs. Kilometers traveled after fill-up</td>
</tr>
<tr>
<td>C</td>
<td>Volume of gas vs. Pressure of gas (temperature constant)</td>
</tr>
<tr>
<td>D</td>
<td>Mass of aluminum sample vs. Temperature of aluminum sample</td>
</tr>
<tr>
<td>E</td>
<td>Position vs. Time</td>
</tr>
<tr>
<td>F</td>
<td>Volume of steel sample vs. Temperature of steel sample</td>
</tr>
</tbody>
</table>

1. Name three graphs which show a direct relationship between variables.
2. Name two graphs which show an inverse relationship between variables.
3. Name three graphs which show a linear relationship between variables.
4. Name two graphs which show non-linear relationships.
5. In which graph does a change in the x-variable cause NO CHANGE in the y-variable?
6. Which graph shows a stronger relationship between variables, graph A or graph F?
2.1 Scientific Processes

The scientific method is a process that helps you find answers to your questions about the world. The process starts with a question and your answer to the question based on experience and knowledge. This “answer” is called your hypothesis. The next step in the process is to test your hypothesis by creating experiments that can be repeated by other people in other places. If your experiment is repeated many times with the same results and conclusions, these findings become part of the body of scientific knowledge we have about the world.

Read the following story. You will use this story to practice using the scientific method.

Maria and Elena are supposed to help their mom chill some soda by putting the cans into a bucket filled with ice cubes, but Maria forgot to fill the ice cube trays. Elena says that she remembers reading somewhere that hot water freezes faster than cold water. Maria is skeptical. She learned in science class that the hotter the liquid, the faster the molecules are moving. Since hot water molecules have to slow down more than cold water molecules to become ice, Maria thinks that it will take hot water longer to freeze than cold water.

The girls decide to conduct a scientific experiment to determine whether it is faster to make ice cubes with hot water or cold water.

Now, answer the following questions about the process they used to reach their conclusion.

### Asking a question
1. What is the question that Maria and Elena want to answer by performing an experiment?

### Formulate a hypothesis
2. What is Maria’s hypothesis for the experiment? State why Maria thinks this is a good hypothesis.

### Design and conduct an experiment
3. **Variables:** There are many variables that Maria and Elena must control so that their results will be valid. Name at least four of these variables.
4. **Measurements**: List at least two types of measurements that Maria and Elena must make during their experiment.

5. **Procedure**: If Maria and Elena want their friends to believe the results of their experiment, they need to conduct the experiment so that others could repeat it. Write a procedure that the girls could follow to answer their question.

**Collect and analyze data**

The girls conducted a carefully controlled experiment and found that after 3 hours and 15 minutes, the hot water had frozen solid, while the trays filled with cold water still contained a mixture of ice and water. They repeated the experiment two more times. Each time the hot water froze first. The second time they found that the hot water froze in 3 hours and 30 minutes. The third time, the hot water froze in 3 hours and 0 minutes.

6. What is the average time that it took for hot water in ice cube trays to freeze?

7. Why is it a good idea to repeat your experiments?

**Make a tentative conclusion**

8. Which of the following statements is a valid conclusion to this experiment? Explain your reasoning for choosing a certain statement.
   a. Hot water molecules don’t move faster than cold water molecules.
   b. Hot water often contains more dissolved minerals than cold water, so dissolved minerals must help water freeze faster.
   c. Cold water can hold more dissolved oxygen than hot water, so dissolved oxygen must slow down the rate at which water freezes.
   d. The temperature of water affects the rate at which it freezes.
   e. The faster the water molecules are moving, the faster they can arrange themselves into the nice, neat patterns that are found in solid ice cubes.

**Test your conclusion or refine your question**

Maria and Elena are pleased with their experiment. They ask their teacher if they can share their findings with their science class. The teacher says that they can present their findings as long as they are sure their conclusion is correct.

The last step of the scientific method is important. At the end of any set of experiments and before you present your findings, you want to make sure that you are confident about your work.

9. Let’s say that there is a small chance that the results of the experiment that Maria and Elena performed were affected by the kind of freezer they used in the experiment. What could the girls do to make sure that their results were not affected by the kind of freezer they used?

10. Statement 8(b) suggests a possible reason why temperature affects the speed at which water freezes. Refine your original question for this experiment. In other words, create a question for an experiment that would prove or disprove statement 8(b).
2.1 What’s Your Hypothesis?

After making observations, a scientist forms a question based on observations and then attempts to answer that question. A guess or a possible answer to a scientific question based on observations is called a hypothesis. It is important to remember that a hypothesis is not always correct. A hypothesis must be testable so that you can determine whether or not it is correct.

In science class your teacher has told you that the ability of a river to transport material depends on how fast the river is flowing. Imagine the river has three speeds—slow, medium, and fast. Now, imagine the river bottom has sand, marble-sized pebbles, and baseball-sized rocks. Come up with a hypothesis for the answer to the following question. Then, justify your reasoning:

Research question: At which flow rate—slow, medium, or fast—would a river be able to transport baseball-sized rock?

Example hypothesis and justification: The river would have to be flowing at a fast flow rate to be able to transport baseball-sized rocks. It takes more force to move larger rocks than small pebbles and sand. Fast flowing water has more pushing force than medium or slow flowing water. I know this from an experience I had wading in a river one time. As I waded from still water to areas where the river was flowing faster, I could feel the water pushing against my legs more and more.

1. You left a glass full of water by a window in your house in the morning. Three hours later you walk by the glass, and the water level is noticeably lower than it was in the morning. You have made the observation that the water level in the cup is lower. Then, you ask the following question: “Why is the water level in the cup lower?”

What is a possible hypothesis you could make?
2. Your teacher shows you a demonstration in which there is a box with two chimneys. Under one chimney is a lit candle, and under the other chimney is smoke from burning incense. You observe that the smoke always goes towards the candle and then exits the box from the chimney above the candle. You ask the following question: “Why does the smoke go toward the candle and leave the chimney above the candle?”

What is a possible hypothesis you could make?

![Diagram of demonstration](image.png)

3. You have learned in science class that *evaporation* is a process that describes when a liquid turns to a gas at a temperature below the boiling point. You are now about to investigate evaporation and factors that may increase the rate at which it occurs. You ask the question, “What causes the evaporation rate of water to increase?”

What is a possible hypothesis you could make?

4. Rivers and streams flow at various speeds. You ask, “What factors increase the flow rate of a river?”

What is a possible hypothesis you could make?

5. It is late fall and you notice that flower bulbs in your yard have been dug up and some have been eaten. You ask, “What has happened?”

What is a possible hypothesis you could make?

6. You know that sea otters eat sea urchins and that sea urchins eat kelp. You ask, “What would happen to this ecosystem if all the kelp died?”

What is a possible hypothesis you could make?

7. In Alaska, lynx (wild cats) are predators of the snowshoe hare. In the wintertime, the coat of the snowshoe hare turns from brown to white. You ask, “Why does the snowshoe hare change color in the winter?”

What is a possible hypothesis you could make?

8. In the deserts of the southwestern United States, coyotes are dog-like animals that eat many different things such as small animals and cactus fruit. They are also scavengers, which means they eat dead and decaying animals. You ask, “Are there coyote-like animals that serve as predator-scavengers in other deserts on other continents?”

What is a possible hypothesis you could make?
2.2 Recording Observations in the Lab

How do you record valid observations for an experiment in the lab?

When you perform an experiment you will be making important observations. You and others will use these observations to test a hypothesis. In order for an experiment to be valid, the evidence you collect must be objective and repeatable. This investigation will give you practice making and recording good observations.

Making valid observations

Valid scientific observations are objective and repeatable. Scientific observations are limited to one's senses and the equipment used to make these observations. An objective observation means that the observer describes only what happened. The observer uses data, words, and pictures to describe the observations as exactly as possible. An experiment is repeatable if other scientists can see or repeat the same result. The following exercise gives you practice identifying good scientific observations.

Exercise 1

1. Which observation is the most objective? Circle the correct letter.
   a. My frog died after 3 days in the aquarium. I miss him.
   b. The frog died after 3 days in the aquarium. We will test the temperature and water conditions to find out why.
   c. Frogs tend to die in captivity. Ours did after three days.

2. Which observation is the most descriptive? Circle the correct letter.
   a. After weighing 3.000 grams of sodium bicarbonate into an Erlenmeyer flask, we slowly added 50.0 milliliters of vinegar. The contents of the flask began to bubble.
   b. We weighed the powder into a glass container. We added acid. It bubbled a lot.
   c. We saw a fizzy reaction.

3. Which experiment has enough detail to repeat? Circle the correct letter.
   a. Each student took a swab culture from his or her teeth. The swab was streaked onto nutrient agar plates and incubated at 37 C.
   b. Each student received a nutrient agar plate and a swab. Each student performed a swab culture of his or her teeth. The swab was streaked onto the agar plate. The plates were stored face down in the 37 C incubator and checked daily for growth. After 48 hours the plates were removed from the incubator and each student recorded his or her results.
   c. Each student received a nutrient agar plate and a swab. Each student performed a swab culture of his or her teeth. The swab was streaked onto the agar plate. The plates were stored face down in the 37 C incubator and checked daily for growth. After 48 hours the plates were removed from the incubator and each student counted the number of colonies present on the surface of the agar.
Recording valid observations

As a part of your investigations you will be asked to record observations on a skill sheet or in the results section of a lab report. There are different ways to show your observations. Here are some examples:

1. **Short description:** Use descriptive words to explain what you did or saw. Write complete sentences. Give as much detail as possible about the experiment. Try to answer the following questions: What? Where? When? Why? and How?

2. **Tables:** Tables are a good way to display the data you have collected. Later, the data can be plotted on a graph. Be sure to include a title for the table, labels for the sets of data, and units for the values. Check values to make sure you have the correct number of significant figures.

   **U.S. penny mass by year**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (grams)</td>
<td>3.0845</td>
<td>3.0921</td>
<td>3.0689</td>
<td>2.9915</td>
<td>3.0023</td>
<td>2.5188</td>
<td>2.5042</td>
<td>2.4883</td>
<td>2.5230</td>
</tr>
</tbody>
</table>

3. **Graphs and charts:** A graph or chart is a picture of your data. There are different kinds of graphs and charts: line graphs, trend charts, bar graphs, and pie graphs, for example. A line graph is shown below.

   Label the important parts of your graph. Give your graph a title. The x-axis and y-axis should have labels for the data, the unit values, and the number range on the graph.

   The line graph in the example has a straight line through the data. Sometimes data does not fit a straight line. Often scientists will plot data first in a trend chart to see how the data looks. Check with your instructor if you are unsure how to display your data.
4. **Drawings:** Sometimes you will record observations by drawing a sketch of what you see. The example below was observed under a microscope.

![Illustration of Ulothrix](image1)

Give the name of the specimen. Draw enough detail to make the sketch look realistic. Use color, when possible. Identify parts of the object you were asked to observe. Provide the magnification or size of the image.

---

**Exercise 2: Practice recording valid observations**

A lab report form has been given to you by your instructor. This exercise gives you a chance to read through an experiment and fill in information in the appropriate sections of the lab report form. Use this opportunity to practice writing and graphing scientific observations. Then answer the following questions about the experiment.

A student notices that when he presses several pennies in a pressed penny machine, his brand new penny has some copper color missing and he can see silver-like material underneath. He wonders, “Are some pennies made differently than others?” The student has a theory that not all U.S. pennies are made the same. He thinks that if pennies are made differently now he might be able to find out when the change occurred. He decides to collect a U.S. penny for each year from 1977 to the present, record the date, and take its mass. The student records the data in a table and creates a graph plotting U.S. penny mass vs. year. Below is a table of some of his data:

<table>
<thead>
<tr>
<th>Year manufactured</th>
<th>Mass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>3.0845</td>
</tr>
<tr>
<td>1978</td>
<td>3.0921</td>
</tr>
<tr>
<td>1979</td>
<td>3.0689</td>
</tr>
<tr>
<td>1980</td>
<td>2.9915</td>
</tr>
<tr>
<td>1981</td>
<td>3.0023</td>
</tr>
<tr>
<td>1982</td>
<td>2.5188</td>
</tr>
<tr>
<td>1983</td>
<td>2.5042</td>
</tr>
<tr>
<td>1984</td>
<td>2.4883</td>
</tr>
<tr>
<td>1985</td>
<td>2.5230</td>
</tr>
</tbody>
</table>

**Stop and think**

a. What observation did the student make first before he began his experiment?
b. How did the student display his observations?


c. In what section of the lab report did you show observations?


d. What method did you use to display the observations? Explain why you chose this one.


2.2 Writing a Lab Report

How do you share the results of an experiment?

A lab report is like a story about an experiment. The details in the story help others learn from what you did. A good lab report makes it possible for someone else to repeat your experiment. If their results and conclusions are similar to yours, you have support for your ideas. Through this process we come to understand more about how the world works.

The parts of a lab report

A lab report follows the steps of the scientific method. Use the checklist below to create your own lab reports:

- **Title**: The title makes it easy for readers to quickly identify the topic of your experiment.
- **Research question**: The research question tells the reader exactly what you want to find out through your experiment.
- **Introduction**: This paragraph describes what you already know about the topic, and shows how this information relates to your experiment.
- **Hypothesis**: The hypothesis states the prediction you plan to test in your experiment.
- **Materials**: List all the materials you need to do the experiment.
- **Procedure**: Describe the steps involved in your experiment. Make sure that you provide enough detail so readers can repeat what you did. You may want to provide sketches of the lab setup. Be sure to name the experimental variable and tell which variables you controlled.
- **Data/Observations**: This is where you record what happened, using descriptive words, data tables, and graphs.
- **Analysis**: In this section, describe your data in words. Here’s a good way to start: My data shows that...
- **Conclusion**: This paragraph states whether your hypothesis was correct or incorrect. It may suggest a new research question or a new hypothesis.

A sample lab report

Use the sample lab report on the next two pages as a guide for writing your own lab reports. Remember that you are telling a story about something you did so that others can repeat your experiment.
Name: Lucy O.  

Date: January 24, 2007

Title: Pressure and Speed

Research question: How does pressure affect the speed of the CPO air rocket?

Introduction:

Air pressure is a term used to describe how tightly air molecules are packed into a certain space. When air pressure increases, more air molecules are packed into the same amount of space. These molecules are moving around and colliding with each other and the walls of the container. As the number of molecules in the container increases, the number of molecular collisions in the container increases. A pressure gauge measures the force of these molecules as they strike a surface.

In this lab, I will measure the speed of the CPO air rocket when it is launched with different amounts of initial pressure inside the plastic bottle. I want to know if a greater amount of initial air pressure will cause the air rocket to travel at a greater speed.

Hypothesis: When I increase the pressure of the air rocket, the speed will increase.

Materials:

- CPO air rocket
- CPO photogates
- CPO timer
- Goggles

Procedure:

1. I put on goggles and made sure the area was clear.
2. The air rocket is attached to an arm so that it travels in a circular path. After it travels about 330°, the air rocket hits a stopper and its flight ends. I set up the photogate at 90°.
3. My control variables were the mass of the rocket and launch technique, so I kept these constant throughout the experiment.
4. My experimental variable was the initial pressure applied to the rocket. I tested the air rocket at three different initial pressures. The pressures that work effectively with this equipment range from 15 psi to 90 psi. I tested the air rocket at 20 psi, 50 psi, and 80 psi. I did three trials at each pressure.
5. The length of the rocket wing is 5 cm. The wing breaks the photogate’s light beam. The photogate reports the amount of time that the wing took to pass through the beam. Therefore, I used wing length as distance and divide by time to calculate speed of the air rocket.
6. I found the average speed in centimeters per second for each pressure.
Data/Observations:

### Air pressure and speed of rocket

<table>
<thead>
<tr>
<th>Initial air pressure</th>
<th>Time (sec) at 90°</th>
<th>Speed (m/sec) at 90°</th>
<th>Average speed cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 psi</td>
<td>0.0227</td>
<td>2.20</td>
<td>216</td>
</tr>
<tr>
<td></td>
<td>0.0231</td>
<td>2.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0237</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>50 psi</td>
<td>0.0097</td>
<td>5.15</td>
<td>510</td>
</tr>
<tr>
<td></td>
<td>0.0099</td>
<td>5.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0098</td>
<td>5.10</td>
<td></td>
</tr>
<tr>
<td>80 psi</td>
<td>0.0060</td>
<td>8.33</td>
<td>794</td>
</tr>
<tr>
<td></td>
<td>0.0064</td>
<td>7.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0065</td>
<td>7.69</td>
<td></td>
</tr>
</tbody>
</table>

Analysis:

My graph shows that the plots of the data for photogates A and B are linear. As the values for pressure increased, the speed increased also.

Conclusion:

The data shows that pressure does have an effect on speed. The graph shows that my hypothesis is correct. As the initial pressure of the rocket increased, the speed of the rocket increased as well. There is a direct relationship between pressure and speed of the rocket.
2.2 Using Computer Spreadsheets

Computer spreadsheets provide an easy way to organize and evaluate data that you collect from an experiment. Numbers are typed into boxes called “cells.” The cells are organized in rows and columns. You can find the average of a lot of numbers or do more complicated calculations by writing formulas into the cells. Each cell has a name based on its column letter and row number. For example, the first cell in most spreadsheets is “A1.”

This skill sheet will show you how to:

1. Record data in a computer spreadsheet program.
2. Do simple calculations for many data values at once using the spreadsheet.
3. Make a graph with the data set.

To complete this skill sheet, you will need:

- Simple calculator
- Access to a computer with a spreadsheet program

1. **Adding data:** Open the spreadsheet program on your computer. You will see a window open that has rows and columns. The rows are numbered. The columns are identified by a letter.
   a. As shown in the graphic above, add headings for columns A, B, and C:
      - cell A1, type “Time (sec)”
      - cell B1, type “Temp (deg C)”
      - cell C1, type “Slope”
      
      *NOTE: You can change the width of the columns on your spreadsheet by clicking on the right-hand border and dragging the border to the left or right.*
   b. Highlight column B. Then, go to the **Format** menu item and click on **Cells**. Make the format of these cells **Number** with one decimal place. Highlight column C and make the format of these cells **Number** with two decimal places.
   c. Type in the data for Time and Temperature as shown in the graphic above.

2. **Making a graph:** Now, you will use the data you have added to the skill sheet to make a graph.
   a. Use your mouse to highlight the titles and data in columns A and B.
   b. Then, go to **Insert** and click on **Chart**.
   c. In step 1 of the chart wizard, choose the **XY (Scatter)** format for your chart and click “Next.”
   d. In step 2 of the chart wizard, you will see a graph of your data. Click “Next” again to get to step 3. Here you can change the appearance of the graph.
   e. In step 3 of the chart wizard, add titles and uncheck the show legend-option. In the box for the chart title write “Temperature vs. Time.” In the box for the value x-axis, write “Time (seconds).” In the box for the value for y-axis, write “Temperature (deg Celsius).”
f. In step 4 of the chart wizard, click the option to show the graph as an object in Sheet 2. At this point you will finish your work with the chart wizard.

g. Setting the scale on the $x$-axis: Place the cursor on the $x$-axis and double click. Set the minimum of the scale to be 0, the maximum to be 310. Set the major unit to be 100 and the minor unit to be 20. Then, click OK. **Note: Make sure the boxes to the left of the changed values are NOT checked.**

h. Setting the scale on the $y$-axis: Place the cursor on the $y$-axis and double click. Set the minimum of the scale to be 20, the maximum to be 41. Set the major unit to be 10 and the minor unit to be 2. Then, click OK. **Note: Make sure the boxes to the left of the changed values are UNchecked.**

i. You are now finished with your graph. It is located on Sheet 2 of your spreadsheet.

3. **Performing calculations:**

   a. Return to Sheet 1 of your spreadsheet.

   b. The third column of data, “Slope,” will be filled by performing a calculation using data in the other two columns.

   c. Highlight the second cell from the top in the Slope column (cell C2). Type the following and hit enter:

   $$\frac{(B3-B2)}{(A3-A2)}$$

   **Explanation of the formula:** The equal sign (=) indicates that the information you type into the cell is a formula. The formula for the slope of a line is as follows. Do you see why the formula for cell C2 is written the way it is?

   \[
   \text{slope} = \frac{y_2 - y_1}{x_2 - x_1}
   \]

   d. Adding the formula to all the cells: Highlight cell C2, then drag the mouse down the column until the cells (C2 to C11) are highlighted. Then click **Edit**, then **Fill**, then **Down**. The formula will copy into each cell in column C. However, the formula pattern will be appropriate for each cell. For example, the formula for C2 reads: $$\frac{(B3-B2)}{(A3-A2)}$$. The formula for C3 reads: $$\frac{(B4-B3)}{(A4-A3)}$$. **Note:** The “=” sign is important. Do not forget to add it to the formula.

   e. In column C, you will see the slope for pairs of data points. Now, answer the questions below.

   1. Which is the independent variable—time or temperature? Which is the dependent variable?

   2. When setting up the data in a spreadsheet, which data set goes in the first column, the independent variable or the dependent variable?

   3. Use the graph you created in step 2 of the example to describe the relationship between temperature and the time it takes to heat up a volume of water.

   4. Look at the values for slope. How do these values change for the graph of temperature versus time?
5. The following data is from an experiment in which the temperature of a substance was taken as it was heated. Transfer this data into a spreadsheet file and make an XY(Scatter) graph.

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent data</td>
<td>Dependent data</td>
</tr>
<tr>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>20</td>
<td>10.8</td>
</tr>
<tr>
<td>30</td>
<td>11.6</td>
</tr>
<tr>
<td>40</td>
<td>11.9</td>
</tr>
<tr>
<td>50</td>
<td>13.3</td>
</tr>
<tr>
<td>60</td>
<td>21.9</td>
</tr>
<tr>
<td>70</td>
<td>26.3</td>
</tr>
<tr>
<td>80</td>
<td>26.6</td>
</tr>
<tr>
<td>90</td>
<td>29.1</td>
</tr>
<tr>
<td>100</td>
<td>31.1</td>
</tr>
</tbody>
</table>

6. Use the following data set to make a graph in a spreadsheet program. Find the slope for pairs of data points along the plot of the graph. Is the slope the same for every pair of points?

<table>
<thead>
<tr>
<th>Independent data</th>
<th>Dependent data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>2.5</td>
<td>8</td>
</tr>
<tr>
<td>3.2</td>
<td>9.4</td>
</tr>
<tr>
<td>1.5</td>
<td>6</td>
</tr>
<tr>
<td>0.5</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>2.8</td>
<td>8.6</td>
</tr>
<tr>
<td>4.2</td>
<td>11.4</td>
</tr>
<tr>
<td>5</td>
<td>13</td>
</tr>
</tbody>
</table>
2.2 Identifying Control and Experimental Variables

An experiment is a situation set up to investigate relationships between variables. In a simple ideal experiment only one variable is changed at a time. You can assume that changes you see in other variables were caused by the one variable you changed. The variable you change is called the experimental variable. This is usually the variable that you can freely manipulate. For example, if you want to know if the mass of a toy car affects its speed down a ramp, the experimental variable is the car’s mass. You can add “cargo” to change the mass of car. The variables that you keep the same are called control variables. In the toy car experiment, control variables include the angle of the ramp, photogate positions, and release technique.

Use this skill sheet to practice identifying control and experimental variables.

• Alex is studying the effect of sunlight on plant growth. His hypothesis is that plants that are exposed to sunlight will grow better than plants that are not exposed to sunlight. In order to test his hypothesis, he follows the following procedures. He obtains two of the same type of plant, puts them in identical pots with potting soil from the same bag. Then he puts one plant in the sunlight and the other in a dark room. He waters the plants with 200 mL of water every other day for two weeks.

Solution:

The experimental variable in the experiment is the light exposure of the plant. One plant is put in sunlight and the other is put in darkness. The control variables are the type of plant, the pot, the soil, amount of water, and the time of the experiment.

1. Julie sees commercials for antibacterial products that claim to kill almost all the bacteria in the area that has been treated with the product. Julie asks, “How effective is antibacterial cleaner in preventing the growth of bacteria?” She sets up an experiment in order to study the effectiveness of antibacterial products. Julie hypothesizes that the antibacterial soap will prevent bacterial growth. In her experiment, she follows the following procedure.

a. Obtain two Petri dishes with nutrient agar.

b. Rub a cotton swab along the surface of a desk at school. Then, carefully rub the nutrient agar with the cotton swab without breaking the gel.

c. Repeat the same process with the other Petri dish.

d. Spray one of the Petri dishes with an antibacterial kitchen spray.

e. Carefully tape shut both of the Petri dishes and place them in an incubator.

f. Check the Petri dishes and record the results once a day for one week.

Identify the experimental variable and three control variables in the experiment.
2. John notices that his mom waters the plants in their house every other day. He asks, “Will plants grow if they are not watered regularly?” He hypothesizes that plants that are not watered regularly will not grow as large as plants that are watered regularly. In order to test his hypothesis, he conducts the following experiment.
   a. Obtain two healthy plants of the same variety and size.
   b. Plant each plant in the same type of pot and the same brand of potting mix.
   c. Place both plants in the same window of the house.
   d. Water one of the plants every other day with 250 mL of water.
   e. Water the other plant once a week with 250 mL of water.
   f. Measure the height of the plants once a day for one month.

Identify the experimental variable and three control variables in the experiment.

3. Mike’s dad always buys bread with preservatives because he says it lasts longer. Mike asks, “Will bread with preservatives stay fresh longer than bread without preservatives?” He hypothesizes that bread with preservatives will not grow mold as quickly as bread without preservatives. In order to test his hypothesis, he conducts the following experiment.
   a. Obtain one slice of bread containing preservatives and one slice of bread without any preservatives.
   b. Dampen two paper towels. Fold the paper towels so that they will lay flat inside a zipper-top bag.
   c. Lay each paper towel inside a separate zipper-top bag.
   d. Place one slice of bread in each bag and seal the bags.
   e. Place bags with bread and paper towels in a dark environment for one week.
   f. Record mold growth once a day for one week.

Identify the experimental variable and three control variables in the experiment.

4. In science class, Kathy has been studying protists. She has been learning specifically about protists called algae that live in ponds. She knows that algae thrive when there are plenty of nutrients available for them. Kathy asks, “Will water that has been treated with fertilizer have more algae than water that has not been treated with fertilizer?” In order to test her hypothesis, Kathy does the following experiment.
   a. Obtain a sample of algae from the teacher.
   b. Obtain two beakers with 500 mL of water in each beaker.
   c. Put one teaspoon of plant fertilizer in one of the beakers.
   d. Put an equal amount of algae sample in each of the beakers.
   e. Place the beakers in a sunny window for two weeks.
   f. Using a microscope, examine algae growth in each of the beakers every other day for the two weeks and record your results.

Identify the experimental variable and three control variables in the experiment.
To describe any location in two dimensions, we use a grid called the **coordinate plane**. You can describe any **position** on the coordinate plane using two numbers called **coordinates**, which are shown in the form of \((x, y)\). These coordinates are compared to a fixed reference point called the **origin**. The table below describes the \(x\) and \(y\) coordinates:

<table>
<thead>
<tr>
<th>Coordinate</th>
<th>Which axis is it on?</th>
<th>Which is the positive direction?</th>
<th>Which is the negative direction?</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x)</td>
<td>horizontal, called the (x)-axis</td>
<td>right or east</td>
<td>left or west</td>
</tr>
<tr>
<td>(y)</td>
<td>vertical, called the (y)-axis</td>
<td>up or north</td>
<td>down or south</td>
</tr>
</tbody>
</table>

**Example**

Your home is at the origin, and a park is located 2 miles north and 1 mile east of your home.
- Show your home and the park on a coordinate plane, and give the coordinates for each.
- After you go to the park, you drive 2 miles east and 1 mile north to the grocery store. What are the coordinates of the grocery store?

**Solution**

If your home is at the origin, it is given the coordinates \((0, 0)\). By counting over 1 box from the origin in the positive \(x\)-direction and up 2 boxes in the positive \(y\)-direction, you can place the park on the coordinate plane. The park’s coordinates are \((+1\ miles, +2\ miles)\).

From the park, count over 2 more boxes in the positive \(x\)-direction and up one more 1 box in the positive \(y\)-direction to place the grocery store. That makes the grocery store’s coordinates \((+3\ miles, +3\ miles)\).

**Practice**

1. You are given directions to a friend’s house from your school. They read: “Go east one block, turn north and go 4 blocks, turn west and go 1 block, then go south for 2 blocks.” Using your school as the origin, draw a map of these directions on a coordinate plane. What are the coordinates of your friend’s house?

2. A dog starts chasing a squirrel at the origin of a coordinate plane. He runs 20 meters east, then 10 meters north and stops to scratch. Then he runs 10 meters west and 10 meters north, where the squirrel climbs a tree and gets away.
   a. Draw the coordinate plane and trace the path the dog took in chasing the squirrel.
   b. Show where the dog scratched and where the squirrel escaped, and give coordinates for each.

3. Does the order of the coordinates matter? Is the coordinate \((2, 3)\) the same as the coordinate \((3, 2)\)? Explain and draw your answer on a coordinate plane.
3.1 Latitude and Longitude

History: Latitude and longitude are part of a grid system that describes the location of any place on Earth. When formalized in the mid-18th century, the idea of a grid system was not a new one. More than 2000 years ago, ancient Greeks drew maps with grids that looked much like our maps today. Using mathematics and logic, they postulated that Earth could be mapped in degrees north and south of the Equator and east and west of a line of reference. From the ancient times, geographers and navigators used devices such as the cross-staff, astrolabe, sextant, and astronomical tables to determine latitude. But determining longitude required accurate timepieces, and they were not reliably designed until the 1700’s.

Latitude: Think of Earth as a transparent sphere, just as the ancient Greeks did. Now imagine yourself standing so that your eyes are at the center of that sphere. If you tip your head back and look straight up, you will see the North Pole above you. If you look straight down, you will see the South Pole below you. If you turn around while looking straight out at the middle of the sphere, your eyes will follow the Equator, the line around the middle of Earth. The ancient Greeks realized that they could describe the location of any place by using its angle from the Equator as measured from that imaginary place at the center of Earth.

All latitude lines run parallel to the Equator, creating circles that get smaller and smaller until they encircle the Poles. Because latitude lines never intersect, latitude lines are sometimes referred to as parallels.

At first, you might be confused because when latitude lines are placed on a map. They appear to run from the left side of the page to the right. You might think they measure east and west, but they don't. The graphic at the right shows latitude lines. If you think of them as steps on a ladder, then you will see the lines are taking you “up” toward the north or “down” toward the south. (Of course, there is no real “up” or “down” on a map or globe, but the association of LAdder and LAtitude may help you.)

The Equator is designated as 0º. The North Latitude lines measure from the Equator (0º) to the North Pole (90ºN). The South Latitude lines measure from the Equator (0º) to the South Pole (90ºS). There are other special latitude lines to note. The Tropic of Cancer is at 23.5ºN latitude, and at 23.5ºS latitude is the Tropic of Capricorn. These lines represent the farthest north and farthest south where the sun can shine directly overhead at noon. Latitudes of 66.5º N and 66.5º S mark the Arctic and Antarctic Circles, respectively. Because of the tilt of the Earth, there are winter days when the Sun does not rise and summer days when the sun does not set at these locations.

Longitude: Now imagine yourself back in the transparent sphere. Look up at the North Pole and begin to draw a continuous line with your eyes along the outside of the sphere to the South Pole. Turn to face the opposite side of the sphere and draw a line from the South Pole to the North Pole. These lines, and all other longitude lines, are the same length because they start and end at the poles. Look at the graphic below and see that although longitude lines are drawn from north to south, they measure distance from east or west.
There are no special longitude lines, so geographers had to choose one from which to measure east and west. Longitude lines are also called meridians, so this special line is called the Prime Meridian and is labeled 0°. The ancient Greeks chose a Prime Meridian that passed through the Greek Island of Rhodes. In the 1700's, the French chose one that passed through Ferro, an island in the Canary Islands. There are maps that show that America even used Philadelphia as their special reference location. But in 1884, the International Meridian Conference met in Washington, DC. They chose to adopt a Prime Meridian that passes through an observatory in Greenwich, England. At the same conference, they also determined a point exactly opposite of the Prime Meridian. This second important longitude line is the 180° meridian. Longitude lines measure eastward and westward from the Prime Meridian (0°) to the 180° meridian. Superimposed on the 180° meridian is the International Dateline. This special line does not follow the 180° meridian exactly. It zigzags a bit to stay in the ocean, which is an unpopulated area. International agreements dictate that the date changes on either side of the Dateline.

GPS and decimal notations. In the past, latitude and longitude lines always had measurement labels of degrees (°), minutes (′), and seconds (″). The labels of “minutes” and “seconds” did not denote time in these cases. Instead they described places between whole degrees of longitude or latitude more exactly. For example, consider Sacramento, CA. Traditionally, its location was said to be at 38° 34′ 54″N (38 degrees, 34 minutes, 54 seconds North) and 121° 29′ 36″W (121 degrees 29 minutes, 36 seconds West). Now GPS (Global Positioning System), in decimal notation would say Sacramento is located at 38.58°N and 121.49°W. Note: As a matter of custom when giving locations, latitude is listed first and longitude second.

**Finding a Location on a Globe**

You can find any location by using latitude and longitude on a globe. See the example in the diagram. The position is 70°N and 40°W. First on the globe, you would find the latitude line 70°N, seventy degrees north of the Equator. Next you would find the longitude line 40°W, forty degrees west of the Prime Meridian. Trace the lines with your fingers. Where they intersect, you will find the location. In this case, you have located Greenland.

**Finding a Location on a Map**

You use the same procedure to find any location on a map. Look at the graphic below. The position is 10°S and 160°E. First you would find the latitude line 10°S, ten degrees south of the Equator. Next you would find the longitude 160°E, one hundred-sixty degrees east of the Prime Meridian. You have located the Solomon Islands.
Use an atlas or globe to answer these practice questions.

1. What country will you find at the following latitude and longitude?
   a. 65°N 20°W
   b. 35°N 5°E
   c. 50°S 70°W
   d. 20°S 140°E
   e. 40°S 175°E

2. What body of water will you find at the following latitude and longitude?
   a. 20°N 90°W
   b. 40°N 25°E
   c. 20°N 38°E
   d. 25°N 95°W
   e. 0°N 60°W

Converting Traditional Notation To Decimal Notation

Sometimes you need to convert the traditional notation of degrees, minutes, and seconds into decimal notation. First you must understand this traditional notation, which was a base-60 system.

<table>
<thead>
<tr>
<th>Traditional Notation</th>
<th>Decimal Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>34º 15'</td>
<td>34.25º</td>
</tr>
<tr>
<td>12º 20' 38&quot;</td>
<td>12.34º</td>
</tr>
</tbody>
</table>

One degree = 60 minutes
One minute = 60 seconds
One degree = 3,600 seconds (60 × 60)

Let's look at 34° 15' (thirty-four degrees 15 minutes).

Regardless of the system, the notation will begin with 34 degrees. To change the minutes into a decimal, you must divide 15 by 60, the number of minutes in one degree (15/60). The answer is 0.25. Therefore, the decimal notation would be 34.25º or thirty-four and twenty-five hundredths degrees.

Let's look at 12° 20' 38" (twelve degrees, twenty minutes, thirty-eight seconds). We know the notation will begin with 12 degrees. Next we have to convert the 20 minutes into seconds (20 × 60 = 1,200 seconds). Then we add the 38 seconds for a total of 1,238 seconds. There are 3,600 seconds in one degree, so you must divide 1,238 by 3,600. (1,238 / 3,600). The answer is 0.34. Therefore the decimal notation would be 12.34º or twelve and thirty-four hundredths degrees.
3. Convert the following latitudes in traditional notation to decimal notation. (Round your answer to the nearest hundredth.)
   a. 30º 20' N
   b. 45º 45' N
   c. 20º 36' 40" S
   d. 60º 19' 38" S

4. Convert the following longitudes in traditional notation to decimal notation. (Round your answer to the nearest hundredth.)
   a. 25º 55' E
   b. 145º 15' E
   c. 130º 37' 10" W
   d. 85º 26' 8" W
3.1 Map Scales

Mapmakers have developed a tool that allows them to accurately draw the entire world on a single piece of paper. It’s not magic—it’s drawing to scale. To be useful, maps must be accurately drawn to scale. The mapmaker must also reveal the scale that was used so that a map-reader can appreciate the larger real-life distances. The scale is usually written in or near the map’s legend or key.

There are three kinds of map scales: fractional, verbal, and bar scales. A fractional scale shows the relationship of the map to actual distance in the form of a fraction. A scale of 1/100,000 means that one centimeter on the map represents 100,000 centimeters (or 1 kilometer) of real life distance.

A verbal scale expresses the relationship using words. For example, “1 centimeter equals 500 kilometers.” This is a more usable scale, especially with large real-life distances. With a scale of 1 cm = 500 km, you could make a scale drawing of North America on one piece of paper.

A bar scale is the most user-friendly scale tool of all. It is simply a bar drawn on the map with the size of the bar equal to a distance in real life. Even if you do not have a ruler, you can measure distances on the map with a bar scale. Just line up the edge of an index card under the bar scale and transfer the vertical marks to the card. Label the distances each mark represents. You can then move the card around your map to determine distances. You might wonder what you should do if a location falls between the vertical interval lines. You must use estimation to determine that distance. Be careful to look at the scale before estimating. For example, if the distance falls half-way between the 10 and the 20 kilometer scale marks, estimate 15 kilometers. If the scale is different and the distance falls half-way between 30 and 60 kilometer marks, you must estimate 45 kilometers.

Let’s explore the different kinds of scales. You will need centimeter graph paper, plain paper, an index card, and a centimeter ruler or measuring tape for these activities.

**EXAMPLES**

**Fractional scale**

Materials: Graph paper

Trace a simple object on a piece of graph paper. (A large paper clip, pen, small scissors, or paperback book works well.) Now make a scale drawing of the object using the fractional scale of 1/4. (Remember this means that for every 4 blocks occupied in the original tracing, you will have only one block on the scale drawing.) Be sure to label the scale on the finished scale drawing.
Verbal scale

Materials: Centimeter graph paper and centimeter measuring tape or ruler.

You are going to make a scale drawing of a person. Ask a classmate to stand against a wall with his/her arms outstretched to the side. Take 4 measurements in centimeters: 1) Distance from top of head to floor. 2) Distance from right finger tip to left finger. 3) Distance from top of head to shoulders. 4) Distance from shoulders to waist. Write the verbal scale of “1 cm equals 10 cm” on the bottom of a piece of centimeter graph paper. On that paper translate the measurements that you took into a simple figure drawing of your classmate. (Remember if a measurement is 25 centimeters in real life, you will have to make a drawing that is within 2 ½ centimeter blocks of the graph paper.)

Bar scale

Materials: Plain paper and centimeter ruler or tape.

Position the paper so that it is wider than it is long.

Draw a bar scale that is a total of 6 centimeters long at bottom of the paper. Make four vertical marks at 0 cm, 2 cm, 4 cm, and 6 cm. Write “0” over the first mark, “50” over the second, “100” over the third and “150” of the last mark. Underneath the bar write “Kilometers.” Mark “N” for north at the top of your paper. Now use your imagination to draw an island (of any shape) that is 450 miles long and 200 miles wide at its widest point. Draw a star to mark the capital city, which is located on the northern coast 100 miles from the west end of the island.

PRACTICE

1. Answer these questions about Andora and Calypso:
   a. Which island appears bigger?
   b. Can you tell whether you can ride a bike in one day from point A to point B on either map? If no, why not?
   c. Measure the distance from the center of the dot to the right of A to the center of the dot to the left of B on both maps. Are the measurements the same?
   d. If the measurements are the same on both maps, does that mean the distance from point A to point B is the same on both maps? Explain your answer.
   e. Let’s write in the scale for these two islands. Write the scale of 1 cm = 5 km on Andora. Write the scale of 1 cm = 1000 km on Calypso. Now answer the question, which island is bigger?

2. On the next page is a map of Monitor Island. Use the bar scale to find distances on this island. Assume that you are measuring “as the crow flies.” That means from point to point by air because there are no roads to follow. Always measure from dot to dot, and be sure to label your answers in kilometers.
   a. Point L to Point M
   b. Point Y to Point Z
   c. Point Z to Point P
   d. Point P to Point M
   e. Point Q to Point T
f. Point Q to Point M

g. Point T to Point M

h. Point Z to Point P to Point X

i. Point X to Point L to Point M

j. Point X to Point P to Point Z to Point Y

**Bonus:** Measure around the coast of Monitor Island. It’s hard to be exact, but write your best estimate.
3.1 Navigation Project

Nautical charts have long been used by ship captains to navigate the oceans. As land has been increasingly developed and harbors built, more and more information is needed to safely navigate near shore. Additionally, offshore shallow banks, reefs, islands, seamounts, and other obstructions needed to be identified so that they don’t hinder the passage of boats.

In this project, you and two other captains will navigate through the waters around Puerto Rico and some of the Virgin Islands using three real nautical maps. Your journey includes a stop at Isla de Vieques, which was a US Navy testing ground for bombs, missiles, and other weapons. It was vacated in May 2003 and now is used by locals and tourists. Bon Voyage.

Materials:

- NOAA map #25640 (laminated)
- NOAA map #25641 (laminated)
- NOAA map #25647 (laminated)

Note:
Laminated maps are available from NOAA (www.noaa.gov) or boating/marine supply stores, as well as some Coast Guard Stations.

- Internet access
- Erasable overhead projector marker

Getting started:

1. Have all three maps accessible.
2. Before beginning your imaginary journey, spend some time studying the maps. Look at any legends (example: note on pipelines and cables), abbreviation lists, and Notes (such as Note E on map 25640). Look at the map scale. Note whether the soundings are in fathoms or feet.
3. Note that the maps are laminated, so you can use an erasable marker to outline your path.

Making predictions:

a. What kind of ecosystem do you expect to find in these warm, sunlit waters?

b. What does this mean about navigating this area?
It’s time to go!

1. You and your two partners are tri-captains on a boat that is 12 feet deep. On board, you have a small row boat. Besides your clothes and toiletries for the trip, you will bring along wading boots, a solar still, a radio, your three maps, water, and food.

2. You will be traveling from the west coast of Puerto Rico, eventually ending your trip on the island of St. John. As captains, you will be making decisions about the course the boat will be taking based on directions given below. You will need to look out for (among other things) shallow water, pipelines, and other obstructions. Listen to what the map is telling you.

3. Let’s start with map 25640. What is the scale of this map?

4. What does that mean?

5. How many feet are there in a fathom? Hint: The answer is outside the border of the map.

6. Find Punta Higuero on the west coast of Puerto Rico. What is located here? Use your abbreviations. You will probably have to look it up.

7. You will now be moving south along the west coast and then the south coast of Puerto Rico. Notice the light blue area around the coast. At the seaward edge of this area is a line. Every few inches along this line, you will see a number 10. What this means is that anywhere along this line the depth of the water is 10 fathoms. Remember, your boat is 12 feet deep. How many fathoms is this?

8. So your boat is fine anywhere along the line. However, as you head toward the coast from this 10-fathom line, the depth decreases, but since the depth is not marked again, you do not know how quickly it decreases and thus can’t take your boat any closer to the shore. Remember this as you travel. So start traveling south. What do you encounter near the Bahia de Mayaguez?

9. What does this mean?

10. Is the depth of the water still suitable for traveling?

11. Travel around the marine conservation district. Should anyone be fishing here?

12. Can you pass between Bajas Gallardo and the Marine Conservation District? If so, trace the path through and if not, find another way around towards the south shore.

13. Stay near to shore so you can have great views of the beautiful shallow blue waters. Find Punta Cayito and Punta Barrancas on the south shore. In the area offshore, there is a section between the 10 fathoms line and the next depth line of 100 fathoms where there are several abbreviated notations. Name three by noting the abbreviation and what it means.

14. Find the lighthouse near Cayos de Ratones. What type of lighthouse is it and why is that different than occulting?

15. 5M means that it can be seen for 5 nautical miles, which is 1.852 kilometers or 1.15 miles.

16. As you travel towards the southeastern coast of Puerto Rico, what area in a square dashed purple box do you see?

17. Do you think it would be a good or bad idea to drop anchor there?
18. Head to Isla de Vieques. There are supposed to be two beautiful bays that are filled with organisms that are bioluminescent. These one-celled organisms give off a blue-green glow when disturbed. You'll have to wait here until night-time in order to see this natural wonder. Can you take your ship right up to the shore? If not, what can you do to get there?

19. How many lighthouses are there on the Island?

20. Two lighthouses are flashing. One is occulting. What is the fourth, what does the symbol mean, and what two colors are associated with it?

21. How far out can you see the flashing and occulting lighthouse lights on the Island?

22. Your next stop is Savana Isle, a small island just west of St. Thomas. As you travel in that direction, what do you notice there are many of in the area of the Virgin Passage?

23. What does that mean you should NOT do in this area?

24. Can you bring your boat in directly to Savana Isle?

25. What does the (269) mean?

26. Now you are going to move to map 25641. The soundings are done in what units?

27. Orient yourselves for a minute. You are currently at Savana Isle. Find it on the map.

28. What is the scale on this map?

29. You can see that the scales on the maps are quite different. What do you notice when you look at the maps themselves. How are they different?

30. When you are sailing in this area, where do you call to report spills of oil and hazardous substances? There are two choices.

31. For weather information, to what station do you tune?

32. From Savana Isle, head toward Cricket Rock using Salt Cay or Dutchcap Passage. How many fathoms deep is the coastline?

33. Should you anchor and row in or go right up to the shore?

34. How much rock is covered and uncovered?

35. What are the local bottom characteristics?

36. By the way, what is a cay?
37. Now you will head to White Horseface Reef at Hans Lollik Isle. Watch your depths as you travel in that direction. What is submerged en route to the Isle?

38. Anchor where you can and spend some time snorkeling. Once you have completed your swim and returned to the ship, start heading through the Leeward Passage. Move to map 25647 at this point. In what units are the soundings measured?

39. What is the scale?

40. Once again, what do you notice about the scale and amount of detail in the map?

41. On this map, what do the green solid and dashed green lines represent?

42. How does that affect your boat?

43. Heading through Leeward Passage and south of Thatch Cay, there is a rectangular box with a blue tint in the waterway. It is there to let you know, as captains, that there is an obstruction, a fish haven, which is an artificial reef. These are usually made of rock, concrete, car bodies, and other debris. If you'll notice, inside the box, it states an authorized minimum depth of 60 feet. If you look at the depth of the water on the map around the box, the values are deeper than 60 feet. Because of the artificial reef, the map is telling you that you can be assured to not have any obstruction down to 60 feet, but it is hazardous after that depth. The minimum depth is checked by sweeping the area with a length of horizontal wire. If there is an obstruction, the wire would get snagged. Is your boat okay to travel through this area?

44. Continue to Cabrita Point and through to St. James Bay. You are headed towards Jersey Bay, but you are going to have to be very careful navigating the Jersey Bay area as you will then head into Banner Bay Channel. It is recommended by the map that you seek local knowledge about some broken piles (wooden columns driven into the harbor sand beds on which structures can be built in the water) which may be below the waterline and are not marked on the map. As you look at the channel, make note of the depth of the water. Will you be able to take your boat in or row in? How can you tell?

45. Bring your wading boots just in case you need them. The symbols that look like ties (colored in green and purple) will help you navigate your way. These are buoys. The first letter of each buoy is either an R for ‘red’ or G for ‘green.’ The rule of thumb is to keep red buoys to the right (starboard) when returning to a harbor and green buoys to the left (port). Using that rule, get yourself to the coast and have some lunch in town, especially after all that rowing.
46. Take a taxi ride west of the harbor to the mangrove lagoon. Can you wade in there with your boots?

47. Mangroves are trees and shrubs that grow in saline marine areas. The mangrove roots impede the water flow. Since the water is carrying sediment, the slowed water deposits the sediment over time and actually builds coastline. These are very special ecosystems.

48. Spend some time here, take the taxi back to the row boat, and get back to your ship.

49. Find a path to St. John and choose a landing site. Describe three more nautical notations that you encounter and how they influenced your route.

50. Congratulations! Your voyage has ended. Hope you learned how important map reading is for nautical navigation. Show your teacher your route.
4.1 Vectors on a Map

You have learned that velocity is a vector quantity—this means that when you talk about velocity, you must mention both speed and direction. You can use velocity vectors on a coordinate plane to help you figure out the position of a moving object at a certain point in time.

**Example**

Your home is at the origin. From there you ride your bicycle to the movie theater. You ride 30. km/hr north for 0.50 hour, and then 20. km/hr east for 0.25 hours.

Show your home and the movie theater on a coordinate plane, and give the coordinates for each.

**Solution:**

If your home is at the origin, it is given the coordinates (0, 0). To find the position of the movie theater, you need to find the change in position. Use the relationship:

\[ \text{change in position} = \text{velocity} \times \text{change in time} \]

First change in position: \(+30. \text{ km/hr} \times 0.50 \text{ hr} = 15 \text{ km}\)
NORTH

Second change in position: \(+20. \text{ km/hr} \times 0.25 = 5 \text{ km}\)
EAST

From home, travel north 15 km. Then turn and go east 5 km.

The coordinates of the movie theater are \((+5 \text{ km}, +15 \text{ km})\).

**Note:** Be careful to report the \(x\)-coordinate first. It does not matter which direction you traveled first. When reporting position, you always give the \(x\)- (east-west) coordinate first, then the \(y\)- (north-south) coordinate.

**Practice**

1. Augustin and Edson are going to a baseball game. To get to the stadium, they travel east on the highway at 120. km/hr for 30. minutes. Then they turn onto the stadium parkway and travel south at 60. km/hr for 10. minutes. Assume their starting point is at the origin. What is the position of the stadium?

2. Destiny and Franijza are at the swimming pool. They decide to walk to the ice cream shop. They walk north at a pace of 6 km/hr for 20. minutes, and then east at the same pace for 10. minutes. If the swimming pool is at the origin \((0,0)\) what is the position of the ice cream shop?

3. After finishing their ice cream, the girls decide to go to Destiny’s house. From the ice cream shop, they walk south at a pace of 4.0 km/hr for 15 minutes. What is the position of Destiny’s house?

4. Draw a map showing the swimming pool at the origin \((0,0)\). Show the coordinates of the ice cream shop and Destiny’s house.

5. **Challenge!** Make up your own velocity question. Your object (or traveler) should make at least one turn. Use at least two different speeds in your problem. Trade questions with a partner. Use a coordinate plane to help you solve the new question.
3.2 Topographic Maps

Flat maps can easily show landmasses and political boundaries. However, mapmakers need to draw special maps, called topographic maps, to show hills, valleys, and mountains. Mapmakers use contour lines to show the elevation of land features. The 0 contour line refers to sea level. The height above sea level is measured in equal intervals. Always look at the legend to see the elevation of each contour line interval. Sometimes these contour lines describe an increase of 20 feet. On other maps, especially those showing mountains, the contour lines may show elevation intervals of 100 to 1000 feet.

- **Contour lines and elevations**

  Look at Figure 1. On this map, the contour interval is 100 feet. Let’s look at the letters marked on the map. Point A is at sea level. That means it is on the 0 contour line all the way around the island. Point B is on the next contour line. That means that B is 100 feet above sea level. What is the elevation at Point C? If you said 200 feet, you would be correct. At what elevation is Point D? The correct answer is somewhere between 0 and 100 feet. You can’t be exact because D is not on a contour line. Where is Point E? Yes, it’s at sea level, the same level as A.

  Take a minute to color the contour key and the map. Color green between 0 and 100 feet, color yellow between 100 and 200 feet, color red between 200 and 300 feet. Mapmakers generally use blue for water only, so do not use it in a contour key.

- **Profile Maps**

  You can also translate contour lines into a profile map. In this way you can actually draw what you would see if you were approaching by sea. Look at the following map as you read the steps to create a profile map. First, you draw a graph above the map that shows the intervals. The contour is 20 feet so you would label the elevation in 20-foot intervals on the left. Your task is to make dots on the lines of the graph directly above the island contour lines. Put a ruler against the left hand edge of the island, and make a dot on the 0’ line of the graph. Slide your ruler to the right hand edge of the island and make a second dot on the 0’ line. Next go to the second contour line and mark two dots on the 20-foot interval line in the graph above the map. Continue marking two dots at the widest dimensions for contour lines 40 feet and 60 feet. Now connect the dots. This shows you the profile of the island. Note, the island’s elevation is probably a little more than 60 feet, so you could draw a peak on the top of the hill taller than 60 but less than 80 feet. Even if the island were 79 feet tall, there would not be an 80-foot contour line.
1. Draw a profile map of the island in Figure 3. (Hint: You will have four dots on the 20' line.)

2. Reverse the process to make a topographic map from the profile map. For each dot on the graph, you will make a small dot on the map showing where the contour line begins or ends. Draw a free form contour line that runs through the two dots. The 0' contour (sea level) has been done for you.
3. Color the following map and contour key, and answer the questions.

\[ 
\begin{array}{c}
\text{Contour} = 100 \text{ feet} \\
\end{array} 
\]

a. What is the lowest elevation on this map? _______
b. What is the highest elevation on this map? _______
c. What is the elevation at X? _______
d. What is the elevation at Y? _______
e. What is the elevation at Z? _______

4. Today scientists worry that global warming may cause the ice caps to melt, causing the sea levels to rise. Look at the map below. It has a contour of 15 feet.

a. Let’s pretend that the sea level has risen 15 feet. Color the first contour (0–15') of the map dark blue, so that the new sea level is revealed. How has this island changed?

b. Now let’s pretend that the sea level rises another 15 feet. Color the next contour light blue and describe the changes in the original island.

c. What if the sea level rose by 30 feet due to global warming, and a hurricane hit the island? Could the people find dry land if there were a 35-foot storm wave?
Imagine that all the water in the oceans disappeared. If this happened, you would be able to see what the bottom of the ocean looks like. Fortunately, we don’t have to drain water from the ocean to get a picture of the ocean floor. Instead, scientists use echo sounding and other techniques to “see” the ocean floor. The result is a bathymetric map. This skill sheet will provide you with the opportunity to practice reading a bathymetric map.

Main features on a bathymetric map

1. Main features on a bathymetric map are mid-ocean ridges, rises, deep ocean trenches, plateaus, and fracture zones. Find one example of each of these on a bathymetric map.
   a. Mid-ocean ridge:____________________
   b. Rise: ____________________
   c. Deep ocean trench: ____________________
   d. Plateau: ____________________
   e. Fracture zones: ____________________

2. All the ridges you see on the bathymetric map behave in the same way even though they may not be in the middle of an ocean. What happens at mid-ocean ridges?

3. Find the Rio Grande Rise on the bathymetric map. Then, find the East Pacific Rise.
   a. Which of these features is an example of a mid-ocean ridge?
   b. Find another example of a rise that is a mid-ocean ridge. Justify your answer.
   c. Find another example of a rise that is not a mid-ocean ridge. Justify your answer.

4. There are a number of deep ocean trenches on the western side of the North Pacific Ocean. What process is going on at these trenches?

5. What plate tectonic process probably caused the fracture zones in the North Pacific Ocean? Justify your answer.

How is the East Pacific Rise different from the Mid-Atlantic Ridge?


8. Which of these features has a noticeable dark line running along the middle of the feature? Look at the legend at the bottom of the map. What does this dark line indicate?
9. Based on your observations of these two features, draw a cross-section of each in the boxes below.

| Mid-Atlantic Ridge cross-section | East Pacific Rise cross-section |

10. One of these mid-ocean ridges has a very fast spreading rate. The other has a very slow spreading rate. Which one is which? Justify your answer based on your answer to questions 8 and 9.
3.3 Tanya Atwater

*Tanya Atwater is a professor of Earth Science at the University of California, Santa Barbara. She has studied sea floor spreading and propagating rifts. She is currently researching the plate tectonic history of western North America. One of her main goals as a geologist is to educate people about our Earth.*

**Artist and adventurer**

While growing up, Tanya Atwater wanted to be an artist. She loved figuring out how to record on paper the things she could see in three dimensions.

Atwater and her family went on many vacations, where, she says, “I always hogged the maps, taking great pleasure in translating between the paper map and the passing countryside.” Whether it was camping, hiking, or river rafting, all of the trips had one thing in common—adventure. As a result, Atwater developed a deep love for the outdoors.

**Geology in the mountains and at sea**

Atwater started her college career at the Massachusetts Institute of Technology (MIT). She tried a variety of majors, including physics, chemistry, and engineering. Atwater then attended the Indiana University geology summer field camp in Montana. There, she learned about geological mapping and how land structures translate into lines and symbols. Atwater was hooked on geology!

Atwater transferred to the University of California at Berkley. She had already completed many math and physics courses at MIT, so she decided to major in geophysics.

After graduation, Atwater held an internship at Woods Hole Oceanographic Institute in Massachusetts. There, she combined the adventures of ocean sailing with geophysics.

**A close look in a tiny submarine**

In 1967, Atwater began graduate school at the Scripps Oceanographic Institution in La Jolla, California. During this time, many exciting geological discoveries were being made. The concept of sea floor spreading was emerging, leading to the current theory of plate tectonics.

While at Scripps, Atwater joined a research group that used sophisticated equipment on ships to study the sea floor near California.

Part of Atwater’s later research on sea floor spreading involved twelve trips down to the ocean floor in the tiny submarine Alvin. Only Atwater and two other people could fit in it. Using mechanical arms, they collected samples on the ocean floor nearly two miles underwater! Atwater’s firsthand view through Alvin’s portholes gave her a better understanding of the pictures and sonar records she had studied.

She was also amazed to see hot springs gushing out of the ocean floor near volcanoes. She adds, “A whole bunch of brand new kinds of animals were living there. We saw giant white tubes with bright red worms living in them, giant clams, octopuses, crabs, giant anemones, and lots of slimy things. Weird!”

**Propagating rifts**

In the 1980s, Atwater was part of a team that researched propagating rifts near the Galapagos Islands off the coast of Ecuador. Propagating rifts are created when sea floor spreading centers realign themselves in response to changes in plate motion or uneven magma supplies.

Atwater also discovered many propagating rifts on the sea floor in the northeast Pacific Ocean and in ancient sea floor records worldwide.

**An Earth educator**

Atwater has been a professor at the University of California, Santa Barbara for over 25 years. She has received many awards for her work in geophysics. She currently studies the plate tectonic history of western North America. This includes how the San Andreas Fault and Rocky Mountains were formed.

Atwater also works with media, museums, and teachers and she creates educational animations to educate people about Earth. She explains, “My job as a geoscience educator is to help as many students as possible to know and understand and respect our planet—to help them really care about it and act on their caring.”
Reading reflection

1. How did Atwater’s family contribute to her passion for planet Earth?

2. Why was it an exciting time to study geology while Atwater was in graduate school?

3. Describe how Atwater has gotten close-up views of the ocean floor.

4. What are propagating rifts and where has Atwater observed them?

5. How does Atwater educate people about Earth?

6. Research: The Woods Hole Oceanographic Institution—Marine Operations has used the submarine Alvin for many research endeavors for over 40 years. Describe some of Alvin’s noteworthy trips.
4.1 Solving Equations with One Variable

It is useful to know formulas for calculating different quantities. Often, the formulas are very straightforward. It’s easy to calculate the volume of a rectangular solid when you know the formula:

\[ \text{Volume} = V = \text{length} \times \text{width} \times \text{height} \ (V = l \times w \times h) \]

and the length, width, and height of the solid. It’s a little more challenging when you know the volume, length, and width, but need to find the height. It then becomes necessary to solve an equation in order to determine the unknown (in this case, the height).

1. The volume of a rectangular solid, with a length of 1.5 cm, is 10.98 cm³. The width of the same solid is 1.2 cm. Find its height.

**Explanation/Answer:** use the formula \( V = l \times w \times h \), and then plug in what is known, leaving the variable \( h \) for the unknown. Solve the equation for \( h \) to find the height.

<table>
<thead>
<tr>
<th>The Work:</th>
<th>What’s happening:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V = l \times w \times h )</td>
<td>Formula</td>
</tr>
<tr>
<td>10.98 cm³ = 1.5 cm × 1.2 cm × h</td>
<td>Plug in known values.</td>
</tr>
<tr>
<td>10.98 cm³ = 1.8 cm² × h</td>
<td>Complete arithmetic, multiply 1.5 × 1.2</td>
</tr>
<tr>
<td>( \frac{10.98 \text{ cm}^3}{1.8 \text{ cm}^2} = \frac{1.8 \text{ cm}^2}{1.8 \text{ cm}^2} \times h )</td>
<td>Divide both sides by 1.8 cm², to get ( h ) alone.</td>
</tr>
<tr>
<td>6.1 cm = 1 × h</td>
<td>Do the division; 10.98 cm³ ÷ 1.8 cm² = 6.1 cm, 1.8 cm² ÷ 1.8 cm² = 1</td>
</tr>
<tr>
<td>6.1 cm = h</td>
<td></td>
</tr>
</tbody>
</table>

**Check the Work:**

\[ V = l \times w \times h \]

\[ V = 1.5 \text{ cm} \times 1.2 \text{ cm} \times 6.1 \text{ cm} \]

Multiply 1.5 cm × 1.2 cm × 6.1 cm.

If the answer is 10.98 cm³, the solution, \( h = 6.1 \text{ cm} \), is correct.

\[ 1.5 \text{ cm} \times 1.2 \text{ cm} \times 6.1 \text{ cm} = 10.98 \text{ cm}^3 \]

The product does equal 10.98 cm³, the solution is correct.

**In summary:**

The height \( h \) of a rectangular solid whose volume is 10.98 cm³, whose length is 1.5 cm, and whose width is 1.2 cm, is 6.1 cm.
2. The density of titanium is 4.5 g/cm³. A titanium pendant’s mass is 2.25 grams. Use the formula Density = \( \frac{\text{mass}}{\text{volume}} \), or \( D = \frac{m}{V} \), or to find its volume.

### The Work:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>( D = \frac{m}{v} )</td>
<td>Formula</td>
</tr>
<tr>
<td>( \frac{4.5 \text{ g/cm}^3}{1 \text{ cm}^3} = \frac{2.25 \text{ g}}{V} )</td>
<td>Plug in known values.</td>
</tr>
<tr>
<td>( \frac{4.5 \text{ g}}{1 \text{ cm}^3} = \frac{2.25 \text{ g}}{V} )</td>
<td>Rewrite 4.5 g/cm³ as ( \frac{4.5 \text{ g}}{1 \text{ cm}^3} )</td>
</tr>
<tr>
<td>( 4.5 \text{ g} \times V = (2.25 \text{ g}) \times (1 \text{ cm}^3) )</td>
<td>Think of ( \frac{4.5 \text{ g}}{1 \text{ cm}^3} = \frac{2.25 \text{ g}}{V} ) as a proportion. Then set the cross products equal</td>
</tr>
<tr>
<td>( 4.5 \text{ g} \times V = 2.25 \text{ g} \times 1 \text{ cm}^3 )</td>
<td>Do arithmetic: ( 2.25 \text{ g} \times 1 \text{ cm}^3 = 2.25 \text{ g} \times 1 \text{ cm}^3 )</td>
</tr>
<tr>
<td>( \frac{4.5 \text{ g} \times V}{4.5 \text{ g}} = \frac{2.25 \text{ g} \times 1 \text{ cm}^3}{4.5 \text{ g}} )</td>
<td>Divide both sides of the equation by 4.5 g to get ( V ) alone.</td>
</tr>
<tr>
<td>( V = 0.5 \text{ cm}^3 )</td>
<td>Do the division on each side. Remember to cancel units as well as divide the numbers.</td>
</tr>
</tbody>
</table>

### Check the Work:

<table>
<thead>
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</tr>
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<tbody>
<tr>
<td>( D = \frac{m}{v} )</td>
<td></td>
</tr>
<tr>
<td>( \frac{4.5 \text{ g/cm}^3}{0.5 \text{ cm}^3} = \frac{2.25 \text{ g}}{V} )</td>
<td>Divide 2.25 ( \div ) 0.5. If the answer is 4.5 g/cm³, the solution, ( V = 0.5 \text{ cm}^3 ), is correct.</td>
</tr>
<tr>
<td>( 2.25 \div 0.5 = 4.5 \text{ g/cm}^3 )</td>
<td>The quotient does equal 4.5 g/cm³; therefore, the solution is correct.</td>
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</tbody>
</table>

### In summary:

The volume of a titanium pendant whose mass is 2.25 grams is 4.5 g/cm³.
Use the formula $V = l \times w \times h$ to set up and solve for the unknown in each.

1. Find the width ($w$) of a rectangular solid whose length is 12 mm, and whose height is 15 mm, if the volume of the solid is 720 mm$^3$.

2. Find the length of this rectangular solid whose volume is 0.12 m$^3$.

   ![Diagram of a rectangular solid with dimensions 0.25 m and 0.6 m]  

3. The length and width of a rectangular solid are 2.15 cm. Its volume is 36.98 cm$^3$. Find the height of this rectangular solid.

Use the formula Speed = distance \ div \ time, or $S = \frac{d}{t}$ to set up and solve for the unknown in each. Here, speed is measured in meters/second (m/s), distance is measured in meters (m), and time is measured in seconds (s).

4. How far will a marble rolling at a speed of 0.25 m/s travel in 30. seconds?

5. Nate throws a paper wad to Ali who is sitting exactly 1.8 meters away. The paper wad was only in the air for 0.45 seconds. How fast was it traveling?

6. How long does it take a battery operated toy car to travel 3 meters at a speed of 0.1 m/s?

7. A dog is running 3.20 m/s. How long will it take him to go 100. meters?

Use the formula Density = mass \ div \ volume, or $D = \frac{m}{V}$, to set up and solve for the unknown in each. Here, density ($D$) is measured in grams per cubic centimeter (g/cm$^3$), mass ($m$) is measured in grams (g), and volume ($V$) is measured in cubic centimeters (cm$^3$).

8. What is the density of a steel nail whose volume is 3.2 cm$^3$ and whose mass is 25 g?

9. Find the mass of a cork whose density is 0.12 g/cm$^3$ and whose volume is 9.0 cm$^3$?

10. An ice cube’s volume is 4.9 cm$^3$. Find its mass if its density is 0.92 g/cm$^3$.

11. A solid plastic ball’s mass is 225 g. The density of the plastic is 2.00 g/cm$^3$. What is the volume of the ball?

12. Find the volume of an ice cube whose mass is 2.08 g. See question #10 for the density of ice.

Use the formula: Force = pressure $\times$ area to set up and solve for each unknown.
Here, force is measured in Newtons (N), pressure is measured in Pascals (Pa), and area is measured in square meters (m²). Hint: 1 Pa = 1 N / m².

**Example**

- A drinking glass is sitting on the kitchen table. The glass has a weight of 2 N. Its base has an area of 0.005 m². How much pressure does the drinking glass exert on the table?

**Explanation/Answer:**

<table>
<thead>
<tr>
<th>The Work</th>
<th>What's happening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force = pressure × area</td>
<td>Formula</td>
</tr>
<tr>
<td>2 N = p × 0.005 m²</td>
<td>Plug in known values.</td>
</tr>
</tbody>
</table>
| \[
\frac{2 \text{ N}}{0.005 \text{ m}^2} = \frac{p \times 0.005 \text{ m}^2}{0.005 \text{ m}^2} \]
| Divide both sides by 0.005 m² to get p alone. | Do the division: 2 N ÷ 0.005 m² = 400 N / m²; 0.005 m² ÷ 0.005 m² = 1 |
| 400 N/m² = p × 1                              | Rewrite 400 N/m² as 400 Pa, multiply; p × 1 = p. |
| 400 Pa = p                                    |                                       |

**In summary:**

A drinking glass with a weight of 2 N and whose base has area 0.005 m² exerts 400 Pa of pressure on the table it sits on.

**Practice**

1. A tea kettle’s base has an area of 0.008 m². It is puts 1,000 Pascals of pressure on the stove where it sits. What is the weight of the kettle?

2. A block of wood whose base has an area of 4 m² has a weight of 80 N. How much pressure does the block place on the floor on which it sits?

3. A sculpture’s base has an area of 2.50 m². How much pressure does the sculpture place on the wooden display case where it sits, if it has a weight of 540. N?

4. A student is breaking class rules by standing on a chair. If her feet have a total area of 0.04 m², and her weight is 600. N, how much pressure is she putting on the chair?
### 4.1 Problem Solving Boxes

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
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<tbody>
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<th>Given</th>
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<tr>
<th>Relationships</th>
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<table>
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<tr>
<th>Looking for</th>
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<th>Relationships</th>
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<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
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<table>
<thead>
<tr>
<th>Relationships</th>
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</tbody>
</table>
4.1 Problem Solving with Rates

Solving mathematical problems often involves using rates. An upside down rate is called a reciprocal rate.

A rate may be written as its reciprocal because no matter how you write it the rate gives you the same amount of one thing per amount of the other thing. For example, you can write 5 cookies/ $1.00 or $1.00/5 cookies. For $1.00, you know you will get 5 cookies no matter how you write the rate. In this activity, you will choose how to write each rate in order to solve the problem the easiest way.

Steps for solving problems with rates are listed below. Remember, after you have set up your problem, analyze and cancel the units by crossing them out, then do the arithmetic, and provide the answer. Remember that the answer always consists of a number and a unit.

<table>
<thead>
<tr>
<th>Step 1</th>
<th>What quantity or rate are you asked for in the problem? Write it down.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2</td>
<td>What do you know from reading the problem? List all known rates and quantities.</td>
</tr>
<tr>
<td>Step 3</td>
<td>Arrange the known quantities and rates to get an answer that has the right units. This arrangement might include a formula.</td>
</tr>
<tr>
<td>Step 4</td>
<td>Plug in the values you know.</td>
</tr>
<tr>
<td>Step 5</td>
<td>Solve the problem and write the answer with a number and a unit.</td>
</tr>
</tbody>
</table>

In the space provided, write the reciprocal rate of each given rate. The first one is done for you.

1. \( \frac{1 \text{ year}}{365 \text{ days}} = \frac{365 \text{ days}}{1 \text{ year}} \)

2. \( \frac{12 \text{ inches}}{\text{foot}} = \)

3. \( \frac{3 \text{ small pizzas}}{\$10.00} = \)

4. \( \frac{36 \text{ pencils}}{3 \text{ boxes}} = \)

5. \( \frac{18 \text{ gallons of gasoline}}{360 \text{ miles}} = \)
In problems 6 and 7, you will be shown how to set up steps 1–4. For step 5, you will need to solve the problem and write the answer as a number and unit.

6. Downhill skiing burns about 600 calories per hour. How many calories will you burn if you downhill ski for 3.5 hours?

   **Step 1**  Looking for *calories*.
   **Step 2**  600 calories/hour; 3.5 hours
   **Step 3**  \[
   \frac{\text{calories}}{\text{hour}} \times \frac{\text{hours}}{\text{calorie}} = \frac{\text{calorie}}{\text{hour}}
   \]
   **Step 4**  \[
   \frac{600 \text{ calories}}{\text{hour}} \times \frac{3.5 \text{ hours}}{\text{calories}} = \text{calories}
   \]
   **Step 5**  Answer:

7. How many cans of soda will John drink in a year if he drinks 3 sodas per day? (Remember that there are 365 days in a year.)

   **Step 1**  Looking for *cans of soda per year*.
   **Step 2**  3 sodas/day; 365 days/year
   **Step 3**  \[
   \frac{\text{soda}}{\text{day}} \times \frac{\text{days}}{\text{year}} = \frac{\text{sodas}}{\text{year}}
   \]
   **Step 4**  \[
   \frac{3 \text{ sodas}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} = \frac{\text{sodas}}{\text{year}}
   \]
   **Step 5**  Answer:

8. How many heartbeats will a person have in a week if he has an average heart rate of 72 beats per minute? (Remember the days/week, hours/day, and minutes/hour.

   **Step 1**  Looking for *number of heartbeats per week*.
   **Step 2**  72 heartbeats/minute, 7 days/week, 24 hours/day, 60 minutes/hour
   **Step 3**  \[
   \frac{\text{heartbeats}}{\text{minute}} \times \frac{\text{minutes}}{\text{hour}} \times \frac{\text{hours}}{\text{day}} \times \frac{\text{days}}{\text{week}} = \frac{\text{heartbeats}}{\text{week}}
   \]
   **Step 4**  \[
   \frac{72 \text{ heartbeats}}{\text{minute}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{24 \text{ hours}}{\text{day}} \times \frac{7 \text{ days}}{\text{week}} = \frac{\text{heartbeats}}{\text{week}}
   \]
   **Step 5**  Answer:
Using the five problem-solving steps, solve the following problems on your own. Be sure to read the problem carefully. Show your work in the blank provided.

<table>
<thead>
<tr>
<th>Step 1</th>
<th>What quantity or rate are you asked for in the problem? Write it down.</th>
</tr>
</thead>
<tbody>
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<td>What do you know from reading the problem? List all known rates and quantities.</td>
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<td>Arrange the known quantities and rates to get an answer that has the right units. This arrangement might include a formula.</td>
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<td>Step 4</td>
<td>Plug in the values you know.</td>
</tr>
<tr>
<td>Step 5</td>
<td>Solve the problem and write the answer with a number and a unit.</td>
</tr>
</tbody>
</table>

9. How much will you pay for 5 pounds of shrimp if the cost is 2 pounds for $10.99?

10. How many miles can you get on one tank of gas if your tank holds 18 gallons and you get 23 miles per gallon?

11. What is your rate in miles/hour if you run at a speed of 2.2 miles in 20. minutes?

12. Suppose for your cookout you need to make 100 hamburgers. You know that 2.00 pounds will make 9 hamburgers. How many pounds will you need?

13. What is your mass in kilograms if you weigh 120. pounds? (There are approximately 2.2 pounds in one kilogram.)

14. Mt. Everest is 29,028 feet high. How many miles is this? (There are exactly 5,280 feet in one mile.)

15. Susan works 8 hours a day and makes $7.00 per hour. How much money does Susan earn in one week if she works 5 days per week?

16. How many years will it take a major hamburger fast food chain to sell 45,000,000 burgers if it sells approximately 12,350 burgers per day?

17. Your science teacher needs to make more of a salt-water mixture. The concentration of the mixture that is needed is 35 grams of salt in 1,000. milliliters of water. How many grams of salt will be needed to make 1,500. milliliters of the salt-water?

18. A cart travels down a ramp at an average speed of 5.00 centimeters/second. What is the speed of the cart in miles/hour? (Remember there are 100 centimeters per meter, 1000 meters/kilometer, and 1.6 kilometer per mile.)

19. A person goes to the doctor and will need a 3-month prescription of medicine. The person will be required to take 3 pills per day. How many pills will the doctor write the prescription for assuming there are 30 days in a month?

20. If you are traveling at 65 miles per hour, how many feet will you be traveling in one second?
4.1 Percent Error

When you do scientific experiments that involve measurements, your results may fit the trend that is expected. However, it is unlikely that the numbers will turn out exactly as expected.

In an experiment, you often make a prediction about an event’s outcome, but find that your actual measured outcome is slightly different. The percent error (% Error) gives you a means to evaluate how far apart your prediction and measured values are.

Percent error is calculated as the absolute value of the difference between the predicted and measured values divided by the true value multiplied by 100, or:

\[
\% \text{ Error} = \left| \frac{\text{measured value} - \text{predicted value}}{\text{true value}} \right| \times 100
\]

Which value is the true value? That depends on your experiment design. If you want to evaluate how well a graph is able to predict an actual event (like how far a marble will travel or how long a car will take to travel down a ramp) then you use the measured value as the true value.

On the other hand, if you have carefully calculated how much product you should get in a chemical reaction, and you want to evaluate how carefully you made your measurements and followed the procedure, then you would use the predicted value as the true value.

Remember that with percent error, smaller is better. A perfect outcome would have zero percent error.

**Example**

Some students are conducting an experiment using a toy car with a track, timer, and photogates.

Their task is to determine how quickly the car will travel a given distance, and then to predict and test the last trip that the car takes. The table below shows the distances and times traveled by the car so far.

<table>
<thead>
<tr>
<th>Distance from A to B (cm)</th>
<th>Time from A to B (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>0.3305</td>
</tr>
<tr>
<td>20.</td>
<td>0.3380</td>
</tr>
<tr>
<td>40.</td>
<td>0.3535</td>
</tr>
<tr>
<td>50.</td>
<td>0.3610</td>
</tr>
<tr>
<td>60.</td>
<td>?</td>
</tr>
</tbody>
</table>

Based on an estimation made by extending their graph, the students predict that it will take the car 0.3685 seconds to travel 60 centimeters. When the experiment was conducted three times, it took the car 0.3669, 0.3680, and 0.3694 seconds to make the trip. Calculate the percent of error based on the predicted and actual outcomes.
Solution:

The process:

1. Average the times recorded in the three 60-centimeter trials to use as the measured value in the formula.
2. Calculate percent error using the formula given above, using the average from (1) as the measured value.

The work:

1. Find the average:

   \[
   \frac{0.3669 + 0.368 + 0.3694}{3} = \frac{1.1043}{3} = 0.3681
   \]

2. Calculate:

   \[
   \text{% Error} = \frac{\text{measured value} - \text{predicted value}}{\text{true value}} \times 100
   \]

   \[
   \text{% Error} = \frac{0.3681 - 0.3685}{0.3681} \times 100 = \frac{0.0004}{0.3981} \times 100 \approx 0.11\%
   \]

The Answer: The percent error in this particular experiment is 0.11%. This means that the student’s predicted time was 0.11% off the actual, measured time.

Use the method shown in the example to calculate the percent error in each of the following problems.

Part I: This table was constructed by a group of students conducting an experiment similar to the one in the example above, but using a different incline. Complete the table using the average time calculated at each distance from the information provided in the problems below.

<table>
<thead>
<tr>
<th>Distance from A to B (cm)</th>
<th>Time from A to B (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>1.0050</td>
</tr>
<tr>
<td>20.</td>
<td>1.8877</td>
</tr>
<tr>
<td>30.</td>
<td>2.8000</td>
</tr>
<tr>
<td>40.</td>
<td>3.7850</td>
</tr>
<tr>
<td>50.</td>
<td>?</td>
</tr>
<tr>
<td>60.</td>
<td>?</td>
</tr>
<tr>
<td>70.</td>
<td>?</td>
</tr>
<tr>
<td>80.</td>
<td>?</td>
</tr>
<tr>
<td>90.</td>
<td>?</td>
</tr>
</tbody>
</table>
1. The lab group conducting this experiment decided to call themselves “the Science Sleuths.” They graphed the data shown in the table and based on their graph, predicted that it would take the car 4.7500 seconds to travel 50 centimeters. The three trials they conducted resulted in 4.8020, 4.8100, and 4.7000 seconds. What is the percent error? Remember to update the table.

2. The Sleuths predict that the car will travel 60 centimeters in 5.7950 seconds. Their trials gave times of 5.7702, 5.8000, and 5.2600 seconds. What is the percent error here?

3. For 70 centimeters, the trial runs resulted in 6.9150, 6.8080, and 7.0003 seconds. The Sleuths had predicted that it would take the car 6.8150 seconds to cover the distance. Calculate the percent error.

4. The Sleuths’ car took 7.9903, 7.9995, and 7.9047 seconds to travel 80 centimeters. They had predicted a time of 7.9520 seconds. What is the percent error?

5. This time, the Sleuths predicted that it would take the car 9.0000 seconds flat to cover the 90 centimeters it needed to travel. It actually took the car 8.9907, 9.0006, and 9.0507 seconds in each of three trials. Find the percent error.

6. Lisa was trying out for the track team at her middle school. The coach asked her to make predictions about how fast she could run each of the sprint events, then timed her in each event on three different days. All the information is shown in the table below. Calculate Lisa’s percent error for her prediction in each event.

<table>
<thead>
<tr>
<th>Event</th>
<th>Predicted time (s)</th>
<th>Actual times (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 m</td>
<td>18.05</td>
<td>17.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.06</td>
</tr>
<tr>
<td>200 m</td>
<td>34.70</td>
<td>41.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>38.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35.90</td>
</tr>
<tr>
<td>400 m</td>
<td>67.45</td>
<td>72.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65.88</td>
</tr>
</tbody>
</table>

Calculate the percent error for each event:

a. 100 m
b. 200 m
c. 400 m
4.1 Speed

To determine the speed of an object, you need to know the distance traveled and the time taken to travel that distance. If you know the speed, you can determine the distance traveled or the time it took—you just rearrange the formula for speed, \( v = \frac{d}{t} \). For example,

<table>
<thead>
<tr>
<th>Equation...</th>
<th>Gives you...</th>
<th>If you know...</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v = \frac{d}{t} )</td>
<td>speed</td>
<td>distance and time</td>
</tr>
<tr>
<td>( d = v \times t )</td>
<td>distance</td>
<td>speed and time</td>
</tr>
<tr>
<td>( t = \frac{d}{v} )</td>
<td>time</td>
<td>distance and speed</td>
</tr>
</tbody>
</table>

Use the SI system to solve the practice problems unless you are asked to write the answer using the English system of measurement. As you solve the problems, include all units and cancel appropriately.

**Example 1:** What is the speed of a cheetah that travels 112.0 meters in 4.0 seconds?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of the cheetah.</td>
<td>speed = ( \frac{d}{t} )</td>
</tr>
</tbody>
</table>

Given
- Distance = 112.0 meters
- Time = 4.0 seconds

Relationship
- speed = \( \frac{d}{t} \)

\[ \text{speed} = \frac{d}{t} = \frac{112.0 \text{ m}}{4.0 \text{ s}} = 28 \text{ m/s} \]

The speed of the cheetah is 28 meters per second.

**Example 2:** There are 1,609 meters in one mile. What is this cheetah’s speed in miles/hour?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of the cheetah in miles per hour.</td>
<td>( \frac{28 \text{ m/s} \times \frac{1 \text{ mile}}{1,609 \text{ m}} \times \frac{3,600 \text{ s}}{1 \text{ hour}}}{1 \text{ s}} = 63 \text{ miles/hour} )</td>
</tr>
</tbody>
</table>

Given
- Speed = 28 m/s (from solution to Example 1)

Relationships
- speed = \( \frac{d}{t} \)

and 1, 609 meters = 1 mile

The speed of the cheetah in miles per hour is 63 mph.
1. A bicyclist travels 60.0 kilometers in 3.5 hours. What is the cyclist’s average speed?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Given</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Relationships</strong></td>
<td></td>
</tr>
</tbody>
</table>

2. What is the average speed of a car that traveled 300.0 miles in 5.5 hours?

3. How much time would it take for the sound of thunder to travel 1,500 meters if sound travels at a speed of 330 m/s?

4. How much time would it take for an airplane to reach its destination if it traveled at an average speed of 790 kilometers/hour for a distance of 4,700 kilometers? What is the airplane’s speed in miles/hour?

5. How far can a person run in 15 minutes if he or she runs at an average speed of 16 km/hr? (HINT: Remember to convert minutes to hours.)

6. In problem 5, what is the runner’s distance traveled in miles?

7. A snail can move approximately 0.30 meters per minute. How many meters can the snail cover in 15 minutes?

8. You know that there are 1,609 meters in a mile. The number of feet in a mile is 5,280. Use these equalities to answer the following problems:
   a. How many centimeters equals one inch?
   b. What is the speed of the snail in problem 7 in inches per minute?

9. Calculate the average speed (in km/h) of a car stuck in traffic that drives 12 kilometers in 2 hours.

10. How long would it take you to swim across a lake that is 900 meters across if you swim at 1.5 m/s?
   a. What is the answer in seconds?
   b. What is the answer in minutes?

11. How far will you travel if you run for 10 minutes at 2.0 m/s?

12. You have trained all year for a marathon. In your first attempt to run a marathon, you decide that you want to complete this 26.2-mile race in 4.5 hours.
   a. What is the length of a marathon in kilometers (1 mile = 1.6 kilometers)?
   b. What would your average speed have to be to complete the race in 4.5 hours? Give your answer in kilometers per hour.
13. Suppose you are walking home after school. The distance from school to your home is five kilometers. On foot, you can get home in 25 minutes. However, if you rode a bicycle, you could get home in 10 minutes.
   a. What is your average speed while walking?
   b. What is your average speed while bicycling?
   c. How much faster you travel on your bicycle?

14. Suppose you ride your bicycle to the library traveling at 0.50 km/min. It takes you 25 minutes to get to the library. How far did you travel?

15. You ride your bike for a distance of 30 km. You travel at a speed of 0.75 km/minute. How many minutes does this take?

16. A train travels 225 kilometers in 2.5 hours. What is the train’s average speed?

17. An airplane travels 3,280 kilometers in 4.0 hours. What is the airplane’s average speed?

18. A person in a kayak paddles down river at an average speed of 10. km/h. After 3.25 hours, how far has she traveled?

19. The same person in question 18 paddles upstream at an average speed of 4 km/h. How long would it take her to get back to her starting point?

20. An airplane travels from St. Louis, Missouri to Portland, Oregon in 4.33 hours. If the distance traveled is 2,742 kilometers, what is the airplane’s average speed?

21. The airplane returns to St. Louis by the same route. Because the prevailing winds push the airplane along, the return trip takes only 3.75 hours. What is the average speed for this trip?

22. The airplane refuels in St. Louis and continues on to Boston. It travels at an average speed of 610 km/h. If the trip takes 2.75 hours, what is the flight distance between St. Louis and Boston?

**Challenge Problems:**

23. The speed of light is about $3.00 \times 10^5$ km/s. It takes approximately 1.28 seconds for light reflected from the moon to reach Earth. What is the average distance from Earth to the moon?

24. The average distance from the sun to Pluto is approximately $6.10 \times 10^9$ km. How long does it take light from the sun to reach Pluto? Use the speed of light from the previous question to help you.

25. Now, make up three speed problems of your own. Give the problems to a friend to solve and check their work.
   a. Make up a problem that involves solving for average speed.
   b. Make up a problem that involves solving for distance.
   c. Make up a problem that involves solving for time.
4.1 Velocity

Speed and velocity do not have the same meaning to scientists. Speed is a *scalar quantity*, which means it can be completely described by its magnitude (or size). The magnitude is given by a number and a unit. For example, an object’s speed may be measured as 15 meters per second.

Velocity is a *vector quantity*. In order to measure a vector quantity, you must know the both its magnitude and direction. The velocity of an object is determined by measuring both the *speed* and *direction* in which an object is traveling.

- If the speed of an object changes, then its velocity also changes.
- If the direction in which an object is traveling changes, then its velocity changes.
- A change in either speed, direction, or both causes a change in velocity.

You can rearrange $v = \frac{d}{t}$ to solve velocity problems the same way you solved speed problems earlier in this course. The boldfaced $v$ is used to represent velocity as a vector quantity. The variables $d$ and $t$ are used for distance and time. The *velocity of an object in motion is equal to the distance it travels per unit of time in a given direction*.

**Examples**

**Example 1:** What is the velocity of a car that travels 100.0 meters, northeast in 4.65 seconds?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity of the car.</td>
<td>velocity $= \frac{d}{t} = \frac{100.0 \text{ m}}{4.65 \text{ s}} = \frac{21.5 \text{ m}}{\text{s}}$</td>
</tr>
<tr>
<td>Given</td>
<td>The velocity of the car is 21.5 meters per second, northeast.</td>
</tr>
<tr>
<td>Distance = 100.0 meters</td>
<td></td>
</tr>
<tr>
<td>Time = 4.65 seconds</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relationship</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>velocity $= \frac{d}{t}$</td>
<td></td>
</tr>
</tbody>
</table>

**Example 2:** A boat travels with a velocity equal to 14.0 meters per second, east in 5.15 seconds. What distance in meters does the boat travel?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance the boat travels.</td>
<td>distance $= v \times t = \frac{14.0 \text{ m}}{\text{s}} \times 5.15 \text{ s} = 72.1 \text{ m}$</td>
</tr>
<tr>
<td>Given</td>
<td>The boat travels 72.1 meters.</td>
</tr>
<tr>
<td>Velocity = 14.0 meters per second, east</td>
<td></td>
</tr>
<tr>
<td>Time = 5.15 seconds</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relationship</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>distance $= v \times t$</td>
<td></td>
</tr>
</tbody>
</table>
1. An airplane flies 525 kilometers north in 1.25 hours. What is the airplane’s velocity?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Given</strong></td>
<td></td>
</tr>
</tbody>
</table>

2. A soccer player kicks a ball 6.5 meters. How much time is needed for the ball to travel this distance if its velocity is 22 meters per second, south?

3. A cruise ship travels east across a river at 19.0 meters per minute. If the river is 4,250 meters wide, how long does it take for the ship to reach the other side?

4. Joaquin mows the lawn at his grandmother’s home during the summer months. Joaquin measured the distance across his grandmother’s lawn as 11.5 meters.
   a. If Joaquin mows one length across the lawn from east to west in 7.10 seconds, then what is the velocity of the lawnmower?
   b. Once he reaches the edge of the lawn, Joaquin turns the lawnmower around. He mows in the opposite direction but maintains the same speed. What is the velocity of the lawnmower?

5. A family drives 881 miles from Houston, Texas to Santa Fe, New Mexico for vacation. How long will it take the family to reach their destination if they travel at a velocity of 55.0 miles per hour, northwest?

6. A shopping cart is pushed 15.6 meters west across a parking lot in 5.2 seconds. What is the velocity of the shopping cart?

7. Katie and her best friend Liam play tennis every Saturday morning. When Katie serves the ball to Liam, it travels 9.5 meters south in 2.1 seconds.
   a. What is the velocity of the tennis ball?
   b. If the tennis ball travels at constant speed, what is its velocity when Liam returns Katie’s serve?

8. A driver realizes that she is traveling in the wrong direction on a one-way street. She has already driven 350 meters at a velocity of 16 meters per second, east before deciding to make a U-turn. How long did it take for the driver to realize her error?

9. Juan’s mother drives 7.25 miles southwest to her favorite shopping mall. What is the average velocity of her automobile if she arrives at the mall in 20. minutes?

10. A bus is traveling at 79.7 kilometers per hour east. How far does the bus travel 1.45 hours?

11. A girl scout troop hiked 5.8 kilometers southeast in 1.5 hours. What was the troop’s velocity?

12. A volcanologist noted that a lahar rushed down a mountain at 32.2 kilometers per hour, south. How far did the mud flow in 17.5 minutes?
4.2 Calculating Slope from a Graph

To determine the slope of a line in a graph, first choose two points on the line. Then count how many steps up or down you must move to be on the same horizontal line as your second point. Multiply this number by the scale of your horizontal axis. For example, if your x-axis has a scale of 1 box = 20 cm, then multiply the number of boxes you counted by 20 cm.

Put the result along with the positive or negative sign as the top (numerator) of your slope ratio. Then count how many steps you must move right or left to land on your second point. Multiply the number of steps by the scale of your vertical axis. Place the results as the bottom (denominator) of your slope ratio. Then reduce the fraction of your ratio. This number is the slope of the line. Note: The letter \( m \) is used to represent slope in an equation.

**EXAMPLES**

**A**

The chosen points for Example A are (0, 0) and (3, 9). There are many choices for this graph, but only one slope. If you have the point (0, 0), you should choose it as one of your points.

It takes 9 vertical steps to move from (0, 0) to (0, 9). Put a 9 in the numerator of your slope ratio (or subtract 9 – 0). Then count the number of steps to move from (0, 9) to (3, 9). This is your denominator of your slope ratio. Again, you can do this by subtraction (3 – 0).

\[
m = \frac{9}{3} = \frac{3}{1}
\]

**B**

The two points that have been chosen for Example B are (0, 24) and (6, 15). Be careful of the scales on each of the axes.

It takes 3 vertical steps to go from (0, 24) to (0, 15). But each of these steps has a scale of 3. So you put a –9 into the numerator of the slope ratio. It is negative because you are moving down from one point to the other. Then count the steps over to (6, 15). There are 3 steps but each counts for 2 so you put a 6 into the denominator of the slope ratio.

\[
m = \frac{-9}{6} = \frac{-3}{2}
\]

**PRACTICE**

Find the slope of the line in each of the following graphs:

Graph #1:

Graph #2:
Graph #3:  
\[ m = \quad \]

Graph #4:  
\[ m = \quad \]

Graph #5:  
\[ m = \quad \]

Graph #6:  
\[ m = \quad \]

Graph #7:  
\[ m = \quad \]

Graph #8:  
\[ m = \quad \]

Graph #9:  
\[ m = \quad \]

Graph #10:  
\[ m = \quad \]
4.2 Analyzing Graphs of Motion With Numbers

Speed can be calculated from position-time graphs and distance can be calculated from speed-time graphs. Both calculations rely on the familiar speed equation: \( v = \frac{d}{t} \).

This graph shows position and time for a sailboat starting from its home port as it sailed to a distant island. By studying the line, you can see that the sailboat traveled 10 miles in 2 hours.

- **Calculating speed from a position-time graph**

  The speed equation allows us to calculate that the boat’s speed during this time was 5 miles per hour.
  
  \[
  v = \frac{d}{t} \\
  v = \frac{10 \text{ miles}}{2 \text{ hours}} \\
  v = 5 \text{ miles/hour, read as 5 miles per hour}
  \]

  This result can now be transferred to a speed-time graph. Remember that this speed was measured during the first two hours.

  The line showing the boat’s speed is horizontal because the speed was constant during the two-hour period.

- **Calculating distance from a speed-time graph**

  Here is the speed-time graph of the same sailboat later in the voyage. Between the second and third hours, the wind freshened and the sailboat gradually increased its speed to 7 miles per hour. The speed remained 7 miles per hour to the end of the voyage.

  How far did the sailboat go during the six-hour trip? We will first calculate the distance traveled during the fourth, fifth, and sixth hours.
On a speed-time graph, distance is equal to the area between the baseline and the plotted line. You know that the area of a rectangle is found with the equation: \( A = L \times W \). Similarly, multiplying the speed from the \( y \)-axis by the time on the \( x \)-axis produces distance. Notice how the labels cancel to produce miles:

\[
\text{speed} \times \text{time} = \text{distance}
\]

\[
7 \text{ miles/hour} \times (6 \text{ hours} - 3 \text{ hours}) = \text{distance}
\]

\[
7 \text{ miles/hour} \times 3 \text{ hours} = \text{distance} = 21 \text{ miles}
\]

Now that we have seen how distance is calculated, we can consider the distance covered between hours 2 and 3.

The easiest way to visualize this problem is to think in geometric terms. Find the area of the triangle (Area A), then find the area of the rectangle (Area B), and add the two areas.

<table>
<thead>
<tr>
<th>Area of triangle A</th>
<th>The area of a triangle is one-half the area of a rectangle.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry formula</td>
<td>( \text{speed} \times \frac{\text{time}}{2} = \text{distance} )</td>
</tr>
<tr>
<td></td>
<td>( (7 \text{ miles/hour} - 5 \text{ miles/hour}) \times \frac{(3 \text{ hours} - 2 \text{ hours})}{2} = \text{distance} = 1 \text{ mile} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area of rectangle B</th>
<th>speed ( \times \text{time} = \text{distance} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry formula</td>
<td>5 miles/hour ( \times (3 \text{ hours} - 2 \text{ hours}) = \text{distance} = 5 \text{ miles} )</td>
</tr>
</tbody>
</table>

Add the two areas

<table>
<thead>
<tr>
<th>Area A + Area B = distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 miles + 5 mile = distance = 6 miles</td>
</tr>
</tbody>
</table>

The Position vs. Time graph on page 1 tells us that the boat traveled 10 miles in the first two hours. According to our calculations, the boat traveled 6 miles during the third hour and 21 miles in hours four through six. Therefore the total distance traveled is 10 + 6 + 21 = 37 miles.

We can now use this information about distance to complete our position-time graph:
1. For each position-time graph, calculate and plot speed on the speed-time graph to the right.
   a. The bicycle trip through hilly country
   ![Position vs. Time](image1)
   ![Speed vs. Time](image2)
   a. A walk in the park
   ![Position vs. Time](image3)
   ![Speed vs. Time](image4)
   b. Strolling up and down the supermarket aisles
   ![Position vs. Time](image5)
   ![Speed vs. Time](image6)
2. For each speed-time graph, calculate and plot the distance on the position-time graph to the right. For this practice, assume that movement is always away from the starting position.

a. The honey bee among the flowers

b. Rover runs the street

c. The amoeba
4.2 Analyzing Graphs of Motion Without Numbers

Position-time graphs

The graph at right represents the story of “The Three Little Pigs.” The parts of the story are listed below.

- The wolf started from his house. The graph starts at the origin.
- Traveled to the straw house. The line moves upward.
- Stayed to blow it down and eat dinner. The line is flat because position is not changing.
- Traveled to the stick house. The line moves upward again.
- Again stayed, blew it down, and ate seconds. The line is flat.
- Traveled to the brick house. The line moves upward.
- Died in the stew pot at the brick house. The line is flat.

The graph illustrates that the pigs’ houses are generally in a line away from the wolf’s house and that the brick house was the farthest away.

Speed-time graphs

A speed-time graph displays the speed of an object over time and is based on position-time data. Speed is the relationship between distance (position) and time, \( v = \frac{d}{t} \). For the first part of the wolf’s trip in the position versus time graph, the line rises steadily. This means the speed for this first leg is constant. If the wolf traveled this first leg faster, the slope of the line would be steeper.

The wolf moved at the same speed toward his first two “visits.” His third trip was slightly slower. Except for this slight difference, the wolf was either at one speed or stopped (shown by a flat line in the speed versus time graph).

Read the steps for each story. Sketch a position-time graph and a speed-time graph for each story.

1. Graph Red Riding Hood’s movements according to the following events listed in the order they occurred:
   - Little Red Riding Hood set out for Grandmother’s cottage at a good walking pace.
   - She stopped briefly to talk to the wolf.
   - She walked a bit slower because they were talking as they walked to the wild flowers.
   - She stopped to pick flowers for quite a while.
   - Realizing she was late, Red Riding Hood ran the rest of the way to Grandmother’s cottage.
2. Graph the movements of the Tortoise and the Hare. Use two lines to show the movements of each animal on each graph. The movements of each animal is listed in the order they occurred.

- The tortoise and the hare began their race from the combined start-finish line. By the end of the race, the two will be at the same position at which they started.
- Quickly outdistancing the tortoise, the hare ran off at a moderate speed.
- The tortoise took off at a slow but steady speed.
- The hare, with an enormous lead, stopped for a short nap.
- With a startle, the hare awoke and realized that he had been sleeping for a long time.
- The hare raced off toward the finish at top speed.
- Before the hare could catch up, the tortoise’s steady pace won the race with an hour to spare.

3. Graph the altitude of the sky rocket on its flight according to the following sequence of events listed in order.

- The sky rocket was placed on the launcher.
- As the rocket motor burned, the rocket flew faster and faster into the sky.
- The motor burned out; although the rocket began to slow, it continued to coast even higher.
- Eventually, the rocket stopped for a split second before it began to fall back to Earth.
- Gravity pulled the rocket faster and faster toward Earth until a parachute popped out, slowing its descent.
- The descent ended as the rocket landed gently on the ground.

4. A story told from a graph: Tim, a student at Cumberland School, was determined to ask Caroline for a movie date. Use these graphs of his movements from his house to Caroline’s to write the story.
4.3 Acceleration

Acceleration is the rate of change in the speed of an object. To determine the rate of acceleration, you use the formula below. The units for acceleration are meters per second per second or \( \text{m/s}^2 \).

\[
\text{Acceleration} = \frac{\text{Final speed} - \text{Beginning speed}}{\text{Time}}
\]

\[
a = \frac{v_2 - v_1}{t}
\]

A positive value for acceleration shows speeding up, and negative value for acceleration shows slowing down. Slowing down is also called deceleration.

The acceleration formula can be rearranged to solve for other variables such as final speed \( (v_2) \) and time \( (t) \).

\[
v_2 = v_1 + (a \times t)
\]

\[
t = \frac{v_2 - v_1}{a}
\]

### EXAMPLES

1. A skater increases her velocity from 2.0 m/s to 10.0 m/s in 3.0 seconds. What is the skater’s acceleration?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration of the skater</td>
<td>Acceleration = ( \frac{10.0 \text{ m/s} - 2.0 \text{ m/s}}{3.0 \text{ s}} ) = 2.7 m/s²</td>
</tr>
</tbody>
</table>

Given:
- Beginning speed = 2.0 m/s
- Final speed = 10.0 m/s
- Change in time = 3.0 seconds

Relationship:
\[
a = \frac{v_2 - v_1}{t}
\]

The acceleration of the skater is 2.7 meters per second per second.

2. A car accelerates at a rate of 3.0 m/s². If its original speed is 8.0 m/s, how many seconds will it take the car to reach a final speed of 25.0 m/s?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>The time to reach the final speed.</td>
<td>Time = ( \frac{25.0 \text{ m/s} - 8.0 \text{ m/s}}{3.0 \text{ m/s}^2} ) = 5.7 s</td>
</tr>
</tbody>
</table>

Given:
- Beginning speed = 8.0 m/s; Final speed = 25.0 m/s
- Acceleration = 3.0 m/s²

Relationship:
\[
t = \frac{v_2 - v_1}{a}
\]

The time for the car to reach its final speed is 5.7 seconds.
1. While traveling along a highway, a driver slows from 24 m/s to 15 m/s in 12 seconds. What is the automobile’s acceleration? (Remember that a negative value indicates a slowing down or deceleration.)

2. A parachute on a racing dragster opens and changes the speed of the car from 85 m/s to 45 m/s in a period of 4.5 seconds. What is the acceleration of the dragster?

3. The table below contains data for a ball rolling down a hill. Fill in the missing data values in the table and determine the acceleration of the rolling ball.

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (start)</td>
<td>0 (start)</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

4. A car traveling at a speed of 30.0 m/s encounters an emergency and comes to a complete stop. How much time will it take for the car to stop if it decelerates at \(-4.0 \text{ m/s}^2\)?

5. If a car can go from 0 to 60. mph in 8.0 seconds, what would be its final speed after 5.0 seconds if its starting speed were 50. mph?

6. A cart rolling down an incline for 5.0 seconds has an acceleration of \(4.0 \text{ m/s}^2\). If the cart has a beginning speed of 2.0 m/s, what is its final speed?

7. A helicopter’s speed increases from 25 m/s to 60 m/s in 5 seconds. What is the acceleration of this helicopter?

8. As she climbs a hill, a cyclist slows down from 25 mph to 6 mph in 10 seconds. What is her deceleration?

9. A motorcycle traveling at 25 m/s accelerates at a rate of \(7.0 \text{ m/s}^2\) for 6.0 seconds. What is the final speed of the motorcycle?

10. A car starting from rest accelerates at a rate of \(8.0 \text{ m/s}\). What is its final speed at the end of 4.0 seconds?

11. After traveling for 6.0 seconds, a runner reaches a speed of 10. m/s. What is the runner’s acceleration?

12. A cyclist accelerates at a rate of \(7.0 \text{ m/s}^2\). How long will it take the cyclist to reach a speed of 18 m/s?

13. A skateboarder traveling at 7.0 meters per second rolls to a stop at the top of a ramp in 3.0 seconds. What is the skateboarder’s acceleration?
4.3 Acceleration and Speed-Time Graphs

Acceleration is the rate of change in the speed of an object. The graph below shows that object A accelerated from rest to 10 miles per hour in two hours. The graph also shows that object B took four hours to accelerate from rest to the same speed. Therefore, object A accelerated twice as fast as object B.

Calculating acceleration from a speed-time graph

The steepness of the line in a speed-time graph is related to acceleration. This angle is the slope of the line and is found by dividing the change in the y-axis value by the change in the x-axis value.

\[
\text{Acceleration} = \frac{\Delta y}{\Delta x}
\]

In everyday terms, we can say that the speed of object A “increased 10 miles per hour in two hours.” Using the slope formula:

\[
\text{Acceleration} = \frac{10 \text{ mph} - 0 \text{ mph}}{2 \text{ hours} - 0 \text{ hour}} = \frac{5 \text{ mph}}{\text{hour}}
\]

• Acceleration = \(\Delta y/\Delta x\) (the symbol Δ means “change in”)
• Acceleration = \((10 \text{ mph} - 0 \text{ mph})/(2 \text{ hours} - 0 \text{ hours})\)
• Acceleration = 5 mph/hour (read as 5 miles per hour per hour)

The double \(\text{per time}\) label attached to all accelerations may seem confusing at first. It is not so alien a concept if you break it down into its parts:

\[
\begin{align*}
\text{The speed changes} & \quad \text{. . . during this amount of time:} \\
5 \text{ miles per hour} & \quad \text{each hour}
\end{align*}
\]

Accelerations can be negative. If the line slopes downward, \(\Delta y\) will be a negative number because a larger value of \(y\) will be subtracted from a smaller value of \(y\).

Calculating distance from a speed-time graph

The area between the line on a speed-time graph and the baseline is equal to the distance that an object travels. This follows from the rate formula:

\[
\text{Rate or Speed} = \frac{\text{Distance}}{\text{Time}}
\]

\[
v = \frac{d}{t}
\]
Or, rewritten:

\[ vt = d \]

\[ \text{miles/hour} \times 3 \text{ hours} = 3 \text{ miles} \]

Notice how the labels cancel to produce a new label that fits the result.

Here is a speed-time graph of a boat starting from one place and sailing to another:

The graph shows that the sailboat accelerated between the second and third hour. We can find the total distance by finding the area between the line and the baseline. The easiest way to do that is to break the area into sections that are easy to solve and then add them together.

\[ A + B + C + D = \text{distance} \]

- Use the formula for the area of a rectangle, \( A = L \times W \), to find areas A, B, and D.
- Use the formula for finding the area of a triangle, \( A = l \times w/2 \), to find area C.

\[ A + B + C + D = \text{distance} \]

10 miles + 5 miles + 1 mile + 21 miles = 37 miles

**Practice**

Calculate acceleration from each of these graphs.

1. Graph 1:

2. Graph 2:
3. Graph 3:

4. Find acceleration for segment 1 and segment 2 in this graph:

5. Calculate total distance for this graph:

6. Calculate total distance for this graph:

7. Calculate total distance for this graph:
4.3 Acceleration Due to Gravity

Acceleration due to gravity is known to be 9.8 meters/second/second or 9.8 m/s² and is represented by \( g \). Three conditions must be met before we can use this value:

1. The object must be in free fall
2. The object must have negligible air resistance, and
3. The object must be close to the surface of Earth.

In all of the examples and problems, we will assume that these conditions have been met. Remember that speed refers to “how fast” in any direction, but velocity refers to “how fast” in a specific direction. The sign of numbers in these calculations is important. Velocities upward shall be positive, and velocities downward shall be negative. Because the \( y \)-axis of a graph is vertical, change in height shall be indicated by \( y \).

Here is the equation for solving for velocity:

\[
\text{final velocity} = \text{initial velocity} + (\text{the acceleration due to the force of gravity} \times \text{time})
\]

OR

\[
v = v_0 + gt
\]

Imagine that an object falls for one second. We know that at the end of the second it will be traveling at 9.8 meters/second. However, it began its fall at zero meters/second. Therefore, its average velocity is half of 9.8 meters/second. We can find distance by multiplying this average velocity by time.

Here is the equation for solving for distance. See if you can find these concepts in the equation:

\[
\text{distance} = \frac{\text{the acceleration due to the force of gravity} \times \text{time}}{2} \times \text{time}
\]

OR

\[
y = \frac{1}{2}gt^2
\]
Example 1: How fast will a pebble be traveling 3.0 seconds after being dropped?

\[ v = v_0 + gt \]

\[ v = 0 + (-9.8 \text{ m/s}^2 \times 3.0 \text{ s}) \]

\[ v = -29 \text{ m/s} \]

(Note that \( gt \) is negative because the direction is downward.)

Example 2: A pebble dropped from a bridge strikes the water in 4.0 seconds. How high is the bridge?

\[ y = \frac{1}{2}gt^2 \]

\[ y = \frac{1}{2} \times 9.8 \text{ m/s} \times 4.0 \text{ s} \times 4.0 \text{ s} \]

\[ y = 78.4 \text{ meters} \]

Note that the seconds cancel. The answer written with the correct number of significant figures is 78 meters. The bridge is 78 meters high.

Practice

1. A penny dropped into a wishing well reaches the bottom in 1.50 seconds. What was the velocity at impact?

2. A pitcher threw a baseball straight up at 35.8 meters per second. What was the ball’s velocity after 2.50 seconds? (Note that, although the baseball is still climbing, gravity is accelerating it downward.)

3. In a bizarre but harmless accident, a watermelon fell from the top of the Eiffel Tower. How fast was the watermelon traveling when it hit the ground 7.80 seconds after falling?

4. A water balloon was dropped from a high window and struck its target 1.1 seconds later. If the balloon left the person’s hand at –5.0 meters per second, what was its velocity on impact?

5. A stone tumbles into a mine shaft and strikes bottom after falling for 4.2 seconds. How deep is the mine shaft?

6. A boy threw a small bundle toward his girlfriend on a balcony 10. meters above him. The bundle stopped rising in 1.5 seconds. How high did the bundle travel? Was that high enough for her to catch it?

The equations demonstrated so far can be used to find time of flight from speed or distance, respectively. Remember that an object thrown into the air represents two mirror-image flights, one up and the other down.
7. At about 55 meters per second, a falling parachuter (before the parachute opens) no longer accelerates. Air friction opposes acceleration. Although the effect of air friction begins gradually, imagine that the parachuter is free falling until terminal speed (the constant falling speed) is reached. How long would that take?

8. The climber dropped her compass at the end of her 240-meter climb. How long did it take to strike bottom?
5.1 Ratios and Proportions

Professional chefs use ratios and proportions daily to figure out how much of various ingredients they will need to make a particular dish. They may serve the same dessert one day to a wedding party with 300 guests, and another day to a dinner party for eight people. Ratios and proportions help them figure out the right quantities of ingredients to buy for each meal. In this skill sheet, you will practice converting a recipe for different group sizes.

A recipe for Double Fudge Brownies

Ingredients:
- \(\frac{3}{4}\) c. sugar
- 2 eggs
- 6 tablespoons unsalted butter
- 1 teaspoon vanilla extract
- 2 tablespoons milk
- \(\frac{3}{4}\) cup all-purpose flour
- 2 cups semi-sweet chocolate chips
- \(\frac{1}{3}\) teaspoon baking soda
- \(\frac{1}{4}\) teaspoon salt
- 2 tablespoons confectioner’s sugar

Makes 16 brownies.

EXAMPLES

1. What is the ratio of milk to chocolate chips in the recipe above?
2. When we know the ratios, we can make proportions by setting two ratios equal to one another. This will help us to find missing answers.

Suppose Patricia needs only 8 brownies and doesn’t want any leftovers. Find out how much of each ingredient she needs. The original recipe will make 16 brownies. You will use the ratio of \(\frac{8}{16} = \frac{1}{2}\) to find the amount for each of the ingredients. Use cross-multiplication to solve the proportions.

For flour:

Step 1 \[ \frac{8}{16} = \frac{x}{\frac{3}{4}} \]
Step 2 \[ 8 \times \frac{3}{4} = 16x \]
Step 3 \[ 6 = 16x \]
Step 4 \[ \frac{6}{16} = \frac{16x}{16} \]
Step 5 \[ \frac{3}{8} = x \]

Patricia needs \(\frac{3}{8}\) cup of flour to make 8 brownies.
1. What is the ratio of unsalted butter to eggs?
   For every __________ tablespoons of butter, you will need __________ eggs.

2. What is the ratio of flour to baking soda?
   For every __________ cups of flour, you will need __________ teaspoon of baking soda.

3. What is the ratio of salt to flour?
   For every __________ teaspoon(s) of salt, you will need __________ cups of flour.

4. Find the correct amount of each ingredient to make 8 brownies ($\frac{1}{2}$ of the recipe).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>$\frac{3}{8}$ cup</td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
</tr>
<tr>
<td>Butter</td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td></td>
</tr>
<tr>
<td>Chocolate chips</td>
<td></td>
</tr>
<tr>
<td>Eggs</td>
<td></td>
</tr>
<tr>
<td>Vanilla extract</td>
<td></td>
</tr>
<tr>
<td>Baking soda</td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td></td>
</tr>
<tr>
<td>Confectioner’s sugar</td>
<td></td>
</tr>
</tbody>
</table>

5. Why are the eggs and confectioner’s sugar amounts easy to work with to make 8 brownies?

6. Patricia has a little extra of all the ingredients. How many brownies can be made using 3 cups of chocolate chips?

7. How much vanilla will she need when she makes the batch of brownies using 3 cups of chocolate chips?
5.1 Internet Research Skills

The Internet is a valuable tool for finding answers to your questions about the world. A search engine is like an on-line index to information on the World Wide Web. There are many different search engines to choose from. Search engines differ in how often they are updated, how many documents they contain in their index, and how they search for information. Your teacher may suggest several search engines for you to try.

Search engines ask you to type a word or phrase into a box known as a field. Knowing how search engines work can help you pinpoint the information you need. However, if your phrase is too vague, you may end up with a lot of unhelpful information.

How could you find out who was the first woman to participate in a space shuttle flight?

First, put key phrases in quotation marks. You want to know about the “first woman” on a “space shuttle.” Quotation marks tell the engine to search for those words together.

Second, if you only want websites that contain both phrases, use a + sign between them. Typing “first woman” + “space shuttle” into a search engine will limit your search to websites that contain both phrases.

If you want to broaden your search, use the word or between two terms. For example, if you type “first female” or “first woman” + “space shuttle” the search engine will list any website that contains either of the first two phrases, as long as it also contains the phrase “space shuttle.”

You can narrow a search by using the word not. For example, if you wanted to know about marine mammals other than whales, you could type “marine mammals” not “whales” into the field. Please note that some search engines use the minus sign (-) rather than the word not.

1. If you wanted to find out about science museums in your state that are not in your own city or town, what would you type into the search engine?

2. If you wanted to find out which dog breeds are inexpensive, what would you type into the search engine?

3. How could you research alternatives to producing electricity through the combustion of coal or natural gas?
The quality of information found on the Internet varies widely. This section will give you some things to think about as you decide which sources to use in your research.

1. **Authority:** How well does the author know the subject matter? If you search for “Newton’s laws” on the Internet, you may find a science report written by a fifth grade student, and a study guide written by a college professor. Which website is the most authoritative source? Museums, national libraries, government sites, and major, well-known “encyclopedia sources” are good places to look for authoritative information.

2. **Bias:** Think about the author’s purpose. Is it to inform, or to persuade? Is it to get you to buy something? Comparing several authoritative sources will help you get a more complete understanding of your subject.

3. **Target audience:** For whom was this website written? Avoid using sites designed for students well below your grade level. You need to have an understanding of your subject matter at or above your own grade level. Even authoritative sites for younger students (children’s encyclopedias, for example) may leave out details and simplify concepts in ways that would leave gaps in your understanding of your subject.

4. **Is the site up-to-date, clear, and easy to use?** Try to find out when the website was created, and when it was last updated. If the site contains links to other sites, but those links don’t work, you may have found a site that is infrequently or no longer maintained. It may not contain the most current information about your subject. Is the site cluttered with distracting advertisements? You may wish to look elsewhere for the information you need.

---

**Practice**

1. What is your favorite sport or activity? Search for information about this sport or activity. List two sites that are authoritative and two sites that are not authoritative. Explain your reasoning. Finally, write down the best site for finding out information about your favorite sport.

2. Search for information about a physical science topic of your choice on the Internet (i.e., “simple machines,” “Newton’s Laws,” “Galileo”). Find one source that you would NOT consider authoritative. Write the key words you used in your search, the web address of the source, and a sentence explaining why this source is not authoritative.

3. Find a different source that is authoritative, but intended for a much younger audience. Write the web address and a sentence describing who you think the intended audience is.

4. Find three sources that you would consider to be good choices for your research here. Write two to three sentence description of each. Describe the author, the intended audience, the purpose of the site, and any special features not found in other sites.
When you write a research paper or prepare a presentation for your class, it is important to document your sources. A bibliography serves two purposes. First, a bibliography gives credit to the authors who wrote the material you used to learn about your subject. Second, a bibliography provides your audience with sources they can use if they would like to learn more about your subject.

This skill sheet provides bibliography formats and examples for various types of research materials you may use when preparing science papers and presentations.

Books:

Author last name, First name. (Year published). *Title of book*. Place of publication: Name of publisher.


Newspaper and Magazine Articles:

Author listed:

Author last name, First name. (Date of publication). Title of Article. *Title of Newspaper or Magazine*, page # or #’s.


No author listed:

Title of article. (Date of publication). *Title of Newspaper or Magazine*, page # or #’s.


Online Newspaper or Magazine:

Author listed:

Author last name, First name. (Date of publication). Title of Article. Title of Newspaper or Magazine, Retrieved date, from web address.


No author listed:

Title of Article. (Date of publication). Title of Newspaper or Magazine. Retrieved date, from web address.


Online document:

Author listed:

Author last name, author first name. (Date of publication). Title of document. Retrieved date, from web address.


No Author listed:

Organization responsible for website. (Date of publication). Title of document. Retrieved date, from web address.

5.1 Mass vs. Weight

What is the difference between mass and weight?

<table>
<thead>
<tr>
<th>mass</th>
<th>weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Mass is a measure of the amount of matter in an object. Mass is not related to gravity.</td>
<td>• Weight is a measure of the gravitational force between two objects.</td>
</tr>
<tr>
<td>• The mass of an object does not change when it is moved from one place to another.</td>
<td>• The weight of an object does change when the amount of gravitational force changes, as when an object is moved from Earth to the moon.</td>
</tr>
<tr>
<td>• Mass is commonly measured in grams or kilograms.</td>
<td>• Weight is commonly measured in newtons or pounds.</td>
</tr>
</tbody>
</table>

Weightlessness: When a diver dives off of a 10-meter diving board, she is in free-fall. If she jumped off the board with a scale attached to her feet, the scale would read zero even though she is under the influence of gravity. She is “weightless” because her feet have nothing to push against. Similarly, astronauts and everything inside a space shuttle seem to be weightless because they are in constant free fall. The space shuttle moves at high speed, therefore its constant fall toward Earth results in an orbit around the planet.

**EXAMPLE**

• On Earth’s surface, the force of gravity acting on one kilogram is 2.2 pounds. So, if an object has a mass of 2.0 kilograms, the force of gravity acting on that mass on Earth will be:

\[
2.0 \text{ kg} \times \frac{0.37 \text{ pounds}}{\text{kg}} = 4.4 \text{ pounds}
\]

• On the moon’s surface, the force of gravity is about 0.37 pounds per kilogram. The same object, if it were carried to the moon, would have a mass of 2.0 kilograms, but its weight would be just 0.74 pounds.

\[
2.0 \text{ kg} \times \frac{0.37 \text{ pounds}}{\text{kg}} = 0.74 \text{ pounds}
\]

**PRACTICE**

1. What is the weight (in pounds) of a 7.0-kilogram bowling ball on Earth’s surface?
2. What is the weight (in pounds) of a 7.0-kilogram bowling ball on the surface of the moon?
3. What is the mass of a 7.0-kilogram bowling ball on the surface of the moon?
4. Would a balance function correctly on the moon? Why or why not?

**Challenge Question**

5. Take a bathroom scale into an elevator. Step on the scale.
   a. What happens to the reading on the scale as the elevator begins to move upward? to move downward?
   b. What happens to the reading on the scale when the elevator stops moving?
   c. Why does your weight appear to change, even though you never left Earth’s gravity?
5.1 Mass, Weight, and Gravity

How do we define mass, weight, and gravity?

<table>
<thead>
<tr>
<th>mass</th>
<th>weight</th>
<th>gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Mass is a measure of the</td>
<td>• Weight is a measure of the</td>
<td>• The force that causes all masses</td>
</tr>
<tr>
<td>amount of matter in an</td>
<td>gravitational force between two</td>
<td>to attract one another. The</td>
</tr>
<tr>
<td>object. Mass is not related</td>
<td>objects.</td>
<td>strength of the force depends on</td>
</tr>
<tr>
<td>to gravity.</td>
<td>• The weight of an object does</td>
<td>the size of the masses and their</td>
</tr>
<tr>
<td></td>
<td>not change when it is moved from one place</td>
<td>distance apart.</td>
</tr>
<tr>
<td></td>
<td>to another.</td>
<td></td>
</tr>
<tr>
<td>• Mass is commonly</td>
<td>• Weight is commonly measured in</td>
<td></td>
</tr>
<tr>
<td>measured in grams or</td>
<td>newtons or pounds.</td>
<td></td>
</tr>
<tr>
<td>kilograms.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How are mass, weight, and gravity related?

The weight equation $W = mg$ shows that an object’s weight (in newtons) is equal to its mass (in kilograms) multiplied by the strength of gravity (in newtons per kilogram) where the object is located. The weight equation can be rearranged to find weight, mass, or the strength of gravity if you know any two of the three.

<table>
<thead>
<tr>
<th>Use...</th>
<th>if you want to find...</th>
<th>and you know...</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W = mg$</td>
<td>weight ($W$)</td>
<td>mass ($m$) and strength of gravity ($g$)</td>
</tr>
<tr>
<td>$m = W/g$</td>
<td>mass ($m$)</td>
<td>weight ($W$) and strength of gravity ($g$)</td>
</tr>
<tr>
<td>$g = W/m$</td>
<td>strength of gravity ($g$)</td>
<td>weight ($W$) and mass ($m$)</td>
</tr>
</tbody>
</table>

**EXAMPLE**

- Calculate the weight (in newtons) of a 5.0-kilogram backpack on Earth ($g = 9.8$ N/kilogram).

  **Solution:**
  
  \[
  W = m(g) \\
  W = (5.0 \text{ kg})(9.8 \text{ N/kg}) \\
  W = 49\text{N}
  \]

- The same backpack weighs 8.2 newtons on Earth’s moon. What is the strength of gravity on the moon?

  **Solution:**
  
  \[
  g = W/m \\
  g = 8.2 \text{ N}/5.0 \text{ kg} \\
  g = 1.6 \text{ N/kg}
  \]
1. A physical science textbook has a mass of 2.2 kilograms.
   a. What is its weight on Earth?
   b. What is its weight on Mars? \((g = 3.7 \text{ N/kg})\)
   c. If the textbook weighs 19.6 newtons on Venus, what is the strength of gravity on that planet?

2. An astronaut weighs 104 newtons on the moon, where the strength of gravity is 1.6 newtons per kilogram.
   a. What is her mass?
   b. What is her weight on Earth?
   c. What would she weigh on Mars?

3. Of all the planets in our solar system, Jupiter has the greatest gravitational strength.
   a. If a 0.500-kilogram pair of running shoes would weigh 11.55 newtons on Jupiter, what is the strength of
gravity there?
   b. If the same pair of shoes weighs 0.3 newtons on Pluto (a dwarf planet), what is the strength of gravity
there?
   c. What does the pair of shoes weigh on Earth?

4. A tractor-trailer truck carrying boxes of toy rubber ducks stops at a weigh station on the highway. The driver
is told that the truck weighs 44,000 pounds.
   a. If there are 4.448 newtons in a pound, what is the weight of the toy-filled truck in newtons?
   b. What is the mass of the toy-filled truck?
   c. The truck drops off its load of toys, then stops at a second weigh station. Now the truck weighs
33,000 pounds. What is its weight in newtons?
   d. Challenge! Find the total mass of the rubber duck-filled boxes that were carried by the truck.
5.1 Gravity Problems

In this skill sheet, you will practice using proportions as you learn more about the strength of gravity on different planets.

Comparing the strength of gravity on the planets

Table 1 lists the strength of gravity on each planet in our solar system. We can see more clearly how these values compare to each other using proportions. First, we assume that Earth’s gravitational strength is equal to “1.” Next, we set up the proportion where \( x \) equals the strength of gravity on another planet (in this case, Mercury) as compared to Earth.

\[
\frac{1}{\text{Earth gravitational strength}} = \frac{x}{\text{Mercury gravitational strength}}
\]

\[
\frac{1}{9.8 \text{ N/kg}} = \frac{x}{3.7 \text{ N/kg}}
\]

\[
(1 \times 3.7 \text{ N/kg}) = (9.8 \text{ N/kg} \times x)
\]

\[
\frac{3.7 \text{ N/kg}}{9.8 \text{ N/kg}} = x
\]

\[
0.38 = x
\]

Note that the units cancel. The result tells us that Mercury’s gravitational strength is a little more than a third of Earth’s. Or, we could say that Mercury’s gravitational strength is 38% as strong as Earth’s.

Now, calculate the proportions for the remaining planets.

**Table 1: The strength of gravity on planets in our solar system**

<table>
<thead>
<tr>
<th>Planet</th>
<th>Strength of gravity (N/kg)</th>
<th>Value compared to Earth’s gravitational strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>3.7</td>
<td>0.38</td>
</tr>
<tr>
<td>Venus</td>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td>9.8</td>
<td>1</td>
</tr>
<tr>
<td>Mars</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td>Saturn</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>Uranus</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>Neptune</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Pluto</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>
How much does it weigh on another planet?

Use your completed Table 1 to solve the following problems.

**Example:**

- A bowling ball weighs 15 pounds on Earth. How much would this bowling ball weigh on Mercury?

\[
\frac{\text{Weight on Earth}}{\text{Weight on Mercury}} = \frac{1}{0.38}
\]

\[
\frac{1}{0.38} = \frac{15 \text{ pounds}}{x}
\]

\[
0.38 \times 15 \text{ pounds} = x
\]

\[
x = 5.7 \text{ pounds}
\]

1. A cat weighs 8.5 pounds on Earth. How much would this cat weigh on Neptune?

2. A baby elephant weighs 250 pounds on Earth. How much would this elephant weigh on Saturn? Give your answer in newtons (4.48 newtons = 1 pound).

3. On Pluto, a baby would weigh 2.7 newtons. How much does this baby weigh on Earth? Give your answer in newtons and pounds.

4. Imagine that it is possible to travel to each planet in our solar system. After a space “cruise,” a tourist returns to Earth. One of the ways he recorded his travels was to weigh himself on each planet he visited. Use the list of these weights on each planet to figure out the order of the planets he visited. On Earth he weighs 720 newtons. List of weights: 655 N; 1,699 N; 806 N; 43 N; and 662 N.

**Challenge: Using the Universal Law of Gravitation**

Here is an example problem that is solved using the equation for Universal Gravitation.

**Example**

What is the force of gravity between Pluto and Earth? The mass of Earth is \(6.0 \times 10^{24}\) kg. The mass of Pluto is \(1.3 \times 10^{22}\) kg. The distance between these two planets is \(5.76 \times 10^{12}\) meters.

\[
\text{Force of gravity between Earth and Pluto} = \left(\frac{6.67 \times 10^{-11} \text{N-m}^2}{\text{kg}^2}\right) \left(\frac{6.0 \times 10^{24} \text{kg}}{5.76 \times 10^{12} \text{m}}\right) \times (1.3 \times 10^{22} \text{kg})
\]

\[
\text{Force of gravity} = \frac{52.0 \times 10^{35}}{33.2 \times 10^{24}} = 1.57 \times 10^{11} \text{N}
\]

Now use the equation for Universal Gravitation to solve this problem:

5. What is the force of gravity between Jupiter and Saturn? The mass of Jupiter is \(6.4 \times 10^{24}\) kg. The mass of Saturn is \(5.7 \times 10^{26}\) kg. The distance between Jupiter and Saturn is \(6.52 \times 10^{11}\) m.
5.1 Universal Gravitation

The law of universal gravitation allows you to calculate the gravitational force between two objects from their masses and the distance between them. The law includes a value called the gravitational constant, or “G.” This value is the same everywhere in the universe. Calculating the force between small objects like grapefruits or huge objects like planets, moons, and stars is possible using this law.

What is the law of universal gravitation?

The force between two masses $m_1$ and $m_2$ that are separated by a distance $r$ is given by:

$$ F = G \frac{m_1 m_2}{r^2} $$

So, when the masses $m_1$ and $m_2$ are given in kilograms and the distance $r$ is given in meters, the force has the unit of newtons. Remember that the distance $r$ corresponds to the distance between the center of gravity of the two objects.

For example, the gravitational force between two spheres that are touching each other, each with a radius of 0.300 meter and a mass of 1,000. kilograms, is given by:

$$ F = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2 \times \frac{1,000. \text{ kg} \times 1,000. \text{ kg}}{(0.300 \text{ m} + 0.300 \text{ m})^2} = 0.000185 \text{ N} $$

Note: A small car has a mass of approximately 1,000. kilograms. Try to visualize this much mass compressed into a sphere with a diameter of 0.300 meters (30.0 centimeters). If two such spheres were touching one another, the gravitational force between them would be only 0.000185 newtons. On Earth, this corresponds to the weight of a mass equal to only 18.9 milligrams. The gravitational force is not very strong!
Answer the following problems. Write your answers using scientific notation.

1. Calculate the force between two objects that have masses of 70. kilograms and 2,000. kilograms. Their centers of gravity are separated by a distance of 1.00 meter.

2. Calculate the force between two touching grapefruits each with a radius of 0.080 meters and a mass of 0.45 kilograms.

3. Calculate the force between one grapefruit as described above and Earth. Earth has a mass of $5.9742 \times 10^{24}$ kilograms and a radius of $6.3710 \times 10^6$ meters. Assume the grapefruit is resting on Earth’s surface.

4. A man on the moon with a mass of 90. kilograms weighs 146 newtons. The radius of the moon is $1.74 \times 10^6$ meters. Find the mass of the moon.

5. For $m = 5.9742 \times 10^{24}$ kilograms and $r = 6.3710 \times 10^6$ meters, what is the value given by: $\frac{Gm}{r^2}$?
   a. Write down your answer and simplify the units.
   b. What does this number remind you of?
   c. What real-life values do $m$ and $r$ correspond to?

6. The distance between the centers of Earth and its moon is $3.84 \times 10^8$ meters. Earth’s mass is $5.9742 \times 10^{24}$ kilograms and the mass of the moon is $7.36 \times 10^{22}$ kilograms. What is the force between Earth and the moon?

7. A satellite is orbiting Earth at a distance of 35.0 kilometers. The satellite has a mass of 500. kilograms. What is the force between the planet and the satellite? Hint: Recall Earth’s mass and radius from earlier problems.

8. The mass of the sun is $1.99 \times 10^{30}$ kilograms and its distance from Earth is 150. million kilometers ($150. \times 10^9$ meters). What is the gravitational force between the sun and Earth?
5.2 Friction

Just about every move we make involves friction of some sort. This skill sheet will provide you with the opportunity to practice identifying the friction force(s) involved in real-world situations.

Marco and his dad are unloading cinder blocks from the back of their pickup truck. They need to haul the blocks across the grass to their backyard, where they are going to make a sandbox for Marco’s younger sister. Marco would like to haul a bunch of blocks at once. In the garage, he finds a plastic sled and his sister’s red wagon.

- Which type of friction would resist Marco’s motion if he pulled the blocks in the sled?

  Solution: Sliding friction.

1. Answer these additional questions about Marco’s sandbox building project.
   a. Which type of friction would resist Marco’s motion if he pulled the blocks in the wagon?
   b. Do you think it would take more force to transport five blocks in the sled or in the wagon? Why?
   c. Would the friction force increase, decrease, or stay the same if Marco added two more blocks to the sled or wagon? Explain your answer.
   d. Marco tries piling twelve cinder blocks into the wagon. He pulls and pulls but the wagon doesn’t move. What type of force is resisting motion now?

2. Brianna is rowing a small boat across a pond. The air is calm; there is no wind blowing.
   a. What type of friction is resisting her motion?
   b. If two friends join her in the boat, will the friction force change? Why or why not?

3. A freight train speeds along the railroad tracks at 150 km/hr.
   a. Name two types of friction resisting this motion.
   b. If this train were replaced with a mag-lev train, which type of friction would be eliminated?

4. Research: Some sports cars are designed with rear spoiler to make the car more stable when turning, accelerating, and braking.
   a. Use the Internet or your local library to find an illustration of a spoiler to share with your class.
   b. Does the spoiler increase or decrease friction between the rear tires and the road?
   c. Some small hybrid cars and sport utility vehicles also have spoilers. What is their purpose? Is it the same or different from the spoiler on a sports car?
5.3 Equilibrium

When all forces acting on a body are balanced, the forces are in equilibrium. This skill sheet provides free-body diagrams for you to use for practice in working with equilibrium.

Remember that an unbalanced force results in acceleration. Therefore, the forces acting on an object that is not accelerating must be balanced. These objects may be at rest, or they could be moving at a constant velocity. Either way, we say that the forces acting on these objects are in equilibrium.

What force is necessary in the free-body diagram at right to achieve equilibrium?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>The unknown force: ? N</td>
<td>600 N = 400 N + ? N</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Given</th>
<th>600 N – 400 N = 400 N – 400 N + ? N</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 N is pressing down on the box.</td>
<td>200 N = ? N</td>
</tr>
<tr>
<td>400 N is pressing up on the box.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>You can solve equilibrium problems using simple equations:</td>
</tr>
<tr>
<td>600 N = 400 N + ? N</td>
</tr>
</tbody>
</table>

1. Supply the missing force necessary to achieve equilibrium.
2. Supply the missing forces necessary to achieve equilibrium.

![Diagram](image)

3. In the picture, a girl with a weight of 540 N is balancing on her bike in equilibrium, not moving at all. If the force exerted by the ground on her front wheel is 200 N, how much force is exerted by the ground on her back wheel?

![Bicycle diagram](image)

**Challenge Question:**

4. Helium balloons stay the same size as you hold them, but swell and burst as they rise to high altitudes when you let them go. Draw and label force arrows inside and/or outside the balloons on the graphic at right to show why the near Earth balloon does not burst, but the high altitude balloon does eventually burst. Hint: What are the forces on the inside of the balloon? What are the forces on the outside of the balloons?

![Balloon diagram](image)
Newton’s first law tells us that when the net force is zero, objects at rest stay at rest and objects in motion keep moving with the same speed and direction. Changes in motion come from unbalanced forces.

In this skill sheet, you will practice identifying balanced and unbalanced forces in everyday situations.

**EXAMPLE**

- An empty shopping cart is pushed along a grocery store aisle at constant velocity. Find the cart’s weight and the friction force if the shopper produces a force of 40.0 newtons between the wheels and the floor, and the normal force on the cart is 105 newtons.

1. **Looking for:** You are asked for the cart’s weight and the friction force.

2. **Given:** You are given the normal force and the force produced by the shopper pushing the cart.

3. **Relationships:** Newton’s first law states that if the shopping cart is moving at a constant velocity, the net force must be zero.

4. **Solution:** The weight of the cart balances the normal force. Therefore, the weight of the cart is a downward force: -105 N. The forward force produced by the shopper balances the friction force, so the friction force is -40.0 N.

**PRACTICE**

1. Identify the forces on the same cart at rest.

2. While the cart is moving along an aisle, it comes in contact with a smear of margarine that had recently been dropped on the floor. Suddenly the friction force is reduced from -40.0 newtons to -20.0 newtons. What is the net force on the cart if the “pushing force” remains at 40.0 newtons? Does the grocery cart move at constant velocity over the spilled margarine?

3. Identify the normal force on the shopping cart after 75 newtons of groceries are added to the cart.

4. The shopper pays for his groceries and pushes the shopping cart out of the store, where he encounters a ramp that helps him move the cart from the sidewalk down to the parking lot. What force accelerates the cart down the ramp?

5. Compare the friction force on the cart when it is rolling along the blacktop parking lot to the friction force on the cart when it is inside the grocery store (assume the flooring is smooth vinyl tile).

6. Why is it easy to get one empty cart moving but difficult to get a line of 20 empty carts moving?
6.1 Isaac Newton

Isaac Newton is one of the most brilliant figures in scientific history. His three laws of motion are probably the most important natural laws in all of science. He also made vital contributions to the fields of optics, calculus, and astronomy.

Plague provides opportunity for genius

Isaac Newton was born in 1642 in Lincolnshire, England. His childhood years were difficult. His father died just before he was born. When he was three, his mother remarried and left her son to live with his grandparents. Newton bitterly resented his stepfather throughout his life.

An uncle helped Newton remain in school and in 1661, he entered Trinity College at Cambridge University. He earned his bachelor’s degree in 1665.

Ironically, it was the closing of the university due to the bubonic plague in 1665 that helped develop Newton’s genius. He returned to Lincolnshire and spent the next two years in solitary academic pursuit.

During this period, he made significant advances in calculus, worked on a revolutionary theory of the nature of light and color, developed early versions of his three laws of motion, and gained new insights into the nature of planetary motion.

Fear of criticism stifles scientist

When Cambridge reopened in 1667, Newton was given a minor position at Trinity and began his academic career. His studies in optics led to his invention of the reflecting telescope in the early 1670s. In 1672, his first public paper was presented, on the nature of light and color.

Newton longed for public recognition of his work but dreaded criticism. When another bright young scientist, Robert Hooke, challenged some of his points, Newton was furious. An angry exchange of words left Newton reluctant to make public more of his work.

Revolutionary law of universal gravitation

In the 1680s, Newton turned his attention to forces and motion. He worked on applying his three laws of motion to orbiting bodies, projectiles, pendulums, and free-fall situations. This work led him to formulate his famous law of universal gravitation.

According to legend, Newton thought of the idea while sitting in his Lincolnshire garden. He watched an apple fall from a tree. He wondered if the same force that caused the apple to fall toward the center of Earth (gravity) might be responsible for keeping the moon in orbit around Earth, and the planets in orbit around the sun.

This concept was truly revolutionary. Less than 50 years earlier, it was commonly believed that some sort of invisible shield held the planets in orbit.

Important contributor in spite of conflict

In 1687, Newton published his ideas in a famous work known as the Principia. He jealously guarded the work as entirely his. He bitterly resented the suggestion that he should acknowledge the exchange of ideas with other scientists (especially Hooke) as he worked on his treatise.

Newton left Cambridge to take a government position in London in 1696. His years of active scientific research were over. However, almost three centuries after his death in 1727, Newton remains one of the most important contributors to our understanding of how the universe works.
Reading reflection

1. Important phases of Newton’s education and scientific work occurred in isolation. Why might this have been helpful to him? On the other hand, why is working in isolation problematic for developing scientific ideas?

2. Newton began his academic career in 1667. For how long was he a working scientist? Was he a very productive scientist? Justify your answer.

3. Briefly state one of Newton’s three laws of motion in your own words. Give an explanation of how this law works.

4. Define the law of universal gravitation in your own words.

5. The orbit of a space shuttle is surprisingly like an apple falling from a tree to Earth. The space shuttle is simply moving so fast that the path of its fall is an orbit around our planet. Which of Newton’s laws helps explain the orbit of a space shuttle around Earth and the orbit of Earth around the sun?

6. **Research:** Newton was outraged when, in 1684, German mathematician Wilhelm Leibniz published a calculus book. Find out why, and describe how the issue is generally resolved today.
Newton's Second Law

- Newton’s second law states that the acceleration of an object is directly related to the force on it, and inversely related to the mass of the object. You need more force to move or stop an object with a lot of mass (or inertia) than you need for an object with less mass.
- The formula for the second law of motion (first row below) can be rearranged to solve for mass and force.

<table>
<thead>
<tr>
<th>What do you want to know?</th>
<th>What do you know?</th>
<th>The formula you will use</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration ((a))</td>
<td>force ((F)) and mass ((m))</td>
<td>acceleration = (\frac{force}{mass})</td>
</tr>
<tr>
<td>mass ((m))</td>
<td>acceleration ((a)) and force ((F))</td>
<td>mass = (\frac{force}{acceleration})</td>
</tr>
<tr>
<td>force ((F))</td>
<td>acceleration ((a)) and mass ((m))</td>
<td>force = acceleration (\times) mass</td>
</tr>
</tbody>
</table>

**Example**

- How much force is needed to accelerate a truck with a mass of 2,000 kilograms at a rate of 3 m/s\(^2\)?
  \[
  F = m \times a = 2,000 \text{ kg} \times 3 \text{ m/s}^2 = 6,000 \text{ kg-m/s}^2 = 6,000 \text{ N}
  \]
- What is the mass of an object that requires 15 N to accelerate it at a rate of 1.5 m/s\(^2\)?
  \[
  m = \frac{F}{a} = \frac{15 \text{ N}}{1.5 \text{ m/s}^2} = \frac{15 \text{ kg-m/s}^2}{1.5 \text{ m/s}^2} = 10 \text{ kg}
  \]

**Practice**

1. What is the acceleration of a 2,000.-kilogram truck if a force of 4,200. N is used to make it start moving forward?
2. What is the acceleration of a 0.30-kilogram ball that is hit with a force of 25 N?
3. How much force is needed to accelerate a 68-kilogram skier at 1.2 m/s\(^2\)?
4. What is the mass of an object that requires a force of 30 N to accelerate at 5 m/s\(^2\)?
5. What is the force on a 1,000.-kilogram elevator that is falling freely under the acceleration of gravity only?
6. What is the mass of an object that needs a force of 4,500 N to accelerate it at a rate of 5 m/s\(^2\)?
7. What is the acceleration of a 6.4-kilogram bowling ball if a force of 12 N is applied to it?
6.3 Applying Newton’s Laws of Motion

In the second column of the table below, write each of Newton’s three laws of motion. Use your own wording. In the third column of the table, describe an example of each law. To find examples of Newton’s laws, think about all the activities you do in one day.

<table>
<thead>
<tr>
<th>Newton’s laws of motion</th>
<th>Write the law here in your own words</th>
<th>Example of the law</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first law</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The second law</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The third law</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. When Jane drives to work, she always places her pocketbook on the passenger’s seat. By the time she gets to work, her pocketbook has fallen on the floor in front of the passenger seat. One day, she asks you to explain why this happens in terms of physical science. What do you say?

2. You are waiting in line to use the diving board at your local pool. While watching people dive into the pool from the board, you realize that using a diving board to spring into the air before a dive is a good example of Newton’s third law of motion. Explain how a diving board illustrates Newton’s third law of motion.

3. You know the mass of an object and the force applied to the object to make it move. Which of Newton’s laws of motion will help you calculate the acceleration of the object?

4. How many newtons of force are represented by the following amount: 3 kg · m/s²? Select the correct answer (a, b, or c) and justify your answer.
   a. 6 newtons  
   b. 3 newtons  
   c. 1 newton

5. Your shopping cart has a mass of 65 kilograms. In order to accelerate the shopping cart down an aisle at 0.30 m/s², what force would you need to use or apply to the cart?

6. A small child has a wagon with a mass of 10 kilograms. The child pulls on the wagon with a force of 2 newtons. What is the acceleration of the wagon?

7. You dribble a basketball while walking on a basketball court. List and describe the pairs of action-reaction forces in this situation.

8. Pretend that there is no friction at all between a pair of ice skates and an ice rink. If a hockey player using this special pair of ice skates was gliding along on the ice at a constant speed and direction, what would be required for him to stop?
Which is more difficult to stop: A tractor-trailer truck barreling down the highway at 35 meters per second, or a small two-seater sports car traveling the same speed?

You probably guessed that it takes more force to stop a large truck than a small car. In physics terms, we say that the truck has greater momentum.

We can find momentum using this equation:

\[ \text{momentum} = \text{mass of object} \times \text{velocity of object} \]

Velocity is a term that refers to both speed and direction. For our purposes we will assume that the vehicles are traveling in a straight line. In that case, velocity and speed are the same.

The equation for momentum is abbreviated like this: \( P = m \times v \).

Momentum, symbolized with a \( P \), is expressed in units of kg \( \cdot \) m/s; \( m \) is the mass of the object, in kilograms; and \( v \) is the velocity of the object in m/s.

Use your knowledge about solving equations to work out the following problems:

1. If the truck has a mass of 4,000. kilograms, what is its momentum? Express your answer in kg \( \cdot \) m/s.
2. If the car has a mass of 1,000. kilograms, what is its momentum?
3. An 8-kilogram bowling ball is rolling in a straight line toward you. If its momentum is 16 kg \( \cdot \) m/s, how fast is it traveling?
4. A beach ball is rolling in a straight line toward you at a speed of 0.5 m/s. Its momentum is 0.25 kg \( \cdot \) m/s. What is the mass of the beach ball?
5. A 4,500.-kilogram truck travels in a straight line at 10. m/s. What is its momentum?
6. A 1,500.-kilogram car is also traveling in a straight line. Its momentum is equal to that of the truck in the previous question. What is the velocity of the car?
7. Which would take more force to stop in 10. seconds: an 8.0-kilogram ball rolling in a straight line at a speed of 0.2 m/s or a 4.0-kilogram ball rolling along the same path at a speed of 1.0 m/s?
8. The momentum of a car traveling in a straight line at 25 m/s is 24,500 kg \( \cdot \) m/s. What is the car’s mass?
9. A 0.14-kilogram baseball is thrown in a straight line at a velocity of 30. m/s. What is the momentum of the baseball?
10. Another pitcher throws the same baseball in a straight line. Its momentum is 2.1 kg \( \cdot \) m/s. What is the velocity of the ball?
11. A 1-kilogram turtle crawls in a straight line at a speed of 0.01 m/s. What is the turtle’s momentum?
6.3 Momentum Conservation

Just as forces are equal and opposite (according to Newton’s third law), changes in momentum are also equal and opposite. This is because when objects exert forces on each other, their motion is affected.

The law of momentum conservation states that if interacting objects in a system are not acted on by outside forces, the total amount of momentum in the system cannot change.

The formula below can be used to find the new velocities of objects if both keep moving after the collision.

\[
m_1 v_1 \text{(initial)} + m_2 v_2 \text{(initial)} = m_1 v_3 \text{(final)} + m_2 v_4 \text{(final)}
\]

If two objects are initially at rest, the total momentum of the system is zero.

\[
\text{the momentum of a system before a collision} = 0
\]

For the final momentum to be zero, the objects must have equal momenta in opposite directions.

\[
0 = m_1 v_3 + m_2 v_4
\]

\[
0 = m_1 v_3 - (m_2 v_4)
\]

Example 1: What is the momentum of a 0.2-kilogram steel ball that is rolling at a velocity of 3.0 m/s?

\[
\text{momentum} = m \times v = 0.2 \text{ kg} \times \frac{3 \text{ m}}{\text{s}} = 0.6 \text{ kg} \cdot \frac{\text{m}}{\text{s}}
\]

Example 2: You and a friend stand facing each other on ice skates. Your mass is 50. kilograms and your friend’s mass is 60. kilograms. As the two of you push off each other, you move with a velocity of 4.0 m/s to the right. What is your friend’s velocity?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your friend’s velocity to the left.</td>
<td>[m_1 v_3 = -(m_2 v_4)]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Given</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your mass of 50. kg.</td>
<td>[(50. \text{ kg})(4.0 \text{ m/s}) = -(60. \text{ kg})(v_4)]</td>
</tr>
<tr>
<td>Your friend’s mass of 60. kg.</td>
<td>[200 \text{ kg-m/s} = v_4 ]</td>
</tr>
<tr>
<td>Your velocity of 4.0 m/s to the right.</td>
<td>[-(60 \text{ kg}) = v_4 ]</td>
</tr>
</tbody>
</table>

\[v_4 = -3.3 \text{ m/s} \]

Your friend’s velocity to the left is 3.3 m/s.
1. If a ball is rolling at a velocity of 1.5 m/s and has a momentum of 10.0 kg·m/s, what is the mass of the ball?

2. What is the velocity of an object that has a mass of 2.5 kg and a momentum of 1,000 kg · m/s?

3. A pro golfer hits 45.0-gram golf ball, giving it a speed of 75.0 m/s. What momentum has the golfer given to the ball?

4. A 400-kilogram cannon fires a 10-kilogram cannonball at 20 m/s. If the cannon is on wheels, at what velocity does it move backward? (This backward motion is called recoil velocity.)

5. Eli stands on a skateboard at rest and throws a 0.5-kg rock at a velocity of 10.0 m/s. Eli moves back at 0.05 m/s. What is the combined mass of Eli and the skateboard?

6. As the boat in which he is riding approaches a dock at 3.0 m/s, Jasper stands up in the boat and jumps toward the dock. Jasper applies an average force of 800. newtons on the boat for 0.30 seconds as he jumps.
   a. How much momentum does Jasper’s 80.-kilogram body have as it lands on the dock?
   b. What is Jasper's speed on the dock?

7. Daryl the delivery guy gets out of his pizza delivery truck but forgets to set the parking brake. The 2,000.-kilogram truck rolls down hill reaching a speed of 30 m/s just before hitting a large oak tree. The vehicle stops 0.72 s after first making contact with the tree.
   a. How much momentum does the truck have just before hitting the tree?
   b. What is the average force applied by the tree?

8. Two billion people jump up in the air at the same time with an average velocity of 7.0 m/s. If the mass of an average person is 60 kilograms and the mass of Earth is $5.98 \times 10^{24}$ kilograms:
   a. What is the total momentum of the two billion people?
   b. What is the effect of their action on Earth?

9. Tammy, a lifeguard, spots a swimmer struggling in the surf and jumps from her lifeguard chair to the sand beach. She makes contact with the sand at a speed of 6.00 m/s, leaving an indentation in the sand 0.10 m deep.
   a. If Tammy's mass is 60. kilograms, what is the momentum as she first touches the sand?
   b. What is the average force applied on Tammy by the sand beach?

10. When a gun is fired, the shooter describes the sensation of the gun kicking. Explain this in terms of momentum conservation.

11. What does it mean to say that momentum is conserved?
6.3 Collisions and Conservation of Momentum

The law of conservation of momentum tells us that as long as colliding objects are not influenced by outside forces like friction, the total amount of momentum in the system before and after the collision is the same.

We can use the law of conservation of momentum to predict how two objects will move after a collision. Use the problem solving steps and the examples below to help you solve collision problems.

**Problem Solving Steps**

1. Draw a diagram.
2. Assign variables to represent the masses and velocities of the objects before and after the collision.
3. Write an equation stating that the total momentum before the collision equals the total after.
4. Plug in the information that you know.
5. Solve your equation.

**Example**

A 2,000-kilogram railroad car moving at 5 m/s collides with a 6,000-kilogram railroad car at rest. If the cars coupled together, what is their velocity after the inelastic collision?

Looking for

\[ v_3 = \text{the velocity of the combined railroad cars after an inelastic collision} \]

**Given**

- Initial speed and mass of both cars:
  \[ m_1 = 2,000 \text{ kg, } v_1 = 5 \text{ m/s} \]
  \[ m_2 = 6,000 \text{ kg, } v_2 = 0 \text{ m/s} \]
- Combined mass of the two cars:
  \[ m_1 + m_2 = 8,000 \text{ kg} \]

**Relationship**

\[ m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_3 \]

**Solution**

\[
(2000 \text{ kg})(5 \text{ m/s}) + (6000 \text{ kg})(0 \text{ m/s}) = (2000 \text{ kg} + 6000 \text{ kg}) v_3 \\
10,000 \text{ kg-m/s} = (8000 \text{ kg}) v_3 \\
\frac{10,000 \text{ kg-m/s}}{8000 \text{ kg}} = v_3 \\
10 \text{ m/s} = v_3
\]

The velocity of the two combined cars after the collision is 10 m/s.
1. What is the momentum of a 100.-kilogram fullback carrying a football on a play at a velocity of 3.5 m/s?

2. What is the momentum of a 75.0-kilogram defensive back chasing the fullback at a velocity of 5.00 m/s?

3. A 2,000-kilogram railroad car moving at 5 m/s to the east collides with a 6,000-kilogram railroad car moving at 3 m/s to the west. If the cars couple together, what is their velocity after the collision?

4. A 4.0-kilogram ball moving at 8.0 m/s to the right collides with a 1.0-kilogram ball at rest. After the collision, the 4.0-kilogram ball moves at 4.8 m/s to the right. What is the velocity of the 1-kilogram ball?

5. A 0.0010-kg pellet is fired at a speed of 50.0 m/s at a motionless 0.35-kg piece of balsa wood. When the pellet hits the wood, it sticks in the wood and they slide off together. With what speed do they slide?

6. Terry, a 70.-kilogram tailback, runs through his offensive line at a speed of 7.0 m/s. Jared, a 100-kilogram linebacker, running in the opposite direction at 6.0 m/s, meets Jared head-on and “wraps him up.” What is the result of this tackle?

7. Snowboarding cautiously down a steep slope at a speed of 7.0 m/s, Sarah, whose mass is 50. kilograms, is afraid she won't have enough speed to travel up a slight uphill grade ahead of her. She extends her hand as her friend Trevor, who has a mass of 100. kilograms, is about to pass her traveling at 16 m/s. If Trevor grabs her hand, calculate the speed at which the friends will be sliding.

8. Tex, an 85.0-kilogram rodeo bull rider is thrown from the bull after a short ride. The 520. kilogram bull chases after Tex at 13.0 m/s. While running away at 3.00 m/s, Tex jumps onto the back of the bull to avoid being trampled. How fast does the bull run with Tex aboard?

9. Identical twins Kate and Karen each have a mass of 45 kg. They are rowing their boat on a hot summer afternoon when they decide to go for a swim. Kate jumps off the front of the boat at a speed of 3.00 m/s. Karen jumps off the back at a speed of 4.00 m/s. If the 70.-kilogram rowboat is moving at 1.00 m/s when the girls jump, what is the speed of the rowboat after the girls jump?

10. A 0.10-kilogram piece of modeling clay is tossed at a motionless 0.10-kilogram block of wood and sticks. The block slides across a frictionless table at 15 m/s.
   a. At what speed was the clay tossed?
   b. The clay is replaced with a “bouncy” ball with the same mass. It is tossed with the same speed. The bouncy ball rebounds from the wooden block at a speed of 10 m/s. What effect does this have on the wooden block? Why?
6.3 Rate of Change of Momentum

Momentum is given by the expression \( p = mv \) where \( p \) is the momentum of an object of mass \( m \) moving with velocity \( v \). The units of momentum are \( \text{kg-m/s} \). Change of momentum (represented \( \Delta p \)) over a time interval (represented \( \Delta t \)) is also called the rate of change of momentum.

Since, momentum is \( p = mv \), if the mass remains constant during the time \( \Delta t \), then:

\[
\frac{\Delta p}{\Delta t} = m \frac{\Delta v}{\Delta t}
\]

The expression, \( \frac{\Delta v}{\Delta t} \), represents change in velocity over change in time, also known as acceleration. From Newton’s second law, we know that acceleration equals force divided by mass \( (a = \frac{F}{m}) \). Rearranging the equation, we see that force equals mass times acceleration \( (F = ma) \). Similarly, force \( (F) \) equals change in momentum over change in time.

\[
F = ma = m \frac{\Delta v}{\Delta t} = \frac{\Delta p}{\Delta t}
\]

A mass, \( m \), moving with velocity, \( v \), has momentum \( mv \). If this momentum becomes zero over some change in time \( (\Delta t) \), then there is a force, \( F = (mv - 0)/\Delta t \).

- \( mv \) is the initial momentum.
- \( 0 \) is the momentum after a change in time \( \Delta t \).

When a car accelerates or decelerates, we feel a force that pushes back during acceleration and pushes us forward during deceleration. When the car brakes slowly, the force is small. However, when the car brakes quickly, the force increases considerably.

**Example 1.** An 80-kg woman is a passenger in a car going 90 km/h. The driver puts on the brakes and the car comes to a stop in 2 seconds. What is the average force felt by the passenger?

First, convert the velocity to a value that is in meters per second: 90 km/h = 25 m/s. Next, use the equation that relates force and momentum:

\[
\text{Force} = \frac{\Delta p}{\Delta t} = m \frac{\Delta v}{\Delta t} = 80 \text{ kg} \frac{(25 - 0) \text{ m/s}}{2 \text{ s}} = 1,000 \text{ N}
\]

This is a large force, and for the passenger to stay in her seat, she must be strapped in with a seat belt.

When the stopping time decreases from 2 seconds to 1 second, the force increases to 2,000 newtons. When the car is involved in a crash, the change in momentum happens over a much shorter period of time, thereby creating very large forces on the passenger. Air bags and seat belts help by slowing down the person’s momentum change, resulting in smaller forces and a reduced chance for injury. Let’s look at some numbers.
The car travels at 90 kilometers per hour, crashes, and comes to a stop in 0.1 seconds. The air bag inflates and cushions the person for 1.5 seconds. Let’s calculate the force experienced by the passenger in an automobile without air bags and in one case with air bags.

- Without the air bag, the momentum change happens over 0.1 seconds. This results in a force:

\[
\text{Force} = 80 \text{ kg} \frac{25 \text{ m/s}}{0.1 \text{ s}} = 2,000 \text{ N}
\]

The human body is not likely to survive a force as large as this.

- With the air bag, the force created is:

\[
\text{Force} = 80 \text{ kg} \frac{25 \text{ m/s}}{1.5 \text{ s}} = 1,333 \text{ N}
\]

The chances for survival are much higher.

**Example 2.** A pile is driven into the ground by hitting it repeatedly. If the pile is hit by the driver mass at a rate of 100 kg/s and with a speed of 10 m/s, calculate the resulting average force on the pile.

We are told that the driver mass hits the pile at a rate of 100 kg/s. What does this mean exactly? We can have a 100-kilogram mass hitting the pile every second, or a 50-kilogram mass hitting the pile every half-second, or a 200-kilogram mass hitting the pile every 2 seconds. You get the idea.

The speed \(v\) with which the mass hits the pile is 10 m/s. The mass \(m\) is 100 kilograms. Time changes occur at 1-second intervals. The force on the pile is:

\[
\text{Force} = m \frac{\Delta v}{\Delta t} = 100 \frac{\text{kg}}{\text{s}} \frac{10 \text{ m/s}}{1 \text{ s}} = 1,000 \frac{\text{kg} \cdot \text{m}}{\text{s}^2} = 1,000 \text{ N}
\]

**Practice**

1. A 1,000-kg wrecking ball hits a wall with a speed of 2 m/s and comes to a stop in 0.01 s. Calculate the force experienced by the wall.
2. A 0.15-kg soccer ball is rolling with a speed of 10 m/s and is stopped by the frictional force between it and the grass. If the average friction force is 0.5 N, how long would this take?
3. Water comes out of a fire hose at a rate of 5.0 kg/s and with a speed of 50 m/s. Calculate the force on the hose. (This is the force that the firefighter has to provide in order to hold the hose.)
4. Water from a fire hose is hitting a wall straight on. The water comes out with a flow rate of 25 kg/s and hits the wall with a speed of 30 m/s. What is the resulting force exerted on the wall by the water?
5. The water at Niagara Falls flows at a rate of 3.0 million kg/s. The water hits the bottom of the falls at a speed of 25 m/s. What is the force generated by the change in momentum of the falling water?
6. A 50.-g (0.050-kg) egg that is dropped from a height of 5.0 m will hit the floor with a speed of about 10. m/s. The hard floor forces the egg to stop very quickly. Let’s say that it will stop in 0.0010 second.
  
a. What is the force created on the egg?
  
b. The egg will break at the force you calculated for 6(a). Imagine that a 50.-kilogram person fell down on the egg falling under the influence of gravity. What would the force of the person on the egg be?
  
c. Do you think the egg will break if the person fell on it? Why or why not?
  
d. If we now drop the egg onto a pillow, it will allow the egg to stop over a much longer time compared with the time it takes for it to stop on the hard surface. The weight and the velocity of the egg is still the same, but now the time it takes for the egg to come to rest is much longer, about 0.5 second or about 500 times longer than the time it took to stop on the floor. What would the force on the egg be under these circumstances?
  
e. Do you think the egg will break when it drops on the pillow? Why or why not?
7.1 Mechanical Advantage

Mechanical advantage (MA) is the ratio of output force to input force for a machine.

\[
MA = \frac{F_o}{F_i}
\]

or

\[
MA = \frac{\text{output force (N)}}{\text{input force (N)}}
\]

Did you notice that the force unit involved in the calculation, the newton (N) is present in both the numerator and the denominator of the fraction? These units cancel each other, leaving the value for mechanical advantage unitless.

\[
\frac{\text{newtons}}{\text{newtons}} = \frac{N}{N} = 1
\]

Mechanical advantage tells you how many times a machine multiplies the force put into it. Some machines provide us with more output force than we applied to the machine—this means MA is greater than one. Some machines produce an output force smaller than our effort force, and MA is less than one. We choose the type of machine that will give us the appropriate MA for the work that needs to be performed.

**Example 1:** A force of 200 newtons is applied to a machine in order to lift a 1,000-newton load. What is the mechanical advantage of the machine?

\[
MA = \frac{\text{output force (N)}}{\text{input force (N)}} = \frac{1000 \text{ N}}{200 \text{ N}} = 5
\]

Machines make work easier. Work is force times distance \((W = F \times d)\). The unit for work is the newton-meter. Using the work equation, as shown in example 2 below, can help calculate the mechanical advantage.

**Example 2:** A force of 30 newtons is applied to a machine through a distance of 10 meters. The machine is designed to lift an object to a height of 2 meters. If the total work output for the machine is 18 newton-meters \((\text{N-m})\), what is the mechanical advantage of the machine?

\[
\begin{align*}
\text{input force} & = 30 \text{ N} \\
\text{output force} & = (\text{work} \div \text{distance}) = (18 \text{ N-m} \div 2 \text{ m}) = 9 \text{ N} \\
MA & = \frac{\text{output force (N)}}{\text{input force (N)}} = \frac{9 \text{ N}}{30 \text{ N}} = 0.3
\end{align*}
\]
1. A machine uses an input force of 200 newtons to produce an output force of 800 newtons. What is the mechanical advantage of this machine?

2. Another machine uses an input force of 200 newtons to produce an output force of 80 newtons. What is the mechanical advantage of this machine?

3. A machine is required to produce an output force of 600 newtons. If the machine has a mechanical advantage of 6, what input force must be applied to the machine?

4. A machine with a mechanical advantage of 10 is used to produce an output force of 250 newtons. What input force is applied to this machine?

5. A machine with a mechanical advantage of 2.5 requires an input force of 120 newtons. What output force is produced by this machine?

6. An input force of 35 newtons is applied to a machine with a mechanical advantage of 0.75. What is the size of the load this machine could lift (how large is the output force)?

7. A machine is designed to lift an object with a weight of 12 newtons. If the input force for the machine is set at 4 newtons, what is the mechanical advantage of the machine?

8. An input force of 50 newtons is applied through a distance of 10 meters to a machine with a mechanical advantage of 3. If the work output for the machine is 450 newton · meters and this work is applied through a distance of 3 meters, what is the output force of the machine?

9. 200 newton·meters of work is put into a machine over a distance of 20 meters. The machine does 150 newton·meters of work as it lifts a load 10 meters high. What is the mechanical advantage of the machine?

10. A machine has a mechanical advantage of 5. If 300 newtons of input force is used to produce 3,000 newton · meters of work,

   a. What is the output force?

   b. What is the distance over which the work is applied?
7.1 Mechanical Advantage of Simple Machines

We use simple machines to make tasks easier. While the output work of a simple machine can never be greater than the input work, a simple machine can multiply input forces OR multiply input distances (but never both at the same time). You can use this skill sheet to practice calculating mechanical advantage (MA) for two common simple machines: levers and ramps.

The general formula for the mechanical advantage (MA) of levers:

\[ MA_{\text{lever}} = \frac{F_o}{F_i} \]

Or you can use the ratio of the input arm length to the output arm length:

\[ MA_{\text{lever}} = \frac{L_i}{L_o} \]

Most of the time, levers are used to multiply force to lift heavy objects.

The general formula for the mechanical advantage (MA) of ramps:

\[ MA_{\text{ramp}} = \frac{\text{ramp length}}{\text{ramp height}} \]

A ramp makes it possible to move a heavy load to a new height using less force (but over a longer distance).

**Example 1:** A construction worker uses a board and log as a lever to lift a heavy rock. If the input arm is 3 meters long and the output arm is 0.75 meters long, what is the mechanical advantage of the lever?

\[ MA = \frac{3 \text{ meters}}{0.75 \text{ meter}} = 4 \]

**Example 2:** Sometimes levers are used to multiply distance. For a broom, your upper hand is the fulcrum and your lower hand provides the input force: Notice the input arm is shorter than the output arm. The mechanical advantage of this broom is:

\[ MA = \frac{3 \text{ meter}}{0.75 \text{ meter}} = 0.25 \]

A mechanical advantage less than one doesn’t mean a machine isn’t useful. It just means that instead of multiplying force, the machine multiplies distance. A broom doesn’t push the dust with as much force as you use to push the broom, but a small movement of your arm pushes the dust a large distance.
Example 3: A 500-newton cart is lifted to a height of 1 meter using a 10-meter long ramp. You can see that the worker only has to use 50 newtons of force to pull the cart. You can figure the mechanical advantage in either of these two ways:

\[ MA_{\text{ramp}} = \frac{\text{ramp length}}{\text{ramp height}} = \frac{10 \text{ meters}}{1 \text{ meter}} = 10 \]

Or using the standard formula for mechanical advantage:

\[ MA = \frac{\text{output force}}{\text{input force}} = \frac{500 \text{ newtons}}{50 \text{ newtons}} = 10 \]

Lever problems

1. A lever used to lift a heavy box has an input arm of 4 meters and an output arm of 0.8 meters. What is the mechanical advantage of the lever?

2. What is the mechanical advantage of a lever that has an input arm of 3 meters and an output arm of 2 meters?

3. A lever with an input arm of 2 meters has a mechanical advantage of 4. What is the output arm’s length?

4. A lever with an output arm of 0.8 meter has a mechanical advantage of 6. What is the length of the input arm?

5. A rake is held so that its input arm is 0.4 meters and its output arm is 1.0 meters. What is the mechanical advantage of the rake?

6. A broom with an input arm length of 0.4 meters has a mechanical advantage of 0.5. What is the length of the output arm?

7. A child’s toy rake is held so that its output arm is 0.75 meters. If the mechanical advantage is 0.33, what is the input arm length?

Ramp problems

8. A 5-meter ramp lifts objects to a height of 0.75 meters. What is the mechanical advantage of the ramp?

9. A 10-meter long ramp has a mechanical advantage of 5. What is the height of the ramp?

10. A ramp with a mechanical advantage of 8 lifts objects to a height of 1.5 meters. How long is the ramp?

11. A child makes a ramp to push his toy dump truck up to his sandbox. If he uses 5 newtons of force to push the 12-newton truck up the ramp, what is the mechanical advantage of his ramp?

12. A ramp with a mechanical advantage of 6 is used to move a 36-newton load. What input force is needed to push the load up the ramp?

13. Gina wheels her wheelchair up a ramp using a force of 80 newtons. If the ramp has a mechanical advantage of 7, what is the output force (in newtons)?

14. Challenge! A mover uses a ramp to pull a 1000-newton cart up to the floor of his truck (0.8 meters high). If it takes a force of 200 newtons to pull the cart, what is the length of the ramp?
7.1 Work

In science, “work” is defined with an equation. Work is the amount of force applied to an object (in the same direction as the motion) over a distance. By measuring how much force you have used to move something over a certain distance, you can calculate how much work you have accomplished.

The formula for work is:

\[ W = F \times d \]

A joule of work is actually a newton·meter; both units represent the same thing: work! In fact, one joule of work is defined as the amount of work done by pushing with a force of one newton for a distance of one meter.

\[ 1.0 \text{ joule} = 1.0 \text{ newton} \times 1.0 \text{ meter} = 1.0 \text{ newton} \cdot \text{meter} \]

**Example**

- How much work is done on a 10-N block that is lifted 5 m off the ground by a pulley?

  **Solution:** The force applied by the pulley to lift the block is equal to the block’s weight. We can use the formula \( W = F \times d \) to solve the problem:

  \[ \text{Work} = 10 \text{ newtons} \times 5 \text{ meters} = 50 \text{ newton} \cdot \text{meters} \]

**Practice**

1. In your own words, define work as a scientific term.
2. How are work, force, and distance related?
3. What are two different units that represent work?
4. For the following situations, determine whether work was done. Write “work done” or “no work done” for each situation.
   a. An ice skater glides for two meters across ice.
   b. The ice skater’s partner lifts her up a distance of 1 m.
   c. The ice skater’s partner carries her across the ice a distance of 3 m.
   d. After setting her down, the ice skater’s partner pulls her across the ice a distance of 10 m.
   e. After skating practice, the ice skater lifts her 20-N gym bag up 0.5 m.
5. A woman lifts her 100-N child up one meter and carries her for a distance of 50 m to the child’s bedroom. How much work does the woman do?
6. How much work does a mother do if she lifts each of her twin babies upward 1.0 m? Each baby weighs 90 N.
7. You pull your sled through the snow a distance of 500 m with a horizontal force of 200 N. How much work did you do?

8. Because the snow suddenly gets too slushy, you decide to carry your 100-N sled the rest of the way home. How much work do you do when you pick up the sled, lifting it 0.5 m upward? How much work do you do to carry the sled if your house is 800 m away?

9. An ant sits on the back of a mouse. The mouse carries the ant across the floor for a distance of 10 m. Was there work done by the mouse? Explain.

10. You decide to add up all the work you did yesterday. If you accomplished 10,000 N · m of work yesterday, how much work did you do in units of joules?

11. You did 150 J of work lifting a 120-N backpack.
   a. How high did you lift the backpack?
   b. How much did the backpack weigh in pounds? (Hint: There are 4.448 N in one pound.)

12. A crane does 62,500 J of work to lift a boulder a distance of 25.0 m. How much did the boulder weigh? (Hint: The weight of an object is considered to be a force in units of newtons.)

13. A bulldozer does 30,000 J of work to push another boulder a distance of 20 m. How much force is applied to push the boulder?

14. You lift a 45-N bag of mulch 1.2 m and carry it a distance of 10 m to the garden. How much work was done?

15. A 450-N gymnast jumps upward a distance of 0.50 m to reach the uneven parallel bars. How much work did she do before she even began her routine?

16. It took a 500-N ballerina a force of 250 J to lift herself upward through the air. How high did she jump?

17. A people-moving conveyor-belt moves a 600-N person a distance of 100 m through the airport.
   a. How much work was done?
   b. The same 600-N person lifts his 100-N carry-on bag upward a distance of 1 m. They travel another 10 m by riding on the “people mover.” How much work was done in this situation?

18. Which person did the most work?
   a. John walks 1000 m to the store. He buys 4.448 N of candy and then carries it to his friend’s house which is 500 m away.
   b. Sally lifts her 22-N cat a distance of 0.50 m.
   c. Henry carries groceries from a car to his house. Each bag of groceries weighs 40 N. He has 10 bags. He lifts each bag up 1 m to carry it and then walks 10 m from his car to his house.
A lever is a simple machine that can be used to multiply force, multiply distance, or change the direction of a force. All levers contain a stiff structure that rotates around a point called the **fulcrum**. The force applied to a lever is called the **input force**. The force applied to a load is called the **output force**.

There are three types or classes of levers. The class of a lever depends on the location of the fulcrum and input and output forces. The picture below shows examples of the three classes of levers. Look at each lever carefully, noticing the location of the fulcrum, input force, and output force.

1. In which class of lever is the output force between the fulcrum and input force?
2. In which class of lever is the fulcrum between the input force and output force?
3. In which class of lever is the fulcrum on one end and the output force on the other end?
4. Do the following for each of the levers shown below and at the top of the next page:
   a. Label the fulcrum (F).
   b. Label the location of the input force (I) and output force (O).
   c. Classify the lever as first, second, or third class.
The relationship between a lever’s input force and output force depends on the length of the **input arm** and **output arm**. The input arm is the distance between the fulcrum and input force. The output arm is the distance between the fulcrum and output force.

If the input and output arms are the same length, the forces are equal. If the input arm is longer, the input force is less than the output force. If the input arm is shorter, the input force is greater than the output force.

---

**PRACTICE 2**

1. Label the input arm (IA) and output arm (OA) on each of the levers you labeled above and on the previous page.

2. In which of the levers is the input force greater than the output force?

3. In which of the levers is the output force greater than the input force?

4. In which of the levers are the input and output forces equal in strength?

5. Find two other examples of levers. Draw each lever and label the fulcrum, input force, output force, input arm, and output arm. State whether the input or output force is stronger.
7.1 Gear Ratios

A gear ratio is used to figure out the number of turns each gear in a pair will make based on the number of teeth each gear has.

To calculate the gear ratio for a pair of gears that are working together, you need to know the number of teeth on each gear. The formula below demonstrates how to calculate a gear ratio.

Notice that knowing the number of teeth on each gear allows you to figure out how many turns each gear will take.

Why would this be important in figuring out how to design a clock that has a minute and hour hand?

A gear with 48 teeth is connected to a gear with 12 teeth. If the 48-tooth gear makes one complete turn, how many times will the 12-tooth gear turn?

\[
\text{Turns of output gear} = \frac{48 \text{ input teeth}}{12 \text{ output teeth}} = 4 \text{ turns}
\]

1. A 36-tooth gear turns three times. It is connected to a 12-tooth gear. How many times does the 12-tooth gear turn?

2. A 12-tooth gear is turned two times. How many times will the 24-tooth gear to which it is connected turn?

3. A 60-tooth gear is connected to a 24-tooth gear. If the smaller gear turns ten times, how many turns does the larger gear make?

4. A 60-tooth gear is connected to a 72-tooth gear. If the smaller gear turns twelve times, how many turns does the larger gear make?

5. A 72-tooth gear is connected to a 12-tooth gear. If the large gear makes one complete turn, how many turns does the small gear make?
6. Use the gear ratio formula to help you fill in the table below.

**Table 1: Using the gear ratio to calculate number of turns**

<table>
<thead>
<tr>
<th>Input Gear (# of teeth)</th>
<th>Output Gear (# of teeth)</th>
<th>Gear ratio (Input Gear: Output Gear)</th>
<th>How many turns does the output gear make if the input gear turns 3 times?</th>
<th>How many turns does the input gear make if the output gear turns 2 times?</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. The problems in this section involve three gears stacked on top of each other. Once you have filled in Table 2, answer the questions that follow. Use the gear ratio formula to help. Remember, knowing the gear ratios allows you to figure out the number of turns for a pair of gears.

**Table 2: Set up for three gears**

<table>
<thead>
<tr>
<th>Setup</th>
<th>Gears</th>
<th>Number of teeth</th>
<th>Ratio (top gear: middle gear)</th>
<th>Ratio 2 (middle gear: bottom gear)</th>
<th>Total gear ratio (Ratio 1 x Ratio 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top gear</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Top gear</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Top gear</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Top gear</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. As you turn the top gear to the right, what direction does the middle gear turn? What direction will the bottom gear turn?

9. How many times will you need to turn the top gear (input) in setup 1 to get the bottom gear (output) to turn once?

10. If you turn the top gear (input) in setup 2 two times, how many times will the bottom gear (output) turn?

11. How many times will the middle gear (output) in setup 3 turn if you turn the top gear (input) two times?

12. How many times will you need to turn the top gear (input) in setup 4 to get the bottom gear (output) to turn 4 times?
7.1 Levers in the Human Body

Your skeletal and muscular systems work together to move your body parts. Some of your body parts can be thought of as simple machines or levers.

There are three parts to all levers:

- Fulcrum - the point at which the lever rotates.
- Input force (also called the effort) - the force applied to the lever.
- Output force (also called the load) - the force applied by the lever to move the load.

There are three types of levers: first class, second class and third class. In a first class lever, the fulcrum is located between the input force and output force. In a second class lever, the output force is between the fulcrum and the input force. In a third class lever, the input force is between the fulcrum and the output force. An example of each type of lever is shown below.
The three classes of levers can be found in your body. Use diagrams A, B, and C to answer the questions below. Also label the effort (input force), fulcrum and load (output force) on each diagram.

**LEVER A**

1. Type of Lever: __________
2. How is this lever used in the body?

**LEVER B**

3. Type of Lever: __________
4. How is this lever used in the body?

**LEVER C**

5. Type of Lever: __________
6. How is this lever used in the body?
7.1 Bicycle Gear Ratios Project

How many gears does your bicycle really have?

Bicycle manufacturers describe any bicycle with two gears in the front and five in the back as a ten-speed. But do you really get ten different speeds? In this project, you will determine and record the gear ratio for each speed of your bicycle. You will then write up an explanation of the importance (or lack of, in some cases) of each speed. You will explain what the rider experiences due to the physics of the gear ratio, and in what situation the rider would take advantage of that particular speed.

To complete this project, you will need:

- Multi-speed bicycle
- Simple calculator
- Access to a library or the Internet for research
- Access to a computer for work with a spreadsheet (optional)

On a multi-speed bicycle, there are two groups of gears: the front group and the rear group. You may want to carefully place your bicycle upside down on the floor to better work with the gears. The seat and handlebars will keep the bicycle balanced.

1. Draw a schematic diagram to show how the gears are set up on your bicycle.

2. Now, count the number of teeth on each gear in each group. Record your data in a table on paper or in a computer spreadsheet. Use these questions to guide you.
   a. How many gears are in the front group?
   b. How many teeth on each gear in the front group?
   c. How many gears are in the rear group?
   d. How many teeth on each gear in the rear group?
3. Now, calculate the gear ratio for each front/rear combination of gears. Use the formula: front gear ÷ rear gear. Organize the results of your calculations into a new table either on paper or in a computer spreadsheet. How many different gear ratios do you actually have?

4. Use your library or the Internet to research the development of the multi-speed bicycle. Take careful notes while you do your research as you will use the information you find to write a report (see step 7). In your research, find the answers to the following questions.

   a. In what circumstances would a low gear ratio be helpful? Why?
   b. In what circumstances would a high gear ratio be helpful? Why?

5. Write up your findings and results according to the guidelines below.

**Your final project should include:**

- **A brief (one page) report** that discusses the evolution of the bicycle. What was the first bicycle like? How did we end up with the modern bicycle? Why was the multi-speed bicycle an important invention?
- **A schematic diagram** of your bicycle’s gears. Include labels.
- **An organized, professional data table** showing the gear ratios of your bicycle.
- **A summary report** (one page) in which you interpret your findings and explain the trade-off between force and distance when pedaling a bicycle in each of the different speeds. Include answers to questions 4(a) and 4(b). In your research, you should make a surprising discovery about the speeds—what is it?
- **Reflection:** Finish the report with one or two paragraphs that express your reflections on this project.
7.2 Potential and Kinetic Energy

This skill sheet reviews various forms of energy and introduces formulas for two kinds of mechanical energy—potential and kinetic. You will learn how to calculate the amount of kinetic or potential energy for an object.

Forms of energy

Forms of energy include radiant energy from the sun, chemical energy from the food you eat, and electrical energy from the outlets in your home. Mechanical energy refers to the energy an object has because of its motion. All these forms of energy may be used or stored. Energy that is stored is called potential energy. Energy that is being used for motion is called kinetic energy. All types of energy are measured in joules or newton-meters.

\[
1 \text{ N} = 1 \text{ kg} \cdot \frac{m}{s^2}
\]

\[
1 \text{ joule} = 1 \text{ kg} \cdot \frac{m^2}{s^2} = 1 \text{ N} \cdot \text{m}
\]

Potential energy

The word potential means that something is capable of becoming active. Potential energy sometimes is referred to as stored energy. This type of energy often comes from the position of an object relative to Earth. A diver on the high diving board has more energy than someone who dives into the pool from the low dive.

The formula to calculate the potential energy of an object is the mass of the object times the acceleration due to gravity (9.8 m/s²) times the height of the object.

\[
E_p = mgh
\]

Did you notice that the mass of the object in kilograms times the acceleration of gravity (g) is the same as the weight of the object in newtons? Therefore you can think of an object’s potential energy as equal to the object’s weight multiplied by its height.

\[
\text{mass of the object (kilograms)} \times \frac{9.8 \text{ m}}{s^2} = \text{weight of the object (newtons)}
\]

So...

\[
E_p = \text{weight of object} \times \text{height of object}
\]

Kinetic energy

Kinetic energy is the energy of motion. Kinetic energy depends on the mass of the object as well as the speed of that object. Just think of a large object moving at a very high speed. You would say that the object has a lot of energy. Since the object is moving, it has kinetic energy. The formula for kinetic energy is:

\[
E_k = \frac{1}{2}mv^2
\]
To do this calculation, square the velocity value. Next, multiply by the mass, and then divide by 2.

**EXAMPLE**

How are these mechanical energy formulas used in everyday situations? Take a look at two example problems.

- A 50 kg boy and his 100 kg father went jogging. Both ran at a rate of 5 m/s. Who had more kinetic energy? Show your work and explain.

**Solution:** Although the boy and his father were running at the same speed, the father has more kinetic energy because he has more mass.

The kinetic energy of the boy:

\[
\frac{1}{2} \times (50 \text{ kg}) \times \left(\frac{5 \text{ m}}{\text{s}}\right)^2 = 625 \text{ kg} \cdot \frac{m^2}{s^2} = 625 \text{ joules}
\]

The kinetic energy of the father:

\[
\frac{1}{2} \times (100 \text{ kg}) \times \left(\frac{5 \text{ m}}{\text{s}}\right)^2 = 1,250 \text{ kg} \cdot \frac{m^2}{s^2} = 1,250 \text{ joules}
\]

- What is the potential energy of a 10 N book that is placed on a shelf that is 2.5 m high?

**Solution:** The book’s weight (10 N) is equal to its mass times the acceleration of gravity. Therefore, you can easily use this value in the potential energy formula:

\[
\text{potential energy} = mgh = (10 \text{ N})(2.5 \text{ m}) = 25 \text{ N} \cdot m = 25 \text{ joules}
\]

**PRACTICE**

Now it is your turn to try calculating potential and kinetic energy. Don’t forget to keep track of the units!

1. Determine the amount of potential energy of a 5.0-N book that is moved to three different shelves on a bookcase. The height of each shelf is 1.0 m, 1.5 m, and 2.0 m.

2. You are on in-line skates at the top of a small hill. Your potential energy is equal to 1,000. J. The last time you checked, your mass was 60.0 kg.
   a. What is your weight in newtons?
   b. What is the height of the hill?
   c. If you start rolling down this hill, your potential energy will be converted to kinetic energy. At the bottom of the hill, your kinetic energy will be equal to your potential energy at the top. Calculate your speed at the bottom of the hill.

3. A 1.0-kg ball is thrown into the air with an initial velocity of 30. m/s.
   a. How much kinetic energy does the ball have?
   b. How much potential energy does the ball have when it reaches the top of its ascent?
   c. How high into the air did the ball travel?

4. What is the kinetic energy of a 2,000.-kg boat moving at 5.0 m/s?

5. What is the velocity of an 500-kg elevator that has 4000 J of energy?

6. What is the mass of an object traveling at 30. m/s if it has 33,750 J of energy?
7.2 Identifying Energy Transformations

Systems change when energy flows and changes from one part of a system to another. Parts of a system may speed up or slow down, get warmer or colder, or change in other measurable ways. Each change transfers energy or transforms energy from one form to another. In this skill sheet, you will practice identifying energy transformations in various systems.

Example:

• At 5:30 a.m., Miranda’s electric alarm clock starts beeping (1). It’s still dark outside so she switches on the light (2). She stumbles sleepily down the hall to the kitchen (3), where she lights a gas burner on the stove (4) to warm some oatmeal for breakfast.

Miranda has been awake for less than ten minutes, and she’s already participated in at least four energy transformations. Describe an energy transformation that took place in each of the numbered events above.

Solution:

1. Electrical energy to sound energy; 2. Electrical energy to radiant energy (light and heat); 3. Chemical energy from food to kinetic energy; 4. Chemical energy from natural gas to radiant energy (heat and light).

Practice:

1. There is a spring attached to the screen door on Elijah’s front porch. Elijah opens the door, stretching the spring (1). After walking through the doorway (2), Elijah lets go of the door, and the spring contracts, pulling the door shut (3). Describe an energy transformation that took place in each of the numbered events above.

2. Name two energy transformations that occur as Gabriella heats a bowl of soup in the microwave.

3. Dmitri uses a hand-operated air pump to inflate a small swimming pool for his younger siblings. Name two energy transformations that occurred.

4. Simon puts new batteries in his radio-controlled car and its controller. He activates the controller, which sends a radio signal to the car. The car moves forward. Name at least three energy transformations that occurred.

5. Name two energy transformations that occur as Adeline pedals her bicycle up a steep hill and then coasts down the other side.
You have learned that the amount of energy in the universe is constant and that in any situation requiring energy, all of it must be accounted for. This is the basis for the law of conservation of energy. In this skill sheet you will analyze different scenarios in terms of what happens to energy. Based on your experience with the CPO energy car, you already know that potential energy can be changed into kinetic energy and vice versa.

As you study the scenarios below, specify whether kinetic energy is being changed to potential energy, potential is being converted to kinetic, or neither. Explain your answers.

For each scenario, see if you can also answer the following questions: Are other energy transformations occurring? In each scenario, where did all the energy go?

### Example

- **A roller coaster car travels from point A to point B.**

  **Solution:**

  First, potential energy is changed into kinetic energy when the roller coaster car rolls down to the bottom of the first hill. But when the car goes up the second hill to point B, kinetic energy is changed to potential energy.

  Some energy is lost to friction. That is why point B is a little lower than point A.

### Practice

1. **A bungee cord begins to exert an upward force on a falling bungee jumper.**

2. **A football is spiraling downward toward a football player.**

3. **A solar cell is charging a battery.**
Energy Scenarios

Read each scenario below. Then complete the following for each scenario:

- Identify which of the following forms of energy are involved in the scenario: mechanical, radiant, electrical, chemical, and nuclear.
- Make an energy flow chart that shows how the energy changes from one form to another, in the correct order. Use a separate paper and colored markers to make your flow charts more interesting.

Solution:

Mechanical energy of the windmill is changed to electrical energy which is changed to the mechanical energy of the toy train.

Practice:

1. A camper is using a wood fire to heat up a pot of water for tea. The pot has a whistle that lets the camper know when the water boils.

2. The state of Illinois generates some of its electricity from nuclear power. A young woman in Chicago is watching a broadcast of a sports game on television.

3. A bicyclist is riding at night. He switches on his bike’s generator so that his headlight comes on. The harder he pedals, the brighter his headlight glows.
7.2 Conservation of Energy

The law of conservation of energy tells us that energy can never be created or destroyed—it is just transformed from one form to another. The total energy after a transformation (from potential to kinetic energy, for example) is equal to the total energy before the transformation. We can use this law to solve real-world problems, as shown in the example below.

**EXAMPLE**

- A 0.50-kilogram ball is tossed upward with a kinetic energy of 100. joules. How high does the ball travel?

**1. Looking for:** The maximum height of the ball.
**2. Given:** The mass of the ball, 0.50 kg, and the kinetic energy at the start: 100. joules
**3. Relationships:** 
\[ E_K = \frac{1}{2}mv^2; \quad E_p = mgh \]
**4. Solution:** The potential energy at the top of the ball’s flight is equal to its kinetic energy at the start. Therefore, 
\[ E_p = mgh = 100. \text{ joules} \]
Substitute into the equation \( m = 0.50 \text{ kg} \) and \( g = 9.8 \text{ m/s}^2 \).
\[ 100. = mgh = (0.50)(9.8)h = 4.9h \]
Solve for \( h \).
\[ 100. = 4.9h; \quad 100. ÷ 4.9 = h \]
\[ h = 20. \text{ m} \]

**PRACTICE**

1. A 3.0-kilogram toy dump truck moving with a speed of 2.0 m/s starts up a ramp. How high does the truck roll before it stops?
2. A 2.0-kilogram ball rolling along a flat surface starts up a hill. If the ball reaches a height of 0.63 meters, what was its initial speed?
3. A 500.-kilogram roller coaster starts from rest at the top of an 80.0-meter hill. What is its speed at the bottom of this hill?
4. Find the potential energy of this roller coaster when it is halfway down the hill.
5. A 2.0-kilogram ball is tossed straight up with a kinetic energy of 196 joules. How high does it go?
6. A 50.-kilogram rock rolls off the edge of a cliff. If it is traveling at a speed of 24.2 m/s when it hits the ground, what is the height of the cliff?
7. Challenge! Make up your own energy conservation problem. Write the problem and the answer on separate index cards. Exchange problem cards with a partner. Solve the problems and then check each other’s work using the answer cards. If your answers don’t agree, work together to find the source of error.
James Joule was known for the accuracy and precision of his work in a time when exactness of measurements was not held in high regard. He demonstrated that heat is a form of energy. He studied the nature of heat and the relationship of heat to mechanical work. Joule has also been credited with finding the relationship between the flow of electricity through a resistance, such as a wire, and the heat given off from it. This is now known as Joule’s Law. He is remembered for his work that led to the First Law of Thermodynamics (Law of Conservation of Energy).

The young student

James Joule was born near Manchester, England on December 24, 1818. His father was a wealthy brewery owner. James injured his spine when he was young and as a result he spent a great deal of time indoors, reading and studying. When he became interested in science, his father built him a lab in the basement.

When James was fifteen years old, his father hired John Dalton, a leading scientist at the time, to tutor James and his brother, Benjamin. Dalton believed that a scientist needed a strong math background. He spent four years teaching the boys Euclidian mathematics. He also taught them the importance of taking exact measurements, a skill that strongly influenced James in his scientific endeavors.

Brewer first, scientist second

After their father became ill, James and Benjamin ran the family brewery. James loved the brewery, but he also loved science. He continued to perform experiments as a serious hobby. In his lab, he tried to make a better electric motor using electromagnets. James wanted to replace the old steam engines in the brewery with these new motors.

Though he learned a lot about magnets, heat, motion, and work, he was not able to change the steam engines in the brewery. The cost of the zinc needed to make the batteries for the electric motors was much too high. Steam engines fired by coal were more cost efficient.

The young scientist

In 1840, when he was only twenty-two years old, Joule wrote what would later be known as Joule’s Law. This law explained that electricity produces heat when it travels through a wire due to the resistance of the wire. Joule’s Law is still used today to calculate the amount of heat produced from electricity.

By 1841, Joule focused most of his attention on the concept of heat. He disagreed with most of his peers who believed that heat was a fluid called caloric. Joule argued that heat was a state of vibration caused by the collision of molecules. He showed that no matter what kind of mechanical work was done, a given amount of mechanical work always produced the same amount of heat. Thus, he concluded, heat was a form of energy. He established this kinetic theory nearly 100 years before others truly accepted that molecules and atoms existed.

On his honeymoon

In 1847, Joule married Amelia Grimes, and the couple spent their honeymoon in the Alps. Joule had always been fascinated by waterfalls. He had observed that water was warmer at the bottom of a waterfall than at the top. He believed that the energy of the falling water was transformed into heat energy. While he and his new bride were in the Alps, he tried to prove his theory. His experiment failed because there was too much spray from the waterfall, and the water did not fall the correct distance for his calculations to work.

From 1847–1854, Joule worked with a scientist named William Thomson. Together they studied thermodynamics and the expansion of gases. They learned how gases react under different conditions. Their law, named the Joule-Thomson effect, explains that compressed gases cool when they are allowed to expand under the right conditions. Their work later led to the invention of refrigeration.

James Joule died on October 11, 1889. The international unit of energy is called the Joule in his honor.
Reading reflection

1. Why do you think that Joule’s father built him a science lab when he was young?

2. What evidence is there that Joule had an exceptional education?

3. Why was Joule so interested in electromagnets?

4. Why would you consider Joule’s early experiments with electric motors important even though he did not achieve his goal?

5. Explain Joule’s Law in your own words.

6. Describe something Joule believed that contradicted the beliefs of his peers.

7. Describe the experiment that Joule tried to conduct on his honeymoon.

8. Name one thing that we use today that was invented as a result of his research.

9. What unit of measurement is named after him?

10. Research: Find out more information about one of Joule’s more well-known experiments, and share your findings with the class. Try to find a picture of some of the apparatus that he used in his experiments. Suggested topics: galvanometer, heat energy, kinetic energy, mechanical work, conservation of energy, Kelvin scale of temperature, thermodynamics, Joule-Thomson Effect, electric welding, electromagnets, resistance in wires.
7.3 Efficiency

In a perfect machine, the work input would equal the work output. However, there aren’t any perfect machines in our everyday world. Bicycles, washing machines, and even pencil sharpeners lose some input work to friction. Efficiency is the ratio of work output to work input. It is expressed as a percent. A perfect machine would have an efficiency of 100 percent.

An engineer designs a new can opener. For every twenty joules of work input, the can opener produces ten joules of work output. The engineer tries different designs and finds that her improved version produces thirteen joules of work output for the same amount of work input. How much more efficient is the new version?

The second design is 15% more efficient than the first.

<table>
<thead>
<tr>
<th>Efficiency of the first design</th>
<th>Efficiency of the second design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency = ( \frac{\text{work output}}{\text{work input}} )</td>
<td>Efficiency = ( \frac{\text{work output}}{\text{work input}} )</td>
</tr>
<tr>
<td>( \frac{10 \text{ joules}}{20 \text{ joules}} ) = 50%</td>
<td>( \frac{13 \text{ joules}}{20 \text{ joules}} ) = 65%</td>
</tr>
</tbody>
</table>

The second design is 15% more efficient than the first.

PRACTICE

1. A cell phone charger uses 4.83 joules per second when plugged into an outlet, but only 1.31 joules per second actually goes into the cell phone battery. The remaining joules are lost as heat. That’s why the battery feels warm after it has been charging for a while. How efficient is the charger?

2. A professional cyclist rides a bicycle that is 92 percent efficient. For every 100 joules of energy he exerts as input work on the pedals, how many joules of output work are used to move the bicycle?

3. An automobile engine is 15 percent efficient. How many joules of input work are required to produce 15,000 joules of output work to move the car?

4. It takes 56.5 kilojoules of energy to raise the temperature of 150 milliliters of water from 5 °C to 95 °C. If you use an electric water heater that is 60% efficient, how many kilojoules of electrical energy will the heater actually use by the time the water reaches its final temperature?

5. A power station burns 75 kilograms of coal per second. Each kg of coal contains 27 million joules of energy.
   a. What is the total power of this power station in watts? (watts = joules/second)
   b. The power station’s output is 800 million watts. How efficient is this power station?

6. A machine requires 2,000 joules to raise a 20-kilogram block a distance of 6.0 meters. How efficient is the machine? (Hint: Work done against gravity = mass \( \times \) acceleration due to gravity \( \times \) height.)
7.3 Power

In science, work is defined as the force needed to move an object a certain distance. The amount of work done per unit of time is called power.

Suppose you and a friend are helping a neighbor to reshingle the roof of his home. You each carry 10 bundles of shingles weighing 300 newtons apiece up to the roof which is 7 meters from the ground. You are able to carry the shingles to the roof in 10 minutes, but your friend needs 20 minutes.

Both of you did the same amount of work ($F \times d$) but you did the work in a shorter time.

$$W = F \times d$$

$$W = 10 \text{ bundles of shingles (300 N/bundle)} \times 7 \text{ m} = 21,000 \text{ joules}$$

However, you had more power than your friend.

$$\text{Power (watts)} = \frac{\text{Work (joules)}}{\text{Time (seconds)}}$$

Let’s do the math to see how this is possible.

**Step one:** Convert minutes to seconds.

$$10 \text{ minutes} \times \frac{60 \text{ seconds}}{\text{minute}} = 600 \text{ seconds (You)}$$

$$20 \text{ minutes} \times \frac{60 \text{ seconds}}{\text{minute}} = 1,200 \text{ seconds (Friend)}$$

**Step two:** Find power.

$$\frac{21,000 \text{ joules}}{600 \text{ seconds}} = 35 \text{ watts (You)}$$

$$\frac{21,000 \text{ joules}}{1,200 \text{ seconds}} = 17.5 \text{ watts (Friend)}$$

As you can see, more power is produced when the same amount of work is done in a shorter time period. You have probably heard the word *watt* used to describe a light bulb. Is it now clear to you why a 100-watt bulb is more powerful than a 40-watt bulb?
1. A motor does 5,000 joules of work in 20 seconds. What is the power of the motor?

2. A machine does 1,500 joules of work in 30 seconds. What is the power of this machine?

3. A hair dryer uses 72,000 joules of energy in 60 seconds. What is the power of this hair dryer?

4. A toaster oven uses 67,500 joules of energy in 45 seconds to toast a piece of bread. What is the power of the oven?

5. A horse moves a sleigh 1.00 kilometer by applying a horizontal 2,000-newton force on its harness for 45.0 minutes. What is the power of the horse? (Hint: Convert time to seconds.)

6. A wagon is pulled at a speed of 0.40 m/s by a horse exerting an 1,800-newton horizontal force. What is the power of this horse?

7. Suppose a force of 100 newtons is used to push an object a distance of 5.0 meters in 15 seconds. Find the work done and the power for this situation.

8. Emily’s vacuum cleaner has a power rating of 200 watts. If the vacuum cleaner does 360,000 joules of work, how long did Emily spend vacuuming?

9. Nicholas spends 20.0 minutes ironing shirts with his 1,800-watt iron. How many joules of energy were used by the iron? (Hint: convert time to seconds).

10. It take a clothes dryer 45 minutes to dry a load of towels. If the dryer uses 6,750,000 joules of energy to dry the towels, what is the power rating of the machine?

11. A 1000-watt microwave oven takes 90 seconds to heat a bowl of soup. How many joules of energy does it use?

12. A force of 100 newtons is used to move an object a distance of 15 meters with a power of 25 watts. Find the work done and the time it takes to do the work.

13. If a small machine does 2,500 joules of work on an object to move it a distance of 100 meters in 10 seconds, what is the force needed to do the work? What is the power of the machine doing the work?

14. A machine uses a force of 200 newtons to do 20,000 joules of work in 20 seconds. Find the distance the object moved and the power of the machine. (Hint: A joule is the same as a Newton-meter.)

15. A machine that uses 200 watts of power moves an object a distance of 15 meters in 25 seconds. Find the force needed and the work done by this machine.
Power is the rate of doing work. You do work if you lift a heavy box up a flight of stairs. You do the same amount of work whether you lift the box slowly or quickly. But your power is greater if you do the work in a shorter amount of time.

Power can also be used to describe the rate at which energy is converted from one form into another. A light bulb converts electrical energy into heat (thermal energy) and light (radiant energy). The power of a light bulb is the rate at which the electrical energy is converted into these other forms.

To calculate the power of a person, machine, or other device, you must know the work done or energy converted and the time. Work can be calculated using the following formula:

\[ W = F \times d \]

Both work and energy are measured in joules. A joule is actually another name for a newton-meter. If you push an object along the floor with a force of 1 newton for a distance of 1 meter, you have done 1 joule of work. A motor could be used to do this same task by converting 1 joule of electrical energy into mechanical energy.

Power is calculated by dividing the work or energy by the time. Power is measured in watts. One watt is equal to one joule of work or energy per second. In one second, a 60-watt light bulb converts 60 joules of electrical energy into heat and light. Power can also be measured in horsepower. One horsepower is equal to 746 watts.

\[ P = \frac{W}{t} \]

A cat who cat weighs 40 newtons climbs 15 meters up a tree in 10 seconds. Calculate the work done by the cat and the cat’s power.

**Looking for**
- The work and power of the cat.

**Given**
- The force is 40 N.
- The distance is 15 m.
- The time is 10 s.

**Relationships**
- Work = Force × distance
- Power = Work/time

**Solution**

Work = 40 N × 15 m = 600 J

Power = \( \frac{600 \text{ J}}{10 \text{ s}} \) = 60 W

The work done by the cat is 600 joules.
- The power of the cat is 60 watts.
- In units of horsepower, the cat’s power is (60 watts)(1 hp / 746 watts) = 0.12 horsepower.
1. Complete the table below:

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Distance (m)</th>
<th>Time (sec)</th>
<th>Work (J)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>10</td>
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<td>4</td>
<td>10</td>
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<td>100</td>
<td>20</td>
<td>25</td>
<td>500</td>
<td></td>
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<tr>
<td>100</td>
<td>30</td>
<td>10</td>
<td>1000</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>10</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>75</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

2. Oliver weighs 600. newtons. He climbs a flight of stairs that is 3.0 meters tall in 4.0 seconds.
   a. How much work did he do?
   b. What was Oliver’s power in watts?

3. An elevator weighing 6,000. newtons moves up a distance of 10.0 meters in 30.0 seconds.
   a. How much work did the elevator's motor do?
   b. What was the power of the elevator’s motor in watt and in horsepower?

4. After a large snowstorm, you shovel 2,500. kilograms of snow off of your sidewalk in half an hour. You lift the shovel to an average height of 1.5 meters while you are piling the snow in your yard.
   a. How much work did you do? Hint: The force is the weight of the snow.
   b. What was your power in watts? Hint: You must always convert time to seconds when calculating power.

5. A television converts 12,000 joules of electrical energy into light and sound every minute. What is the power of the television?

6. The power of a typical adult's body over the course of a day is 100. watts. This means that 100. joules of energy from food are needed each second.
   a. An average apple contains 500,000 joules of energy. For how many seconds would an apple power a person?
   b. How many joules are needed each day?
   c. How many apples would a person need to eat to get enough energy for one day?

7. A mass of 1,000. kilograms of water drops 10.0 meters down a waterfall every second.
   a. How much potential energy is converted into kinetic energy every second?
   b. What is the power of the waterfall in watts and in horsepower

8. An alkaline AA battery stores approximately 12,000 joules of energy. A small flashlight uses two AA batteries and will produce light for 2.0 hours. What is the power of the flashlight bulb? Assume all of the energy in the batteries is used.
Efficiency and Energy

Efficiency describes how well energy is converted from one form into another. A process is 100% efficient if no energy is “lost” due to friction, to create sound, or for other reasons. In reality, no process is 100% efficient.

Efficiency is calculated by dividing the output energy by the input energy. If you multiply the result by 100, you will get efficiency as a percentage. For example, if the answer you get is 0.50, you can multiply by 100 and write your answer as 50%.

You drop a 2-kilogram box from a height of 3 meters. Its speed is 7 m/s when it hits the ground. How efficiently did the potential energy turn into kinetic energy?

Looking for
You are asked to find the efficiency.

Given
The mass is 2 kilograms, the height is 3 meters, and the landing speed is 7 m/s.

Relationships
Kinetic energy $= \frac{1}{2}mv^2$
Potential energy $= mgh$
Efficiency $= \frac{\text{output energy}}{\text{input energy}}$

Solution
\[ E_p = (2 \text{ kg})(9.8 \text{ m/s}^2)(3 \text{ m}) = 58.8 \text{ J} \]
\[ E_K = \frac{1}{2}(2 \text{ kg})(7 \text{ m/s})^2 = 49 \text{ J} \]
The input energy is the potential energy, and the output energy is the kinetic energy.
Efficiency $= \frac{49 \text{ J}}{58.8 \text{ J}} = 0.83$ or 83%
The efficiency is 0.83 or 83% ($0.83 \times 100$).

Practice

1. Engineers who design battery-operated devices such as cell phones and MP3 players try to make them as efficient as possible. An engineer tests a cell phone and finds that the batteries supply 10,000 J of energy to make 5500 J of output energy in the form of sound and light for the screen. How efficient is the phone?

2. What’s the efficiency of a car that uses 400,000 J of energy from gasoline to make 48,000 J of kinetic energy?

3. A 1000.-kilogram roller coaster goes down a hill that is 90. meters tall. Its speed at the bottom is 40. m/s.
   a. What is the efficiency of the roller coaster? Assume it starts from rest at the top of the hill.
   b. What do you think happens to the “lost” energy?
   c. Use the concepts of energy and efficiency to explain why the first hill on a roller coaster is the tallest.

4. You see an advertisement for a new free fall ride at an amusement park. The ad says the ride is 50. meters tall and reaches a speed of 28 m/s at the bottom. How efficient is the ride? Hint: You can use any mass you wish because it cancels out.

5. Imagine that you are working as a roller coaster designer. You want to build a record-breaking coaster that goes 70.0 m/s at the bottom of the first hill. You estimate that the efficiency of the tracks and cars you are using is 90.0%. How high must the first hill be?
8.2 Measuring Temperature

How do you find the temperature of a substance?

There are many different kinds of thermometers used to measure temperature. Can you think of some you find at home? In your classroom you will use a glass immersion thermometer to find the temperature of a liquid. The thermometer contains alcohol with a red dye in it so you can see the alcohol level inside the thermometer. The alcohol level changes depending on the surrounding temperature. You will practice reading the scale on the thermometer and report your readings in degrees Celsius.

Safety: Glass thermometers are breakable. Handle them carefully. Overheating the thermometer can cause the alcohol to separate and give incorrect readings. Glass thermometers should be stored horizontally or vertically (never upside down) to prevent alcohol from separating.

Reading the temperature scale correctly

Look at the picture at right. See the close-up of the line inside the thermometer on the scale. The tens scale numbers are given. The ones scale appears as lines. Each small line equals 1 degree Celsius. Practice reading the scale from the bottom to the top. One small line above 20 °C is read as 21 °C. When the level of the alcohol is between two small lines on the scale, report the number to the nearest 0.5 °C.

Stop and think

a. What number does the large line between 20 °C and 10 °C equal? Figure out by counting the number of small lines between 20 °C and 10 °C.

b. Give the temperature of the thermometer in the picture above.

c. Practice rounding the following temperature values to the nearest 0.5 °C: 23.1 °C, 29.8 °C, 30.0 °C, 31.6 °C, 31.4 °C.

d. Water at 0 °C and 100 °C has different properties. Describe what water looks like at these temperatures.

e. What will happen to the level of the alcohol if you hold the thermometer by the bulb?

Materials

- Alcohol immersion thermometer
- Beakers
- Water at different temperatures
- Ice
Reading the temperature of water in a beaker

An immersion thermometer must be placed in liquid up to the solid line on the thermometer (at least 2 and one half inches of liquid). Wait about 3 minutes for the temperature of the thermometer to equal the temperature of the liquid. Record the temperature to the nearest 0.5 °C when the level stops moving.

1. Place the thermometer in the beaker. Check to make sure that the water level is above the solid line on the thermometer.

2. Wait until the alcohol level stops moving (about three minutes). Record the temperature to the nearest 0.5 °C.

Reading the temperature of warm water in a beaker

A warm liquid will cool to room temperature. For a warm liquid, record the warmest temperature you observe before the temperature begins to decrease.

1. Repeat the procedure above with a beaker of warm (not boiling) water.

2. Take temperature readings every 30 seconds. Record the warmest temperature you observe.

Reading the temperature of ice water in a beaker

When a large amount of ice is added to water, the temperature of the water will drop until the ice and water are the same temperature. After the ice has melted, the cold water will warm to room temperature.

1. Repeat the procedure above with a beaker of ice and water.

2. Take temperature readings every 30 seconds. Record the coldest temperature you observe.
8.2 Temperature Scales

The Fahrenheit and Celsius temperature scales are commonly used scales for reporting temperature values. Scientists use the Celsius scale almost exclusively, as do many countries of the world. The United States relies on the Fahrenheit scale for reporting temperature information. You can convert information reported in degrees Celsius to degrees Fahrenheit or vice versa using conversion formulas.

Fahrenheit (°F) to Celsius (°C) conversion formula:

\[ ^\circ C = \left( \frac{5}{9} \right) (^\circ F - 32) \]

Celsius (°C) to Fahrenheit (°F) conversion formula:

\[ ^\circ F = \left( \frac{9}{5} \times ^\circ C \right) + 32 \]

**EXAMPLES**

- **What is the Celsius value for 65° Fahrenheit?**
  
  **Solution:**

  \[ ^\circ C = \left( \frac{5}{9} \right) (65 ^\circ F - 32) \]
  \[ ^\circ C = \left( \frac{5}{9} \right) (33) = \left( 5 \times 33 \right) ÷ 9 \]
  \[ ^\circ C = 165 ÷ 9 \]
  \[ ^\circ C = 18.3 \]

- **200 °C is the same temperature as what value on the Fahrenheit scale?**
  
  **Solution:**

  \[ ^\circ F = \left( \frac{9}{5} \right) (200 ^\circ C) + 32 \]
  \[ ^\circ F = \left[ \left( 9 \times 200 ^\circ C \right) ÷ 5 \right] + 32 \]
  \[ ^\circ F = 1800 ÷ 5 + 32 \]
  \[ ^\circ F = 360 + 32 \]
  \[ ^\circ F = 392 \]
1. For each of the problems below, show your calculations. Follow the steps from the examples on the previous page.
   a. What is the Celsius value for 212 °F?
   b. What is the Celsius value for 98.6 °F?
   c. What is the Celsius value for 40 °F?
   d. What is the Celsius value for 10 °F?
   e. What is the Fahrenheit value for 0 °C?
   f. What is the Fahrenheit value for 25 °C?
   g. What is the Fahrenheit value for 75 °C?

2. The weatherman reports that today will reach a high of 45 °F. Your friend from Sweden asks what the temperature will be in degrees Celsius. What value would you report to your friend?

3. Your parents order an oven from England. The temperature dial on the new oven is calibrated in degrees Celsius. If you need to bake a cake at 350 °F in the new oven, at what temperature should you set the dial?

4. A German automobile’s engine temperature gauge reads in Celsius, not Fahrenheit. The engine temperature should not rise above about 225 °F. What is the corresponding Celsius temperature on this car’s gauge?

5. Your grandmother in Ireland sends you her favorite cookie recipe. Her instructions say to bake the cookies at 190 °C. To what Fahrenheit temperature would you set the oven to bake the cookies?

6. A scientist wishes to generate a chemical reaction in his laboratory. The temperature values in his laboratory manual are given in degrees Celsius. However, his lab thermometers are calibrated in degrees Fahrenheit. If he needs to heat his reactants to 232 °C, what temperature will he need to monitor on his lab thermometers?

7. You call a friend in Europe during the winter holidays and say that the temperature in Boston is 15 degrees. He replies that you must enjoy the warm weather. Explain his comment using your knowledge of the Fahrenheit and Celsius scales. To help you get started, fill in this table. What is 15 °F on the Celsius scale? What is 15 °C on the Fahrenheit scale?

<table>
<thead>
<tr>
<th>°F</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

8. Challenge questions:
   a. A gas has a boiling point of –175 °C. At what Fahrenheit temperature would this gas boil?
   b. A chemist notices some silvery liquid on the floor in her lab. She wonders if someone accidentally broke a mercury thermometer, but did not thoroughly clean up the mess. She decides to find out if the silver stuff is really mercury. From her tests with the substance, she finds out that the melting point for the liquid is 35 °F. A reference book says that the melting point for mercury is –38.87 °C. Is this substance mercury? Explain your answer and show all relevant calculations.
Extension: the Kelvin temperature scale

For some scientific applications, a third temperature scale is used: the Kelvin scale. The Kelvin scale is calibrated so that raising the temperature one degree Kelvin raises it by the same amount as one degree Celsius. The difference between the scales is that 0 °C is the freezing point of water, while 0 K is much, much colder. On the Kelvin scale, 0K (degree symbols are not used for Kelvin values) represents absolute zero. Absolute zero is the temperature when the average kinetic energy of a perfect gas is zero—the molecules display no energy of motion. Absolute zero is equal to –273 °C, or –459 °F. When scientists are conducting research, they often obtain or report their temperature values in Celsius, and other scientists must convert these values into Kelvin for their own use, or vice versa. To convert Celsius values to their Kelvin equivalents, use the formula:

\[ K = ^\circ C + 273 \]

**Example**

Water boils at a temperature of 100 °C. What would be the corresponding temperature for the Kelvin scale?

\[ K = ^\circ C + 273 \]
\[ K = 100 ^\circ C + 273 \]
\[ K = 373 \]

To convert Kelvin values to Celsius, you perform the opposite operation; subtract 273 from the Kelvin value to find the Celsius equivalent.

**Example**

A substance has a melting point of 625 K. At what Celsius temperature would this substance melt?

\[ ^\circ C = K + 273 \]
\[ ^\circ C = 625 K - 273 \]
\[ ^\circ C = 352 \]

Although we rarely need to convert between Kelvin and Fahrenheit, use the following formulas to do so:

\[ ^\circ F = \left(\frac{9}{5} \times K \right) - 460 \]
\[ K = \frac{5}{9} (^\circ F + 460) \]
1. Surface temperatures on the planet Mars range from –89 °C to –31 °C. Express this temperature range in Kelvin.

2. The average surface temperature on Jupiter is about 165K. Express this temperature in degrees Celsius.

3. The average surface temperature on Saturn is 134K. Express this temperature in degrees Celsius.

4. The average surface temperature on the dwarf planet Pluto is 50K. Express this temperature in degrees Celsius.

5. The Sun has several regions. The apparent surface that we can see from a distance is called the photosphere. Temperatures of the photosphere range from 5,000 °C to 8,000 °C. Express this temperature range in Kelvin.

6. The chromosphere is a hot layer of plasma just above the photosphere. Chromosphere temperatures can reach 10,000 °C. Express this temperature in Kelvin.

7. The outermost layer of the Sun’s atmosphere is called the corona. Its temperatures can reach over 1,000,000 °C. Express this temperature in Kelvin.

8. Nuclear fusion takes place in the center, or core, of the Sun. Temperatures there can reach 15,000,000 °C. Express this temperature in Kelvin.

9. **Challenge!** Surface temperatures on Mercury can reach 660 °F. Express this temperature in Kelvin.

10. **Challenge!** Surface temperatures on Venus, the hottest planet in our solar system, can reach 755K. Express this temperature in degrees Fahrenheit.
8.3 Reading a Heating/Cooling Curve

A heating curve shows how the temperature of a substance changes as heat is added at a constant rate. The heating curve at right shows what happens when heat is added at a constant rate to a beaker of ice. The flat spot on the graph, at zero degrees, shows that although heat was being added, the temperature did not rise while the solid ice was changing to liquid water. The heat energy was used to break the intermolecular forces between water molecules. Once all the ice changed to water, the temperature began to rise again. In this skill sheet, you will practice reading heating and cooling curves.

The heating curve at right shows the temperature change in a sample of iron as heat is added at a constant rate. The sample starts out as a solid and ends as a gas.

- Describe the phase change that occurred between points B and C on the graph.

Solution:
Between points B and C, the sample changed from solid to liquid.

1. In the heating curve for iron, describe the phase change that occurred between points D and E on the graph.

2. Explain why the temperature stayed constant between points D and E.

3. What is the melting temperature of iron?

4. What is the freezing temperature of iron? How do you know?

5. What is the boiling temperature of iron?

6. Compare the boiling temperatures of iron and water (water boils at 100°C). Which substance has stronger intermolecular forces? How do you know?
The graph below shows a cooling curve for stearic acid. Stearic acid is a waxy solid at room temperature. It is derived from animal and vegetable fats and oils. It is used as an ingredient in soap, candles, and cosmetics. In this activity, a sample of stearic acid was placed in a heat-resistant test tube and heated to 95 °C, at which point the stearic acid was completely liquefied. The test tube was placed in a beaker of ice water, and the temperature monitored until it reached 40 °C. Answer the following questions about the cooling curve:

7. Between which two points on the graph did freezing occur?
8. What is the freezing temperature of stearic acid? What is its melting temperature?
9. Compare the melting temperature of stearic acid with the melting temperature of water. Which substance has stronger intermolecular forces? How do you know?
10. Can a substance be cooled to a temperature below its freezing point? Use evidence from any of the graphs in this skill sheet to defend your answer.
9.1 Specific Heat

Specific heat is the amount of thermal energy needed to raise the temperature of 1 gram of a substance 1 °C.

The higher the specific heat, the more energy is required to cause a change in temperature. Substances with higher specific heats must lose more thermal energy to lower their temperature than substances with a low specific heat. Some sample specific heat values are presented in the table below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Heat (J/kg °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>water (pure)</td>
<td>4,184</td>
</tr>
<tr>
<td>aluminum</td>
<td>897</td>
</tr>
<tr>
<td>silver</td>
<td>235</td>
</tr>
<tr>
<td>oil</td>
<td>1,900</td>
</tr>
<tr>
<td>concrete</td>
<td>880</td>
</tr>
<tr>
<td>gold</td>
<td>129</td>
</tr>
<tr>
<td>wood</td>
<td>1,700</td>
</tr>
</tbody>
</table>

Water has the highest specific heat of the listed types of matter. This means that water is slower to heat but is also slower to lose heat.

Using the table above, solve the following heat problems.

1. If 100 joules of energy were applied to all of the substances listed in the table at the same time, which would have the greatest temperature change? Explain your answer.

2. Which of the substances listed in the table would you choose as the best thermal insulator? A thermal insulator is a substance that requires a lot of heat energy to change its temperature. Explain your answer.

3. Which substance—wood or silver—is the better thermal conductor? A thermal conductor is a material that requires very little heat energy to change its temperature. Explain your answer.

4. Which has more thermal energy, 1 kg of aluminum at 20 °C or 1 kg of gold at 20 °C?

5. How much heat in joules would you need to raise the temperature of 1 kg of water by 5 °C?

6. How does the thermal energy of a large container of water compare to a small container of water at the same temperature?
9.1 Using the Heat Equation

You can solve real-world heat and temperature problems using the following equation:

\[
E = mc \Delta T
\]

Where:
- \( E \) is the heat energy (J)
- \( m \) is the mass (kg)
- \( c \) is the specific heat (J/kg °C)
- \( \Delta T \) is the change in temperature (°C)

Below is a table that provides the specific heat of six everyday materials:

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Heat (J/kg °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>water (pure)</td>
<td>4,184</td>
</tr>
<tr>
<td>aluminum</td>
<td>897</td>
</tr>
<tr>
<td>silver</td>
<td>235</td>
</tr>
<tr>
<td>concrete</td>
<td>880</td>
</tr>
<tr>
<td>gold</td>
<td>129</td>
</tr>
<tr>
<td>wood</td>
<td>1,700</td>
</tr>
</tbody>
</table>

**Example**
- How much heat does it take to raise the temperature of 10 kg of water by 10 °C?

**Solution:**
Find the specific heat of water from the table above: 4,184 J/kg °C. Plug the values into the equation.

\[
E = mc \Delta T = 10 \text{ kg} \times 10 \text{ °C} \times 4,184 \text{ J/kg °C} = 418,400 \text{ joules}
\]

**Practice**
Use the specific heat table to answer the following questions. Don’t forget to show your work.

1. How much heat does it take to raise the temperature of 0.10 kg of gold by 25 °C?
2. How much heat does it take to raise the temperature of 0.10 kg of silver by 25 °C?
3. How much heat does it take to raise the temperature of 0.10 kg of aluminum by 25 °C?
4. Which one of the three materials above would cool down fastest after the heat was applied? Explain.
5. A coffee maker heats 2 kg of water from 15 °C to 100 °C. How much thermal energy was required?
6. The Sun warms a 100-kg slab of concrete from 20 °C to 25 °C. How much thermal energy did it absorb?
7. 5,000 joules of thermal energy were applied to 1-kg aluminum bar. What was the temperature increase?
8. In the 1920’s, many American homes did not have hot running water from the tap. Bath water was heated on the stove and poured into a basin. How much thermal energy would it take to heat 30 kg of water from 15 °C to a comfortable bath temperature of 50 °C?
9.2 Heat Transfer

Thermal energy flows from higher temperature to lower temperature. This process is called heat transfer. Heat transfer can occur three different ways: heat conduction, convection, and thermal radiation. Using section 9.2 of your student text as a guide, define each method of heat transfer.

Heat conduction:

______________________________________________________________________________________
______________________________________________________________________________________
______________________________________________________________________________________

Convection:

______________________________________________________________________________________
______________________________________________________________________________________
______________________________________________________________________________________

Thermal radiation:

______________________________________________________________________________________
______________________________________________________________________________________
______________________________________________________________________________________

Read each scenario below. Then explain which type of heat transfer is described. Some scenarios involve more than one type of heat transfer.

1. Mia places some frozen shrimp in a strainer and pours hot water over it so the shrimp will thaw faster.
2. On a hot summer day, Juan can walk comfortably in bare feet on the concrete sidewalk, but finds that the asphalt road will burn the soles of his feet.
3. A hawk soars upward, riding a thermal.
4. An electric space heater warms an office.
5. A mother duck sits on her eggs to keep them warm.
6. A car parked in the sun reaches an interior temperature of 140°F in 40 minutes.
7. Nick always adds milk to his coffee so that it’s not too hot to drink.
8. A strong sea breeze makes a regatta (sailboat race) more exciting.
9. Warm water piped under a marble floor makes the floor feel warm to bare feet.
10. The warm water pipes under the marble floor heat the entire room.
10.1 Measuring Mass with a Triple Beam Balance

How do you find the mass of an object?

Why can’t you use a bathroom scale to measure the mass of a paperclip? You could if you were finding the mass of a lot of them at one time! To find the mass of objects less than a kilogram you will need to use the triple beam balance.

Materials
- Triple beam balance
- Small objects
- Mass set (optional)
- Beaker

Parts of the triple beam balance

Setting up and zeroing the balance

The triple beam balance works like a see-saw. When the mass of your object is perfectly balanced by the counter masses on the beam, the pointer will rest at 0. Add up the readings on the three beams to find the mass of your object. The unit of measure for this triple beam balance is grams.

1. Place the balance on a level surface.
2. Clean any objects or dust off the pan.
3. Move all counter masses to 0. The pointer should rest at 0. Use the adjustment screw to adjust the pointer to 0, if necessary. When the pointer rests at 0 with no objects on the pan, the balance is said to be zeroed.
Finding a known mass

You can check that the triple beam balance is working correctly by using a mass set. Your teacher will provide the correct mass value for these objects.

1. After zeroing the balance, place an object with a known mass on the pan.
2. Move the counter masses to the right one at a time from largest to smallest. When the pointer is resting at 0 the numbers under the three counter masses should add up to the known mass.
3. If the pointer is above or below 0, recheck the balance setup. Recheck the position of the counter masses. Counter masses must be properly seated in a groove. Check with your teacher to make sure you are getting the correct mass before finding the mass an unknown object.

Finding the mass of an unknown object

1. After zeroing the balance, place an object with an unknown mass on the pan. Do not place hot objects or chemicals directly on the pan.
2. Move the largest counter mass first. Place it in the first notch after zero. Wait until the pointer stops moving. If the pointer is above 0, move the counter mass to the next notch. Continue to move the counter mass to the right, one notch at a time until the pointer is slightly above 0. Go to step 3. If the pointer is below 0, move the counter mass back one notch. When the pointer rests at 0, you do not need to move any more counter masses.
3. Move the next largest counter mass from 0 to the first notch. Watch to see where the pointer rests. If it rests above 0, move the counter mass to the next notch. Repeat until the point rests at 0, or slightly above. If the pointer is slightly above 0, go to step 4.
4. Move the smallest counter mass from 0 to the position on the beam where the pointer rests at 0.
5. Add the masses from the three beams to get the mass of the unknown object. You should be able to record a number for the hundreds place, the tens place, the ones place, and the tenths place and the hundredths place. The hundredths place can be read to 0.00 or 0.05. You may have zeros in your answer.
Reading the balance correctly

Look at the picture above. To find the mass of the object, locate the counter mass on each beam. Read the numbers directly below each counter mass. You can read the smallest mass to 0.05 grams. Write down the three numbers. Add them together. Report your answer in grams. Does your answer agree with others? If not, check your mass values from each beam to find your mistake.

Finding the mass of an object in a container

To measure the mass of a liquid or powder you will need an empty container on the pan to hold the sample. You must find the mass of the empty container first. After you place the object in the container and find the total mass, you can subtract the container’s mass from the total to find the object’s mass.

1. After zeroing the balance, place a beaker on the pan.
2. Follow directions for finding the mass of an unknown object. Record the mass of the beaker.
3. Place a small object in the beaker.
4. Move the counter masses to the right, largest to smallest, to find the total mass.
5. Subtract the beaker’s mass from the total mass. This is the mass of your object in grams.
10.1 Measuring Volume

How do you find the volume of an irregular object?

It’s easy to find the volume of a shoebox or a basketball. You just take a few measurements, plug the numbers into a math formula, and you have figured it out. But what if you want to find the volume of a bumpy rock, or an acorn, or a house key? There aren’t any simple math formulas to help you out. However, there’s an easy way to find the volume of an irregular object, as long the object is waterproof!

Materials

- Displacement tank
- Water source
- Disposable cup
- Beaker
- Graduated cylinder
- Sponges or paper towel
- Object to be measured

Setting up the displacement tank

Set the displacement tank on a level surface. Place a disposable cup under the tank’s spout. Carefully fill the tank until the water begins to drip out of the spout. When the water stops flowing, discard the water collected in the disposable cup. Set the cup aside and place a beaker under the spout.

Stop and think

a. What do you think will happen when you place an object into the tank?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

b. Which object would cause more water to come out of the spout, an acorn or a fist-sized rock?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

c. Why are we interested in how much water comes out of the spout?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
Measuring volume with the displacement tank

1. Gently place a waterproof object into the displacement tank. It is important to avoid splashing the water or creating a wave that causes extra water to flow out of the spout. It may take a little practice to master this step.

2. When the water stops flowing out of the spout, it can be poured from the beaker into a graduated cylinder for precise measurement. The volume of the water displaced is equal to the object’s volume. Note: Occasionally, when a small object is placed in the tank, no water will flow out. This happens because an air bubble has formed in the spout. Simply tap the spout with a pencil to release the air bubble.

3. If you wish to measure the volume of another object, don’t forget to refill the tank with water first!
10.1 Calculating Volume

How do you find the volume of a three dimensional shape?

Volume is the amount of space an object takes up. If you know the dimensions of a solid object, you can find the object's volume. A two dimensional shape has length and width. A three dimensional object has length, width, and height. This investigation will give you practice finding volume for different solid objects.

Calculating volume of a cube

A cube is a geometric solid that has length, width and height. If you measure the sides of a cube, you will find that all the edges have the same measurement. The volume of a cube is found by multiplying the length times width times height. In the picture each side is 4 centimeters so the problem looks like this:

\[ V = l \times w \times h \]

Example:

Volume = 4 centimeters \times 4 centimeters \times 4 centimeters = 64 centimeters\(^3\)

Stop and think

a. What are the units for volume in the example above?

b. In the example above, if the edge of the cube is 4 inches, what will the volume be? Give the units.

c. How is finding volume different from finding area?

d. If you had cubes with a length of 1 centimeter, how many would you need to build the cube in the picture above?

Calculating volume of a rectangular prism

Rectangular prisms are like cubes, except not all of the sides are equal. A shoebox is a rectangular prism. You can find the volume of a rectangular prism using the same formula given above \((V = l \times w \times h)\).

Another way to say it is to multiply the area of the base times the height.

1. Find the area of the base for the rectangular prism pictured above.

2. Multiply the area of the base times the height. Record the volume of the rectangular prism.

3. PRACTICE: Find the volume for a rectangular prism with a height 6 cm, length 5 cm, and width 3 cm. Be sure to include the units in all of your answers.
Calculating volume of a triangular prism

Triangular prisms have three sides and two triangular bases. The volume of the triangular prism is found by multiplying the area of the base times the height. The base is a triangle.

1. Find the area of the base by solving for the area of the triangle: \( B = \frac{1}{2} \times l \times w \).
2. Find the volume by multiplying the area of the base times the height of the prism: \( V = B \times h \). Record the volume of the triangular prism shown above.
3. PRACTICE: Find the volume of the triangular prism with a height 10 cm, triangular base width 4 cm, and triangular base length 5 cm.

Calculating volume of a cylinder

A soup can is a cylinder. A cylinder has two circular bases and a round surface. The volume of the cylinder is found by multiplying the area of the base times the height. The base is a circle.

1. Find the area of the base by solving for the area of a circle: \( A = \pi \times r^2 \).
2. Find the volume by multiplying the area of the base times the height of the cylinder: \( V = A \times h \). Record the volume of the cylinder shown above.
3. PRACTICE: Find the volume of the cylinder with height 8 cm and radius 4 cm.

Calculating volume of a cone

An ice cream cone really is a cone! A cone has height and a circular base. The volume of the cone is found by multiplying \( \frac{1}{3} \) times the area of the base times the height.

1. Find the area of the base by solving for the area of a circle: \( A = \pi \times r^2 \).
2. Find the volume by multiplying \( \frac{1}{3} \) times the area of the base times the height: \( V = \frac{1}{3} \times A \times h \). Record the volume of the cone shown above.
3. PRACTICE: Find the volume of the cone with height 8 cm and radius 4 cm. Contrast your answer with the volume you found for the cylinder with the same dimensions. What is the difference in volume? Does this make sense?
Calculating the volume of a rectangular pyramid

A pyramid looks like a cone. It has height and a rectangular base. The volume of the rectangular pyramid is found by multiplying $\frac{1}{3}$ times the area of the base times the height.

1. Find the area of the base by multiplying the length times the width: $A = l \times w$.
2. Find the volume by multiplying $\frac{1}{3}$ times the area of the base times the height: $V = \frac{1}{3} \times A \times h$. Record the volume of the rectangular pyramid shown above.
3. PRACTICE: Find the volume of a rectangular pyramid with height 10 cm and width 4 cm and length 5 cm.
4. EXTRA CHALLENGE: If a rectangular pyramid had a height of 8 cm and a width of 4 cm, what length would it need to have to give the same volume as the cone in practice question 3 above?

Calculating volume of a triangular pyramid

A triangular pyramid is like a rectangular pyramid, but its base is a triangle. Find the area of the base first. Then calculate the volume by multiplying $\frac{1}{3}$ times the area of the base times the height.

1. Find the area of the base by solving for the area of a triangle: $B = \frac{1}{2} \times l \times w$.
2. Find the volume by multiplying $\frac{1}{3}$ times the area of the base times the height: $V = \frac{1}{3} \times A \times h$. Find the volume of the triangular pyramid shown above.
3. PRACTICE: Find the volume of the triangular pyramid with height 10 cm and whose base has width 6 cm and length 5 cm.

Calculating volume of a sphere

To find the volume of a sphere, you only need to know one dimension about the sphere, its radius.

1. Find the volume of a sphere: $V = \frac{4}{3} \pi r^3$. Find the volume for the sphere shown above.
2. PRACTICE: Find the volume for a sphere with radius 2 cm.
3. EXTRA CHALLENGE: Find the volume for a sphere with diameter 10 cm.
10.1 Density

The density of a substance does not depend on its size or shape. As long as a substance is homogeneous, the density will be the same. This means that a steel nail has the same density as a cube of steel or a steel girder used to build a bridge.

The formula for density is: \[ \text{density} = \frac{\text{mass}}{\text{volume}} \]

One milliliter takes up the same amount of space as one cubic centimeter. Therefore, density can be expressed in units of g/mL or g/cm\(^3\). Liquid volumes are most commonly expressed in milliliters, while volumes of solids are usually expressed in cubic centimeters.

Density can also be expressed in units of kilograms per cubic meter (kg/m\(^3\)).

If you know the density of a substance and the volume of a sample, you can calculate the mass of the sample. To do this, rearrange the equation above to find mass: \[ \text{volume} \times \text{density} = \text{mass} \]

If you know the density of a substance and the mass of a sample, you can find the volume of the sample. This time, you will rearrange the density equation to find volume: \[ \text{volume} = \frac{\text{mass}}{\text{density}} \]

**EXAMPLES**

**Example 1:** What is the density of a block of aluminum with a volume of 30.0 cm\(^3\) and a mass of 81.0 grams?

\[ \text{density} = \frac{81.0 \text{ g}}{30.0 \text{ cm}^3} = 2.70 \text{ g/cm}^3 \]

**Answer:** The density of aluminum is 2.70 g/cm\(^3\).

**Example 2:** What is the mass of an iron horseshoe with a volume of 89.0 cm\(^3\)? The density of iron is 7.90 g/cm\(^3\).

\[ \text{mass} = 89.0 \text{ cm}^3 \times 7.90 \text{ g/cm}^3 = 703 \text{ grams} \]

**Answer:** The mass of the horseshoe is 703 grams.

**Example 3:** What is the volume of a 525-gram block of lead? The density of lead is 11.3 g/cm\(^3\).

\[ \text{volume} = \frac{525 \text{ g}}{11.3 \text{ g/cm}^3} = 46.5 \text{ cm}^3 \]

**Answer:** The volume of the block is 46.5 cm\(^3\).
Answer the following density questions. Report your answers using the correct number of significant digits.

1. A solid rubber stopper has a mass of 33.0 grams and a volume of 30.0 cm$^3$. What is the density of rubber?
2. A chunk of paraffin (wax) has a mass of 50.4 grams and a volume of 57.9 cm$^3$. What is its density?
3. A marble statue has a mass of 6,200 grams and a volume of 2,296 cm$^3$. What is the density of marble?
4. The density of ice is 0.92 g/cm$^3$. An ice sculptor orders a 1.0-m$^3$ block of ice. What is the mass of the block? Hint: 1 m$^3$ = 1,000,000 cm$^3$. Give your answer in grams and kilograms.
5. What is the mass of a pure platinum disk with a volume of 113 cm$^3$? The density of platinum is 21.4 g/cm$^3$. Give your answer in grams and kilograms.
6. The density of seawater is 1.025 g/mL. What is the mass of 1.000 liter of seawater in grams and in kilograms? (Hint: 1 liter = 1,000 mL)
7. The density of cork is 0.24 g/cm$^3$. What is the volume of a 288-gram piece of cork?
8. The density of gold is 19.3 g/cm$^3$. What is the volume of a 575-gram bar of pure gold?
9. The density of mercury is 13.6 g/mL. What is the volume of a 155-gram sample of mercury?
10. Recycling centers use density to help sort and identify different types of plastics so that they can be properly recycled. The table below shows common types of plastics, their recycling code, and density. Use the table to solve problems 10a–d.

<table>
<thead>
<tr>
<th>Plastic name</th>
<th>Common uses</th>
<th>Recycling code</th>
<th>Density (g/cm$^3$)</th>
<th>Density (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PETE</td>
<td>plastic soda bottles</td>
<td>1</td>
<td>1.38–1.39</td>
<td>1,380–1,390</td>
</tr>
<tr>
<td>HDPE</td>
<td>milk cartons</td>
<td>2</td>
<td>0.95–0.97</td>
<td>950–970</td>
</tr>
<tr>
<td>PVC</td>
<td>plumbing pipe</td>
<td>3</td>
<td>1.15–1.35</td>
<td>1,150–1,350</td>
</tr>
<tr>
<td>LDPE</td>
<td>trash can liners</td>
<td>4</td>
<td>0.92–0.94</td>
<td>920–940</td>
</tr>
<tr>
<td>PP</td>
<td>yogurt containers</td>
<td>5</td>
<td>0.90–0.91</td>
<td>900–910</td>
</tr>
<tr>
<td>PS</td>
<td>cd “jewel cases”</td>
<td>6</td>
<td>1.05–1.07</td>
<td>1,050–1,070</td>
</tr>
</tbody>
</table>

a. A recycling center has a 0.125 m$^3$ box filled with one type of plastic. When empty, the box had a mass of 0.755 kilograms. The full box has a mass of 120.8 kilograms. What is the density of the plastic? What type of plastic is in the box?

b. A truckload of plastic soda bottles was finely shredded at a recycling center. The plastic shreds were placed into 55-liter drums. What is the mass of the plastic shreds inside one of the drums? Hint: 55 liters = 55,000 milliliters = 55,000 cm$^3$.

c. A recycling center has 100 kilograms of shredded plastic yogurt containers. What volume is needed to hold this amount of shredded plastic? How many 10.-liter (10,000 mL) containers do they need to hold all of this plastic? Hint: 1 m$^3$ = 1,000,000 mL.

d. A solid will float in a liquid if it is less dense than the liquid, and sink if it is more dense than the liquid. If the density of seawater is 1.025 g/mL, which types of plastics would definitely float in seawater?
10.3 Pressure in Fluids

Have you ever wondered how a 1,500-kilogram car is raised off the ground in a mechanic’s shop? A hydraulic lift does the trick. All hydraulic machines operate on the basis of Pascal’s principle, which states that the pressure applied to an incompressible fluid in a closed container is transmitted equally in all parts of the fluid.

In the diagram above, a piston at the top of the small tube pushes down on the fluid. This input force generates a certain amount of pressure, which can be calculated using the formula:

\[ \text{Pressure} = \frac{\text{Force}}{\text{Area}} \]

That pressure stays the same throughout the fluid, so it remains the same in the large cylinder. Since the large cylinder has more area, the output force generated by the large cylinder is greater. The output force exerted by the piston at the top of the large cylinder can be calculated using the formula:

\[ \text{Force} = \text{Pressure} \times \text{Area} \]

You can see that the small input force created a large output force. But there’s a price: The small piston must be pushed a greater distance than the large piston moves. Work output (output force \( \times \) output distance) can never be greater than work input (input force \( \times \) input distance).

**EXAMPLE**

- A 50.-newton force is applied to a small piston with an area of 0.0025 m\(^2\). What pressure, in pascals, will be transmitted in the hydraulic system?

**Solution:**

\[ \text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{50. \text{ N}}{0.0025 \text{ m}^2} = 20000 \text{ Pa} \]

- The area of the large cylinder’s piston in this hydraulic system is 2.5 m\(^2\). What is the output force?

**Solution:**

\[ \text{Force} = \text{Pressure} \times \text{Area} = 20000 \text{ Pa} \times 2.5 \text{ m}^2 = 50000 \text{ N} \]
1. In a hydraulic system, a 100.-newton force is applied to a small piston with an area of 0.0020 m$^2$. What pressure, in pascals, will be transmitted in the hydraulic system?

2. The area of the large cylinder’s piston in this hydraulic system is 3.14 m$^2$. What is the output force?

3. An engineer wishes to design a hydraulic system that will transmit a pressure of 10,000 pascals using a force of 15 newtons. How large an area should the input piston have?

4. This hydraulic system should produce an output force of 50,000 newtons. How large an area should the output piston have?

5. Another engineer is running a series of experiments with hydraulic systems. If she doubles the area of the input piston, what happens to the amount of pressure transmitted by the system?

6. If all other variables remain unchanged, what happens to the output force when the area of the input piston is doubled?

7. If the small piston in the hydraulic system described in problems 1 and 2 is moved a distance of 2 meters, will the large piston also move 2 meters? Explain why or why not.

8. A 540-newton woman can make dents in a hardwood floor wearing high-heeled shoes, yet if she wears snowshoes, she can step effortlessly over soft snow without sinking in. Explain why, using what you know about pressure, force, and area.
10.3 Boyle’s Law

The relationship between the volume of a gas and the pressure of a gas, at a constant temperature, is known as Boyle’s law. The equation for Boyle’s law is shown at right.

Units for pressure include: atmospheres (atm), pascals (Pa), or kilopascals (kPa). Units for volume include: cubic centimeters (cm³), cubic meters (m³), or liters.

EXAMPLE

A kit used to fix flat tires consists of an aerosol can containing compressed air and a patch to seal the hole in the tire. Suppose 10.0 L of air at atmospheric pressure (101.3 kilopascals, or kPa) is compressed into a 1.0-L aerosol can. What is the pressure of the compressed air in the can?

Looking for
Pressure of compressed air in a can ($P_2$)

Given
$P_1 = 101.3$ kPa; $V_1 = 10.0$ liters; $V_2 = 1.0$ liters

Relationship
Use Boyle’s Law to solve for $P_2$. Divide each side by $V_2$ to isolate $P_2$ on one side of the equation:

$$P_2 = \frac{P_1 V_1}{V_2}$$

Solution

$$P_2 = \frac{101.3 \text{ kPa} \times 10.0 \text{ L}}{1.0 \text{ L}} = 1,013 \text{ kPa}$$

The pressure inside the aerosol can is 1,013 kPa.

PRACTICE

1. The air inside a tire pump occupies a volume of 130. cm³ at a pressure of one atmosphere. If the volume decreases to 40.0 cm³, what is the pressure, in atmospheres, inside the pump?

2. A gas occupies a volume of 20. m³ at 9,000. Pa. If the pressure is lowered to 5,000. Pa, what volume will the gas occupy?

3. You pump 25.0 L of air at atmospheric pressure (101.3 kPa) into a soccer ball that has a volume of 4.50 L. What is the pressure inside the soccer ball if the temperature does not change?

4. Hyperbaric oxygen chambers (HBO) are used to treat divers with decompression sickness. As pressure increases inside the HBO, more oxygen is forced into the bloodstream of the patient inside the chamber. To work properly, the pressure inside the chamber should be three times greater than atmospheric pressure (101.3 kPa). What volume of oxygen, held at atmospheric pressure, will need to be pumped into a 190.-L HBO chamber to make the pressure inside three times greater than atmospheric pressure?

5. A 12.5-liter scuba tank holds oxygen at a pressure of 202.6 kPa. What is the original volume of oxygen at 101.3 kPa that is required to fill the scuba tank?
**10.4 Buoyancy**

When an object is placed in a fluid (liquid or gas), the fluid exerts an *upward force* upon the object. This force is called a **buoyant force**.

At the same time, there is an attractive force between the object and Earth—the force of gravity. It acts as a *downward force*. You can compare the two forces to determine whether the object floats or sinks in the fluid.

<table>
<thead>
<tr>
<th>Buoyant force &gt; Gravitational force</th>
<th>Buoyant force &lt; Gravitational force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object floats</td>
<td>Object sinks</td>
</tr>
</tbody>
</table>

**EXAMPLES**

**Example 1:** A 13-N object is placed in a container of fluid. If the fluid exerts a 60-N buoyant (upward) force on the object, will the object float or sink?  
**Answer:** Float. The upward buoyant force (60 N) is greater than the weight of the object (13 N).

**Example 2:** The rock weighs 2.25 N when suspended in air. In water, it appears to weigh only 1.8 N. Why?  
**Answer:** The water exerts a buoyant force on the rock. This buoyant force equals the difference between the rock’s weight in air and its apparent weight in water.  
\[2.25 \text{ N} - 1.8 \text{ N} = 0.45 \text{ N}\]  
The water exerts a buoyant force of 0.45 newtons on the rock.

**PRACTICE**

1. A 4.5-N object is placed in a tank of water. If the water exerts a force of 4.0 N on the object, will the object sink or float?  
2. The same 4.5-N object is placed in a tank of glycerin. If the glycerin exerts a force of 5.0 N on the object, will the object sink or float?  
3. You suspend a brass ring from a spring scale. Its weight is 0.83 N while it is suspended in air. Next, you immerse the ring in a container of light corn syrup. The ring appears to weigh 0.71 N. What is the buoyant force acting on the ring in the light corn syrup?  
4. You wash the brass ring (from question 3) and then suspend it in a container of vegetable oil. The ring appears to weigh 0.73 N. What is the buoyant force acting on the ring?  
5. Which has greater buoyant force, light corn syrup or the vegetable oil? Why do you think this is so?  
6. A cube of gold weighs 1.89 N when suspended in air from a spring scale. When suspended in molasses, it appears to weigh 1.76 N. What is the buoyant force acting on the cube?  
7. Do you think the buoyant force would be greater or smaller if the gold cube were suspended in water? Explain your answer.
10.4 Charles’s Law

Charles’s law shows a direct relationship between the volume of a gas and the temperature of a gas when the temperature is given in the Kelvin scale. The Charles’s law equation is below.

![Charles's Law Equation](image)

Converting from degrees Celsius to Kelvin is easy—you add 273 to the Celsius temperature. To convert from Kelvins to degrees Celsius, you subtract 273 from the Kelvin temperature.

**Example**

A truck tire holds 25.0 liters of air at 25 °C. If the temperature drops to 0 °C, and the pressure remains constant, what will be the new volume of the tire?

**Looking for**
The new volume of the tire ($V_2$)

**Given**
- $V_1 = 25.0$ liters
- $T_1 = 25$ °C
- $T_2 = 0$ °C

**Relationships**

Use Charles’ Law to solve for $V_2$. Multiply each side by $T_2$ to isolate $V_2$ on one side of the equation.

$$V_2 = \frac{V_1 T_2}{T_1}$$

Convert temperature values in Celsius degrees to Kelvin: $T_{Kelvin} = T_{Celsius} + 273$

**Solution**

$$T_1 = 25 \, ^{\circ}C + 273 = 298$$

$$T_2 = 0 \, ^{\circ}C + 273 = 273$$

$$V_2 = \frac{25.0 \text{ L} \times 273}{298} = 23.0 \text{ L}$$

The new volume inside the tire is 23.0 liters.

**Practice**

1. If a truck tire holds 25.0 liters of air at 25.0 °C, what is the new volume of air in the tire if the temperature increases to 30.0 °C?

2. A balloon holds 20.0 liters of helium at 10.0 °C. If the temperature increases to 50.0 °C, and the pressure does not change, what is the new volume of the balloon?

3. Use Charles’ Law to fill in the following table with the correct values. Pay attention to the temperature units.

<table>
<thead>
<tr>
<th></th>
<th>$V_1$</th>
<th>$T_1$</th>
<th>$V_2$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td></td>
<td>840 K</td>
<td>1,070 mL</td>
<td>147 K</td>
</tr>
<tr>
<td>b.</td>
<td>3250 mL</td>
<td>475 °C</td>
<td></td>
<td>50 °C</td>
</tr>
<tr>
<td>c.</td>
<td>10 L</td>
<td></td>
<td>15 L</td>
<td>50 °C</td>
</tr>
</tbody>
</table>
10.4 Pressure-Temperature Relationship

The pressure-temperature relationship shows a direct relationship between the pressure of a gas and its temperature when the temperature is given in the Kelvin scale. Another name for this relationship is the Gay-Lussac Law. The pressure-temperature equation is shown at right.

Converting from degrees Celsius to Kelvin is easy—you add 273 to the Celsius temperature. To convert from Kelvins to degrees Celsius, you subtract 273 from the Kelvin temperature.

**Example**

A constant volume of gas is heated from 25.0°C to 100°C. If the gas pressure starts at 1.00 atmosphere, what is the final pressure of this gas?

<table>
<thead>
<tr>
<th>Looking for</th>
<th>The new pressure of the gas ($P_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Given</td>
<td>$T_1 = 25$ °C; $P_1 = 1$ atm; $T_2 = 100$ °C</td>
</tr>
<tr>
<td>Relationships</td>
<td>Use pressure-temperature relation to solve for $P_2$. Multiply each side by $T_2$ to isolate $P_2$ on one side of the equation. $P_2 = \frac{P_1 T_2}{T_1}$ Convert temperature values in Celsius degrees to Kelvin: $T_{Kelvin} = T_{Celsius} + 273$</td>
</tr>
<tr>
<td>Solution</td>
<td>$T_1 = 25$ °C + 273 = 298 $T_2 = 100$ °C + 373 = 313 $P_2 = \frac{1 \text{ atm} \times 373}{298} = 1.25$ atm The new pressure of the volume of gas is 1.25 atmospheres.</td>
</tr>
</tbody>
</table>

**Practice**

1. At 400. K, a volume of gas has a pressure of 0.40 atmospheres. What is the pressure of this gas at 273 K?
2. What is the temperature of the volume of gas (starting at 400. K with a pressure of 0.4 atmospheres), when the pressure increases to 1 atmosphere?
3. Use the pressure-temperature relationship to fill in the following table with the correct values. Pay attention to the temperature units.

<table>
<thead>
<tr>
<th></th>
<th>$P_1$</th>
<th>$T_1$</th>
<th>$P_2$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>30.0 atm</td>
<td>−100 °C</td>
<td>500 °C</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>15.0 atm</td>
<td>25.0 °C</td>
<td>18.0 atm</td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>5.00 atm</td>
<td>3.00 atm</td>
<td>293 K</td>
<td></td>
</tr>
</tbody>
</table>
Archimedes was a Greek mathematician who specialized in geometry. He figured out the value of pi and the volume of a sphere, and has been called “the father of integral calculus.” During his lifetime, he was famous for using compound pulleys and levers to invent war machines that successfully held off an attack on his city for three years. Today he is best known for Archimedes’ principle, which was the first explanation of how buoyancy works.

Archimedes’ screw

Archimedes was born in Syracuse, on Sicily (then an independent Greek city-state), in 287 B.C. His letters suggest that he studied in Alexandria, Egypt, as a young man. Historians believe it was there that he invented a device for raising water by means of a rotating screw or spirally bent tube within an inclined hollow cylinder. The device known as Archimedes’ screw is still used in many parts of the world.

“Eureka!”

A famous Greek legend says that King Hieron II of Syracuse asked Archimedes to figure out if his new crown was pure gold or if the craftsman had mixed some less expensive silver into it. Archimedes had to determine the answer without destroying the crown. He thought about it for days and then, as he lowered himself into a bath, the method for figuring it out struck him. The legend says Archimedes ran through the streets, shouting “Eureka!”—meaning “I have found it.”

A massive problem

Archimedes realized that if he had equal masses of gold and silver, the denser gold would have a smaller volume. Therefore, the gold would displace less water than the silver when submerged.

Archimedes found the mass of the crown and then made a bar of pure gold with the same mass. He submerged the gold bar and measured the volume of water it displaced. Next, he submerged the crown. He found the crown displaced more water than the gold bar had and, therefore, could not be pure gold. The gold had been mixed with a less dense material. Archimedes had confirmed the king’s doubts.

Why do things float?

Archimedes wrote a treatise titled On Floating Bodies, further exploring density and buoyancy. He explained that an object immersed in a fluid is pushed upward by a force equal to the weight of the fluid displaced by the object. Therefore, if an object weighs more than the fluid it displaces, it will sink. If it weighs less than the fluid it displaces, it will float. This statement is known as Archimedes’ principle. Although we commonly assume the fluid is water, the statement holds true for any fluid, whether liquid or gas. A helium balloon floats because the air it displaces weighs more than the balloon filled with lightweight gas.

Cylinders, circles, and exponents

Archimedes wrote several other treatises, including “On the Sphere and the Cylinder,” “On the Measurement of the Circle,” “On Spirals,” and “The Sand Reckoner.” In this last treatise, he devised a system of exponents that allowed him to represent large numbers on paper—up to $8 \times 10^{63}$ in modern scientific notation. This was large enough, he said, to count the grains of sand that would be needed to fill the universe. This paper is even more remarkable for its astronomical calculations than for its new mathematics. Archimedes first had to figure out the size of the universe in order to estimate the amount of sand needed to fill it. He based his size calculations on the writings of three astronomers (one of them was his father). While his estimate is considered too small by today’s standard, it was much, much larger than anyone had previously suggested. Archimedes was the first to think on an “astronomical scale.”

Archimedes was killed by a Roman soldier during an invasion of Syracuse in 212 B.C.
Reading reflection

1. The boldface words in the article are defined in the glossary of your textbook. Look them up and then explain the meaning of each in your own words.

2. Imagine you are Archimedes and have to write your resume for a job. Describe yourself in a brief paragraph. Be sure to include in the paragraph your skills and the jobs you are capable of doing.

3. What was Archimedes’ treatise “The Sand Reckoner” about?

4. Why does a balloon filled with helium float in air, but a balloon filled with air from your lungs sink?

5. Research one of Archimedes’ inventions and create a poster that shows how the device worked.
10.4 Narcís Monturiol

Monturiol, a visionary and peaceful revolutionary, wanted to improve the social and economic lives of his countrymen. Moved by the suffering of coral divers due to their extremely dangerous working conditions, Monturiol built a submarine to transport the divers to the reefs. He hoped that in time, his invention would also help people understand the ocean world.

Birth of a Spanish inventor

Narcís Monturiol was born on September 28, 1819, in Figueres, Catalonia, a region of northeastern Spain. Monturiol’s father was a cooper—which means that he handcrafted wooden barrels that held wine, oil, and milk. Narcís was one of five children. At an early age he showed an interest in design and invention. When he was ten, he created a realistic model of a wooden clock.

His mother wanted Narcís to become a priest, but he earned a law degree instead. He never practiced law, however. Instead, he became a self-taught engineer.

Monturiol was active politically. He supported socialism, communism, and the ideal of a utopia where everyone lived together in harmony. He turned to science with the hope of creating that utopia.

The perils of coral diving

Monturiol was concerned about the danger involved in the work of Spanish coral fishermen. A diver, holding his breath for several minutes, dove nearly 20 meters beneath the ocean surface to retrieve valuable pieces of coral. The divers risked drowning, injuries from rocks and coral, and possible shark attacks.

In 1857, Monturiol formed a company to design and build a submarine. His goal was to develop a vessel to help coral divers with their physical work and to lessen the risk involved.

Monturiol was not the first to build a submarine. Historical records show that Aristotle, Renaissance period inventors, and others had attempted to build submarines. These models were often created for warfare. Most early submarines were unsuccessful and dangerous.

Ictineo I

Monturiol’s first submarine, Ictineo I, made its first dive in 1859. The name Ictineo is derived from Greek, and is translated “fish ship.” During its initial dive, Ictineo I hit underwater pilings. Repairing what he could, Monturiol sent Ictineo I on its second dive within a few hours.

Monturiol’s seven-meter submarine had a spherical inner hull built to withstand water pressure, and an elliptical (egg-shaped) outer hull for ease of movement. Between the two hulls were tanks that stored and released water to control the submarine’s depth. Oxygen tanks were also stored in this space. The submarine was powered by four men turning the propeller by hand.

Ictineo I was equipped with a ventilator, two sets of propellers, and several portholes. The submarine had the ability to retrieve objects and was equipped with a back-up system to raise it to the surface in an emergency.

Ictineo I made nearly 20 dives that first year, to a depth of 20 meters. The submarine eventually stayed underwater for nearly two hours.

Ictineo II

Monturiol created a second and improved model called Ictineo II. Rather than relying on manpower, the Ictineo II had a steam engine. These engines were traditionally powered by an open flame. Monturiol created a submarine-safe alternative to power the engine using a chemical reaction. The open flame would have removed oxygen, but the chemical reaction added oxygen to the cabin instead.

The Ictineo II was 17 meters long, had two engines, dove to depths of nearly 30 meters, had many portholes, and remained underwater for almost seven hours.

Unfortunately, Monturiol ran out of funds and was forced to sell his submarine for scrap. Although he didn’t receive much credit for his inventions during his lifetime, he is now recognized as an important contributor to submarine development. Monturiol died in 1885.
**Reading reflection**

1. What moved Monturiol to create a submarine?
2. Identify key features of the *Ictineo I* and II.
3. **Research:** Where are model replicas of *Ictineo I* and II located?
4. **Research:** What happened to Monturiol’s *Ictineo I*?
5. **Research:** Name three things Monturiol invented in addition to the submarine.
6. **Research:** How did Spain honor Monturiol in 1987?
7. **Research:** What is the Narcís Monturiol medal?
10.4 Archimedes’ Principle

More than 2,000 years ago, Archimedes discovered the relationship between buoyant force and how much fluid is displaced by an object. Archimedes’ principle states:

The buoyant force acting on an object in a fluid is equal to the weight of the fluid displaced by the object.

We can practice figuring out the buoyant force using a beach ball and a big tub of water. Our beach ball has a volume of 14,130 cm³. The weight of the beach ball in air is 1.5 N.

If you put the beach ball into the water and don’t push down on it, you’ll see that the beach ball floats on top of the water by itself. Only a small part of the beach ball is underwater. Measuring the volume of the beach ball that is under water, we find it is 153 cm³. Knowing that 1 cm³ of water has a mass of 1 g, you can calculate the weight of the water displaced by the beach ball.

\[
153 \text{ cm}^3 \text{ of water} = 153 \text{ grams} = 0.153 \text{ kg} \\
\text{weight} = \text{mass} \times \text{force of gravity per kg} = (0.153 \text{ kg}) \times 9.8 \text{ N/kg} = 1.5 \text{ N}
\]

According to Archimedes principle, the buoyant force acting on the beach ball equals the weight of the water displaced by the beach ball. Since the beach ball is floating in equilibrium, the weight of the ball pushing down must equal the buoyant force pushing up on the ball. We just showed this to be true for our beach ball.

Have you ever tried to hold a beach ball underwater? It takes a lot of effort! That is because as you submerge more of the beach ball, the more the buoyant force acting on the ball pushes it up. Let’s calculate the buoyant force on our beach ball if we push it all the way under the water. Completely submerged, the beach ball displaces 14,130 cm³ of water. Archimedes principle tells us that the buoyant force on the ball is equal to the weight of that water:

\[
14,130 \text{ cm}^3 \text{ of water} = 14,130 \text{ grams} = 14.13 \text{ kg} \\
\text{weight} = \text{mass} \times \text{force of gravity per kg} = (14.13 \text{ kg}) \times 9.8 \text{ N/kg} = 138 \text{ N}
\]

If the buoyant force is pushing up with 138 N, and the weight of the ball is only 1.5 N, your hand pushing down on the ball supplies the rest of the force, 136.5 N.

**EXAMPLE**

- A 10-cm³ block of lead weighs 1.1 N. The lead is placed in a tank of water. One cm³ of water weighs 0.0098 N. What is the buoyant force on the block of lead?

**Solution:**

The lead displaces 10 cm³ of water.

\[\text{buoyant force} = \text{weight of water displaced} \times \text{density of water} = 10 \text{ cm}^3 \times 0.0098 \text{ N/cm}^3 = 0.098 \text{ N}\]
1. A block of gold and a block of wood both have the same volume. If they are both submerged in water, which has the greater buoyant force acting on it?

2. A 100-cm³ block of lead that weighs 11 N is carefully submerged in water. One cm³ of water weighs 0.0098 N.
   a. What volume of water does the lead displace?
   b. How much does that volume of water weigh?
   c. What is the buoyant force on the lead?
   d. Will the lead block sink or float in the water?

3. The same 100-cm³ lead block is carefully submerged in a container of mercury. One cm³ of mercury weighs 0.13 N.
   a. What volume of mercury is displaced?
   b. How much does that volume of mercury weigh?
   c. What is the buoyant force on the lead?
   d. Will the lead block sink or float in the mercury?

4. According to problems 2 and 3, does an object’s density have anything to do with whether or not it will float in a particular liquid? Justify your answer.

5. Based on the table of densities, explain whether the object would float or sink in the following situations:

<table>
<thead>
<tr>
<th>material</th>
<th>density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gasoline</td>
<td>0.7</td>
</tr>
<tr>
<td>gold</td>
<td>19.3</td>
</tr>
<tr>
<td>lead</td>
<td>11.3</td>
</tr>
<tr>
<td>mercury</td>
<td>13.6</td>
</tr>
<tr>
<td>molasses</td>
<td>1.37</td>
</tr>
<tr>
<td>paraffin</td>
<td>0.87</td>
</tr>
<tr>
<td>platinum</td>
<td>21.4</td>
</tr>
</tbody>
</table>

   a. A block of solid paraffin (wax) in molasses.
   b. A bar of gold in mercury.
   c. A piece of platinum in gasoline.
   d. A block of paraffin in gasoline.
11.1 Layers of the Atmosphere

Use the table below to organize the information in Section 11.1 of your text. You can use the table as a study guide as you review for tests.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Distance from Earth’s Surface</th>
<th>Thickness</th>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Troposphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stratosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11.2 Gaspard Gustave de Coriolis

Gaspard Gustave de Coriolis was a French mechanical engineer and mathematician in the early 1800’s. His name is famous today for his work on wind deflection by the Coriolis effect.

From Paris to Nancy to Paris again

Gaspard Gustave de Coriolis (Kor-e-olis) was born in 1792 in Paris, France. Shortly after his birth, his family left Paris and settled in the town of Nancy, pronounced nasi in French. It was here in Nancy that Coriolis grew up and attended school.

He was exceptionally gifted in the area of mathematics, and took the entrance exam for Ecole Polytechnique when he was 16 years old. Ecole is French for school. Ecole Polytechnique is one of the best-known French Grandes ecoles (Great Schools) for engineering. Coriolis ranked second out of all the students entering Ecole Polytechnique that year.

After graduating from Ecole Polytechnique, he continued his studies at Ecole des Ponts et Chaussees (School of Bridges and Roads) in Paris.

Then Coriolis’ dreams of becoming an engineer were put on hold. Faced with the responsibility of supporting his family after his father’s death in 1816, he accepted a position as a tutor in mathematical analysis and mechanics back at Ecole Polytechnique. At this time, Coriolis was only 24 years old.

The tutor becomes a professor

Coriolis earned great respect for his studies and research in mechanics, engineering, and mathematics. He published his first official work in 1829 titled On the Calculation of Mechanical Action. This same year he became professor of mechanics at Ecole Centrales des Artes et Manufactures. Coriolis became one of the leading scientific thinkers by introducing the terms work and kinetic energy.

In 1830 he once again found himself back at Ecole Polytechnique after accepting the position of professor. Coriolis went on to be elected chair of the Academie des Sciences, and later appointed director of studies at Ecole Polytechnique.

The paper that made him famous

In 1835, Coriolis published the paper that made his name famous: On the Equations of Relative Motion of Systems of Bodies. The paper discussed the transfer of energy in rotating systems. Coriolis’s research helped explain how the Earth’s rotation causes the motion of air to curve with respect to the surface of the Earth.

His name did not become linked with meteorology until the beginning of the twentieth century. He is noted for the explanation of the bending of air currents known as the Coriolis effect.

Bending of currents

There are patterns of winds that naturally cover the Earth. The global surface wind patterns in the northern and southern hemisphere bend due to the Earth’s rotation.

For example, the Coriolis effect bends the trade winds moving across the surface. They flow from northeast to southwest in the northern hemisphere, and from southwest to northeast in the southern hemisphere.

The Coriolis effect has helped scientist explain many rotational patterns, yet it does not determine the direction of water draining in sinks, bathtubs, and toilets (as some have suggested). However, it does explain the rotation of cyclones.

Gaspard Gustave de Coriolis died in 1843 in Paris.
**Reading reflection**

1. How did Coriolis’s education influence his work?

2. Explain the importance of Coriolis’s first book titled *On the Calculation of Mechanical Action*.

3. To understand why Earth’s rotation affects the path of air currents, imagine the following situation: You are a pilot who wants to fly an airplane from St. Paul, Minnesota, 700 miles south to Little Rock, Arkansas. If you set your compass and try to fly straight south, you will probably end up in New Mexico! Why would you end up in New Mexico instead of Little Rock?

4. Compare the Coriolis effect in the northern hemisphere with the Coriolis effect in the southern hemisphere.

5. Research the following global surface wind patterns: **trade winds**, **polar easterlies**, **prevailing westerlies**, and explain the Coriolis effect on each wind pattern.

6. Research why Coriolis’s work on Earth’s rotation was not accepted until long after his death in 1843.

7. Research the other books that Coriolis wrote, such as *Mathematical Theory of the Game of Billiards* and *Treatise on the Mechanics of Solid Bodies*, and explain their scientific impact.
11.2 Degree Days

Freezing winter weather or sweltering summer heat—in either condition, people use energy to keep their homes, schools, and businesses comfortable. You can use degree day values to help predict how much energy will be needed each month to heat or cool a building. In this activity, you will learn how degree day values are calculated and how to use them to evaluate energy needs.

Understanding degree days

Degree day values are calculated by comparing a day’s average temperature to 65 °Fahrenheit. The more extreme the temperature, the higher the degree day value. For example, if the average daily temperature were 72°F, the degree day value would be 72 minus 65, or 7. On a day with an average temperature of 35°F, the degree day value would be 65 minus 35, or 30.

When the average daily temperature is lower than 65°F, we use the term heating degree day value, because you need to add heat to a building to bring it to a comfortable temperature. When the average daily temperature is higher than 65°F, we talk about the cooling degree day value.

We compare the daily average temperature to 65°F because 65°F is a temperature at which most people are comfortable without heating or air conditioning. If the average temperature is close to 65°F, you won’t need to spend much money heating or cooling your home that day. However, if the average temperature is well above or below 65°F, you’ll be spending a lot more money on electricity or fuel.

1. On July 22, 2002, the average daily temperature in St. Louis, Missouri, was 88°F. Calculate the cooling degree day value.

2. On January 22, 2003, the average daily temperature in St. Louis was 14°F. Calculate the cooling degree day value.

3. On which day—July 22, 2002 or January 22, 2003—was the heating degree day value zero? On which day was the cooling degree day value zero?
Using temperature data to calculate degree day values

The table below shows temperature data recorded by the National Weather Service in May 2003.

Table 1: Temperature data for St. Louis, May 1-14, 2003

<table>
<thead>
<tr>
<th>Day</th>
<th>High temp (°F)</th>
<th>Low temp (°F)</th>
<th>Average temp (high + low)(^{\div} 2)</th>
<th>Heating degree day value</th>
<th>Cooling degree day value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73</td>
<td>61</td>
<td>(73 + 61)(^{\div} 2) = 67</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>63</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>65</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>83</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>79</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>74</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>71</td>
<td>53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>90</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>82</td>
<td>62</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>65</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>71</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>74</td>
<td>56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>75</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Two week totals:

1. Calculate the average temperature, the heating degree day value, and the cooling degree day value for each day. Record your answers in the Table 1. The first one is done for you.
2. During the first two weeks of May, on how many days were St. Louis residents more likely to use their heating systems? On how many days were they more likely to cool their homes?

Calculating monthly totals for degree day values

3. Find the sum of the numbers in the fifth column of Table 1. This will give you the total heating degree day value for May 1–14, 2003. Record your answer in the table’s last row.
4. Find the total cooling degree day value for same time period by finding the sum of the sixth column of Table 1. Record your answer in the table’s last row.
5. The total heating degree day value for May 15-31, 2003 was 31. The total cooling degree day value was 32. Find the monthly total heating and cooling degree day values.

6. In St. Louis, the average total heating degree day value for May is 79. The average total cooling degree day value for May is 114. How was May 2003 different from the average? Do you think residents used more energy than usual to keep their homes comfortable, or less?
Using average monthly degree day values

The National Weather Service provides average monthly degree day values to help citizens better evaluate their energy needs.

### Average monthly heating degree day (HDD) and cooling degree day (CDD) values for St. Louis

<table>
<thead>
<tr>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDD 1097</td>
<td>CDD 0</td>
<td>HDD 844</td>
<td>CDD 0</td>
<td>HDD 613</td>
<td>CDD 7</td>
</tr>
<tr>
<td>HDD 294</td>
<td>CDD 32</td>
<td>HDD 79</td>
<td>CDD 114</td>
<td>HDD 6</td>
<td>CDD 316</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDD 0</td>
<td>CDD 461</td>
<td>HDD 1</td>
<td>CDD 396</td>
<td>HDD 46</td>
<td>CDD 196</td>
</tr>
</tbody>
</table>

1. On a separate piece of paper, make a bar graph showing the average monthly heating and cooling degree day values for St. Louis. Place months on the x-axis and monthly average degree day values on the y-axis. Use red bars for the heating degree day values and blue bars for the cooling degree day values. Use your graph to answer the following questions:

2. In which month should a St. Louis resident budget the most money for heating costs?

3. In which month should a St. Louis resident budget the most money for cooling costs?

4. 
   a. In which month do you think a St. Louis resident will spend the least amount of money to keep their home at a comfortable temperature? Explain.

   b. Challenge! What additional information would you need to calculate the actual monthly heating and cooling costs for a particular building?

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*All climate data courtesy of the National Weather Service St. Louis Weather Station.*
Dr. Joanne Simpson was the first woman to serve as president of the American Meteorological Society. Her road to success was not easy. She chose to forge ahead in the field of meteorology for the sake of women who would enter the field after her.

Early goals

Joanne Simpson was born in 1923 in Boston, Massachusetts. At a young age, Simpson was determined to have a career that would provide her with financial independence. Her mother, a journalist, remained in a difficult marriage because she could not afford to provide for her children on her own. Simpson knew at age ten that she wanted to be able to support herself and any future children.

So Simpson’s journey began. As a child, Simpson loved clouds. She spent time gazing at clouds when she sailed off the Cape Cod coast. Simpson’s father, aviation editor for the Boston Herald newspaper, probably sparked Simpson’s interest in flight. Joanne loved to fly and earned her pilot’s license at 16. Her interest in weather took off.

The sky’s the limit

Simpson earned her degree from the University of Chicago in 1943. It was here that she developed a love for science. She planned to study astrophysics. However, as a student pilot she was required to take a meteorology course. Meteorology was fascinating. She wanted to take more courses. Carl-Gustaf Rossby, a great twentieth century meteorologist, had just started an institute of meteorology at the university. Simpson met with Rossby and enrolled in the World War II meteorology program as a teacher-in-training. She taught meteorology to aviation cadets.

Women temporarily filled the roles of men away at war. At the end of the war, most women returned home, but not Simpson. She completed a master’s degree and wanted to earn a Ph.D. Her advisor said that women did not earn Ph.D.s in meteorology. The all-male faculty felt that women were unable to do the work which included night shifts and flying planes. She was even told that if she earned the degree no one would ever hire a woman.

Determined even more, Simpson pursued her dream. She took a course with Herbert Riehl, a leader in the field of tropical meteorology. She asked Riehl if he would be her advisor and he agreed. Not surprisingly, Simpson chose to study clouds. Her new advisor thought it would be a perfect topic “for a little girl to study.” Throughout her Ph.D. program, she studied in an unsupportive academic environment. She persevered and became the first woman to earn a Ph.D. in meteorology.

Working woman

As a woman, Simpson did have difficulty finding a job. Eventually she became an assistant physics professor. Two years later, she took a job at Woods Hole Oceanographic Institute to study tropical clouds. People at the time believed clouds were produced by the weather and were not the cause for weather. Simpson, studying cumulus clouds in the tropics, proved that clouds do affect the weather. She found that very tall clouds near the equator created enough energy to circulate the atmosphere. Together, Simpson and Riehl developed the “Hot Tower Theory.” Tall cloud towers can carry moist ocean air as high as 50,000 feet into the air, create heat, and release energy.

While studying hurricanes, Simpson discovered that hot towers release energy to the hurricane eye and act as the hurricane’s engine. Simpson’s work with clouds continued as she created the first cloud model. Using a slide rule, she created a model well before computers were invented. She later became the first person to create a computerized cloud model.

A life of achievement

Simpson’s career spans many decades, many institutions, and many positions. She has won numerous awards including the Carl-Gustaf Rossby Research Award. In 1979, she joined NASA’s Goddard Space Flight Center and enjoyed finally working with other female scientists. As a NASA chief scientist, Simpson does not plan to retire. Today, she continues to study rainfall, satellite images, and hurricanes.
1. Dr. Simpson achieved many “firsts” in the field of meteorology. Identify three of these first time achievements.

2. Simpson’s road to success in the field of meteorology was not easy. What obstacles did she overcome on her journey to eventual success?

3. What have you learned about working towards goals based on Simpson’s biography?

4. **Research:** What is a slide rule? What caused the slide rule to fade from use?

5. **Research:** What is the Carl-Gustaf Rossby Research Award?

6. **Research:** Where is the Woods Hole Oceanographic Institute located and what does it do?

7. **Research:** Use a library or the Internet to find a photo or sketch of hot tower clouds. Present the image to your class, citing your source.
11.3 Weather Maps

You have learned how the Sun heats Earth and how the heating of land is different than the heating of water. In this skill sheet, you will analyze the national weather forecast and make inferences as to what causes differences in weather across the nation. To complete this skill sheet, you will need a national weather forecast from a daily newspaper and a map of North America from an atlas.

Analyzing temperature

Study the national weather forecast from a daily newspaper. Locate the list of the temperature and sky cover in cities around the country. Also, locate the weather map showing sunny regions, the temperature, high- and low-pressure regions, and fronts. Record the high and low temperatures for cities in the table below. Then find the difference between the two temperature readings. Sky cover and pressure will be filled in later.

<table>
<thead>
<tr>
<th>City</th>
<th>High</th>
<th>Low</th>
<th>Temp difference</th>
<th>Sky cover</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle, Washington</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Los Angeles, California</td>
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</tr>
<tr>
<td>Las Vegas, Nevada</td>
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<td></td>
</tr>
<tr>
<td>Phoenix, Arizona</td>
<td></td>
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</tr>
<tr>
<td>Atlanta, Georgia</td>
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<td></td>
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</tr>
<tr>
<td>Tampa, Florida</td>
<td></td>
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<td></td>
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<tr>
<td>San Francisco, California</td>
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<td></td>
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<tr>
<td>Oklahoma City, Oklahoma</td>
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<tr>
<td>New Orleans, Louisiana</td>
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<tr>
<td>Kansas City, Kansas</td>
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<tr>
<td>Tucson, Arizona</td>
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<tr>
<td>Denver, Colorado</td>
<td></td>
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<tr>
<td>Dallas, Texas</td>
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<tr>
<td>Houston, Texas</td>
<td></td>
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<tr>
<td>Minneapolis, Minnesota</td>
<td></td>
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<tr>
<td>Memphis, Tennessee</td>
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<tr>
<td>Chicago, Illinois</td>
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<tr>
<td>Miami, Florida</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>New York, New York</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baltimore, Maryland</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
What causes the wide variety of temperature conditions across the map?

Use the table on the first page to respond to the following questions. It will also be helpful for you to study a map of the United States that includes the Pacific and Atlantic Oceans and details about major topographical features.

1. Give examples of differences in the cities’ high temperatures due to latitude. For example, Dallas, Texas is in a lower latitude than Seattle, Washington. Explain why these differences exist.

2. Give examples of differences in the cities’ high temperatures due to geographical features such as the Pacific Ocean, the Rocky Mountains, the Great Lakes, or the Atlantic Ocean. Explain why geography influences temperatures.

3. Fill in the table for the sky cover for each city. How does the sky cover affect the temperatures of cities near the same latitude? Why do you think this is?

What does atmospheric pressure tell us about the weather?

4. On your weather map, over which states are areas of high pressure centered? Over which states are low-pressure areas centered?

5. In the sixth column of the table (the heading is Pressure), record whether you think each city is in a region of high pressure, low pressure, or in-between.

6. What kind of cloud cover or weather is associated with high-pressure regions? Look at the sky cover for the cities in the high-pressure regions. What do you think the humidity is like in these regions?

7. What kind of cloud cover or weather is associated with low-pressure regions? Look at the sky cover for the cities in the low-pressure regions. What do you think the humidity is like in these regions?

8. Locate the fronts shown on the weather map. The flags on the fronts tell us the direction of the wind. The cold fronts are symbolized by triangular flags, the warm fronts by semicircular flags. Are fronts associated with high- or low-pressure regions?

9. What type of weather is associated with a warm front? What type of weather is associated with a cold front?

10. Based on what you have learned so far about low- and high-pressure regions, let’s investigate the effect they have on the wind. High-pressure regions tend to push air toward low-pressure regions. Do you think the air in a low-pressure region tends to sink or rise? Does the air in a high-pressure region sink or rise?

11. Based on those conclusions, how do you think low-pressure regions contribute to the formation of rainstorms?

12. Precipitation occurs when warm, moist air is cooled to a certain temperature called the dew point. At the dew point temperature water in the air condenses into droplets of water called “dew” and soon these droplets fall out of the sky as precipitation. Why would a low-pressure region be a good place for a volume of air to reach the dew point temperature?
11.3 Tracking a Hurricane

Hurricane Andrew (August 1992) was one of the most devastating storms of the twentieth century. Originally labelled a Category 4 storm, it was recently upgraded to a Category 5, the most severe type of hurricane. Scientists use satellite data and weather instruments dropped by aircraft to measure the storm’s intensity. As research techniques improve, weather experts can more accurately analyze data collected by these instruments. NOAA scientists have now determined that Andrew’s sustained winds reached at least 165 miles per hour. In this activity, you will track Hurricane Andrew’s treacherous journey.

The storm’s beginning

Hurricane Andrew was born as a result of a tropical wave which moved off the west coast of Africa and passed south of the Cape Verde Islands. On August 17, 1992, it became a tropical storm. That means it had sustained winds of 39-73 miles per hour.

1. At 1200 Greenwich Mean Time (GMT) on August 17, Tropical Storm Andrew was located at 12.3°N latitude and 42.0°W longitude. The wind speed was 40 miles per hour. Plot the storm’s location on your map.

2. For the next four days, Tropical Storm Andrew moved uneventfully west-northwest across the Atlantic. Plot the storm’s path as it traveled toward the Caribbean Islands.

Table 1: Tropical Storm Andrew’s path

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Wind speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/18/1992</td>
<td>1200</td>
<td>14.6</td>
<td>49.9</td>
<td>52</td>
</tr>
<tr>
<td>8/19/1992</td>
<td>1200</td>
<td>18.0</td>
<td>56.9</td>
<td>52</td>
</tr>
<tr>
<td>8/20/1992</td>
<td>1200</td>
<td>21.7</td>
<td>60.7</td>
<td>46</td>
</tr>
<tr>
<td>8/21/1992</td>
<td>1200</td>
<td>24.4</td>
<td>64.2</td>
<td>58</td>
</tr>
</tbody>
</table>
The storm intensifies

Late on August 21, a deep high pressure center developed over the southeastern United States and extended eastward to an area just north of Tropical Storm Andrew. In response to this more favorable environment, the storm strengthened rapidly and turned westward. At 1200 GMT on August 22, the storm reached hurricane status, meaning it had sustained winds of at least 74 miles per hour.

1. Plot Hurricane Andrew’s path over the next two days.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Wind speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/22/1992</td>
<td>1200</td>
<td>25.8</td>
<td>68.3</td>
<td>81</td>
</tr>
<tr>
<td>8/23/1992</td>
<td>1200</td>
<td>25.4</td>
<td>74.2</td>
<td>138</td>
</tr>
</tbody>
</table>

2. Hurricane watches are issued when hurricane conditions are possible in the area, usually within 36 hours. Hurricane warnings are issued when hurricane conditions are expected in the area within 24 hours. Look at the distance the hurricane travelled in the last 24 hours and use that information to predict where it might be in 24 hours, and in 36 hours. Name one area that you would declare under a hurricane watch, and an area that you would declare under a hurricane warning.

Landfall

On the evening of August 23, Hurricane Andrew first made landfall. Landfall is defined as when the center of the hurricane’s eye is over land.

1. Plot the point of Hurricane Andrew’s first landfall.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Wind speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/23/1992</td>
<td>2100</td>
<td>25.4</td>
<td>76.6</td>
<td>150</td>
</tr>
</tbody>
</table>

2. Where did this first landfall occur?
Hurricane Andrew crosses the Gulf Stream and strikes the U.S.

During the night of August 23, Hurricane Andrew briefly weakened as it moved over land. However, once the storm moved back over open waters, it rapidly regained strength. The warm water of the Gulf Stream increased the intensity of the hurricane’s convection cycle. At 0905 GMT on August 24, Hurricane Andrew made landfall again.

1. Plot the point of Hurricane Andrew’s next landfall.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Wind speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/24/1992</td>
<td>0905</td>
<td>25.5</td>
<td>80.3</td>
<td>144</td>
</tr>
</tbody>
</table>

2. Where did this landfall occur?

The final landfall

After making its first landfall in the United States (where it caused an estimated $25 billion in damage), Hurricane Andrew moved northwest across the Gulf of Mexico. On the morning of August 26, 1992, Hurricane Andrew made its final landfall. Afterward, Andrew weakened rapidly to tropical storm strength in about 10 hours, and then began to dissipate.

1. Plot Andrew’s course across the Gulf of Mexico and its final landfall.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Wind speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/24/1992</td>
<td>1800</td>
<td>25.8</td>
<td>83.1</td>
<td>133</td>
</tr>
<tr>
<td>8/25/1992</td>
<td>1800</td>
<td>27.8</td>
<td>89.6</td>
<td>138</td>
</tr>
<tr>
<td>8/26/1992</td>
<td>0830</td>
<td>29.6</td>
<td>91.5</td>
<td>121</td>
</tr>
</tbody>
</table>

2. In which state did Hurricane Andrew’s final landfall occur?

Hurricane information provided by National Oceanographic and Atmospheric Administration’s National Hurricane Center.
12.1 Structure of the Atom

Atoms are made of three tiny subatomic particles: protons, neutrons, and electrons. The protons and neutrons are grouped together in the nucleus, which is at the center of the atom. The chart below compares electrons, protons, and neutrons in terms of charge and mass.

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Charge</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>-1</td>
<td>$9.109 \times 10^{-28}$</td>
</tr>
<tr>
<td>Proton</td>
<td>+1</td>
<td>$1.673 \times 10^{-24}$</td>
</tr>
<tr>
<td>Neutron</td>
<td>0</td>
<td>$1.675 \times 10^{-24}$</td>
</tr>
</tbody>
</table>

The **atomic number** of an element is the number of protons in the nucleus of every atom of that element.

**Isotopes** are atoms of the same element that have different numbers of neutrons. The number of protons in isotopes of an element is the same.

The **mass number** of an isotope tells you the number of protons plus the number of neutrons.

Mass number = number of protons + number of neutrons

**EXAMPLE**

- Carbon has three isotopes: carbon-12, carbon-13, and carbon-14. The atomic number of carbon is 6.
  
  a. How many protons are in the nucleus of a carbon atom?
    
    **Solution:**
    
    6 protons
    
    The atomic number indicates how many protons are in the nucleus of an atom. All atoms of carbon have 6 protons, no matter which isotope they are.

  b. How many neutrons are in the nucleus of a carbon-12 atom?
    
    **Solution:**
    
    the mass number - the atomic number = the number of neutrons.
    
    $12 - 6 = 6$
    
    6 neutrons

  c. How many electrons are in a neutral atom of carbon-13?
    
    **Solution:**
    
    6 electrons. All neutral carbon atoms have 6 protons and 6 electrons.

  d. How many neutrons are in the nucleus of a carbon-14 atom?
    
    **Solution:**
    
    the mass number - the atomic number = the number of neutrons
    
    $14 - 6 = 8$
    
    8 neutrons
Use a periodic table of the elements to answer these questions.

1. The following graphics represent the nuclei of atoms. Using a periodic table of elements, fill in the table.

<table>
<thead>
<tr>
<th>What the nucleus looks like</th>
<th>What is this element?</th>
<th>How many electrons does the neutral atom have?</th>
<th>What is the mass number?</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Nucleus 1" /></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image2" alt="Nucleus 2" /></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Nucleus 3" /></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image4" alt="Nucleus 4" /></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. How many protons and neutrons are in the nucleus of each isotope?
   a. hydrogen-2 (atomic number = 1)
   b. scandium-45 (atomic number = 21)
   c. aluminum-27 (atomic number = 13)
   d. uranium-235 (atomic number = 92)
   e. carbon-12 (atomic number = 6)

3. Although electrons have mass, they are not considered in determining the mass number of an atom. Why?

4. A hydrogen atom has one proton, two neutrons, and no electrons. Is this atom an ion? Explain your answer.

5. An atom of sodium-23 (atomic number = 11) has a positive charge of +1. Given this information, how many electrons does it have? How many protons and neutrons does this atom have?
12.1 Atoms and Isotopes

You have learned that atoms contain three smaller particles called protons, neutrons, and electrons, and that the number of protons determines the type of atom. How can you figure out how many neutrons an atom contains, and whether it is neutral or has a charge? Once you know how many protons and neutrons are in an atom, you can also figure out its mass.

In this skill sheet, you will learn about isotopes, which are atoms that have the same number of protons but different numbers of neutrons.

What are isotopes?

In addition to its atomic number, every atom can also be described by its mass number:

\[
\text{mass number} = \text{number of protons} + \text{number of neutrons}
\]

Atoms of the same element always have the same number of protons, but can have different numbers of neutrons. These different forms of the same element are called isotopes.

Sometimes the mass number for an element is included in its symbol. When the symbol is written in this way, we call it isotope notation. The isotope notation for carbon-12 is shown to the right. How many neutrons does an atom of carbon-12 have? To find out, simply take the mass number and subtract the atomic number: 

\[12 - 6 = 6\] neutrons.

Hydrogen has three isotopes as shown below.

1. How many neutrons does protium have? What about deuterium and tritium?

2. Use the diagram of an atom to answer the questions:
   a. What is the atomic number of the element?
   b. What is the name of the element?
   c. What is the mass number of the element?
   d. Write the isotope notation for this isotope.
What is the atomic mass?

If you look at a periodic table, you will notice that the atomic number increases by one whole number at a time. This is because you add one proton at a time for each element. The atomic mass however, increases by amounts greater than one. This difference is due to the neutrons in the nucleus. The value of the atomic mass reflects the abundance of the stable isotopes for an element that exist in the universe.

Since silver has an atomic mass of 107.87, this means that most of the stable isotopes that exist have a mass number of 108. In other words, the most common silver isotope is “silver-108.” To figure out the most common isotope for an element, round the atomic mass to the nearest whole number.

1. Look up bromine on the periodic table. What is the most common isotope of bromine?
2. Look up potassium. How many neutrons does the most common isotope of potassium have?
3. Look up lithium. What is its most common isotope?
4. How many neutrons does the most common isotope of neon have?
12.1 Ernest Rutherford

Ernest Rutherford initiated a new and radical view of the atom. He explained the mysterious phenomenon of radiation as the spontaneous disintegration of atoms. He was the first to describe the atom’s internal structure and performed the first successful nuclear reaction.

**Ambitious immigrants**

Ernest Rutherford was born in rural New Zealand on August 31, 1871. His father was a Scottish immigrant, his mother English. Both valued education and instilled a strong work ethic in their 12 children. Ernest enjoyed the family farm, but was encouraged by his parents and teachers to pursue scholarships. He first received a scholarship to a secondary school, Nelson College. Then, in 1890, after twice taking the qualifying exam, he received a scholarship to Canterbury College of the University of New Zealand.

**Investigating radioactivity**

After earning three degrees in his homeland, Rutherford traveled to Cambridge, England, to pursue graduate research under the guidance of the man who discovered the electron, J. J. Thomson. Through his research with Thomson, Rutherford became interested in studying radioactivity. In 1898 he described two kinds of particles emitted from radioactive atoms, calling them alpha and beta particles. He also coined the term half-life to describe the amount of time taken for radioactivity to decrease to half its original level.

**An observer of transformations**

Rutherford accepted a professorship at McGill University in Montreal, Canada, in 1898. It was there that he proved that atoms of a radioactive element could spontaneously decay into another element by expelling a piece of the atom. This was surprising to the scientific community—the idea that atoms could change into other atoms had been scorned as alchemy.

In 1908 Rutherford received the Nobel Prize in chemistry for “his investigations into the disintegration of the elements and the chemistry of radioactive substances.” He considered himself a physicist and joked that, “of all the transformations I have seen in my lifetime, the fastest was my own transformation from physicist to chemist.”

**Exploring atomic space**

Rutherford had returned to England in 1907, to Manchester University. There, he and two students bombarded gold foil with alpha particles. Most of the particles passed through the foil, but a few bounced back. They reasoned these particles must have hit denser areas of foil.

Rutherford hypothesized that the atom must be mostly empty space, through which the alpha particles passed, with a tiny dense core he called the nucleus, which some of the particles hit and bounced off. From this experiment he developed a new “planetary model” of the atom. The inside of the atom, Rutherford suggested, contained electrons orbiting a small nucleus the way the planets of our solar system orbit the sun.

‘Playing with marbles’

In 1917, Rutherford made another discovery. He bombarded nitrogen gas with alpha particles and found that occasionally an oxygen atom was produced. He concluded that the alpha particles must have knocked a positively charged particle (which he named the proton) from the nucleus. He called this “playing with marbles” but word quickly spread that he had become the first person to split an atom. Rutherford, who was knighted in 1914 (and later elevated to the peerage, in 1931) returned to Cambridge in 1919 to head the Cavendish Laboratory where he had begun his research in radioactivity. He remained there until his death at 66 in 1937.
Reading reflection

1. What are alpha and beta particles? Use your textbook to find the definitions of these terms. Make a diagram of each particle; include labels in your diagram.

2. The term “alchemy” refers to early pseudoscientific attempts to transform common elements into more valuable elements (such as lead into gold). For one kind of atom to become another kind of atom, which particles of the atom need to be expelled or gained?

3. Make a diagram of the “planetary model” of the atom. Include the nucleus and electrons in your diagram.

4. Compare and contrast Rutherford’s “planetary model” of the atom with our current understanding of an atom’s internal structure.

5. Why did Rutherford say that bombarding atoms with particles was like “playing with marbles”? What subatomic particle did Rutherford discover during this phase of his work?

6. Choose one of Rutherford’s discoveries and explain why it intrigues you.
12.2 Electrons and Energy Levels

Danish physicist Neils Bohr (1885–1962) proposed the concept of energy levels to explain electron behavior in atoms. While we know today that his model doesn’t explain everything about how electrons behave, it is still a useful starting point for understanding what is happening inside atoms.

The number of electrons in an atom is equal to the number of protons in the nucleus. That means each element has a different number of electrons and therefore fills the energy levels to a different point. The innermost energy level is filled first, and then each additional electron occupies the lowest unfilled energy level in the atom.

An atom of the element carbon has six electrons. Show how the electrons are arranged in energy levels.

Solution

Note: remember that atoms are actually three-dimensional, and that it is impossible to show the exact location of a particular electron within the electron cloud. Therefore, as long as the entire first energy level is filled, and four of the spaces in the second level are filled, the answer is acceptable. However, because electrons repel each other, it is standard procedure to show the electrons evenly spaced within the energy level.

Answer the following questions about electrons and energy levels. Use section 12.2 of your text if needed.

1. Who proposed the concept of energy levels inside atoms?
2. Explain how energy levels are like a set of stairs. Where can electrons exist?
3. In a stable atom, how are the energy levels filled?
4. Show how the electrons of the following atoms are arranged in energy levels.
12.2 Niels Bohr

Danish physicist Niels Bohr first proposed the idea that electrons exist in specific orbits around the atom’s nucleus. He showed that when an electron falls from a higher orbital to a lower one, it releases energy in the form of visible light.

At home among ideas

Niels Bohr was born October 7, 1885, in Copenhagen, Denmark. His father was a physiology professor at the University of Copenhagen, his mother the daughter of a prominent Jewish politician and businessman. His parents often invited professors to the house for dinners and discussions.

Bohr entered the University of Copenhagen in 1903 to study physics. Because the university had no physics laboratory, Bohr conducted experiments in his father’s physiology lab. He graduated with a doctorate in 1911.

Meeting of great minds

In 1912, Bohr went to Manchester, England, to study under Ernest Rutherford, who became a lifelong friend. Rutherford had recently published his new planetary model of the atom, which explained that an atom contains a tiny dense core surrounded by orbiting electrons.

Bohr began researching the orbiting electrons, hoping to describe their behavior in greater detail.

Electrons and the atom’s chemistry

Bohr studied the quantum ideas of Max Planck and Albert Einstein as he attempted to describe the electrons’ orbits. In 1913 he published his results. He proposed that electrons traveled only in specific orbits. The orbits were like rungs on a ladder—electrons could move up and down orbits, but did not exist in between the orbital paths.

He explained that outer orbits could hold more electrons than inner orbits, and that many chemical properties of the atom were determined by the number of electrons in the outer orbit.

Bohr also described how atoms emit light. He explained that an electron needs to absorb energy to jump from an inner orbit to an outer one. When the electron falls back to the inner orbit, it releases that energy in the form of visible light.

An institute, then a Nobel Prize

In 1916, Bohr accepted a position as professor of physics at the University of Copenhagen. The University created the Institute of Theoretical Physics that Bohr directed for the rest of his life. In 1922, he was awarded the Nobel Prize in physics for his work in atomic structure and radiation.

In 1940, World War II spread across Europe and Germany occupied Denmark. Though he had been baptized a Christian, Bohr’s family history and his own anti-Nazi sentiments made life difficult.

In 1943, he escaped in a fishing boat to Sweden, where he convinced the king to offer sanctuary to all Jewish refugees from Denmark. The British offered him a position in England to work with researchers on the atomic bomb. A few months later, the team went to Los Alamos, New Mexico, to continue their work.

A warrior for peace

Although Bohr believed the creation of the atomic bomb was necessary in the face of the Nazi threat, he was deeply concerned about its future implications.

Bohr promoted disarmament efforts through the United Nations and won the first U.S. Atoms for Peace Award in 1957, the same year his son Aage shared the Nobel Prize in physics. He died in 1962 in Copenhagen.
Reading reflection

1. How did Niels Bohr’s model of the atom compare with Ernest Rutherford’s?
2. Name two specific contributions Bohr made to our understanding of atomic structure.
3. Make a drawing of Bohr’s model of the atom.
4. In your own words describe how atoms emit light.
5. Why do you think Bohr was concerned with the future implications of his work on atomic bombs?
12.3 The Periodic Table

Many science laboratories have a copy of the periodic table of the elements on display. This important chart holds an amazing amount of information. In this skill sheet, you will use a periodic table to identify information about specific elements, make calculations, and make predictions.

Periodic table primer

To work through this skill sheet, you will use the periodic table of the elements. The periodic table shows five basic pieces of information. Four are labeled on the graphic at right; the fifth piece of information is the location of the element in the table itself. The location shows the element group, chemical behavior, approximate atomic mass and size, and other characteristic properties.

Review: Atomic number, Symbol, and Atomic Mass

Use the periodic table to find the answers to the following questions. As you become more familiar with the layout of the periodic table, you’ll be able to find this information quickly.

Atomic Number: Write the name of the element that corresponds to each of the following atomic numbers.

1. 9  
2. 18  
3. 25  
4. 15  
5. 43

6. What does the atomic number tell you about an element?

Symbol and atomic mass: For each of the following, write the element name that corresponds to the symbol. In addition, write the atomic mass for each element.

7. Fe  
8. Cs  
9. Si  
10. Na  
11. Bi

12. What does the atomic mass tell you about an element?

13. Why isn’t the atomic mass always a whole number?

14. Why don’t we include the mass of an atom’s electrons in the atomic mass?
Periodic Table Groups

The periodic table’s vertical columns are called groups. Groups of elements have similar properties. Use the periodic table and the information found in Chapter 15 of your text to answer the following questions:

15. The first group of the periodic table is known by what name?

16. Name two characteristics of the elements in the first group.

17. Name three members of the halogen group.

18. Describe two characteristics of halogens.

19. Where are the noble gases found on the periodic table?

20. Why are the noble gases sometimes called the inert gases?

Periodic Table Rows

The rows of the periodic table correspond to the energy levels in the atom. The first energy level can accept up to two electrons. The second and third energy levels can accept up to eight electrons each. The example to the right shows how the electrons of an oxygen atom fill the energy level.

Show how the electrons are arranged in energy levels in the following atoms:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="He electrons" /></td>
<td><img src="image" alt="N electrons" /></td>
<td><img src="image" alt="Ne electrons" /></td>
<td><img src="image" alt="Al electrons" /></td>
<td><img src="image" alt="Ar electrons" /></td>
</tr>
</tbody>
</table>

Identify each of the following elements:

<table>
<thead>
<tr>
<th>26.</th>
<th>27.</th>
<th>28.</th>
<th>29.</th>
<th>30.</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="He" /></td>
<td><img src="image" alt="N" /></td>
<td><img src="image" alt="Ne" /></td>
<td><img src="image" alt="Al" /></td>
<td><img src="image" alt="Ar" /></td>
</tr>
</tbody>
</table>
13.1 Dot Diagrams

You have learned that atoms are composed of protons, neutrons, and electrons. The electrons occupy energy levels that surround the nucleus in the form of an “electron cloud.” The electrons that are involved in forming chemical bonds are called **valence electrons**. Atoms can have up to eight valence electrons. These electrons exist in the outermost region of the electron cloud, often called the “valence shell.”

The most stable atoms have eight valence electrons. When an atom has eight valence electrons, it is said to have a complete **octet**. Atoms will gain or lose electrons in order to complete their octet. In the process of gaining or losing electrons, atoms will form chemical bonds with other atoms. One method we use to show an atom’s valence state is called a **dot diagram**, and you will be able to practice drawing these in the following exercise.

**What is a dot diagram?**

Dot diagrams are composed of two parts—the chemical symbol for the element and the dots surrounding the chemical symbol. Each dot represents one valence electron.

- If an element, such as oxygen (O), has six valence electrons, then six dots will surround the chemical symbol as shown to the right.

- Boron (B) has three valence electrons, so three dots surround the chemical symbol for boron as shown to the right.

There can be up to eight dots around a symbol, depending on the number of valence electrons the atom has. The first four dots are single, and then as more dots are added, they fill in as pairs.

**Practice**

Using a periodic table, complete the following chart. With this information, draw a dot diagram for each element in the chart. Remember, only the valence electrons are represented in the diagram, not the total number of electrons.

<table>
<thead>
<tr>
<th>Element</th>
<th>Chemical symbol</th>
<th>Total number of electrons</th>
<th>Number of valence electrons</th>
<th>Dot diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium</td>
<td>K</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td>Be</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Using dot diagrams to represent chemical reactivity

Once you have a dot diagram for an element, you can predict how an atom will achieve a full valence shell. For instance, it is easy to see that chlorine has one empty space in its valence shell. It is likely that chlorine will try to gain one electron to fill this empty space rather than lose the remaining seven. However, potassium has a single dot or electron in its dot diagram. This diagram shows how much easier it is to lose this lone electron than to find seven to fill the seven empty spaces. When the potassium loses its electron, it becomes positively charged. When chlorine gains the electron, it becomes negatively charged. Opposite charges attract, and this attraction draws the atoms together to form what is termed an ionic bond, a bond between two charged atoms or ions.

Because chlorine needs one electron, and potassium needs to lose one electron, these two elements can achieve a complete set of eight valence electrons by forming a chemical bond. We can use dot diagrams to represent the chemical bond between chlorine and potassium as shown above.

For magnesium and chlorine, however, the situation is a bit different. By examining the electron or Lewis dot diagrams for these atoms, we see why magnesium requires two atoms of chlorine to produce the compound, magnesium chloride, when these two elements chemically combine.

Magnesium can easily donate one of its valence electrons to the chlorine to fill chlorine’s valence shell, but this still leaves magnesium unstable; it still has one lone electron in its valence shell. However, if it donates that electron to another chlorine atom, the second chlorine atom has a full shell, and now so does the magnesium.

The chemical formula for potassium chloride is KCl. This means that one unit of the compound is made of one potassium atom and one chlorine atom.

The formula for magnesium chloride is MgCl₂. This means that one unit of the compound is made of one magnesium atom and two chlorine atoms.

Now try using dot diagrams to predict chemical formulas. Fill in the table below:

<table>
<thead>
<tr>
<th>Elements</th>
<th>Dot diagram for each element</th>
<th>Dot diagram for compound formed</th>
<th>Chemical formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na and F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Br and Br</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg and O</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
13.2 Finding the Least Common Multiple

Knowing how to find the least common multiple of two or more numbers is helpful in physical science classes. You need to find the least common multiple in order to add fractions with different denominators, or to predict the chemical formula of many common compounds.

**Example**

The least common multiple is the smallest multiple of two or more whole numbers. To find the least common multiple of 3 and 4, simply list the multiples of each number:

- multiples of 3: 3, 6, 9, 12, 15...
- multiples of 4: 4, 8, 12, 16, 20...

Then, look for the smallest multiple that occurs in both lists. In this case, the least common multiple is 12.

**Example**

Sometimes it’s a little trickier to find the least common multiple. Suppose you are asked to find the least common multiple of 15 and 36. Rather than making a long list of multiples, you can use the prime factorization method.

First, factor each number into primes (remember that prime numbers are numbers that can’t be divided evenly by any whole number except one).

- Prime factorization of 15: $3 \times 5$
- Prime factorization of 36: $3 \times 3 \times 2 \times 2$

Next, create a Venn diagram. Show the factors unique to each number in the separate parts of the circles and the factors common to both in the overlapping circles. Since 15 and 36 each have one 3, put one 3 in the middle.

Finally, multiply all the factors in your diagram from left to right:

$$5 \times 3 \times 3 \times 2 \times 2 = 180.$$ The least common multiple of 15 and 36 is 180.
Important note: If the two numbers each have more than one copy of a certain prime factor, place the factor in the overlapping circles as many times as necessary. To find the least common multiple of 60 and 72:

Prime factorization of 60: \(2 \times 2 \times 3 \times 5\)
Prime factorization of 72: \(2 \times 2 \times 3 \times 2 \times 3\)

Notice that 2 appears twice in the overlapping circles because 60 and 72 have two 2’s apiece.

\[5 \times 3 \times 2 \times 2 \times 2 \times 3 = 360.\] The least common multiple of 60 and 72 is 360.

Find the least common multiple of each of the following pairs of numbers:

1. 3 and 7
2. 6 and 8
3. 9 and 15
4. 10 and 25
5. 16 and 40
6. 21 and 49
7. 36 and 54
8. 45 and 63
9. 55 and 80
10. 64 and 96
Compounds have unique names that we use to identify them when we study chemical properties and changes. Chemists have devised a shorthand way of representing chemical names that provides important information about the substance. This shorthand representation for a compound’s name is called a chemical formula. You will practice writing chemical formulas in the following activity.

**What is a chemical formula?**

Chemical formulas have two important parts: chemical symbols for the elements in the compound and subscripts that tell how many atoms of each element are needed to form the compound. The chemical formula for water, H₂O, tells us that a water molecule is made of the elements hydrogen (H) and oxygen (O) and that it takes two atoms of hydrogen and one atom of oxygen to build the molecule. For sodium nitrate, NaNO₃, the chemical formula tells us there are three elements in the compound: sodium (Na), nitrogen (N), and oxygen (O). To make a molecule of this compound, you need one atom of sodium, one atom of nitrogen, and three atoms of oxygen.

**How to write chemical formulas**

How do chemists know how many atoms of each element are needed to build a molecule? For ionic compounds, oxidation numbers are the key. An element’s oxidation number is the number of electrons it will gain or lose in a chemical reaction. We can use the periodic table to find the oxidation number for an element. When we add up the oxidation numbers of the elements in an ionic compound, the sum must be zero. Therefore, we need to find a balance of negative and positive ions in the compound for the molecule to form.

**Example 1:**

A compound is formed by the reaction between magnesium and chlorine. What is the chemical formula for this compound?

From the periodic table, we find that the oxidation number of magnesium is 2+. Magnesium loses 2 electrons in chemical reactions. The oxidation number for chlorine is 1−. Chlorine tends to gain one electron in a chemical reaction.

Remember that the sum of the oxidation numbers of the elements in a molecule will equal zero. This compound requires one atom of magnesium with an oxidation number of 2+ to combine with two atoms of chlorine, each with an oxidation number of 1−, for the sum of the oxidation numbers to be zero.

\[(2+) + 2(1−) = 0\]

To write the chemical formula for this compound, first write the chemical symbol for the positive ion (Mg) and then the chemical symbol for the negative ion (Cl). Next, use subscripts to show how many atoms of each element are required to form the molecule. When one atom of an element is required, no subscript is used. Therefore, the correct chemical formula for magnesium chloride is MgCl₂.
Example 2:

Aluminum and bromine combine to form a compound. What is the chemical formula for the compound they form?

From the periodic table, we find that the oxidation number for aluminum (Al) is 3+. The oxidation number for bromine (Br) is 1−. In order for the oxidation numbers of this compound to add up to zero, one atom of aluminum must combine with three atoms of bromine:

\[(3+) + 3(1−) = 0\]

The correct chemical formula for this compound, aluminum bromide, is AlBr₃.

**Practice writing chemical formulas for ionic compounds**

Use the periodic table to find the oxidation numbers of each element. Then write the correct chemical formula for the compound formed by the following elements:

<table>
<thead>
<tr>
<th>Element</th>
<th>Oxidation Number</th>
<th>Element</th>
<th>Oxidation Number</th>
<th>Chemical Formula for Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium (K)</td>
<td></td>
<td>Chlorine (Cl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td></td>
<td>Chlorine (Cl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td></td>
<td>Oxygen (O)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron (B)</td>
<td></td>
<td>Phosphorus (P)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lithium (Li)</td>
<td></td>
<td>Sulfur (S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td></td>
<td>Oxygen (O)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beryllium (Be)</td>
<td></td>
<td>Iodine (I)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td></td>
<td>Nitrogen (N)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td></td>
<td>Bromine (Br)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
13.2 Naming Compounds

Compounds have unique names that identify them for us when we study chemical properties and changes. Predicting the name of a compound is fairly easy provided certain rules are kept in mind. In this skill sheet, you will practice naming a variety of chemical compounds.

Chemical Formulas and Compound Names

Chemical formulas tell a great deal of information about a compound—the types of elements forming the compound, the numbers of atoms of each element in one molecule, and even some indication, perhaps, of the arrangement of the atoms when they form the molecule.

In addition to having a unique chemical formula, each compound has a unique name. These names provide scientists with valuable information. Just like chemical formulas, chemical names tell which elements form the compound. However, the names may also identify a “family” or group to which the compound belongs. It is useful for scientists, therefore, to recognize and understand both a compound’s formula and its name.

Naming Ionic Compounds

Naming ionic compounds is relatively simple, especially if the compound is formed only from monoatomic ions. Follow these steps:

1. Write the name of the first element or the positive ion of the compound.
2. Write the root of the second element or negative ion of the compound.
3. For example, write fluor- to represent fluorine, chlor- to represent chlorine.
4. Replace the ending of the negative ion's name with the suffix -ide.
5. Fluorine → Fluoride; Chlorine → Chloride

A compound containing potassium (K\(^{1+}\)) and iodine (I\(^{1-}\)) would be named potassium iodide.

Lithium (Li\(^{1+}\)) combined with sulfur (S\(^{2-}\)) would be named lithium sulfide.

Naming Compounds with Polyatomic Ions

Naming compounds that contain polyatomic ions is even easier. Just follow these two steps:

1. Write the name of the positive ion first. Use the periodic table or an ion chart to find the name.
2. Write the name of the negative ion second. Again, use the periodic table or an ion chart to find the name.

A compound containing aluminum (Al\(^{1+}\)) and sulfate (SO\(_4^{2-}\)) would be called aluminum sulfate.

A compound containing magnesium (Mg\(^{2+}\)) and carbonate (CO\(_3^{2-}\)) would be called magnesium carbonate.
Predict the name of the compound formed from the reaction between the following elements and/or polyatomic ions. Use the periodic table and the polyatomic ion chart in section 13.2 of your student text to help you name the ions.

<table>
<thead>
<tr>
<th>Combination</th>
<th>Compound Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al + Br</td>
<td></td>
</tr>
<tr>
<td>Be + O</td>
<td></td>
</tr>
<tr>
<td>K + N</td>
<td></td>
</tr>
<tr>
<td>Ba + CrO$_4^{2-}$</td>
<td></td>
</tr>
<tr>
<td>Cs + F</td>
<td></td>
</tr>
<tr>
<td>NH$_3^{1+}$ + S</td>
<td></td>
</tr>
<tr>
<td>Mg + Cl</td>
<td></td>
</tr>
<tr>
<td>B + I</td>
<td></td>
</tr>
<tr>
<td>Na + SO$_4^{2-}$</td>
<td></td>
</tr>
<tr>
<td>Si + C$_2$H$_3$O$_2^{1-}$</td>
<td></td>
</tr>
</tbody>
</table>
13.2 Families of Compounds

Certain compounds have common characteristics, so we place them into groups or families. The group called “enzymes” contains thousands of representative chemicals, but all share certain critical features that allow them to be placed into this group.

The name of a compound often identifies the family of chemical to which it belongs. The clue is usually found in the suffix for the compound's name. The table below lists suffixes for some common chemical families.

<table>
<thead>
<tr>
<th>Chemical Family</th>
<th>Suffix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugars</td>
<td>-ose</td>
</tr>
<tr>
<td>Alcohols</td>
<td>-ol</td>
</tr>
<tr>
<td>Enzymes</td>
<td>-ase</td>
</tr>
<tr>
<td>Ketones</td>
<td>-one</td>
</tr>
<tr>
<td>Organic acids</td>
<td>-oic or -ic acid</td>
</tr>
<tr>
<td>Alkanes</td>
<td>-ane</td>
</tr>
</tbody>
</table>

Glucose, the compound used by your brain as its primary fuel, is a sugar. The suffix -ose indicates its membership in the sugar family. Propane, the compound used to operate your gas barbecue grill, is an alkane, a compound formed from carbon and hydrogen atoms that are covalently bonded with single pairs of electrons. We know this from the suffix -ane.

Knowing such information about a compound can be very useful when you are reading the labels of consumer products. Compound names can be found in the ingredients list on the label. If you are purchasing a hand lotion to alleviate dry skin, you should avoid one that lists a compound with an -ol suffix early in the ingredients list.

The ingredients are listed from largest amount to smallest amount. The earlier a compound is listed, the greater the amount of that compound in the product. A compound with an -ol suffix is an alcohol. Hand lotions with high percentages of alcohols are less effective since alcohols tend to dry out rather than moisturize the skin!

In later chemistry courses, you will learn more about the names and characteristics of “families” of compounds. This knowledge will provide you with a powerful tool for making informed consumer decisions.
Using the information in the table on the previous page to predict the chemical family to which the following compounds are members:

<table>
<thead>
<tr>
<th>Compound Name</th>
<th>Chemical Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipase</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td></td>
</tr>
<tr>
<td>Formic Acid</td>
<td></td>
</tr>
<tr>
<td>Butane</td>
<td></td>
</tr>
<tr>
<td>Sucrose</td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td></td>
</tr>
<tr>
<td>Acetic Acid</td>
<td></td>
</tr>
</tbody>
</table>
14.1 Chemical Equations

Chemical symbols provide us with a shorthand method of writing the name of an element. Chemical formulas do the same for compounds. But what about chemical reactions? To write out, in words, the process of a chemical change would be long and tedious. Is there a shorthand method of writing a chemical reaction so that all the information is presented correctly and is understood by all scientists? Yes! This is the function of chemical equations. You will practice writing and balancing chemical equations in this skill sheet.

What are chemical equations?

Chemical equations show what is happening in a chemical reaction. They provide you with the identities of the reactants (substances entering the reaction) and the products (substances formed by the reaction). They also tell you how much of each substance is involved in the reaction. Chemical equations use symbols for elements and formulas for compounds. The reactants are written to the left of the arrow. Products go on the right side of the arrow.

\[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} \]

The arrow should be read as “yields” or “produces.” This equation, therefore, says that hydrogen gas (\(\text{H}_2\)) plus oxygen gas (\(\text{O}_2\)) yields or produces the compound water (\(\text{H}_2\text{O}\)).

### Practice

Write chemical equations for the following reactions:

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
<th>Unbalanced Chemical Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric acid (\text{HCl}) and Sodium hydroxide (\text{NaOH})</td>
<td>Water (\text{H}_2\text{O}) and Sodium chloride (\text{NaCl})</td>
<td>(\text{HCl} + \text{NaOH} \rightarrow \text{H}_2\text{O} + \text{NaCl})</td>
</tr>
<tr>
<td>Calcium carbonate (\text{CaCO}_3) and Potassium iodide (\text{KI})</td>
<td>Potassium carbonate (\text{K}_2\text{CO}_3) and Calcium iodide (\text{CaI}_2)</td>
<td>(\text{CaCO}_3 + \text{KI} \rightarrow \text{K}_2\text{CO}_3 + \text{CaI}_2)</td>
</tr>
<tr>
<td>Aluminum fluoride (\text{AlF}_3) and Magnesium nitrate (\text{Mg(NO}_3)_2)</td>
<td>Aluminum nitrate (\text{Al(NO}_3)_3) and Magnesium fluoride (\text{MgF}_2)</td>
<td>(\text{AlF}_3 + \text{Mg(NO}_3)_2 \rightarrow \text{Al(NO}_3)_3 + \text{MgF}_2)</td>
</tr>
</tbody>
</table>
Conservation of atoms

Take another look at the chemical equation for making water:

\[ 2H_2 + O_2 \rightarrow 2H_2O \]

Did you notice that something has been added?

The large number in front of \( H_2 \) tells how many molecules of \( H_2 \) are required for the reaction to proceed. The large number in front of \( H_2O \) tells how many molecules of water are formed by the reaction. These numbers are called \textit{coefficients}. Using coefficients, we can balance chemical equations so that the equation demonstrates conservation of atoms. The law of conservation of atoms says that no atoms are lost or gained in a chemical reaction. The same types and numbers of atoms must be found in the reactants and the products of a chemical reaction.

Coefficients are placed before the chemical symbol for single elements and before the chemical formula of compounds to show how many atoms or molecules of each substance are participating in the chemical reaction. When counting atoms to balance an equation, remember that the coefficient applies to all atoms within the chemical formula for a compound. For example, \( 5CH_4 \) means that 5 atoms of carbon and 20 atoms \((5 \times 4)\) of hydrogen are contributed to the chemical reaction by the compound methane.

\textbf{Balancing chemical equations}

To write a chemical equation correctly, first write the equation using the correct chemical symbols or formulas for the reactants and products.

The displacement reaction between sodium chloride and iodine to form sodium iodide and chlorine gas is written as:

\[ NaCl + I_2 \rightarrow NaI + Cl_2 \]

Next, count the number of atoms of each element present on the reactant and product side of the chemical equation:

<table>
<thead>
<tr>
<th>Reactant Side of Equation</th>
<th>Element</th>
<th>Product Side of Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Na</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Cl</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>1</td>
</tr>
</tbody>
</table>

For the chemical equation to be balanced, the numbers of atoms of each element must be the same on either side of the reaction. This is clearly not the case with the equation above. We need coefficients to balance the equation.
First, choose one element to balance. Let’s start by balancing chlorine. Since there are two atoms of chlorine on the product side and only one on the reactant side, we need to place a “2” in front of the substance containing the chlorine, the NaCl.

\[2\text{NaCl} + I_2 \rightarrow \text{NaI} + \text{Cl}_2\]

This now gives us two atoms of chlorine on both the reactant and product sides of the equation. However, it also give us two atoms of sodium on the reactant side! This is fine—often balancing one element will temporarily unbalance another. By the end of the process, however, all elements will be balanced.

We now have the choice of balancing either the iodine or the sodium. Let's balance the iodine. (It doesn’t matter which element we choose.)

There are two atoms of iodine on the reactant side of the equation and only one on the product side. Placing a coefficient of “2” in front of the substance containing iodine on the product side:

\[2\text{NaCl} + I_2 \rightarrow 2\text{NaI} + \text{Cl}_2\]

There are now two atoms of iodine on either side of the equation, and at the same time we balanced the number of sodium atoms!

In this chemical reaction, two molecules of sodium chloride react with one molecule of iodine to produce two molecules of sodium iodide and one molecule of chlorine. Our equation is balanced.

Balance the following equations using the appropriate coefficients. Remember that balancing one element may temporarily unbalance another. You will have to correct the imbalance in the final equation. Check your work by counting the total number of atoms of each element—the numbers should be equal on the reactant and product sides of the equation. Remember, the equations cannot be balanced by changing subscript numbers!

1. \[\text{Al} + \text{O}_2 \rightarrow \text{Al}_2\text{O}_3\]
2. \[\text{CO} + \text{H}_2 \rightarrow \text{H}_2\text{O} + \text{CH}_4\]
3. \[\text{HgO} \rightarrow \text{Hg} + \text{O}_2\]
4. \[\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2\]
5. \[\text{C} + \text{Fe}_2\text{O}_3 \rightarrow \text{Fe} + \text{CO}_2\]
6. \[\text{N}_2 + \text{H}_2 \rightarrow \text{NH}_3\]
7. \[\text{K} + \text{H}_2\text{O} \rightarrow \text{KOH} + \text{H}_2\]
8. \[\text{P} + \text{O}_2 \rightarrow \text{P}_2\text{O}_5\]
9. \[\text{Ba(OH)}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{H}_2\text{O} + \text{BaSO}_4\]
10. \[\text{CaF}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{CaSO}_4 + \text{HF}\]
11. \[\text{KClO}_3 \rightarrow \text{KClO}_4 + \text{KCl}\]
14.1 The Avogadro Number

Atoms are so small that you could fit millions of them on the head of a pin. As you have learned, the masses of atoms and molecules are measured in atomic mass units. Working with atomic mass units in the laboratory is very difficult because each atomic mass unit has a mass of \(\frac{1}{12}\) the mass of one carbon atom.

In order to make atomic mass units more useful, it would be convenient to relate the value of one atomic mass unit to one gram. One gram is an amount of matter we can actually see. For example, the mass of one paper clip is about 2.5 grams. The Avogadro number, \(6.02 \times 10^{23}\), allows us to convert atomic mass units to grams.

What is a mole?

In chemistry, the term “mole” does not refer to a furry animal that lives underground. In chemistry, a mole is quantity of something and is used just like we use the term “dozen.” One dozen is equal to 12. One mole is equal to \(6.02 \times 10^{23}\), or the Avogadro number. If you have a dozen oranges, you have 12. If you have a mole of oranges, you have \(6.02 \times 10^{23}\). This would be enough oranges to cover the entire surface of Earth seven feet deep in oranges!

Could you work with only a dozen atoms in the laboratory? You cannot see 12 atoms without the aid of a very powerful microscope. A mole of atoms would be much easier to work with in the laboratory because the mass of one mole of atoms can be measured in grams. Moles allow us to convert atomic mass units to grams. This relationship is illustrated below:

\[
1 \text{ carbon atom} = 12.0 \text{ amu} \\
1 \text{ mole of carbon atoms} = 6.02 \times 10^{23} \text{ atoms} = 12.0 \text{ grams}
\]

To calculate the mass of one mole of any substance (the molar mass), you use the periodic table to find the atomic mass (not the mass number) for the element or for the elements that create the compound. You then express this value in grams.

### Example

<table>
<thead>
<tr>
<th>Substance</th>
<th>Elements in Substance</th>
<th>Atomic mass of element (amu)</th>
<th>No. of atoms of each element</th>
<th>Formula mass (amu)</th>
<th>Molar mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>Na</td>
<td>22.99</td>
<td>1</td>
<td>22.99</td>
<td>22.99</td>
</tr>
<tr>
<td>U</td>
<td>U</td>
<td>238.03</td>
<td>1</td>
<td>238.03</td>
<td>238.03</td>
</tr>
<tr>
<td>H₂O</td>
<td>H, O</td>
<td>1.01, 16.00</td>
<td>2, 1</td>
<td>18.02</td>
<td>18.02</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>Ca, C, O</td>
<td>40.08, 12.01, 16.00</td>
<td>1, 1, 3</td>
<td>100.09</td>
<td>100.09</td>
</tr>
<tr>
<td>Al(NO₃)₃</td>
<td>Al, N, O</td>
<td>26.98, 14.01, 16.00</td>
<td>1, 3, 9</td>
<td>213.01</td>
<td>213.01</td>
</tr>
</tbody>
</table>
For the following elements and compounds, complete the following table to calculate the mass of one mole of the substance:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Elements in substance</th>
<th>Atomic mass of element (amu)</th>
<th>No. of atoms of each element</th>
<th>Formula mass (amu)</th>
<th>Molar mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ne</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₆H₁₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The molar mass of a substance can be used to calculate the number of particles (atoms or molecules) present in any given mass of a substance. You can determine the number of particles present by using the Avogadro number.

Using the Avogadro number

The Avogadro number states that for one mole of any substance, whether element or compound, there are $6.02 \times 10^{23}$ particles present in the sample. Those particles are atoms if the substance is an element and molecules if the substance is a compound. If we look again at our previous examples we see that every substance has a different molar mass:
However, one mole of each of these substances contains exactly the same number of fundamental particles, $6.02 \times 10^{23}$. The difference is that each of these fundamental particles, atoms, and molecules, has a different mass based on its composition (number of protons and neutrons, numbers and types of atoms). Therefore, the number of particles in one mole of any substance is identical; however, the mass of one mole of substances varies based on the formula mass for that substance.

When a substance’s mass is reported in grams and you need to find the number of particles present in the sample, you must first convert the mass in grams to the mass in moles. By using proportions and ratios, you can easily calculate the molar mass of any given amount of substance.

**Example**

How many molecules are in a sample of NaCl that has a mass of 38.9 grams?

**First, determine the molar mass of NaCl:**

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic mass (amu)</th>
<th>No. of atoms</th>
<th>Molar mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (Na)</td>
<td>22.99</td>
<td>1</td>
<td>22.99</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>35.45</td>
<td>1</td>
<td>35.45</td>
</tr>
</tbody>
</table>

**Molar mass of NaCl**

Next, determine how many particles are in 38.9 g of NaCl:

We know that 58.44 g of NaCl contains $6.02 \times 10^{23}$ molecules of NaCl. Therefore, we can set up a proportion to determine the number of molecules in 38.9 g of NaCl:

$$\frac{58.44 \text{ g NaCl}}{6.02 \times 10^{23}} = \frac{38.9 \text{ g NaCl}}{x}$$

Solving for $x$ using cross-multiplication gives us a value of $4.0 \times 10^{23}$ molecules of NaCl.
Complete the following table by determining the molar mass of each listed substance and either providing the number of particles in the given mass of sample or the mass of the sample that contains the given number of particles.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molar Mass (g)</th>
<th>Mass of Sample (g)</th>
<th>Number of Particles Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgCO₃</td>
<td></td>
<td>12.75</td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td></td>
<td></td>
<td>296 × 10⁵⁰</td>
</tr>
<tr>
<td>N₂</td>
<td></td>
<td></td>
<td>7.1 × 10⁸</td>
</tr>
<tr>
<td>Yb</td>
<td></td>
<td>0.00038</td>
<td></td>
</tr>
<tr>
<td>Al₂(SO₃)₃</td>
<td></td>
<td>4657</td>
<td></td>
</tr>
<tr>
<td>K₂CrO₄</td>
<td></td>
<td></td>
<td>0.23 × 10¹⁹</td>
</tr>
</tbody>
</table>
14.1 Formula Mass

A chemical formula gives you useful information about a compound. First, it tells you which types of atoms and how many of each are present. Second, it lets you know which types of ions are present in a compound. Finally, it allows you to determine the mass of one molecule of a compound, relative to the mass of other compounds. We call this the formula mass. This skill sheet will show you how to calculate the formula mass of a compound.

Calculating formula mass: a step-by-step approach

A common ingredient in toothpaste is a compound called sodium phosphate. If you examine a tube of toothpaste, you will find that it is usually listed as trisodium phosphate.

• What is the formula mass of sodium phosphate?

Step 1: Determine the formulas and oxidation numbers of the ions in the compound.

Sodium phosphate is made up of the sodium ion and the phosphate ion. The oxidation number for the sodium ion can be determined from the periodic table. Since sodium, Na, is located in group 1 of the periodic table, it has an oxidation number of 1+ like all of the elements in group 1.

The chemical formula and oxidation number for sodium is: Na⁺

To find the formula and oxidation number for the phosphate ion, use the ion chart in Chapter 16 of your textbook.

The chemical formula and oxidation number for the phosphate ion is: PO₄³⁻

Step 2: Write the chemical formula of the compound.

Remember that compounds must be neutral that is, the oxidation numbers of the elements and ions must be equal to zero. Since sodium = Na⁺ and phosphate = PO₄³⁻ how many of each do you need to make a neutral compound? You need three sodium ions for each phosphate ion to make a neutral compound.

The chemical formula of sodium phosphate is: Na₃PO₄.

Step 3: List the type of atom, quantity, atomic mass, and total mass of each atom.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Quantity</th>
<th>Atomic mass (from the periodic table)</th>
<th>Total mass (number × atomic mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>3</td>
<td>22.99 amu</td>
<td>3 × 22.99 = 68.97 amu</td>
</tr>
<tr>
<td>P</td>
<td>1</td>
<td>30.97 amu</td>
<td>1 × 30.97 = 30.97 amu</td>
</tr>
<tr>
<td>O</td>
<td>4</td>
<td>16.00 amu</td>
<td>4 × 16.00 = 64.00 amu</td>
</tr>
</tbody>
</table>

Step 4: Add up the values and calculate the formula mass of the compound.

68.97 amu + 30.97 amu + 64.00 amu = 163.94 amu

The formula mass of sodium phosphate is 163.94 amu
Now try one on your own:

Eggshells are made mostly of a brittle compound called calcium phosphate. What is the formula mass of this compound?

1. Write the chemical formula and oxidation number of each ion in the compound:

   First ion:  
   Second ion: 

2. Write the chemical formula of the compound:

3. List the type of atom, quantity, atomic mass, and total mass of each atom.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Quantity</th>
<th>Atomic mass (from the periodic table)</th>
<th>Total mass (number × atomic mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

4. Add up the values to calculate the formula mass of the compound.

   

   

Write the chemical formula and the formula mass for each of the compounds below. Use separate paper and show all of your work.

1. barium chloride
2. sodium hydrogen carbonate
3. magnesium hydroxide
4. ammonium nitrate
5. strontium phosphate
14.2 Classifying Reactions

Chemical reactions may be classified into different groups according to the reactants and products. The five major groups of chemical reactions are summarized below.

**Synthesis reactions** - when two or more substances combine to form a new compound.
- **General equation**: \( A + B \rightarrow AB \)
- **Example**: When rust forms, iron reacts with oxygen to form iron oxide (rust).
  \[ 4Fe (s) + 3O_2 (g) \rightarrow 2 Fe_2O_3 (s) \]

**Decomposition reactions** - when a single compound is broken down to produce two or more smaller compounds.
- **General equation**: \( AB \rightarrow A + B \)
- **Example**: Water can be broken down into hydrogen and oxygen gases.
  \[ 2H_2O (l) \rightarrow 2H_2 (g) + O_2 (g) \]

**Single displacement reactions** - when one element replaces a similar element in a compound.
- **General equation**: \( A + BX \rightarrow AX + B \)
- **Example**: When iron is added to a solution of copper chloride, iron replaces copper in the solution and copper falls out of the solution.
  \[ Fe (s) + CuCl_2 (aq) \rightarrow Cu (s) + FeCl_2 (aq) \]

**Double displacement reactions** - when ions from two compounds in solution exchange places to produce two new compounds.
- **General equation**: \( AX + BY \rightarrow AY + BX \)
- **Example**: When carbon dioxide gas is bubbled into lime water, a precipitate of calcium carbonate is formed along with water.
  \[ CO_2 (g) + CaO_2H_2 (aq) \rightarrow CaCO_3 (s) + H_2O (l) \]

**Combustion reactions** - when a carbon compound reacts with oxygen gas to produce carbon dioxide and water vapor. Energy is released from the reaction.
- **General equation**: Carbon Compound + \( O_2 \rightarrow CO_2 + H_2O + \text{energy} \)
- **Example**: The combustion of methane gas.
  \[ CH_4 (g) + 2O_2 \rightarrow CO_2 (g) + 2H_2O (g) \]

Classify the following reaction as synthesis, decomposition, single displacement, double displacement, or combustion. Explain your answer.

\[ Mg (s) + CuSO_4 (s) \rightarrow MgSO_4 (aq) + Cu (s) \]

**Answer**: Displacement. Magnesium replaces copper in the compound.
14.2

Classify the reactions below as synthesis, decomposition, single displacement, double displacement, or combustion. Explain your answers.

1. \( \text{CO}_2 (g) + \text{H}_2\text{O} (l) \rightarrow \text{H}_2\text{CO}_3 (aq) \)
2. \( \text{Cl}_2 (g) + 2\text{KI} (aq) \rightarrow 2\text{KCl} (aq) + \text{I}_2 (g) \)
3. \( \text{H}_2\text{O}_2 (l) \rightarrow \text{H}_2\text{O} (l) + \text{O}_2 (g) \)
4. \( \text{MnSO}_4 (s) \rightarrow \text{MnO} (s) + \text{SO}_3 (g) \)
5. \( \text{C}_6\text{H}_12\text{O}_6 (s) + 6\text{O}_2 (g) \rightarrow 6\text{CO}_2 (g) + 6\text{H}_2\text{O} (g) \)
6. \( \text{CaCl}_2 (aq) + 2\text{AgNO}_3 (aq) \rightarrow \text{Ca(NO}_3)_2 (aq) + 2\text{AgCl} (s) \)
7. \( 2\text{NaCl} (aq) + \text{CuSO}_4 (aq) \rightarrow \text{Na}_2\text{SO}_4 (aq) + \text{CuCl}_2 (s) \)
8. \( \text{CaCl}_2 (aq) + 2\text{Na} (s) \rightarrow \text{Ca} (s) + 2\text{NaCl} (aq) \)
9. \( \text{CaCO}_3 (s) \rightarrow \text{CaO} (s) + \text{CO}_2 (g) \)
10. \( \text{C}_3\text{H}_8 (g) + 5\text{O}_2 (g) \rightarrow 3\text{CO}_2 (g) + 4\text{H}_2\text{O} (g) \)

Answer the following questions.

11. You mix two clear solutions. Instantly, you see a bright yellow precipitate form. What type of reaction did you just observe? Explain your answer.

12. What type of reaction occurs when you strike a match?

13. Solid sodium reacts violently with chlorine gas. The product formed in the reaction is sodium chloride, also known as table salt. What type of reaction is this? Explain your answer.

14. Hydrogen-powered cars burn hydrogen gas to produce water and energy. The reaction is:

\[
2\text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2\text{H}_2\text{O} (g) + \text{Energy}
\]

While this reaction can be classified as a synthesis reaction, it is sometimes referred to as combustion. What characteristics does this reaction share with other combustion reactions? How is it different?
14.2 Predicting Chemical Equations

Chemical reactions cause chemical changes. Elements and compounds enter into a reaction, and new substances are formed as a result. Often, we know the types of substances that entered the reaction and can tell what types of substance(s) were formed. Sometimes, though, it might be helpful if we could predict the products of the chemical reaction—know in advance what would be formed and how much of it would be produced.

For certain chemical reactions, this is possible, using our knowledge of oxidation numbers, types of chemical reactions, and how equations are balanced. In this skill sheet, you will practice writing a complete balanced equation for chemical reactions when only the identities of the reactants are known.

**Review: Chemical equations**

Recall that chemical equations show the process of a chemical reaction. The equation reads from left to right with the reactants separated from the products by an arrow that indicates “yields” or “produces.”

In the chemical equation:

\[ 2\text{Li} + \text{BaCl}_2 \rightarrow 2\text{LiCl} + \text{Ba} \]

Two atoms of lithium combine with one molecule of barium chloride to yield two molecules of lithium chloride and one atom of barium. The equation fully describes the chemical change for this reaction.

For reactions such as the one above, a single displacement reaction, we are often able to predict the products in advance and write a completely balanced equation for the chemical change. Here are the steps involved:

1. **Predict the replacements for the reaction.**

In single displacement reactions, one element is replaced by a similar element in a compound. The pattern for this replacement is easily predictable: if the element doing the replacing forms a positive ion, it replaces the element in the compound that forms a positive ion. If the substance doing the replacing forms a negative ion, it replaces the element in the compound that forms a negative ion.

For the reaction described above, we could predict that the lithium would replace the barium in the compound barium chloride since both lithium and barium have positive oxidation numbers. The resulting product would pair lithium (1+) and chlorine (1-): the positive/negative combination required for ionic compounds.

2. **Determine the chemical formula for the products.**

Once you have determined which elements will be swapped to form the products, you can use oxidation numbers and the fact that the sum of the oxidation numbers for an ionic compound must equal zero in order to determine the chemical formula for the reaction products.

3. **Balance the chemical equation**

Once you have determined the nature and formulas of the products for a chemical reaction, the final step is to write a balanced equation for the reaction.
If beryllium (Be) combines with potassium iodide (KI) in a chemical reaction, what are the products?

**Solution:**
First, we decide which element of KI will be replaced by the beryllium. Since beryllium has an oxidation number of 2+, it replaces the element in KI that also has a positive oxidation number—the potassium (K¹⁺). It will therefore combine with the iodine to form a new compound.
Because beryllium has an oxidation number of 2+ and iodine's oxidation number is 1−, it is necessary for two atoms of iodine to combine with one atom of beryllium to form an electrically neutral compound. The resulting chemical formula for beryllium iodide is BeI₂.
In single-displacement reactions, the component of the compound that has been replaced by the uncombined reactant now stands alone and uncombined. The resulting products of this chemical reaction, therefore, are BeI₂ and K. Balancing the equation gives us:

\[ \text{Be} + 2\text{KI} \rightarrow \text{BeI}_2 + 2\text{K} \]

**Predict replacements**
1. If Na¹⁺ were to combine with CaCl₂, what component of CaCl₂ would be replaced by the Na¹⁺?
2. If Fe²⁺ were to combine with K₂Br, what component of K₂Br would be replaced by the Fe²⁺?
3. If Mg²⁺ were to combine with AlCl₃, what component of AlCl₃ would be replaced by the Mg²⁺?

**Predict product formulas**
For the following combinations of reactants, predict the formulas of the products:
4. Li + AlCl₃
5. K + CaO
6. F₂ + KI

**Predicting chemical equations for displacement reactions**
Write complete balanced equations for the following combinations of reactants.
7. Ca and K₂S
8. Mg and Fe₂O₃
9. Li and NaCl
14.2 Percent Yield

You can predict the amount of product to expect from a reaction if you know how much reactant you started with. For example, if you start out with one mole of limiting reactant, you can expect to produce one mole of product.

In real-world chemical reactions, the actual amount of product is usually less than the predicted amount. This is due to experimental error and other factors (such as the fact that some product is difficult to collect and measure).

The amount of product you expect to produce is called the **predicted yield**. The amount of product that you are able to measure after the reaction is called the **actual yield**. The **percent yield** is the **actual yield** divided by the **predicted yield** and then multiplied by 100.

\[
\text{Percent yield} = \frac{\text{Actual yield}}{\text{Predicted yield}} \times 100
\]

The percent yield can provide information about how carefully the experiment was performed. If a percent yield is low, chemical engineers look for sources of error. Manufacturers of chemical products try to maximize their percent yield so that they can get the maximum amount of product to sell from the reactants that they purchased.

**Example**

- In the reaction below, potassium and water are combined in a chemical reaction that produces potassium hydroxide and hydrogen gas. If two moles of potassium (the limiting reactant) are used, what is the predicted yield of potassium hydroxide (KOH) in grams?

\[2K + 2H_2O \rightarrow 2KOH + H_2\]

1. **Looking for:** Predicted yield of KOH in grams
2. **Given:** Two moles of the limiting reactant (K) are used
3. **Relationships:** Two moles of limiting reactant should produce two moles of product. Two moles of the product will have a mass twice its molar mass.
4. **Solution:**

   Molar mass of KOH = atomic mass of K + atomic mass of O + atomic mass of H

   From periodic table, molar mass of KOH = 39.10 + 16.00 + 1.01 = 56.11 grams

   Because we started with two moles of limiting reactant, we should end up with two moles, or 112.22 grams, of KOH.

- If the actual yield of KOH was 102.5 grams, what was the percent yield for this reaction?

1. **Looking for:** Percent yield of KOH
2. **Given:** Actual yield = 102.5 g; predicted yield = 122.22 g
3. **Relationships:** Percent yield = actual yield ÷ predicted yield × 100
4. **Solution:**

   Percent yield = \(\frac{102.5 \text{ g}}{122.22 \text{ g}} \times 100 = 84.2\%\)
1. In the balanced reaction below, hydrochloric acid reacts with calcium carbonate to produce calcium chloride, carbon dioxide, and water.

$$2\text{HCL} + \text{CaCO}_3 \rightarrow \text{CaCl}_2 + \text{CO}_2 + \text{H}_2\text{O}$$

If one mole of calcium carbonate (the limiting reactant) is used, how much calcium chloride should the reaction produce? Give your answer in grams. (Hint: use your periodic table to find the atomic masses of calcium and chlorine).

2. If the actual yield of calcium chloride in the reaction is 97.6 grams, what is the percent yield?

3. In order to get a 94% actual yield for this reaction, how many grams of calcium chloride would the reaction need to produce?

4. If you put an iron nail into a beaker of copper (II) chloride, you will begin to see a reddish precipitate forming on the nail. In this reaction, iron replaces copper in the solution and copper falls out of the solution as a metal. Here is the balanced reaction:

$$\text{Fe} + \text{CuCl}_2 \rightarrow \text{FeCl}_2 + \text{Cu}$$

If you start out with one mole of your limiting reactant (Fe), how many grams of copper can you expect to produce through this reaction?

5. If the actual yield of copper in the reaction is 55.9 grams, what is the percent yield?

6. How much copper would the reaction need to produce to achieve a 96% yield?

7. When sodium hydroxide and sulfuric acid react, sodium sulfate and water are produced. Here is the balanced reaction:

$$2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{NaSO}_4 + 2\text{H}_2\text{O}$$

If two moles of sodium hydroxide (the limiting reactant) are used, one mole of NaSO$_4$ should be produced. How many grams of NaSO$_4$ should be produced?

8. If 100.0 grams of NaSO$_4$ are actually produced, what is the percent yield?

9. How much NaSO$_4$ would have to be produced to achieve a 90% yield?

10. Name two reasons why the actual yield in a reaction is usually lower than the predicted yield.
Lise Meitner identified and explained nuclear fission, proving it was possible to split an atom.

**Prepared to learn**

Lise Meitner was born in Vienna on November 7, 1878, one of eight children; her father was among the first Jews to practice law in Austria. At 13, she completed the schooling provided to girls. Her father hired a tutor to help her prepare for a university education, although women were not yet allowed to attend.

The preparation was worthwhile. When the University of Vienna opened its doors to women in 1901, Meitner was ready. She found a mentor there in physics professor Ludwig Boltzmann, who encouraged her to pursue a doctoral degree. Physicist Otto Robert Frisch, Meitner’s nephew, wrote that “Boltzmann gave her the vision of physics as a battle for ultimate truth, a vision she never lost.”

**Pioneer in radioactivity**

In 1906 Meitner went to Berlin after earning her doctorate, only the second in physics awarded to a woman by the university. There was great interest in theoretical physics in Berlin. There she began a 30-year collaboration with chemist Otto Hahn. Together, they studied radioactive substances. One of their first successes was the development of a new technique for purifying radioactive material.

During World War I, Meitner volunteered as an X-ray nurse-technician with the Austrian army. She pioneered cautious handling techniques for radioactive substances, and when she was off duty, continued her work with Hahn.

**Elemental discoveries**

In 1917, they discovered the element protactinium. Afterward, Meitner was appointed head of the physics department at the Kaiser Wilhelm Institute for Chemistry in Berlin, where Hahn was head of the chemistry department. The two continued their study of radioactivity, and Meitner became the first to explain how conversion electrons were produced when gamma rays were used to remove orbital electrons.

**Atomic-age puzzles**

In 1934, when Enrico Fermi produced radioactive isotopes of uranium by neutron bombardment, he was puzzled by the products. Meitner, Hahn, and German chemist Fritz Strassmann began looking for answers.

Their research was interrupted when Nazi Germany annexed Austria in 1938 and restrictions on “non-Aryan” academics tightened. Meitner, though she had been baptized and raised a Protestant, went into exile in Sweden. She continued to correspond with her collaborators and suggested that they perform further tests on a product of the uranium bombardment.

When tests showed it was barium, the group was puzzled. Barium was so much smaller than uranium. Hahn wrote to Meitner that uranium “can’t really break into barium … try to think of some other possible explanation.”

Meitner and Frisch (who was also in Sweden) worked on the problem and proved that splitting the uranium atom was energetically possible. Using Niels Bohr’s model of the nucleus, they explained how the neutron bombardment could cause the nucleus to elongate into a dumbbell shape. Occasionally, they explained, the narrow center of the dumbbell could separate, leaving two nuclei. Meitner and Frisch called this process nuclear fission.

**Meitnerium honors achievement**

In 1944, Hahn received the Nobel Prize in chemistry for the discovery of nuclear fission. Meitner’s role was overlooked or obscured.

In 1966, she, Hahn, and Strassman shared the Enrico Fermi Award, given by President Lyndon B. Johnson and the Department of Energy. Meitner died two years later, just days before her 90th birthday. In 1992, element 109 was named meitnerium to honor her work.
Reading reflection

1. **Research:** Ludwig Boltzmann was an important mentor to Lise Meitner. Who was Boltzmann? Research and list one of his contributions to science.

2. What element did Meitner and Otto Hahn discover? Using the periodic table, list the atomic number and mass number of this element. Does this element have stable isotopes?

3. What is nuclear fission? Explain this event in your own words and draw a diagram showing how fission occurs in a uranium nucleus.

4. **Research** and describe at least two ways nuclear fission was used in the twentieth century.

5. Meitner did not receive the Nobel Prize for her work on nuclear fission, though she was honored in other ways. List how she was honored for her work in physics.

6. On a separate sheet of paper, compose a letter to the Nobel Prize Committee explaining why Meitner deserved this prize for her work. Be sure to explain your reasoning clearly and be sure to use formal language and correct grammar in your letter.
14.4 Marie and Pierre Curie

Marie and Pierre Curie’s pioneering studies of radioactivity had a dramatic impact on the development of twentieth-century science. Marie Curie’s bold view that uranium rays seemed to be an intrinsic part of uranium atoms encouraged physicists to explore the possibility that atoms might have an internal structure. Out of this idea the field of nuclear physics was born. Together the Curies discovered two radioactive elements, polonium and radium. Through Pierre Curie’s study of how living tissue responds to radiation, a new era in cancer treatment was born.

The allure of learning

Marie Skłodowska was born on November 7, 1867, in Russian-occupied Warsaw, Poland. She was the youngest of five children of two teachers, her father a teacher of physics and mathematics, her mother also a singer and pianist.

Marya loved school, and especially liked math and science. However, in Poland, as in much of the rest of the world, opportunities for higher education were limited for women. At 17, she and one of her sisters enrolled in an illegal, underground “floating university” in Warsaw.

After these studies, she worked for three years as a governess. Her employer allowed her to teach reading to the children of peasant workers at his beet-sugar factory. This was forbidden under Russian rule. At the same time, she took chemistry lessons from the factory’s chemist, mathematics lessons from her father by mail, and studied on her own.

By fall 1891, Sklodowska had saved enough money to enroll at the University of Paris (also called the Sorbonne). She earned two master’s degrees, in physics and mathematics.

A Polish friend introduced Marie, as she was called in French, to Pierre Curie, the laboratory chief at the Sorbonne’s Physics and Industrial Chemistry Schools.

The piezoelectric effect

Pierre Curie’s early research centered on properties of crystals. He and his brother Jacques discovered the piezoelectric effect, which describes how a crystal will oscillate when electric current is applied. The oscillation of crystals is now used to precisely control timing in computers and watches and many other devices.

Pierre Curie and Marie Sklodowska found that despite their different nationalities and background, they had the same passion for scientific research and shared the desire to use their discoveries to promote humanitarian causes. They married in 1895.

Crystals and uranium rays

Pierre continued his pioneering research in crystal structures, while Marie pursued a physics doctorate. She chose uranium rays as her research topic. Uranium rays had been discovered only recently by French physicist Henri Becquerel.

Becquerel’s report explained that uranium compounds emitted some sort of ray that fogged photographic plates. Marie Curie decided to research the effect these rays had on the air’s ability to conduct electricity. To measure this effect, she adapted a device that Pierre and Jacques Curie had invented 15 years earlier.
Marie Curie confirmed that the electrical effects of uranium rays were similar to the photographic effects that Becquerel reported—both were present whether the uranium was solid or powdered, pure or in compound, wet or dry, exposed to heat or to light. She concluded that the emission of rays by uranium was not the product of a chemical reaction, but could be something built into the very structure of uranium atoms.

**Allies behind a revolutionary idea**

Marie Curie’s idea was revolutionary because atoms were still believed to be tiny, featureless particles. She decided to test every known element to see if any others would, like uranium, improve the air’s ability to conduct electricity. She found that the element thorium had this property.

Pierre Curie decided to join Marie after she found that two different uranium ores (raw materials gathered from uranium mines) caused the air to conduct electricity much better than even pure uranium or thorium. They wondered if an undiscovered element might be mixed into each ore.

They worked to separate the chemicals in the ores and found two substances that were responsible for the increased conductivity. They called these elements polonium, in honor of Marie’s native country, and radium, from the Greek word for ray.

**A new field of medicine**

While Marie Curie searched for ways to extract these pure elements from the ores, Pierre turned his attention to the properties of the rays themselves. He tested the radiation on his own skin and found that it damaged living tissue.

As Pierre published his findings, a whole new field of medicine developed, using targeted rays to destroy cancerous tumors and cure skin diseases. Unfortunately, both Curies became ill from overexposure to radiation.

**Curies share the Nobel Prize**

In June 1903, Madame Curie became the first woman in Europe to receive a doctorate in science. In December of that year, the Curies and Becquerel shared the Nobel Prize in physics. The Curies were honored for their work on the spontaneous radiation that Becquerel had discovered. Marie Curie called spontaneous radiation “radioactivity.” She was the first woman to win the Nobel in physics. And in 1904, her second daughter, Eve, was born. The elder daughter, Irene, was seven.

**Tragedy intrudes**

In April 1906, Pierre was killed by a horse-drawn wagon in a Paris street accident. A month later, the Sorbonne asked Madame Curie to take over her husband’s position there. She agreed, in hopes of creating a state-of-the-art research center in her husband’s memory.

Marie Curie threw herself into the busy academic schedule of teaching and conducting research (she was the first woman to lecture, the first to be named professor, and the first to head a laboratory at the Sorbonne), and found time to work on raising money for the new center. The Radium Institute of the University of Paris opened in 1914 and Madame Curie was named director of its Curie Laboratory.

**The scientist-humanitarian**

In 1911, Curie received a second Nobel Prize (the first person so honored), this time in chemistry for her work in finding elements and determining the atomic weight of radium.

With the start of World War I in 1914, she turned her attention to the use of radiation to help wounded soldiers. Assisted by her daughter Irene, she created a fleet of 20 mobile x-ray units to help medics quickly determine and then treat injuries in the field. Next, she set up nearly 200 x-ray labs in hospitals and trained 150 women to operate the equipment.

**Legacy continues**

After the war, Curie went back to direct the Radium Institute, which grew to two centers, one devoted to research and the other to treatment of cancer. In July 1934, she died at 66 of radiation-induced leukemia. The next year, Irene Joliot-Curie and her husband, Frederic Joliot-Curie, were awarded the Nobel Prize in chemistry for their discovery of artificial radiation.
Reading reflection

1. Why might Marie Curie have been motivated to teach the children of beet workers? Recall that this was forbidden by Russian rule.

2. What fundamental change in our understanding of the atom was brought about by the work of Marie Curie?

3. Describe how Marie and Pierre Curie discovered two elements.

4. Name at least three new fields of science that stem from the work of Marie and/or Pierre Curie.

5. Research: In your own words, describe Marie Curie as a role model for women in science. Use your library or the Internet to research how she worked to balance a scientific career and motherhood.
Rosalyn Sussman Yalow and her research partner, Solomon Berson, developed radioimmunoassay, or RIA. This important medical diagnostic tool uses radioactive isotopes to trace hormones, enzymes, and medicines that exist in such low concentrations in blood that they were previously impossible to detect using other laboratory methods.

Encouraged and inspired

Rosalyn Sussman was born in 1921 in New York City. Neither of her parents attended school beyond eighth grade, but they encouraged Rosalyn and her older brother to value education. In the early grades, Rosalyn enjoyed math, but in high school her chemistry teacher encouraged her interest in science.

She stayed in New York after high school, studying physics and chemistry at Hunter College. After her graduation in 1941, she took a job as a secretary at Columbia University. There were few opportunities for women to attend graduate school, and Sussman hoped that by working at Columbia, she might be able to sit in on some courses.

A wartime opportunity

However, as the United States began drafting large numbers of men in preparation for war, universities began to accept women rather than close down. In fall 1941, Sussman arrived at the University of Illinois with a teaching assistantship in the School of Engineering, where she was the only woman.

There, she specialized in the construction and use of devices for measuring radioactive substances. By January 1945 she had earned her doctorate, with honors, in nuclear physics, and married Aaron Yalow, a fellow student.

From medical physics to ‘radioimmunoassay’

From 1946–50, Yalow taught physics at Hunter College, which had only introduced it as a major her senior year and which now admitted men. In 1947, she also began working part time at the Veterans Administration Hospital in the Bronx, which was researching medical uses of radioactive substances.

In 1950 she joined the hospital full time and began a research partnership with Solomon A. Berson, an internist. Together they developed the basic science, instruments, and mathematical analysis necessary to use radioactive isotopes to measure tiny concentrations of biological substances and certain drugs in blood and other body fluids. They called their technique radioimmunoassay, or RIA. (Yalow also had two children by 1954.)

RIA helps diabetes research

One early application of RIA was in diabetes research, which was especially significant to Yalow because her husband was diabetic. Diabetes is a condition in which the body is unable to regulate blood sugar levels. This is normally accomplished through the release of a hormone called insulin from the pancreas.

Using RIA, they showed that adult diabetics did not always lack insulin in their blood, and that, therefore, something must be blocking their insulin’s normal action. They also studied the body’s immune system response to insulin injected into the bloodstream.

Commercial applications, not commerce

RIA’s current uses include screening donated blood, determining effective doses of medicines, detecting foreign substances in the blood, testing hormone levels in infertile couples, and treating certain children with growth hormones.

Yalow and Berson changed theoretical immunology and could have made their fortunes had they chosen to patent RIA, but instead, Yalow explained, “Patents are about keeping things away from people for the purpose of making money. We wanted others to be able to use RIA.” Berson died unexpectedly in 1972; Yalow had their VA research laboratory named after him, and lamented later that his death had excluded him from sharing the team’s greatest recognition.

A rare Nobel winner

Yalow was awarded the Nobel Prize in Physiology or Medicine in 1977. She was only the second woman to win in that category, for her work on radioimmunoassay of peptide hormones.
Reading reflection

1. Rosalyn Yalow has said that Eve Curie’s biography of her mother, Marie Curie, helped spark her interest in science. Compare the lives of these two scientists.

2. Describe radioimmunoassay in your own words.

3. What information about adult diabetes was discovered using RIA?

4. Find out more about the role of patents in medical research. Do you agree or disagree with Yalow’s statement? Why?
14.4 Chien-Shiung Wu

During World War II, Chinese-American physicist Chien-Shiung Wu played an important role in the Manhattan Project, the Army’s secret work to develop the atomic bomb. In 1957, she overthrew what was considered an indisputable law of physics, changing the way we understand the weak nuclear force.

Determined to learn

Chien-Shiung Wu was born on May 31, 1912, in a small town outside Shanghai, China. Her father had opened the region’s first school for young girls, which Chien-Shiung finished at age 10.

She then attended a girls boarding school in Suzhou that had two sections—a teacher training school and an academic school with a standard Western curriculum. Chien-Shiung enrolled in teacher training, because tuition was free and graduates were guaranteed jobs.

Students from both sections lived in the dormitory, and as Chien-Shiung became friends with girls in the academic school, she learned that their science and math curriculum was more rigorous than hers. She asked to borrow their books and stayed up late teaching herself the material.

Chien-Shiung Wu graduated first in her class and was invited to attend prestigious National Central University in Nanjing. There, she earned a bachelor’s degree in physics and did research for two years. In 1936 Wu emigrated from China to the United States. She earned her doctorate from the University of California at Berkeley in 1940.

A key scientist in the Manhattan Project

Wu taught at Smith College and Princeton University until 1944, when she went to Columbia University as a senior scientist and researcher and was asked to join the Manhattan Project. There she helped develop the process to enrich uranium ore.

In the course of the project, her renowned colleague Enrico Fermi turned to Wu for help with a fission experiment. A rare gas which she had studied in graduate school was causing the problem. With Wu’s assistance, Fermi was able to solve the problem and continue his work.

Right and left in nature?

After the war, Wu continued her research in nuclear physics at Columbia. In 1956, she and two colleagues, Tsung-Dao Lee of Columbia and Chen Ning Yang of Princeton, reconsidered the law of conservation of parity. This law stated that nature does not distinguish between left and right in nuclear reactions. They wondered if the law might not be valid for interactions of subatomic particles involving the weak nuclear force.

Wu was a leading specialist in beta decay. She figured out a means of testing their theory. She cooled cobalt-60, a radioactive isotope, to 0.01 degree above absolute zero. Next, she placed the cobalt-60 in a strong magnetic field so that the cobalt nuclei lined up and spun along the same axis. She observed what happened as the cobalt-60 broke down and gave off electrons.

According to the law of conservation of parity, equal numbers of electrons should have been given off in each direction. However, Wu found that many more electrons flew off in the direction opposite the spin of the cobalt-60 nuclei. She proved that in beta decay, nature does in fact distinguish between left and right.

Always a landmark achiever

Unfortunately, when Lee and Yang were awarded the Nobel Prize in physics in 1957, Wu’s contribution to the project was overlooked. However, among her many honors and awards, she later received the National Medal of Science, the nation’s highest award for science achievement.

In 1973, she became the first female president of the American Physical Society. Wu died at 84 in 1997, leaving a husband and son who were both physicists.
Reading reflection

1. Use a dictionary to look up the meaning of each boldface word. Write a definition for each word. Be sure to credit your source.

2. How did Chien-Shiung Wu’s work in graduate school help her with her work on the Manhattan Project?

3. From the reading, define the law of conservation of parity in your own words.

4. How many protons and neutrons does cobalt-60 have? List the nonradioactive isotopes of cobalt.

5. Briefly describe Wu’s elegant experiment that proved that nature distinguishes between right and left.

6. **Research:** Wu was the first woman recipient of the National Medal of Science in physical science. Two other women have since received this award. Who were they and what did they do?

7. What are three questions that you have about Wu and her work?

8. Suggest some possible reasons why Wu did not receive the Nobel Prize for her work.
14.4 Radioactivity

There are three main types of radiation that involve the decay of the nucleus of an atom:

- **alpha radiation** (α): release of a helium-4 nucleus (two protons and two neutrons). We can represent helium-4 using isotope notation: $^4_2\text{He}$. The top number, 4, represents the mass number, and the bottom number represents the atomic number for helium, 2.

- **beta radiation** (β): release of an electron.

- **gamma radiation** (γ): release of an electromagnetic wave.

### Half-life

The time it takes for half of the atoms in a sample to decay is called the half-life. Four kilograms of a certain substance undergo radioactive decay. Let’s calculate the amount of substance left over after 1, 2, and 3 half-lives.

- After one half-life, the substance will be reduced by half, to 2 kilograms.
- After two half-lives, the substance will be reduced by another half, to 1 kilogram.
- After three half-lives, the substance will be reduced by another half, to 0.5 kilogram.

So, if we start with a sample of mass $m$ that decays, after a few half-lives, the mass of the sample will be:

<table>
<thead>
<tr>
<th>Number of half-lives</th>
<th>Mass left</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\frac{1}{2}m = \frac{1}{2}m$</td>
</tr>
<tr>
<td>2</td>
<td>$\frac{1}{2}^2m = \frac{1}{4}m$</td>
</tr>
<tr>
<td>3</td>
<td>$\frac{1}{2}^3m = \frac{1}{8}m$</td>
</tr>
<tr>
<td>4</td>
<td>$\frac{1}{2}^4m = \frac{1}{16}m$</td>
</tr>
</tbody>
</table>
1. The decay series for uranium-238 and plutonium-240 are listed below. Above each arrow, write “a” for alpha decay or “b” for beta decay to indicate which type of decay took place at each step.

\[ ^{238}_{92}U \rightarrow ^{234}_{90}Th \rightarrow ^{234}_{91}Pa \rightarrow ^{234}_{92}U \rightarrow ^{230}_{90}Th \rightarrow \]
\[ ^{226}_{88}Ra \rightarrow ^{222}_{86}Rn \rightarrow ^{218}_{84}Po \rightarrow ^{214}_{82}Pb \rightarrow ^{214}_{83}Bi \rightarrow \]
\[ ^{214}_{84}Po \rightarrow ^{210}_{82}Pb \rightarrow ^{210}_{83}Bi \rightarrow ^{210}_{84}Po \rightarrow ^{206}_{82}Pb \]

\[ ^{240}_{94}Pu \rightarrow ^{240}_{95}Am \rightarrow ^{236}_{93}Np \rightarrow ^{232}_{91}Pa \rightarrow ^{232}_{92}U \rightarrow \]
\[ ^{228}_{90}Bi \rightarrow ^{224}_{88}Ra \rightarrow ^{224}_{89}Ac \rightarrow ^{220}_{87}Fr \rightarrow ^{216}_{85}At \rightarrow \]
\[ ^{212}_{83}Bi \rightarrow ^{212}_{84}Po \rightarrow ^{208}_{82}Pb \rightarrow ^{208}_{83}Bi \]

2. Fluorine-18 (\( ^{18}_{9}F \)) has a half-life of 110 seconds. This material is used extensively in medicine. The hospital laboratory starts the day at 9 a.m. with 10 grams of \( ^{18}_{9}F \).
   a. How many half-lives for fluorine-18 occur in 11 minutes (660 seconds)?
   b. How much of the 10-gram sample of fluorine-18 would be left after 11 minutes?

3. The isotope \( ^{14}_{6}C \) has a half-life of 5,730 years. What is the fraction of \( ^{14}_{6}C \) in a sample with mass, \( m \), after 28,650 years?

4. What is the half-life of this radioactive isotope that decreases to one-fourth its original amount in 18 months?

5. This diagram illustrates a formula that is used to calculate the intensity of radiation from a radioactive source. Radiation “radiates” from a source into a spherical area. Therefore, you can calculate intensity using the area of a sphere \((4\pi r^2)\). Use the formula and the diagram to help you answer the questions below.

**Intensity**

\[
I = \frac{P}{A}
\]

Area, \( A = 4\pi r^2 = 12.6 \text{ m}^2 \)

Intensity, \( I = \frac{100 \text{ W}}{12.6 \text{ m}^2} = 7.96 \text{ W/m}^2 \)

a. A radiation source with a power of 1,000. watts is located at a point in space. What is the intensity of radiation at a distance of 10. meters from the source?

b. The fusion reaction \( ^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + n + \text{energy} \) releases \( 2.8 \times 10^{-12} \) joules of energy. How many such reactions must occur every second in order to light a 100-watt light bulb? Note that one watt equals one joule per second.
Svante Arrhenius was a Swedish Chemist who won the Nobel Prize in 1903 for his work on acid and base chemistry. He is also known for recognizing that carbon dioxide (CO₂) is added to the atmosphere when fossil fuels are burned, and that it is a greenhouse gas. Arrhenius calculated that doubling the CO₂ in the atmosphere would increase Earth’s temperature by 4-5°C. His prediction, made without computers or modern scientific equipment, is close to current estimates!

Young scholar

Svante Arrhenius was born in 1859 in Wijk, Sweden. His father was a land surveyor. Svante taught himself to read at the age of three. He was a strong student and especially enjoyed math and physics. He graduated at the top of his high school class, although he was the youngest student.

Arrhenius went on to study mathematics, chemistry, and physics at the University of Uppsala in Sweden. In 1881 he moved to Stockholm to study with Professor E. Edlund at the Academy of Sciences. Arrhenius was especially interested in what happens when electricity is passed through solutions. For his doctoral thesis, he proposed that molecules in solutions could break up into electrically charged fragments called ions.

Setback, perseverance, and recognition

Unfortunately, the value of Arhenius’s work was not recognized by the faculty at the University of Uppsala, where he defended his dissertation. The idea that a molecule could break up in water was difficult to accept. Finally, Arrhenius was given a “fourth rank” degree--which meant that he barely passed. Arrhenius could not hope to obtain a university professorship with that degree!

Arrhenius’s mentor, Professor Edlund, helped him obtain a travel grant to meet and work with leading scientists in the field of physical chemistry. They helped Arrhenius clarify his ionic theory. In the late 1890’s, when electrically charged subatomic particles were discovered, the importance of Arrhenius’s work was finally recognized. Arrhenius was awarded the Nobel Prize for Chemistry in 1903.

A man of many interests

Arrhenius was fascinated by many branches of science. He studied electrolytes in the human body, publishing papers about their role in digestion and absorption, and about their function as antitoxins.

Along with his scientific publications, Arrhenius wrote books intended to introduce the general public to advances in various scientific fields. These included Smallpox and its Combating (1913) and Chemistry and Modern Life (1919).

Arrhenius was also interested in Astronomy. In 1908 he put forth the theory of panspermia—which suggested that life may spread through the universe when spores from a life-bearing planet escape their atmosphere and are then driven by radiation pressure across long expanses of space, until they come to rest on another planet where hospitable conditions allow them to flourish. While this theory hasn’t withstood the test of time, Arrhenius did contribute to our understanding of the phenomenon known as Aurora Borealis, or northern lights.

Pioneering climate research

Arrhenius was curious about what caused the beginning and end of Earth’s ice ages. In 1895, he presented a paper to the Stockholm Physical Society called “On the Influence of Carbonic Acid (CO₂) in the Air upon the Temperature of the Ground.” He proposed that variations in the amount of CO₂ in the atmosphere could influence climate.

In 1903, he wrote a book called Worlds in the Making in which he explained that atmospheric gases like carbon dioxide trap heat near Earth’s surface, increasing its average temperature. In 1904, he suggested that human activity could affect Earth’s climate, if industrial emissions increased the amount of CO₂ in the atmosphere. He was not concerned about this increase; in fact he thought that it might be beneficial for growing crops to feed a larger human population.

Arrhenius died in Stockholm in 1927.
Reading reflection

1. Describe Arrhenius’s doctoral thesis.
2. What was the setback that Arrhenius had to overcome early in his career?
3. Name three fields of science that interested Arrhenius.
4. Describe a scientific theory proposed by Arrhenius that has never received widespread acceptance.
5. Why is Arrhenius considered a pioneer in the field of climate change study?
16.1 Open and Closed Circuits

Where is the current flowing?

You have built and tested different kinds of circuits in the lab. Now you can use what you learned to make predictions about circuits you haven’t seen before. Use the circuit diagrams pictured below to answer the questions. You may wish to write on the diagrams in order to keep track where the current is flowing. As a result, each diagram is repeated several times.

1. Which devices (A, B, C, or D) in the circuit pictured below will be on when the following conditions are met? For your answer, give the letter of the device or devices.

   - Switch 3 is open, and all other switches are closed.
   - Switch 2 is open, and all other switches are closed.
   - Switch 4 is open, and all other switches are closed.
   - Switch 1 is open, and all other switches are closed.
   - Bulb C blows out, and all switches are closed.
   - Bulb A blows out, and all switches are closed.
   - Switches 2 and 4 are open, and switches 1 and 3 are closed.
   - Switches 2 and 3 are open, and switches 1 and 4 are closed.
i. Switches 2, 3, and 4 are open, and switch 1 is closed.

j. Switches 1 and 2 are open, and switches 3 and 4 are closed.

2. Which of the devices (A-G) in the circuit below will be *on* when the following conditions are met? For your answer, give the letter of the device or devices.

a. Switch 5 is open, and all other switches are closed.

b. Switch 6 is open, and all others are closed.

c. Switch 7 is open, and all others are closed.

d. Switch 4 is open, and all others are closed.

e. Switch 3 is open, and all others are closed.

f. Switch 2 is open, and all others are closed.

g. Switch 1 is open, and all others are closed.

h. Switches 2 and 4 are open, and all others are closed.
i. Switches 4 and 6 are open, and all others are closed.

j. Switches 4 and 7 are open, and all others are closed.

k. Switches 5 and 7 are open, and all others are closed.

l. Switches 2 and 3 are open, and all others are closed.

m. Bulb D blows out with all switches closed.

n. Bulbs A and B blow out with all switches closed.

o. Bulbs A and D blow out with all switches closed.

3. Use arrows to draw the direction of the current in each of the circuits below. Make sure to show current direction in all paths of the circuits within each diagram.

4. How many possible paths are there in circuit diagrams in questions (1) and (2)?

5. Draw a circuit of your own. Use one battery, show at least 4 devices (bulbs and bells), and divide the current at some point in the circuit. Finally, use arrows to show the direction of the current in all parts of your circuit.
16.1 Benjamin Franklin

Benjamin Franklin overcame a lack of formal education to become a prominent businessman, community leader, inventor, scientist, and statesman. His study of “electric fire” changed our basic understanding of how electricity works.

An eye toward inventiveness

Benjamin Franklin was born in Boston in 1706. With only one year of schooling he became an avid reader and writer. He was apprenticed at age 12 to his brother James, a printer. The siblings did not always see eye to eye, and at 17, Ben ran away to Philadelphia.

In his new city, Franklin developed his own printing and publishing business. Over the years, he became a community leader, starting the first library, fire department, hospital, and fire insurance company. He loved gadgets and invented some of his own: the Franklin stove, the glass armonica (a musical instrument), bifocal eyeglasses, and swim fins.

‘Electric fire’

In 1746, Franklin saw some demonstrations of static electricity that were meant for entertainment. He became determined to figure out how this so-called “electric fire” worked.

Undeterred by his lack of science education, Franklin began experimenting. He generated static electricity using a glass rod and silk cloth, and then recorded how the charge could attract and repel lightweight objects.

Franklin read everything he could about this “electric fire” and became convinced that a lightning bolt was a large-scale example of the same phenomenon.

Father and son experiment

In June 1752, Franklin and his 21-year-old son, William, conducted an experiment to test his theory. Although there is some debate over the details, most historians agree that Franklin flew a kite on a stormy day in order to collect static charges.

Franklin explained that he and his son constructed a kite of silk cloth and two cedar strips. They attached a metal wire to the top. Hemp string was used to fly the kite. A key was tied near the string’s lower end. A silk ribbon was affixed to the hemp, below the key.

Shocking results

It is probable that Franklin and his son were under some sort of shelter, to keep the silk ribbon dry. They got the kite flying, and once it was high in the sky they held onto it by the dry silk ribbon, not the wet hemp string. Nothing happened for a while. Then they noticed that the loose threads of the hemp suddenly stood straight up.

The kite probably was not struck directly by lightning, but instead collected charge from the clouds. Franklin touched his knuckle to the key and received a static electric shock. He had proved that lightning was a discharge of static electricity.

Those are charged words

Through his experiments, Franklin determined that “electric fire” was a single “fluid” rather than two separate fluids, as European scientists had thought. He proposed that this “fluid” existed in two states, which he called “positive” and “negative.” Franklin was the first to explain that if there is an excess buildup of charge on one item, such as a glass rod, it must be exactly balanced by a lack of charge on another item, such as the silk cloth. Therefore, electric charge is conserved. He also explained that when there is a discharge of static electricity between two items, the charges become balanced again.

Many of Franklin’s electrical terms remain in use today, including battery, charge, discharge, electric shock, condenser, conductor, plus and minus, and positive and negative.
**Reading reflection**

1. Although Ben Franklin had only one year of schooling, he became a highly educated person. Describe how Franklin learned about the world.

2. What hypothesis did Franklin test with his kite experiment?

3. Describe the results and conclusion of Franklin’s kite experiment.

4. Franklin’s kite experiment was dangerous. Explain why.

5. Silk has an affinity for electrons. When you rub a glass rod with silk, the glass is left with a positive charge. Make a diagram that shows the direction that charges move in this example. Illustrate and label positive and negative charges on the silk and glass rod in your diagram. Note: Show the same number of positive and negative charges in your diagram.

6. **Research:** Among Franklin’s many inventions is the lightning rod. Find out how this device works, and create a model or diagram to show how it functions.
16.2 Using an Electric Meter

What do you measure in a circuit and how do you measure it? This skill sheet gives you useful tips to help you use an electric meter and understand electrical measurements.

The digital multimeter

Most people who work with electric circuits use a digital multimeter to measure electrical quantities. These measurements help them analyze circuits. Most multimeters measure voltage, current, and resistance. A typical multimeter is shown below:
**Using the digital multimeter**

This table summarizes how to use and interpret any digital meter in a battery circuit. Note: A *component* is any part of a circuit, such as a battery, a bulb, or a wire.

<table>
<thead>
<tr>
<th>Measuring Voltage</th>
<th>Measuring Current</th>
<th>Measuring Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit is ON</td>
<td>Circuit is ON</td>
<td>Circuit is OFF</td>
</tr>
<tr>
<td>Turn dial to voltage, labeled $V, \text{VDC}, \text{or} \overline{V}$</td>
<td>Turn dial to current, labeled $A, \text{ADC}, \text{or} \overline{A}$</td>
<td>Turn dial to resistance, labeled $\Omega$</td>
</tr>
<tr>
<td>Connect leads to meter following meter instructions</td>
<td>Connect leads to meter following meter instructions</td>
<td>Connect leads to meter following meter instructions</td>
</tr>
<tr>
<td>Place leads at each end of component (leads are ACROSS the component)</td>
<td>Break circuit and place leads on each side of the break (meter is IN the circuit)</td>
<td>Place leads at each end of component (leads are ACROSS the component)</td>
</tr>
<tr>
<td>Measurement in VOLTS (V)</td>
<td>Measurement in AMPS (A)</td>
<td>Measurement in OHMS (Ω)</td>
</tr>
<tr>
<td>Battery measurement shows relative energy provided</td>
<td>Measurement shows the value of current at the point where meter is placed</td>
<td>Measurement shows the resistance of the component</td>
</tr>
<tr>
<td>Component measurement shows relative energy used by that component</td>
<td>Current is the flow of charge through the wire</td>
<td>When the resistance is too high, the display shows OL (overload) or $\infty$ (infinity)</td>
</tr>
</tbody>
</table>
Build a series circuit with 2 batteries and 2 bulbs.

1. Measure and record the voltage across each battery:

2. Measure and record the voltage across each bulb:

3. Measure and record the voltage across both batteries:

4. Draw a circuit diagram or sketch that shows all the posts in the circuit (posts are where wires and holders connect together).

5. Break the circuit at one post. Measure the current and record the value below. Repeat until you have measured the current at every post.
6. Create a set of instructions on how to use the meter to do a task. Find someone unfamiliar with the meter. See if he or she can follow your instructions.

7. A fuse breaks a circuit when current is too high. A fuse must be replaced when it breaks a circuit. Explain how measuring the resistance of a fuse can tell you if it is defective.

8. You suspect that a wire is defective but can't see a break in it. Explain how measuring the resistance of the wire can tell you if it has a break.
16.3 Voltage, Current, and Resistance

Electricity is one of the most fascinating topics in physical science. It’s also one of the most useful to understand, since we all use electricity daily. This skill sheet reviews some of the important terms in the study of electricity. In the reading section, you’ll find questions that check your understanding. If you’re not sure of the answer, go back and read that section again. In the practice section, you will have an opportunity to show that you know how voltage, current, and resistance are related in real-world situations.

What is voltage?

You know that water will flow from a higher tank through a hose into a lower tank. The water in the higher tank has greater potential energy than the water in the lower tank. A similar thing happens with the flow of charges in an electric circuit.

Charges flow in a circuit when there is a difference in energy level from one end of the battery (or any other energy source) to the other. This energy difference is measured in volts. The energy difference causes the charges to move from a higher to a lower voltage in a closed circuit.

Think of voltage as the amount of “push” the electrical source supplies to the circuit. A meter is used to measure the amount of energy difference or “push” in a circuit. The meter reads the voltage difference (in volts) between the positive and the negative ends of the power source (the battery). This voltage difference supplies the energy to make charges flow in a circuit.

1. What is the difference between placing a 1.5-volt battery in a circuit and placing a 9-volt battery in a circuit?

What is current?

Current describes the flow of electric charges. Current is the actual measure of how many charges are flowing through the circuit in a certain amount of time. Current is measured in units called amperes.

Just as the rate of water flowing out of a faucet can be fast or slow, electrical current can move at different rates. The type, length, and thickness of wire all effect how much current flows in a circuit. Resistors slow the flow of current. Adding voltage causes the current to speed up.

2. What could you do to a closed circuit consisting of a battery, a light bulb, and a switch that would increase the amount of current? Explain your answer.

3. What could you do to a closed circuit consisting of a battery, a light bulb, and a switch that would decrease the amount of current? Explain your answer.
What is resistance?

Resistance is the measure of how easily charges flow through a circuit. High resistance means it is difficult for charges to flow. Low resistance means it is easy for charges to flow. Electrical resistance is measured in units called **ohms** (abbreviated with the symbol \( \Omega \)).

Resistors are items that reduce the flow of charge in a circuit. They act like “speed bumps” in a circuit. A light bulb is an example of a resistor.

4. Describe one thing that you could do to the wire used in a circuit to **decrease** the amount of resistance presented by the wire.

How are voltage, current, and resistance related?

When the voltage (push) increases, the current (flow of charges) will also increase, and when the voltage decreases, the current likewise decreases. These two variables, voltage and current, are said to be directly proportional.

When the resistance in an electric circuit increases, the flow of charges (current) decreases. These two variables, resistance and current, are said to be inversely proportional. When one goes up, the other goes down, and vice versa.

The law that relates these three variables is called Ohm’s Law. The formula is:

\[
\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms, } \Omega)}
\]

5. In your own words, state the relationship between resistance and current, as well as the relationship between voltage and current.

- In a circuit, how many amps of current flow through a resistor such as a 6-ohm light bulb when using four 1.5-volt batteries as an energy supply?

**Solution:**

\[
\text{Current} = \frac{4 \times 1.5 \text{ volts}}{6 \text{ ohms}} = \frac{6 \text{ volts}}{6 \text{ ohms}}
\]

\[
\text{Current} = 1 \text{ amp}
\]
Now you will have the opportunity to demonstrate your understanding of the relationship between current, voltage and resistance. Answer each of the following questions and show your work.

1. How many amps of current flow through a circuit that includes a 9-volt battery and a bulb with a resistance of 6 ohms?

2. How many amps of current flow through a circuit that includes a 9-volt battery and a bulb with a resistance of 12 ohms?

3. How much voltage would be necessary to generate 10 amps of current in a circuit that has 5 ohms of resistance?

4. How many ohms of resistance must be present in a circuit that has 120 volts and a current of 10 amps?
16.3 Ohm’s Law

A German physicist, Georg S. Ohm, developed this mathematical relationship, known as Ohm’s Law, which is present in most circuits. It states that if the voltage in a circuit increases, so does the current. If the resistance increases, the current decreases.

\[ \text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms, } \Omega \text{)}} \]

To work through this skill sheet, you will need the symbols used to depict circuits in diagrams. The symbols that are most commonly used for circuit diagrams are provided to the right.

If a circuit contains more than one battery, the total voltage is the sum of the individual voltages. A circuit containing two 6 V batteries has a total voltage of 12 V. [Note: The batteries must be connected positive to negative for the voltages to add.]

**EXAMPLE**

- If a toaster produces 12 ohms of resistance in a 120-volt circuit, what is the amount of current in the circuit?

**Solution:**

\[ I = \frac{V}{R} = \frac{120 \text{ volts}}{12 \text{ ohms}} = 10 \text{ amps} \]

The current in the toaster circuit is 10 amps.

**Note:** If a problem asks you to calculate the voltage or resistance, you must rearrange the equation to solve for V or R. All three forms of the equation are listed below.

\[ I = \frac{V}{R}, \quad V = IR, \quad R = \frac{V}{I} \]

**PRACTICE**

Answer the following question using Ohm’s law. Don’t forget to show your work.

1. How much current is in a circuit that includes a 9-volt battery and a bulb with a resistance of 3 ohms?
2. How much current is in a circuit that includes a 9-volt battery and a bulb with a resistance of 12 ohms?
3. A circuit contains a 1.5 volt battery and a bulb with a resistance of 3 ohms. Calculate the current.
4. A circuit contains two 1.5 volt batteries and a bulb with a resistance of 3 ohms. Calculate the current.
5. What is the voltage of a circuit with 15 amps of current and toaster with 8 ohms of resistance?
6. A light bulb has a resistance of 4 ohms and a current of 2 A. What is the voltage across the bulb?
7. How much voltage would be necessary to generate 10 amps of current in a circuit that has 5 ohms of resistance?

8. How many ohms of resistance must be present in a circuit that has 120 volts and a current of 10 amps?

9. An alarm clock draws 0.5 A of current when connected to a 120 volt circuit. Calculate its resistance.

10. A portable CD player uses two 1.5 V batteries. If the current in the CD player is 2 A, what is its resistance?

11. You have a large flashlight that takes 4 D-cell batteries. If the current in the flashlight is 2 amps, what is the resistance of the light bulb? (Hint: A D-cell battery has 1.5 volts.)

12. Use the diagram below to answer the following problems.

![Diagram of two circuits](image)

a. What is the total voltage in each circuit?
b. How much current would be measured in each circuit if the light bulb has a resistance of 6 ohms?
c. How much current would be measured in each circuit if the light bulb has a resistance of 12 ohms?
d. Is the bulb brighter in circuit A or circuit B? Why?

13. What happens to the current in a circuit if a 1.5-volt battery is removed and is replaced by a 9-volt battery?


15. In your own words, state the relationship between voltage and current in a circuit.

16. What could you do to a closed circuit consisting of 2 batteries, 2 light bulbs, and a switch to increase the current? Explain your answer.

17. What could you do to a closed circuit consisting of 2 batteries, 2 light bulbs, and a switch to decrease the current? Explain your answer.

18. You have four 1.5 V batteries, a 1 Ω bulb, a 2 Ω bulb, and a 3 Ω bulb. Draw a circuit you could build to create each of the following currents. There may be more than one possible answer for each.

a. 1 ampere
b. 2 amperes
c. 3 amperes
d. 6 amperes
16.4 Series Circuits

In a series circuit, current follows only one path from the positive end of the battery toward the negative end. The total resistance of a series circuit is equal to the sum of the individual resistances. The amount of energy used by a series circuit must equal the energy supplied by the battery. In this way, electrical circuits follow the law of conservation of energy. Understanding these facts will help you solve problems that deal with series circuits.

To answer the questions in the practice section, you will have to use Ohm’s law. Remember that:

\[
\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms, } \Omega)}
\]

Some questions ask you to calculate a voltage drop. We often say that each resistor (or light bulb) creates a separate voltage drop. As current flows along a series circuit, each resistor uses up some energy. As a result, the voltage gets lower after each resistor. If you know the current in the circuit and the resistance of a particular resistor, you can calculate the voltage drop using Ohm’s law.

\[
\text{Voltage drop across resistor (volts)} = \text{Current through resistor (amps)} \times \text{Resistance of one resistor (ohms)}
\]

1. Use the series circuit pictured to the right to answer questions (a)–(e).
   a. What is the total voltage across the bulbs?
   b. What is the total resistance of the circuit?
   c. What is the current in the circuit?
   d. What is the voltage drop across each light bulb? (Remember that voltage drop is calculated by multiplying current in the circuit by the resistance of a particular resistor: \(V = IR\).)
   e. Draw the path of the current on the diagram.

2. Use the series circuit pictured to the right to answer questions (a)–(e).
   a. What is the total voltage across the bulbs?
   b. What is the total resistance of the circuit?
   c. What is the current in the circuit?
   d. What is the voltage drop across each light bulb?
   e. Draw the path of the current on the diagram.

3. What happens to the current in a series circuit as more light bulbs are added? Why?

4. What happens to the brightness of each bulb in a series circuit as additional bulbs are added? Why?
5. Use the series circuit pictured to the right to answer questions (a), (b), and (c).
   a. What is the total resistance of the circuit?
   b. What is the current in the circuit?
   c. What is the voltage drop across each resistor?

6. Use the series circuit pictured to the right to answer questions (a)–(e).
   a. What is the total voltage of the circuit?
   b. What is the total resistance of the circuit?
   c. What is the current in the circuit?
   d. What is the voltage drop across each light bulb?
   e. Draw the path of the current on the diagram.

7. Use the series circuit pictured right to answer questions (a), (b), and (c). Consider each resistor equal to all others.
   a. What is the resistance of each resistor?
   b. What is the voltage drop across each resistor?
   c. On the diagram, show the amount of voltage in the circuit before and after each resistor.

8. Use the series circuit pictured right to answer questions (a)–(d).
   a. What is the total resistance of the circuit?
   b. What is the current in the circuit?
   c. What is the voltage drop across each resistor?
   d. What is the sum of the voltage drops across the three resistors? What do you notice about this sum?

9. Use the diagram to the right to answer questions (a), (b), and (c).
   a. How much current would be measured in each circuit if each light bulb has a resistance of 6 ohms?
   b. How much current would be measured in each circuit if each light bulb has a resistance of 12 ohms?
   c. What happens to the amount of current in a series circuit as the number of batteries increases?
16.4 Parallel Circuits

A parallel circuit has at least one point where the circuit divides, creating more than one path for current. Each path is called a branch. The current through a branch is called branch current. If current flows into a branch in a circuit, the same amount of current must flow out again. This rule is known as Kirchoff’s current law.

Because each branch in a parallel circuit has its own path to the battery, the voltage across each branch is equal to the battery’s voltage. If you know the resistance and voltage of a branch you can calculate the current with Ohm’s Law \((I = \frac{V}{R})\).

1. Use the parallel circuit pictured right to answer questions (a)–(d).
   a. What is the voltage across each bulb?
   b. What is the current in each branch?
   c. What is the total current provided by the battery?
   d. Use the total current and the total voltage to calculate the total resistance of the circuit.

2. Use the parallel circuit pictured right to answer questions (a)–(d).
   a. What is the voltage across each bulb?
   b. What is the current in each branch?
   c. What is the total current provided by the battery?
   d. Use the total current and the total voltage to calculate the total resistance of the circuit.

3. Use the parallel circuit pictured right to answer questions (a)–(d).
   a. What is the voltage across each resistor?
   b. What is the current in each branch?
   c. What is the total current provided by the batteries?
   d. Use the total current and the total voltage to calculate the total resistance of the circuit.

4. Use the parallel circuit pictured right to answer questions (a)–(c).
   a. What is the voltage across each resistor?
   b. What is the current in each branch?
   c. What is the total current provided by the battery?
In part (d) of problems 1, 2, and 3, you calculated the total resistance of each circuit. This required you to first find the current in each branch. Then you found the total current and used Ohm’s law to calculate the total resistance. Another way to find the total resistance of two parallel resistors is to use the formula shown below.

$$R_{total} = \frac{R_1 \times R_2}{R_1 + R_2}$$

**EXAMPLE**

Calculate the total resistance of a circuit containing two 6 ohm resistors.

<table>
<thead>
<tr>
<th>Given</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>The circuit contains two 6 Ω resistors in parallel.</td>
<td>$R_{total} = \frac{6 , \Omega \times 6 , \Omega}{6 , \Omega + 6 , \Omega}$</td>
</tr>
<tr>
<td>The total resistance of the circuit.</td>
<td>$R_{total} = 3 , \Omega$</td>
</tr>
</tbody>
</table>

The total resistance is 3 ohms.

**PRACTICE 2**

1. Calculate the total resistance of a circuit containing each of the following combinations of resistors.
   a. Two 8 Ω resistors in parallel
   b. Two 12 Ω resistors in parallel
   c. A 4 Ω resistor and an 8 Ω resistor in parallel
   d. A 12 Ω resistor and a 3 Ω resistor in parallel

2. To find the total resistance of three resistors A, B, and C in parallel, first use the formula to find the total of resistors A and B. Then use the formula again to combine resistor C with the total of A and B. Use this method to find the total resistance of a circuit containing each of the following combinations of resistors.
   a. Three 8 Ω resistors in parallel
   b. Two 6 Ω resistors and a 2 Ω resistor in parallel
   c. A 1 Ω, a 2 Ω, and a 3 Ω resistor in parallel
16.4 Thomas Edison

Thomas Alva Edison holds the record for the most patents issued to an individual in the United States: 1,093. He is famous for saying that “Genius is one percent inspiration and ninety-nine percent perspiration.” Edison’s hard work and imagination brought us the phonograph, practical incandescent lighting, motion pictures, and the alkaline storage battery.

The young entrepreneur

Thomas Alva Edison was born February 11, 1847, in Milan, Ohio, the youngest of seven children. His family moved to Port Huron, Michigan, in 1854 and Thomas attended school there—for a few months. He was taught reading, writing, and simple arithmetic by his mother, a former teacher, and he read widely and voraciously. The basement was his first laboratory.

When he was 13, Thomas started selling newspapers and candy on the train from Port Huron to Detroit. Waiting for the return train, he often read science and technology books. He set up a chemistry lab in an empty boxcar, until he accidentally set the car on fire.

At 16, Thomas learned to be a telegraph operator and began to travel the country for work. His interest in experiments and gadgets grew and he invented an automatic timer to send telegraph messages while he slept. About this time his hearing was deteriorating; he was left with only about 20 percent hearing in one ear.

First a patent, then business

In 1868 Edison arrived in Boston. His first patent was issued there for an electronic vote recorder. While the device worked very well, it was a commercial failure. Edison vowed that, in the future, he would only invent things he was certain the public would want.

He moved on to New York, where he invented a “Universal Stock Printer” for which he was paid $40,000, a huge sum he found hard to comprehend. After developing some devices to improve telegraph communications, Edison had enough money to build a research lab in Menlo Park, New Jersey.

The invention factory

Edison’s facility had everything he needed for inventing: machine and carpentry shops, a lab, offices, and a library. He hired assistants who specialized where he felt he was lacking, in mathematics, for instance.

The concept of a commercial research facility—an “invention factory” of sorts—was new. Some consider Menlo Park itself to be one of Edison’s most important inventions.

It was there Edison invented the tin foil phonograph, the first machine to record and play back sounds. Next, he developed a practical, safe, and affordable incandescent light. The company he formed to manufacture and market this invention eventually became General Electric.

In 1888, Edison opened an even larger research complex in West Orange, New Jersey. Here he improved the phonograph and created a device that “does for the eye what the phonograph does for the ear.” This was the first motion picture player.

Not a man to be discouraged

Not all of Edison’s ideas were successful. In the 1890s he sold all his stock in General Electric and invested millions to develop better methods of mining iron ore. He never was able to come up with a workable process and the investment was a loss.

One of the most remarkable aspects of Edison’s character was his refusal to be discouraged by failure. The 3,500 notebooks he kept illustrate his typical approach to inventing: brainstorm as many avenues as possible to create a product, try anything that seems remotely workable, and record everything. Failed experiments, he said, helped direct his thinking toward more useful designs.

Edison also worked to create an efficient storage battery to use in electric cars. By the time his alkaline battery was ready, electric cars were uncommon. But the invention proved useful in other devices, like lighting railway cars and miners’ lamps. Edison’s last patent was granted when he was 83, the year before he died, and his last big undertaking was an attempt, at Henry Ford’s request, to develop an alternative source of rubber. He was still working on the project when he died in 1931.
Reading reflection

1. Name three different avenues by which Thomas Edison received an education.

2. What did Edison learn from his attempts to sell his first patented invention?

3. Describe Edison’s “invention factory.”

4. Name two important inventions that came out of Menlo Park.

5. Describe the process Edison used to invent things.

6. How did Edison view his projects that failed?

7. How do you think the tin foil phonograph worked? Discuss and compare your ideas with a fellow member of your class.

8. **Research:** Edison holds the record for the most patents issued to an individual in the United States. Use a library or the Internet to research three of his inventions that are not mentioned in this biography, and briefly describe each one.
16.4 George Westinghouse

George Westinghouse was both an imaginative tinkerer and a bold entrepreneur. His inventions had a profound effect on nineteenth-century transportation and industrial development in the United States. His air brakes and signaling systems made railway systems safer at higher speeds, so that railroads became a practical method of transporting goods across the country. He promoted alternating current as the best means of providing electric power to businesses and homes, and his method became the worldwide standard. Westinghouse obtained 361 patents over the course of his life.

A boyhood among machines

George Westinghouse was born October 6, 1846, in Central Bridge, New York. When he was 10, his family moved to Schenectady, where his father opened a shop that manufactured agricultural machinery. George spent a great deal of time working and tinkering there.

After serving in both the Union Army and Navy in the Civil War, Westinghouse attended college for three months. He dropped out after receiving his first patent in 1865, for a rotary steam engine he had invented in his father’s shop.

An inventive train of thought

In 1866, Westinghouse was aboard a train that had to come to a sudden halt to avoid colliding with a wrecked train. To stop the train, brakemen manually applied brakes to each individual car based on a signal from the engineer.

Westinghouse believed there could be a safer way to stop these heavy trains. In April 1869, he patented an air brake that enabled the engineer to stop all the cars in tandem. That July he founded the Westinghouse Air Brake Company, and soon his brakes were used by most of the world’s railways.

The new braking system made it possible for trains to travel safely at much higher speeds. Westinghouse next turned his attention to improving railway signaling and switching systems. Combining his own inventions with others, he created the Union Switch and Signal Company.

Long-distance electricity

Next, Westinghouse became interested in transmitting electricity over long distances. He saw the potential benefits of providing electric power to individual homes and businesses, and in 1884 formed the Westinghouse Electric Company. Westinghouse learned that Nikola Tesla had developed alternating current and he persuaded Tesla to join the company.

Initially, Westinghouse met with resistance from Thomas Edison and others who argued that direct current was a safer alternative. But direct current could not be transmitted over distances longer than three miles. Westinghouse demonstrated the potential of alternating current by lighting the streets of Pittsburgh, Pennsylvania, and, in 1893, the entire Chicago World’s Fair. Afterward, alternating current became the standard means of transmitting electricity.

From waterfalls to elevated railway

Also in 1893, Westinghouse began yet another new project: the construction of three hydroelectric generators to harness the power of Niagara Falls on the New York-Canada border. By November 1895, electricity generated there was being used to power industries in Buffalo, some 20 miles away.

Another Westinghouse interest was alternating current locomotives. He introduced this new technology first in 1905 with the Manhattan Elevated Railway in New York City, and later with the city’s subway system.

An always inquiring mind

The financial panic of 1907 caused Westinghouse to lose control of his companies. He spent much of his last years in public service. Westinghouse died in 1914 and left a legacy of 361 patents in his name—the final one received four years after his death.
Reading reflection

1. Where did George Westinghouse first develop his talent for inventing things?

2. How did Westinghouse make it possible for trains to travel more safely at higher speeds?

3. Why did Westinghouse promote alternating current over direct current for delivering electricity to businesses and homes?

4. How did Westinghouse turn public opinion in favor of alternating current?

5. Together with a partner, explain the difference between direct and alternating current. Write your explanation as a short paragraph and include a diagram.

6. How did Westinghouse provide electrical power to the city of Buffalo, New York?

7. Ordinary trains in Westinghouse’s time were coal-powered steam engines. How were Westinghouse’s Manhattan elevated trains different?

8. Research: Westinghouse had a total of 361 patents to his name. Use a library or the Internet to find out about three inventions not mentioned in this brief biography, and describe each one.
16.4 Lewis Latimer

Latimer, often called a “Renaissance Man,” was an accomplished African-American inventor receiving seven U.S. patents. His professional and personal achievements define him as a humanitarian, artist, and scientist.

Son of former slaves

Lewis Howard Latimer was born on September 4, 1848 in Chelsea, Massachusetts. Latimer's parents had escaped from slavery in Virginia and moved north. In Boston, Latimer's father, George, was arrested and jailed because he was considered a fugitive. The Massachusetts Supreme Court ruled that he belonged to his owner in Virginia.

The people of Boston protested and local supporters paid for his release. George was free. George and his wife settled in Chelsea where they started their family. In 1858, George, fearing he would be forced to return to slavery, went into hiding, leaving his family behind.

Young Lewis Latimer attended grammar school in Chelsea and was a high-achieving student. As a teenager, Lewis lied about his age to join the Union Navy during the Civil War. After four years of military service, the war ended and Latimer was honorably discharged.

Drafting a career

Latimer looked for work in Boston and finally found a job as an office boy with a patent law firm, Crosby and Gould. He earned $3.00 per week. At the firm, Lewis studied the detailed patent drawings prepared by the draftsmen. Over time, he taught himself the drafting trade using the tools and books available there.

Latimer showed his drawings to his boss and secured a job as a draftsman earning $20.00 per week. He eventually became chief draftsman and worked at the firm for eleven years.

During this time, Latimer created patent drawings for Alexander Graham Bell. He completed the drawings and submitted them only hours before a competing inventor. Bell was awarded the telephone patent in 1876 due to Latimer's hard work and drafting skills.

An enlightened inventor

Latimer was not only a talented draftsman, but also a successful inventor. While at Crosby and Gould, he developed his first invention—mechanical improvements for railroad train water closets (also known as toilets!).

After Crosby and Gould, Latimer worked as a draftsman at the Follandsbee Machine Shop. Here he met Hiram Maxim and was hired to work at Maxim's company, U.S. Electric Lighting. Maxim was an inventor searching for ways to improve Thomas Edison's light bulb. Edison held the patent for the light bulb, but the life span of the bulb was very short. Maxim wanted to extend the life of the light bulb and turned to Latimer for help.

Latimer taught himself the details of electricity. In 1881, he invented carbon filaments to replace paper filaments in light bulbs. He then went on to improve the manufacturing process for carbon filaments. Now light bulbs lasted longer, were more affordable, and had more uses. Latimer oversaw the installation of electric street lights in North America and London. He became chief electrical engineer for U.S. Electric Lighting and supervised The Maxim-Westin Electric Lighting Company in London.

Edison and beyond

In 1885, Thomas Edison hired Latimer to work in the legal department of Edison Electric Light Company. Latimer was the chief draftsman and patent authority working to protect Edison's patents. He wrote the widely acclaimed electrical engineering book called *Incandescent Electric Lighting: A Practical Description of the Edison System*. Latimer became one of only 28 members of the “Edison Pioneers” and the only African-American member. The Edison Pioneers were the most highly regarded men in the electrical field. Edison's company eventually became the General Electric Company.

Latimer’s additional inventions included an early version of the air conditioner; a locking rack for hats, coats, and umbrellas; and a book support. He was also a poet, musician, playwright, painter, civil rights activist, husband, and father. Latimer died in 1928 at age 80.
Reading reflection

1. How did Lewis Latimer become a draftsman and electrical engineer?

2. List Latimer's major inventions. What was his most important invention and why?

3. **Research:** What is a “Renaissance man”? Why is Latimer referred to as a Renaissance man?

4. **Research:** Latimer was an accomplished poet. Locate and identify the names of two of his poems.

5. **Research:** When did the Edison Pioneers first meet? Locate an excerpt from the obituary published by the Edison Pioneers honoring Lewis Latimer.
17.1 Magnetic Earth

Earth’s magnetic field is very weak compared with the strength of the field on the surface of the ceramic magnets you probably have in your classroom. The gauss is a unit used to measure the strength of a magnetic field. A small ceramic permanent magnet has a field of a few hundred up to 1,000 gauss at its surface. At Earth’s surface, the magnetic field averages about 0.5 gauss. Of course, the field is much stronger nearer to the core of the planet.

1. What is the source of Earth’s magnetic field according to what you have read in chapter 17?

2. Today, Earth’s magnetic field is losing approximately 7 percent of its strength every 100 years. If the strength of Earth’s magnetic field at its surface is 0.5 gauss today, what will it be 100 years from now?

3. Describe what you think might happen if Earth’s magnetic field continues to lose strength.

4. The graphic to the right illustrates one piece of evidence that proves the reversal of Earth’s poles during the past millions of years. The ‘crust’ of Earth is a layer of rock that covers Earth’s surface. There are two kinds of crust—continental and oceanic. Oceanic crust is made continually (but slowly) as magma from Earth’s interior erupts at the surface. Newly formed crust is near the site of eruption and older crust is at a distance from the site. Based on what you know about magnetism, why might oceanic crust rock be a record of the reversal of Earth’s magnetic field? (HINT: What happens to materials when they are exposed to a magnetic field?)

5. The terms magnetic south pole and geographic north pole refer to locations on Earth. If you think of Earth as a giant bar magnet, the magnetic south pole is the point on Earth’s surface above the south end of the magnet. The geographic north pole is the point where Earth’s axis of rotation intersects its surface in the northern hemisphere. Explain these terms by answering the following questions.
   a. Are the locations of the magnetic south pole and the geographic north pole near Antarctica or the Arctic?
   b. How far is the magnetic south pole from the geographic north pole?
   c. In your own words, define the difference between the magnetic south pole and the geographic north pole.

6. A compass is a magnet and Earth is a magnet. How does the magnetism of a compass work with the magnetism of Earth so that a compass is a useful tool for navigating?
7. The directions—north, east, south, and west—are arranged on a compass so that they align with 360 degrees. This means that zero degrees (0°) and 360° both represent north. For each of the following directions by degrees, write down the direction in words. The first one is done for you.
   a. 45°  Answer: The direction is northeast.
   b. 180°
   c. 270°
   d. 90°
   e. 135°
   f. 315°

Magnetic declination

Earth’s geographic north pole (true north) and magnetic south pole are located near each other, but they are not at the same exact location. Because a compass needle is attracted to the magnetic south pole, it points slightly east or west of true north. The angle between the direction a compass points and the direction of the geographic north pole is called magnetic declination. Magnetic declination is measured in degrees and is indicated on topographical maps.

8. Let’s say you were hiking in the woods and relying on a map and compass to navigate. What would happen if you didn’t correct your compass for magnetic declination?

9. Are there places on Earth where magnetic declination equals 0°? Use the Internet or your local library to find out where on Earth there is no magnetic declination.
17.2 Model Maglev Train Project

Magnetically levitating (Maglev) trains use electromagnetic force to lift the train above the tracks. This system greatly reduces wear because there are few moving parts that carry heavy loads. It’s also more fuel efficient, since the energy needed to overcome friction is greatly reduced. Although maglev technology is still in its experimental stages, many engineers believe it will become the standard for mass transit systems over the next 100 years.

This project will give you an opportunity to create a model maglev train. You can even experiment with different means of providing power to your train.

Materials

- 52 one-inch square magnets with north and south poles on the faces, rather than ends (found at hobby shops)
- One strip of 1/4-inch thick foam core, 24 inches long by 4 inches wide
- Two strips of 1/4-inch thick foam core, 24 inches long by 2.5 inches wide
- One strip of 1/4-inch thick foam core, 6 inches long by 3.75 inches wide
- Hot melt glue and glue gun
- Masking tape

Directions

1. Cut a strip of masking tape 24 inches long. Press a line of 24 magnets onto the tape, north sides up.

2. Hold an additional magnet north side down and run it along the strip to make sure that the entire “track” will repel the magnet. Flip over any magnets that attract your test magnet.

3. Glue the magnet strip along one long side of the 24-by-4-inch foam core rectangle.

4. Repeat steps 1-2, then glue the second magnet strip along the opposite side to create the other track.

5. Place a bead of hot glue along the cut edge and attach one 24-by-2.5 inch foam core rectangle to form a short wall.
6. Repeat step 5 to form the opposite wall. This keeps the train from sliding sideways off the track.

7. To create your train, glue the south side of a magnet to each corner of the small foam core rectangle.

8. Turn the train over so that the north side of its magnets face the tracks. Place your train above the track and watch what happens!

**Extensions:**

1. Experiment with various means to propel your train along the tracks. Consider using balloons, rubber bands and toy propellers, small motors (available at hobby stores) or even jet propulsion using vinegar and baking soda as fuel.

2. Build a longer, more permanent track using plywood shelving. Use clear, flexible plastic for the front wall so that you can see the train floating above the track.

3. Find out how much weight your train can carry. Are some propulsion systems able to carry more weight than others? Why?

4. Have a design contest to see who can build the fastest train, or the train that can carry the most weight from one end of the track to the other.
Despite little formal schooling, Michael Faraday rose to become one of England’s top research scientists of the nineteenth century. He is best known for his discovery of electromagnetic induction, which made possible the large-scale production of electricity in power plants.

Reading his way to a job

Michael Faraday was born on September 22, 1791, in Surrey, England, the son of a blacksmith. His family moved to London, where Michael received a rudimentary education at a local school.

At 14, he was apprenticed to a bookbinder. He enjoyed reading the materials he was asked to bind, and found himself mesmerized by scientific papers that outlined new discoveries.

A wealthy client of the bookbinder noticed this voracious reader and gave him tickets to hear Humphry Davy, the British chemist who had discovered potassium and sodium, give a series of lectures to the public.

Faraday took detailed notes at each lecture. He bound the notes and sent them to Davy, asking him for a job. In 1812, Davy hired him as a chemistry laboratory assistant at the Royal Institution, London’s top scientific research facility.

Despite his lack of formal training in science or math, Faraday was an able assistant and soon began independent research in his spare time. In the early 1820s, he discovered how to liquefy chlorine and became the first to isolate benzene, an organic solvent with many commercial uses.

The first electric motor

Faraday also was interested in electricity and magnetism. After reading about the work of Hans Christian Oersted, the Danish physicist, chemist, and electromagnetist, he repeated Oersted’s experiments and used what he learned to build a machine that used an electromagnet to cause rotation—the first electric motor.

Next, he tried to do the opposite, to use a moving magnet to cause an electric current. In 1831, he succeeded. Faraday’s discovery is called electromagnetic induction, and it is used by power plants to generate electricity even today.

The Faraday effect

Faraday first developed the concept of a field to describe magnetic and electric forces, and used iron filings to demonstrate magnetic field lines. He also conducted important research in electrolysis and invented a voltmeter.

Faraday was interested in finding a connection between magnetism and light. In 1845 he discovered that a strong magnetic field could rotate the plane of polarized light. Today this is known as the Faraday effect.

A scientist’s public education

Faraday was a teacher as well as a researcher. When he became director of the Royal Institution laboratory in 1825, he instituted a popular series of Friday Evening Discourses. Here paying guests (including Prince Albert, who was Queen Victoria’s husband) were entertained with demonstrations of the latest discoveries in science.

A series of lectures on the chemistry and physics of flames, titled “The Natural History of a Candle,” was among the original Christmas Lectures for Children, which continue to this day.

Named in his honor

Faraday continued his work at the Royal Institution until just a few years before his death in 1867. Two units of measure have been named in his honor: the farad, a unit of capacitance, and the faraday, a unit of charge.
Reading reflection

1. What did Michael Faraday do to get a job with Humphry Davy? Why was this effort important in getting Faraday started in science?

2. Research benzene and list two modern-day commercial uses for this chemical.

3. Based on the reading, define electromagnetic induction.

4. In your own words, describe the Faraday effect. In your description, explain the term “polarized light.”

5. How did Faraday contribute to society during his time as the director of the Royal Institution laboratory?

6. Name two ways in which Faraday’s work affects your own life in the twenty-first century.

7. Imagine you could go back in time to see one of Faraday’s demonstrations. Explain why you would like to attend one of his demonstrations.

8. **Activity:** Use iron filings and a magnet to demonstrate magnetic field lines, or prepare a simple demonstration of electromagnetic induction for your classmates.
17.4 Transformers

A transformer is a device used to change voltage and current. You may have noticed the gray electrical boxes often located between two houses or buildings. These boxes protect the transformers that “step down” high voltage from power lines (13,800 volts) to standard household voltage (120 volts).

17.4 How a transformer works:

1. The primary coil is connected to outside power lines. Current in the primary coil creates a magnetic field through the secondary coil.

2. The current in the primary coil changes frequently because it is alternating current.

3. As the current changes, so does the strength and direction of the magnetic field through the secondary coil.

4. The changing magnetic field through the secondary coil induces current in the secondary coil. The secondary coil is connected to the wiring in your home.

Transformers work because the primary and secondary coils have different numbers of turns. If the secondary coil has fewer turns, the induced voltage in the secondary coil is lower than the voltage applied to the primary coil. You can use the proportion below to figure out how number of turns affects voltage:

\[
\frac{V_1}{V_2} = \frac{N_1}{N_2}
\]
A transformer steps down the power line voltage (13,800 volts) to standard household voltage (120 volts). If the primary coil has 5,750 turns, how many turns must the secondary coil have?

Solution:

\[
\frac{V_1}{V_2} = \frac{N_1}{N_2}
\]

\[
\frac{13,800 \text{ volts}}{120 \text{ volts}} = \frac{5,750 \text{ turns}}{N_2}
\]

\[
N_2 = 50 \text{ turns}
\]

1. In England, standard household voltage is 240 volts. If you brought your own hair dryer on a trip there, you would need a transformer to step down the voltage before you plug in the appliance. If the transformer steps down voltage from 240 to 120 volts, and the primary coil has 50 turns, how many turns does the secondary coil have?

2. You are planning a trip to Singapore. Your travel agent gives you the proper transformer to step down the voltage so you can use your electric appliances there. Curious, you open the case and find that the primary coil has 46 turns and the secondary has 24 turns. Assuming the output voltage is 120 volts, what is the standard household voltage in Singapore?

3. A businessman from Zimbabwe buys a transformer so that he can use his own electric appliances on a trip to the United States. The input coil has 60 turns while the output coil has 110 turns. Assuming the input voltage is 120 volts, what is the output voltage necessary for his appliances to work properly? (This is the standard household output voltage in Zimbabwe.)

4. A family from Finland, where standard household voltage is 220 volts, is planning a trip to Japan. The transformer they need to use their appliances in Japan has an input coil with 250 turns and an output coil with 550 turns. What is the standard household voltage in Japan?

5. An engineer in India (standard household voltage = 220 volts) is designing a transformer for use on her upcoming trip to Canada (standard household voltage = 120 volts). If her input coil has 240 turns, how many turns should her output coil have?

6. While in Canada, the engineer buys a new electric toothbrush. When she returns home she designs another transformer so she can use the toothbrush in India. This transformer also has an input coil with 240 turns. How many turns should the output coil have?
17.4 Electrical Power

How do you calculate electrical power?

In this skill sheet you will review the relationship between electrical power and Ohm’s law. As you work through the problems, you will practice calculating the power used by common appliances in your home.

During everyday life we hear the word *watt* mentioned in reference to things like light bulbs and electric bills. The watt is the unit that describes the rate at which energy is used by an electrical device. Energy is never created or destroyed, so “used” means it is converted from electrical energy into another form such as light or heat. Since energy is measured in joules, power is measured in joules per second. One joule per second is equal to one watt.

To calculate the electrical power “used” by an electrical component, multiply the voltage by the current.

\[
\text{Current} \times \text{Voltage} = \text{Power}, \text{ or } P = IV
\]

A kilowatt (kWh) is 1,000 watts or 1,000 joules of energy per second. On an electric bill you may have noticed the term kilowatt-hour. A kilowatt-hour means that one kilowatt of power has been used for one hour. To determine the kilowatt-hours of electricity used, multiply the number of kilowatts by the time in hours.

**EXAMPLE**

- You use a 1,500-watt heater for 3 hours. How many kilowatt-hours of electricity did you use?

\[
1,500 \text{ watts} \times \frac{1 \text{ kilowatt}}{1,000 \text{ watts}} = 1.5 \text{ kilowatts}
\]

\[
1.5 \text{ kilowatts} \times 3 \text{ hours} = 4.5 \text{ kilowatt-hours}
\]

You used 4.5 kilowatt-hours of electricity.

**PRACTICE**

1. Your oven has a power rating of 5,000 watts.
   a. How many kilowatts is this?
   b. If the oven is used for 2 hours to bake cookies, how many kilowatt-hours (kWh) are used?
   c. If your town charges $0.15 per kWh, what is the cost to use the oven to bake the cookies?

2. You use a 1,200-watt hair dryer for 10 minutes each day.
   a. How many minutes do you use the hair dryer in a month? (Assume there are 30 days in the month.)
   b. How many hours do you use the hair dryer in a month?
   c. What is the power of the hair dryer in kilowatts?
   d. How many kilowatt-hours of electricity does the hair dryer use in a month?
   e. If your town charges $0.15 per kWh, what is the cost to use the hair dryer for a month?

3. Calculate the power rating of a home appliance (in kilowatts) that uses 8 amps of current when plugged into a 120-volt outlet.
4. Calculate the power of a motor that draws a current of 2 amps when connected to a 12 volt battery.

5. Your alarm clock is connected to a 120 volt circuit and draws 0.5 amps of current.
   a. Calculate the power of the alarm clock in watts.
   b. Convert the power to kilowatts.
   c. Calculate the number of kilowatt-hours of electricity used by the alarm clock if it is left on for one year.
   d. Calculate the cost of using the alarm clock for one year if your town charges $0.15 per kilowatt-hour.

6. Using the formula for power, calculate the amount of current through a 75-watt light bulb that is connected to a 120-volt circuit in your home.

7. The following questions refer to the diagram.
   a. What is the total voltage of the circuit?
   b. What is the current in the circuit?
   c. What is the power of the light bulb?

8. A toaster is plugged into a 120-volt household circuit. It draws 5 amps of current.
   a. What is the resistance of the toaster?
   b. What is the power of the toaster in watts?
   c. What is the power in kilowatts?

9. A clothes dryer in a home has a power of 4,500 watts and runs on a special 220-volt household circuit.
   a. What is the current through the dryer?
   b. What is the resistance of the dryer?
   c. How many kilowatt-hours of electricity are used by the dryer if it is used for 4 hours in one week?
   d. How much does it cost to run the dryer for one year if it is used for 4 hours each week at a cost of $0.15 per kilowatt-hour?

10. A circuit contains a 12-volt battery and two 3-ohm bulbs in series.
    a. Calculate the total resistance of the circuit.
    b. Calculate the current in the circuit.
    c. Calculate the power of each bulb.
    d. Calculate the power supplied by the battery.

11. A circuit contains a 12-volt battery and two 3-ohm bulbs in parallel.
    a. What is the voltage across each branch?
    b. Calculate the current in each branch.
    c. Calculate the power of each bulb.
    d. Calculate the total current in the circuit.
    e. Calculate the power supplied by the battery.
18.1 Andrew Ellicott Douglass

Douglass, a successful American astronomer, is better known as the father of dendrochronology. His accomplishments in tree ring analysis and cross-dating allowed him to create a tree calendar dating back to AD 700 for the American Southwest.

Vermont Native

Andrew Ellicott Douglass was born on July 5, 1867 in Windsor, Vermont. Andrew was one of five children born to Sarah and Malcolm Douglass. Malcolm, an Episcopalian minister, and his wife moved frequently. They settled for a period of time in Windsor where Malcolm became a minister for St. Pauls Church and they raised their children.

Douglass attended Trinity College in Hartford, Connecticut. An astronomer, Douglass worked at Harvard College Observatory from 1889-1894. While working for the observatory, he traveled to Peru to find a suitable location for another observatory. He helped to establish the Harvard Southern Hemisphere Observatory in Arequipa, Peru.

From sunspots to tree rings

When Douglass returned home, he met astronomer Percival Lowell of Boston, Massachusetts. Working for Lowell, Douglass set out again to find a location for an observatory, but this time in Arizona. In 1894, he found a site on a Flagstaff mesa and oversaw the building of the Lowell Observatory. While at the observatory, Douglass was Lowell’s chief assistant and worked with Lowell to observe the planet Mars. However, Douglass and Lowell did not always agree on how to use the gathered data and Lowell fired Douglass.

Douglass remained in Flagstaff to teach Spanish and geography at what is now known as Northern Arizona University. While in Flagstaff, he became interested in tree rings and their possible connection to sunspot cycles. While researching the eleven-year sunspot cycle, he examined ponderosa pine tree rings. He noted that rings held information about weather patterns and hoped he could find a link between periods of drought and sunspot activity.

In 1906, Douglass moved to Tucson, Arizona and taught at the University of Arizona. Here, he created the science of dendrochronology. He found that differences in tree ring width corresponded to weather patterns. A period of drought produced narrower rings than a time of increased rainfall. In 1929, Douglass was able to place a date on Native American ruins in Arizona with accuracy. He studied Ponderosa pine tree rings dating back to the time of these Native American dwellings. He matched wooden beam samples against pine tree rings to determine a precise date for the ancient ruins. Douglass development of this cross-dating technique was a tremendous breakthrough in the field of archaeology. Archaeologists now had a tool to date ancient ruins.

Despite his work in tree ring analysis, Douglass remained an active astronomer. From 1918 to 1937, Douglass worked at the Steward Observatory at the University of Arizona. Within this period of time, he also wrote *Climate Cycles and Tree Growth, Volumes I, II, and III*. In 1937, he retired as director of the observatory and devoted his time to tree ring research.

Dendrochronology and beyond

Douglass quickly discovered that tree ring studies required time and physical space. He asked the University of Arizona president for a tree ring research facility. In 1938, Douglass became the first director of the Laboratory of Tree-Ring Research at the University of Arizona. The Laboratory of Tree-Ring Research has the largest number of tree ring samples in the world. He remained director of the laboratory until 1958.

In 1984, an asteroid was identified and named Minor Planet or Asteroid (2196) Ellicott, after Douglass middle name. Douglass died on March 20, 1962 at age 94. Later, Spacewatch astronomer Tom Gehrels discovered an asteroid in 1998 using a telescope that Douglass had dedicated to the Steward Observatory many years earlier. A second asteroid was then named after Douglass. On the planet Mars, a crater has also been named in honor of Douglass.
Reading reflection

1. How did Douglass move from studying planets and stars to studying trees?

2. What is the name of the science and specific technique that Douglass discovered?

3. How has Douglass work with tree rings been useful to archaeologists?

4. Research: The first asteroid named after Douglass is called Minor Planet (2196) Ellicott. What is the name of the second asteroid named after Douglass?

5. Research: The Harvard Southern Hemisphere Observatory, also called the Boyden Observatory, was originally located in Arequipa, Peru. It has moved. Where is the observatory now located?

6. Research: Tom Gehrels is an astronomer associated with the Spacewatch program. What is the Spacewatch program?
18.2 Relative Dating

Earth is very old and many of its features were formed before people came along to study them. For that reason, studying Earth now is like detective work—using clues to uncover fascinating stories. The work of geologists and paleontologists is very much like the work of forensic scientists at a crime scene. In all three fields, the ability to put events in their proper order is the key to unraveling the hidden story.

Relative dating is a method used to determine the general age of a rock, rock formation, or fossil. When you use relative dating, you are not trying to determine the exact age of something. Instead, you use clues to sequence events that occurred first, then second, and so on. A number of concepts are used to identify the clues that indicate the order of events that made a rock formation.

Sequencing events after a thunderstorm

Carefully examine this illustration. It contains evidence of the following events:

- The baking heat of the sun caused cracks to formed in the dried mud puddle.
- A thunderstorm began.
- The mud puddle dried.
- A child ran through the mud puddle.
- Hailstones fell during the thunderstorm.

1. From the clues in the illustration, sequence the events listed above in the order in which they happened.

2. Write a brief story that explains the appearance of the dried mud puddle and includes all the events. In your story, justify the order of the events.
Determining the relative ages of rock formations

Relative dating is an earth science term that describes the set of principles and techniques used to sequence geologic events and determine the relative age of rock formations. Below are graphics that illustrate some of these basic principles used by geologists. You will find that these concepts are easy to understand.

Match each principle to its explanation. One relative dating term will be new to you! Which is it? There is one explanation that does not have a matching picture. Write the name of this explanation.

Explanations

3. In undisturbed rock layers, the oldest layer is at the bottom and the youngest layer is at the top.

4. In some rock formations, layers or parts of layers may be missing. This is often due to erosion. Erosion by water or wind removes sediment from exposed surfaces. Erosion often leaves a new flat surface with some of the original material missing.

5. Sediments are originally deposited in horizontal layers.

6. Any feature that cuts across rock layers is younger than the layers.

7. Sedimentary layers or lava flows extend sideways in all directions until they thin out or reach a barrier.

8. Any part of a previous rock layer, like a piece of stone, is older than the layer containing it.

9. Fossils can be used to identify the relative ages of the layers of a rock formation.
Sequencing events in a geologic cross-section

Understanding how a land formation with its many layers of soil was created begins with the same time-ordering process you used earlier in this skill sheet. Geologists use logical thinking and geology principles to determine the order of events for a geologic formation. Cross-sections of Earth, like the one shown below, are our best records of what has happened in the past.

Rock bodies in this cross-section are labeled A through H. One of these rock bodies is an intrusion. Intrusions occur when molten rock called magma penetrates into layers from below. The magma is always younger than the layers that it penetrates. Likewise, a fault is always younger than the layers that have faulted. A fault is a crack or break that occurs across rock layers, and the term faulting is used to describe the occurrence of a fault. The broken layers may move so that one side of the fault is higher than the other. Faulted layers may also tilt.

10. List the rock bodies illustrated below in order based on when they formed.

11. Relative to the other rock bodies, when did the fault occur?

12. Compared with the formation of the rock bodies, when did the stream form? Justify your answer.
Extension—Creating clues for a story

Collect some materials to use to create a set of clues that will tell a story. Examples of materials: construction paper, colored markers, tape, glue, scissors, different colors of modeling clay, different colors of sand or soil, rocks, an empty shoe box or a clear tank for clues.

Then, give another group in your class the opportunity to sequence the clues into a story. Follow these guidelines in setting up your story:

• Set up a situation that includes clues that represent at least five events.
• Each of the five events must happen independently. In other words, two events cannot have happened at the same time.
• Use at least one geology principle that you learned through this skill sheet.
• Answer the questions below.

13. Describe your set of clues in a paragraph. Include enough details in your paragraph so that someone can recreate the set of clues.

14. What relative dating principles are represented with your set of clues? Explain how these principles are represented.

15. Now, have a group of your classmates put your set of clues in order. When they are done, evaluate their work. Write a short paragraph that explains how they did and whether or not they figured out the correct sequence of clues. Describe the clue they missed if they made an error.
18.2 Nicolas Steno

Nicolas Steno was a keen observer of nature at a time when many scientists were content to learn about the world by reading books. Through dissection, Steno made important advances in the field of medicine. Later he applied his observational skills to the field of geology, identifying three important principles that geologists still use to determine the order in which geological events occurred.

Steno’s childhood

Nicolas Steno was born in 1638 in Copenhagen, Denmark. He became ill at age three and spent most of his time indoors until age six. He saw few children, but spent time listening to adults discuss religion. Religion later became an important part of his life.

Steno, the son of a goldsmith, had skillful hands like his father. However, his skill was not in making jewelry. He was an expert in dissecting animals to learn about anatomy. He was fascinated by the structure of living things.

The young scientist

When Nicolas was not yet ten years old, his father died. He spent his teen years living in Copenhagen with a half-sister and her husband. Steno was smart, curious, and a good listener. He gained the attention of two scholars in Copenhagen.

The first scholar, Ole Borch, welcomed Steno into his alchemy laboratory. There, Steno watched as sediments settled out of liquid solutions. He thought it was interesting that even when the bottom of the jar was bumpy, the sediments formed a smooth horizontal layer on top of the bumpy surface.

Thomas Bartholin, a famous anatomist from the University of Copenhagen, also mentored Steno. Perhaps through this friendship, Steno developed a keen interest in dissection and anatomy. In 1660, he left Denmark to study medicine at the University of Leiden in the Netherlands. There, through careful dissection of mammals, he made discoveries related to glands, ducts, the heart, brain, and muscles.

A shark’s tooth unlocks a mystery

In 1665, Steno moved to Italy. The following year, fishermen there captured a great white shark. The Italian Duke Ferdinand sent the head to Steno for dissection. Steno carefully observed the shark’s teeth. They looked like glossopetrae or “tongue stones,” common stony items found inside rocks.

While we now know that these tongue stones are fossilized remains of living things, in Steno’s time many people believed tongue stones either grew inside rocks, fell from the sky, or even fell from the Moon.

Steno suggested a different explanation for the tongue stones. He said they had once been actual shark teeth! Then Steno started to think about how a solid object, like a shark tooth, could get inside another solid object, like a rock.

Three important principles

Based on his work, Steno came up with three important principles of geology.

- The principle of superposition says that layers of sediment settle on top of each other. The oldest layers are on the bottom and the more recent layers are on top.
- The principle of original horizontality says that sedimentary rock layers form in horizontal patterns, even if they form on a bumpy surface.
- The principle of lateral continuity says that sediment layers spread out until they reach something that stops the spreading.

Steno explained that the shark teeth had been in soft sediment that eventually hardened into a layer of rock. Steno used his principles to write a book about the geology of a region of Italy called Tuscany. Even today, geologists use Steno’s principles to determine the order in which geologic events occurred.

Father Steno

In 1675, Steno gave up science to become a priest. He died in 1686 at the age of 48. In 1988, Pope John Paul II beatified Steno, the first step in the process of naming someone a saint. Today, the Steno Museum in Denmark and craters on both Mars and the Moon bear his name.
Reading reflection

1. Name and briefly describe the three important principles of geology developed by Steno.

2. How did most people in the 1600s explain the origin of fossils?

3. How did Steno explain the existence of tongue stones or shark teeth in rocks?

4. How did Steno’s medical background and skills help him with his geological discoveries?

5. Observing is very important in science. What things do you like to observe? What have you learned through observation?

6. **Research:** Steno’s father was a goldsmith and one of his teachers was interested in alchemy. What does a goldsmith do? What is alchemy? How could these two fields have been helpful to Steno’s work?
18.3 The Rock Cycle

In Section 18.3 of your student text, you will learn about the rock cycle. Place the three main groups of rocks in the ovals below. Then, fill in the blank lines with the materials or processes at work in each stage of the rock cycle. Use this diagram as a study aid. Describe to a friend or family member what is happening at each stage.
19.1 Earth’s Interior
19.1 Charles Richter

Richter is the most recognized name in seismology due to the earthquake magnitude scale he codeveloped. But Earth science was never a subject of interest to this bright young physicist, until a mentor made an interesting suggestion and a “happy accident” introduced him to seismology.

The unexpected path

Charles F. Richter was born on April 26, 1900 in Hamilton, Ohio. When he was 16, Charles and his mother left their Ohio farm and moved to Los Angeles. Richter attended the University of Southern California from 1916–1917, and then earned a bachelor’s degree in physics at Stanford University.

It was during his Ph.D. studies in theoretical physics at the California Institute of Technology (Caltech) that Richter began his work in seismology, quite by accident.

In 1927, Richter was working on his Ph.D. under the Nobel Prize winning physicist Dr. Robert Millikan. One day, Dr. Millikan called Richter into his office and presented him with an opportunity. The Caltech Seismology Laboratory was in need of a physicist, and although Richter had never done any Earth science work, Dr. Millikan thought he might be a good person for the job.

Richter was a little surprised, but decided to talk to Harry Wood, the lead scientist in charge of the lab. Richter became intrigued and decided to join the seismology lab located in Pasadena, California. Richter described this introduction to the science that would become his life’s work as a “happy accident.”

Doing something ordinary

One of Charles Richter’s most famous sayings is based on looking back at his own life: “Don’t wait for extraordinary circumstance to do good; try to use ordinary situations.”

When he first started at the seismology lab, Richter was busy with the routine work of measuring seismograms and locating earthquakes, so that a catalog of epicenters and occurrence times could be set up. At the time, this kind of earthquake study was new. Harry Wood was leading the effort to use southern California’s active seismic setting to gain a better understanding of earthquakes.

This creative setting allowed Richter to attempt to develop new ways to “rate” earthquakes based on the seismic waves they produced. Since the lab used seven seismographs to record activity, Richter suggested that they compare quakes to one another using the amplitude of each quake measured at all seven locations. To do this, the seismic readings needed to be corrected to take into account the differences in distance from the epicenters. Richter had learned of a method to do this based on large earthquakes, but the magnitudes that Richter was studying ranged from tiny to very large.

Collaboration and success

Richter thought that the size difference in the magnitudes was unmanageably large. Fellow scientist Dr. Beno Gutenberg suggested that they plot the magnitudes using powers of 10. A magnitude two earthquake would represent 10 times the amplitude of ground motion of a magnitude one. A magnitude three would be 100 times a magnitude one, a four would be 1,000 times a magnitude one, and so on.

Richter realized this was the obvious answer to his problem. When he used this method and graphed the results, it worked! At first it could be used only for southern California, because the system was only meant to compare quakes of that region using the seven seismographs in their lab.

A new way to rate earthquakes

In 1935, Richter and Gutenberg published their magnitude scale system. By 1936, they had worked out how their system could be used in all parts of the world, with any type of instrument. Before this, the Mercalli scale had been used to rate the magnitude of earthquakes, but it was based on local damage to buildings and people’s reactions to a quake.

Richter and Gutenberg’s scale allowed for a more absolute and scientific method to be used by anyone, anywhere in the world.
Reading reflection

1. Look up the definition of each boldface word in the article. Write down the definitions and be sure to credit your source.

2. What do you think you would feel like if a world reknown scientist like Dr. Robert Millikan recommended you for a job? How would you feel if accepting that job meant that you could no longer work closely with Dr. Millikan?

3. How did Richter respond to his new job?

4. Who helped Richter refine his idea into a working model?

5. Name a scale other than the Richter scale that scientists use to evaluate earthquakes.

6. Research: Why do scientists use different scales to rate earthquakes?

7. Research: What is the difference between a seismograph and a seismometer?
19.1 Jules Verne

Jules Verne was an enormously successful nineteenth century author. He introduced the world to science fiction. His stories of adventure and imaginative methods of travel were decades ahead of their time. His ideas have entertained and inspired generations of readers. Several of his books have been made into popular movies.

A great imagination yearning for adventure

Jules Verne was born on February 8, 1828 in the busy port city of Nantes, France. The oldest of five children, Jules came from a family with a strong seafaring tradition rich with the spirit for travel and adventure.

The family’s summer home just outside the city of Nantes may have inspired Jules to search for adventure. The house was on the banks of the Loire River. Jules and his younger brother Paul would often play outside and watch ships from all over the world sail down the river.

The boys would make up stories about these ships; where they were from, where they were going, the characters aboard the vessels, and especially the wild escapades they had during their journeys.

While Jules’ father was part of a family that included many travelers, he did not intend his sons to follow in those footsteps. Both Jules and Paul were sent to a boarding school, right in their hometown of Nantes. There they were expected to get an education that would take them out of the seafaring class and into wealthy society.

Expectations and creativity clash

After graduating from the boarding school, Verne’s father sent him to Paris in 1847, where he was expected to study law. While he studied and prepared for the bar exam, Verne found his time was increasingly spent writing.

An uncle that had been asked to check up on Verne saw that he was having some quiet success writing the words for operas. This uncle understood Verne’s true calling. He began to introduce Verne to people involved with Paris’ literary circles.

Verne managed to get a few plays published and even performed. Although busy, he still was able to get his law degree. This came in handy, because as soon as Verne’s father found out about his writing, he furiously stopped sending his son money. With his money supply gone, Verne took a job as a stockbroker. He hated this job, yet was quite good at it.

A career takes off

Around this time Verne began to meet important authors like Alexander Dumas and Victor Hugo. They offered advice to the young writer. In 1857 Verne married, and was encouraged by his wife to pursue his dream of writing.

Verne became a fan of Edgar Allen Poe, modelling some of his early work on Poe’s style, and in 1897 he wrote a sequel to one of Poe’s unfinished novels. In 1862 Verne met Pierre-Jules Hetzel, an editor with a keen eye and feel for what a story needed to be successful.

Verne’s writing had often been criticized for being too scientific. Hetzel knew how to make Verne’s stories appeal to the common person. In 1863, Verne began publishing his “Extraordinary Voyages” series of novels and thankfully quit his stockbroking job.

In rapid succession Verne tackled the sky, the sea, the land, and even space in his novels. In 1863 he wrote *Five Weeks in a Balloon*, a story about exploring Africa in a hot air balloon. In 1864 he wrote *Journey to the Center of the Earth*, a trek by scientists down a volcano on their way to Earth’s core. In 1865 he wrote *From Earth to the Moon*, a visionary work that preceded NASA missions by 100 years. He published *20,000 Leagues Under the Sea* in 1869, introducing the world to Captain Nemo, a mysterious genius who built the futuristic submarine *The Nautilus*.

Jules Verne’s 65 novels took readers on marvelous adventures, introducing futuristic ideas that while not always based on scientific facts, incorporated concepts that inspired future thinkers and entertained millions. Verne died in 1905, as the world’s most translated author, making up for his lack of scientific training and actual travel experience with a vivid imagination.
Reading reflection

1. Why do you think Jules Verne’s novels appealed so widely to readers around the world?

2. **Research** which novels written by Verne have been made into movies. Have any of them won awards?

3. **Research** the bar exam. Why would Jules Verne need to pass it?

4. **Research** Victor Hugo and explain why meeting him may have been important to Verne.

5. **Research** some of the machines, ideas, and predictions Verne made in his novels that have come to exist today.
19.2 Alfred Wegener

Alfred Wegener was a man ahead of his time. He was an astronomer and a meteorologist, yet his greatest work was in the field of earth science. His theory of plate tectonics is widely accepted today. Yet, in 1912 when he proposed the idea, he was ridiculed. It took fifty years for other scientists to find the evidence that would prove his theory.

The young man

Alfred Wegener was born in Berlin in 1880. He was the son of a German minister who ran an orphanage. As a boy, he became interested in Greenland, and as a scientist, he went to Greenland several times to study the movement of air masses over the ice cap. This was at a time when most scientists doubted the existence of the jet stream. Just after his fiftieth birthday, he died there in a blizzard during one of his expeditions.

Wegener graduated from the University of Berlin in 1905 with a degree in astronomy. Soon, however, his interest shifted to meteorology. This was a new and exciting field of science. Wegener was one of the first scientists to track air masses using weather balloons. No doubt, he got the idea from his hobby of flying in hot air balloons. In 1906, he and his brother set a world record by staying up in a balloon for over fifty-two hours.

The search for evidence

In 1910, in a letter to his future bride, Wegener wrote about the way that South America and Africa seemed to fit together like pieces of a puzzle. To Wegener, this was not just an odd coincidence. It was a mystery that he felt he must solve. He began to look for evidence to prove that the continents had once been joined together and had moved apart.

Fossils of a small reptile had been found on the west coast of Africa and the east coast of South America. That meant that this reptile had lived in both places at the same time millions of years ago. Wegener figured that the only way this was possible was if the two continents were connected when animals were alive. They could not have traveled across the ocean.

Geological evidence

There was also geological evidence. The rock structures and types of rocks on the coasts of these two continents were identical. Again, Wegener could find no explanation for how this could have happened by accident on opposite sides of the ocean. The rock structures had to have been formed at the same time and place under the same conditions.

A study of climates produced other evidence. Coal deposits had been found in Antarctica and in England. Since coal is formed only from plants that grow in warm, wet climates, Wegener concluded that those land masses must have once been near the equator, far from their locations today.

Ridiculed and rejected

Wegener explained that all of the continents had been part of one large land mass about 300 million years ago. This super-continent was called Pangaea, a Greek word that means “all earth.” It broke up over time, and the pieces have been drifting apart ever since. Wegener compared the drifting continents to icebergs.

Wegener’s peers called his theory “utter rot!” Many scientists attacked him with rage and hostility. Wegener had two main problems. First, he was an unknown outsider, not a geologist, who was challenging everything that scientists believed at the time. Second, he was not able to explain what caused the continents to drift. While there seemed to be evidence to show that they had indeed moved, he could not identify a force that made it happen.

About fifty years after Wegener proposed his theory, a scientist named Harry Hess made a discovery about sea floor spreading that seemed to support Wegener’s ideas. As a result, the theory of plate tectonics was finally accepted by most scientists.
Reading reflection

1. Explain the significance of Greenland in Wegener’s life.

2. What world record did Wegener set in 1906?

3. Why could Wegener be called an interdisciplinary scientist? Identify the fields of science of which he was knowledgeable.

4. Explain how the fossil of a small reptile provided evidence to help prove Wegener’s theory of drifting continents.

5. How did the discovery of coal deposits in England and Antarctica strengthen Wegener’s argument?

6. **Research:** In his search for evidence to support his theory of drifting continents, Wegener studied the rock strata in the Karroo section of South Africa and the Santa Catarina section of Brazil. He also studied the Appalachian Mountains in North America and the Scottish Highlands. Use a library or the Internet to research these areas. What evidence do they provide for Wegener’s theory? Share your findings with the class.

7. What were the two main problems that Wegener faced when he tried to convince others that his theory of drifting continents was valid?

8. **Research:** Wegener and some colleagues drew maps of what they thought the world looked like at different times as the super continent broke up and the continents drifted apart. Use a library or the Internet to find pictures of these maps. Make a poster displaying Wegener’s vision of the world at:

   - 300 million years ago (Pangaea)
   - 225 million years ago (Permian period)
   - 200 million years ago (Triassic period)
   - 135 million years ago (Jurassic period)
   - 65 million years ago (Cretaceous period)
   - Today
19.2 Harry Hess

Harry Hammond Hess was a geology professor at Princeton University and served many years in the U.S. Navy. In 1962, Hess published a landmark paper that described his theory of sea floor spreading. Hess also made major contributions to our national space program.

A globe-trotting geologist

Harry Hammond Hess was born in New York City on May 24, 1906. He first studied electrical engineering at Yale University, but later changed his major to geology. He received his degree in 1927.

After graduation, Hess worked for two years as a mineral prospector in southern Rhodesia (currently Zimbabwe, Africa). He then returned to the United States to study at Princeton University. In 1932, Hess became a professor of geology at Princeton. Years later, his geological research took him to the far depths of the Pacific Ocean floor.

The Navy commander

Harry Hess was part of the Naval Reserve. In 1941 he was called to active duty. His first duty during World War II was in New York City where he tracked enemy positions in the North Atlantic. He later commanded an attack transport ship in the Pacific.

Although he was a Naval commander, Hess seized the opportunity of being on a ship to further his geological research. Between battles, Hess and his crew gathered data about the structure of the ocean floor using the ship’s sounding equipment. They recorded thousands of miles worth of depth recordings.

In 1945, Hess measured the deepest point of the ocean ever recorded—nearly 7 miles deep. He also discovered hundreds of flat-topped mountains lining the Pacific Ocean floor. He named these unusual mountains “guyouts” (after his first geology professor at Princeton).

A ground breaking theory

After the war, Hess continued to study guyouts, midocean ridges, and minerals. In 1959, his research led him to propose the ground breaking theory of sea floor spreading. At first, Hess’ idea was met with some resistance because little information was available to test this concept.

In 1962, his sea floor spreading theory was published in a paper titled “History of Ocean Basins.” Hess explained that sea floor spreading occurs when molten rock (or magma) oozes up from inside the Earth along the mid-oceanic ridges. This magma creates new sea floor that spreads away from the ridge and eventually sinks into the deep oceanic trenches where it is destroyed. Hess’ theory became one of the most important contributions to the study of plate tectonics.

The sea floor spreading theory explained many unsolved geological questions. Most geologists at the time believed that the oceans had existed for at least 4 billion years. But they wondered why there wasn’t more sediment deposited on the ocean floor after such a long time period.

Hess explained that the ocean floor is continually being recycled and that sediment has been accumulating for no more than 300 million years. This is about the time period needed for the ocean floor to spread from the ridge crest to the trenches. Hess’s theory helped geologists understand why the oldest fossils found on the sea floor are 180 million years old at most, while marine fossils found on land may be much older.

From the ocean to the moon

Harry Hess also played a key role in developing our country’s space program. In 1962, President John F. Kennedy appointed Hess as Chairman of the Space Science Board—a NASA advisory group. During the late 1960s, Hess helped plan the first landing of humans on the moon. He was part of a committee assigned to analyze rock samples brought back by the Apollo 11 crew.

Harry Hess died in August 1969, only one month after the successful Apollo 11 lunar mission. He was buried in the Arlington National Cemetery. After his death, he was awarded NASA’s Distinguished Public Service Award.
Reading reflection

1. How did Harry Hess’ career in the Navy contribute to his geological research?

2. What were some of the geological discoveries Hess made while aboard his attack transport ship?


4. How did Hess’ sea floor spreading theory explain why so little sediment is deposited on the ocean floor?

5. What were Hess’ contributions to space research?

6. Research: Harry Hess made significant contributions in the fields of geology, geophysics, and mineralogy. What scientific society established the Harry H. Hess Medal and what achievements does it recognize?
19.2 John Tuzo Wilson

John Tuzo Wilson was a professor at the University of Toronto whose love for adventure helped him make major contributions in the field of geophysics. His research on plate tectonics explained volcanic island formation and led to the discovery of transform faults. He also described the formation of oceans, a process later named the Wilson Cycle.

A noteworthy family

John Tuzo Wilson was born in Ottawa, Canada on October 24, 1908. His adventurous parents helped to expand Canada’s frontiers. Wilson’s mother, Henrietta Tuzo, was a famous mountaineer. Mount Tuzo in western Canada was named in her honor after she scaled its peak. Wilson’s father, also named John, helped plan the Canadian Arctic Expedition of 1913 to 1918. He also helped develop airfields throughout Canada.

In 1930, Wilson was the first graduate of geophysics from the University of Toronto. He earned a second degree from Cambridge University. In 1936, Wilson received a doctorate in geology from Princeton University.

An adventurous scholar

Throughout his career, Wilson enjoyed traveling to unusual locations. While a student at Princeton, Wilson became the first person to scale Mount Hague in Montana—an elevation of 12,328 feet.

When World War II broke, Wilson served in the Royal Canadian Army. After the war, Wilson led an expedition called Exercise Musk-Ox. He directed ten army vehicles 3,400 miles through the Canadian Arctic. This journey proved that people could travel to Canada’s north country.

In 1946, Wilson began his 30-year career as a professor of geophysics at the University of Toronto. While a professor, Wilson mapped glaciers in Northern Canada. Between 1946 and 1947, he became the second Canadian to fly over the North Pole during his search for unknown Arctic islands.

Plate tectonics and a hot idea

Many scientists contributed to the development of the plate tectonics theory. However, they had difficulty explaining the formation of volcanic islands. These islands, like the Hawaiian Islands, are thousands of kilometers away from plate boundaries.

In the early 1960s, Wilson solved the volcanic island mystery. He explained that sometimes a single hot mantle plume will break through a plate and form a volcanic island. As the plate moves over the mantle plume, a chain of islands forms. At first this theory was rejected. Finally, in 1963, Wilson published his paper.

Slipping and sliding plates

In 1965, Wilson proposed that a type of plate boundary must connect ocean ridges and trenches. He suggested that a plate boundary ends abruptly and transforms into major faults that slip horizontally. Wilson called these boundaries “transform faults.”

Wilson’s idea was confirmed and quickly became a major milestone in the plate tectonics theory. The San Andreas Fault of southern California is a well-known transform fault.

Opening and closing ocean basins

Wilson was one of the first geologists to link seafloor spreading with land geology. In 1967, Wilson published an article that described the repeated process of ocean basins opening and closing. This process later became known as the Wilson Cycle.

Geologists believe that the Atlantic Ocean basin closed millions of years ago. This event led to the formation of the Appalachian and Caledonian mountain systems. The basin later re-opened to form today’s Atlantic Ocean.

An honored geologist

Wilson’s contributions to the field of geophysics led to many honors and awards throughout his career. In 1967, Wilson became the principle of Erindale College at the University of Toronto. From 1974 to 1985, Wilson served as director of the world-renowned Ontario Science Center. On April 15, 1993, Wilson died at age 84.
**Reading reflection**

1. How did John Tuzo Wilson’s parents contribute to his passion for the outdoors?

2. Why is Wilson sometimes referred to as an adventurous scholar?

3. Describe Wilson’s theory of how volcanic islands are formed.

4. What did Wilson discover about plate boundaries and the formation of faults?

5. What is the Wilson Cycle? Give an example of this process.

6. **Research:** On which continent are mountains named in honor of John Tuzo Wilson?
19.3 Earth’s Largest Plates
You have learned about the plates that make up the surface of Earth. You have also learned how plates are formed at mid-ocean ridges and are destroyed at subduction zones. Here is a very brief look at how plate tectonics formed the land mass that we call the United States. It covers only the last chapter of the Earth history of the 48 contiguous states.

The full history of the surface of Earth is a very long and complicated story. To give you an idea of the difficulty of understanding the full story, imagine this: A young child is given a new box of modeling clay. In the box are four sticks of differently colored clay. The child plays with the clay for hours making different figures. First a set of animals, then a fort, and so on. Between each idea, the child balls up all of the clay. Now imagine that it’s the next day and the ball of swirled clay colors is in your hand. Your task is to figure out what the child made and in what order.

That sounds impossible, and it probably is. The amazing thing is that geologists have figured out a lot of the equally difficult story of Earth’s surface. We have a pretty good idea about how the early crust was formed. And we know that there was a super continent called Rodinia that formed before Pangaea, the last super continent. But like the child’s clay figures, the further back we look, the more the clues are mixed up.

The last chapter

Our story begins late. Most of the history of Earth has already passed. During this time rift valleys formed that split continents into smaller pieces. First the land moved apart on both sides of a rift valley. Then, once the rift valley opened wide enough, water flooded in and a new ocean was born. Underwater, the rift valley then became a mid-ocean ridge.

At the same time, subducting plates acted like conveyor belts. Anything that was part of a subducting plate was carried toward the subduction zone. In this way continents were carried together. Collisions between continents welded them together. Mountain ranges formed at the point of contact.

The combination of rifting and subduction worked together to form, destroy, and reform the early continents. You can see that the result is very much like playing with modeling clay.

The craton

Even though most of Earth’s history had passed, it was still an incredibly long time ago. Rifting had broken up Rodinia, but subduction had not yet formed Pangaea. The break-up of Rodinia left six continents scattered across the world oceans. These continents were not the continents that we see today. One of these, Gondwanaland, was larger than the others put together.
Two other continents are important to our story. They are called Baltica and Laurentia. At the center of Laurentia was a core piece that was very old even then. This core piece is called the craton. The craton had been changed again and again, but it was stable inside Laurentia. Today the craton of Laurentia forms the central United States.

You may wonder where these names came from. After all, these continents were gone many millions of years before humans appeared on Earth. They are modern names proposed and adopted by geologists.

**The first collision**

Rifting and subduction caused Baltica to move in a jerky path. Eventually, Baltica collided with Laurentia to form a larger combined continent. This new continent is called Laurasia. A high mountain range formed where the colliding continents made contact. This mountain range lay deep inside Laurasia. Today the remains of this high mountain range form our northern Appalachian Mountains.

**Gondwanaland collides**

Subduction continued to bring continents together. Next mighty Gondwanaland was drawn ever closer to Laurasia. Gondwanaland collided just below where Laurentia and Baltica collided with each other. This new collision raised another set of mountains that continued the northern Appalachians into what are now the southern Appalachians. The combined Appalachians were as high as the Himalayans of today! The super continent Pangaea was then complete and the lofty Appalachian Mountains stood near its center.

**Pangaea breaks up**

Pangaea did not remain together for very long, only a few tens of millions of years. The same rifting process that broke up Rodinia split the new super continent into smaller pieces. Our future East Coast had been deep inside the central part of Pangaea. But in the break-up, a rift valley split our eastern shore away from what is now Africa. Instead of an inland place, our East Coast became an eastern shore.

**The East Coast after Pangaea**

One of the amazing things in geology is how quickly mountain ranges are eroded away. After Pangaea broke up, the Appalachians completely eroded away. All that was left was a flat plain! The sediments produced from this erosion formed deep layers on the eastern shore and near-shore waters. These coastal margin sediments make up most of the eastern states today. But wait a minute; today we see rounded mountains where there had been only flat plains. What formed the rounded Appalachian Mountains of today?
When a mountain is formed, some of it is pressed deep into the mantle by the weight of the mountain above. It’s like stacking wood blocks in water. As the stack grows taller, it also sinks deeper. Erosion takes a tall mountain down quickly. With the top gone, its bottom rebounds back to the surface. In this way, the Appalachian Mountains that we see today are actually the rebounded lower section of the mountains that once had been pressed deep below Earth’s surface.

The West Coast and the Ancestral Rocky Mountains

There are two Rocky Mountain ranges. The first is called the Ancestral Rocky Mountains. The Ancestral Rocky Mountains were formed when subduction caused an ancient collision with Laurentia. The collision struck Laurentia on the side that would become our western states. In other words, the Ancestral Rocky Mountains already existed before Pangaea formed. The Ancestral Rockies were then heavily weathered and the sediment deposited on the surrounding plains. Today the Front Range of Colorado is part of the exposed remains of the Ancestral Rocky Mountains.

Pangaea and the West Coast

Our West Coast did not exist as Pangaea began to break up. The shoreline was near the present eastern border of California. What would become our West Coast states were sediments and islands scattered in the ocean to the west.

North America began to move westward as it was rifted apart from Pangaea. A subduction zone appeared in front of the moving continent. As the ocean floor dove under the westward-moving continent, these sediments, islands and even pieces of ocean floor became permanently attached to the continent. Our western shore grew in this way, forming the shape that we see today.

The modern Rocky Mountains

The mid-ocean ridge that was forming the subducting ocean plate was not too far away to the west. As the plate subducted, the mid-ocean ridge got closer and closer to the edge of the continent. This changed the way that the plate subducted. The result was that stronger push pressure caused the continent to buckle well back from its edge. In this way, the modern Rocky Mountains were formed near the remains of the Ancestral Rocky Mountains.
Inland volcanoes

The subducting plate also caused volcanoes to form and erupt inland. These eruptions produced the Sierra Nevada Mountains to the south and High Cascades to the north.

A small plate disappears

The plate that had been subducting along the southern West Coast was small. Eventually it disappeared when its mid-ocean ridge was subducted. This changed the western edge of the United States from a converging boundary to a transform boundary. Now instead of one plate diving under another, the remaining Pacific Plate slides by the West Coast. Today this slide-by motion is well known as the San Andreas Fault.

When subduction stopped along the lower West Coast, the Sierra volcanoes became extinct. Magma cooled and solidified below the surface. Today this cooled magma is exposed as the domes of Yosemite National Park. Further north, the Pacific Plate is still subducting under the West Coast. That subduction continues to drive the volcanoes of the High Cascades.

The United States today

In geologic terms, the East Coast is quiet and the West Coast is active. The contiguous United States are part of the North American Plate. The active eastern boundary of the plate lies in the middle of the Atlantic Ocean, far from our East Coast. But the active western boundary is also our western shore. The San Andreas Fault slowly moves slivers of California northward. Baja California will eventually be attached to San Diego. Map makers won’t have to redraw New England, but they will have to watch for West Coast changes. The good news is that they’ll have plenty of time to make those changes.
20.1 Averaging

The most common type of average is called the mean. To find the mean, just add all the data, then divide the total by the number of items in the data set. This type of average is used daily by many people; teachers and students use it to average grades, meteorologists use it to average normal high and low temperatures for a certain date, and sports statisticians use it to calculate batting averages, among many other things.

Example

Seven students in Mrs. Ramos’ homeroom have part time jobs on the weekends. Some of them babysit, some mow lawns, and others help their parents with their businesses. They all listed their hourly wages to see how their own pay compares to that of the others. Here is the list: $11.00, $4.50, $12.20, $5.25, $8.77, $15.33, $5.75. What is the average (mean) hourly wage earned by students in Mrs. Ramos’ homeroom?

1. Find the sum of the data: $11.00 + $4.50 + $12.20 + $5.25 + $8.77 + $15.33 + $5.75 = $62.80
2. Divide the sum ($62.80) by the number of items in the data set (7): $62.80 ÷ 7 ≈ $8.97
3. Solution: The average hourly wage of the students in Mrs. Ramos’ homeroom is $8.97.

Practice

1. Jill’s test grades in science class so far this grading period are: 77%, 64%, 88%, and 82%. What is her average test grade so far?
2. The total team salaries in 2005 for teams in a professional baseball league are as follows: Team One, $63,015,833 (24 players); Team Two, $48,107,500 (24 players); Team Three, $81,029,500 (29 players); Team Four, $62,888,192 (22 players); Team Five, $89,487,426 (18 players). What is the average amount of money spent by a team in this league on players salaries in 2005?
3. During a weekend landscaping job, Raul worked 8 hours, Ben worked 15 hours, Michelle worked 22 hours, Rosa worked 5 hours, and Sammie worked 15 hours. What was the average number of hours worked by one person during this landscaping job? If each worker was paid $12.00 an hour, what was the average pay per person for the job?
4. The 8th grade girls basketball team at George Washington Carver Middle School played the team from Rockwood Valley Middle School last night. The Rockwood Valley team won, 53-37. Altogether, there were three girls who scored 11 points each, four who scored 8 points each, one who scored 6 points, two who scored 4 points each, four who scored 2 points each, three who scored one point each, and two girls who did not score at all. What is the average number of points scored by a player on either team?
5. During a weekend car trip that covered 220 miles each way, Rowan kept track of the price per gallon of regular unleaded gasoline at different gas stations along the way. Here is the list he kept: $2.79, $3.23, $3.99, $2.89, $3.09, $2.99, $2.97, $3.11, $2.88, $3.01, $3.00, $2.99. What was the average price per gallon of gas among the different gas stations on the list?
20.1 Finding an Earthquake Epicenter

The location of an earthquake’s epicenter can be determined if you have data from at least three seismographic stations. One method of finding the epicenter utilizes a graph and you need to know the difference between the arrival times of the P- and S-waves at each of three seismic stations. Another method uses a formula and you need to know the arrival times and speeds of the P- and S-waves. The only other items you need to find an epicenter are a calculator, a compass, and a map.

Finding the epicenter using a graph

Table 1 provides the arrival time difference between P- and S-waves. Use this value to find the distance to the epicenter on the graph. Record the distance values in the table in the third column from the left.

<table>
<thead>
<tr>
<th>Station name</th>
<th>Arrival time difference between P- and S-waves</th>
<th>Distance to epicenter in kilometers</th>
<th>Scale distance to epicenter in centimeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>25 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>42 seconds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Locating the epicenter on a map

Once you have determined the distance to the epicenter for three stations in kilometers, you can use a map to locate the epicenter. The steps are as follows:

**Step 1:** Determine the radius of a circle around each seismographic station on a map. The radius will be proportional to distance from the epicenter. Use the formula below to convert the distances in kilometers to distances in centimeters. For this situation, we will assume that 100 kilometers = 1 centimeter. Record the scale distances in centimeters in the fourth column of Table 1.

\[
\frac{1 \text{ cm}}{100 \text{ km}} = \frac{x}{\text{distance to epicenter in km}}
\]

**Step 2:** Draw circles around each seismic station. Use a geometric compass to make circles around each station. Remember that the radius of each circle is proportional to the distance to the epicenter.

**Step 3:** The location where the three circles intersect is the location of the epicenter.
Finding the epicenter using a formula

To calculate the distance to the epicenter for each station, you will use the equation:

\[
\text{Distance} = \text{Rate} \times \text{Time}
\]

Table 2 lists the variables that are used in the equation for finding the distance to the epicenter. This table also lists values that are given to you.

Table 2: Variables for the equation to calculate the distance to the epicenter

<table>
<thead>
<tr>
<th>Variable</th>
<th>What it means</th>
<th>Given</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_p)</td>
<td>distance traveled by P-waves</td>
<td>(r_p = 5 \text{ km/s})</td>
</tr>
<tr>
<td>(r_p)</td>
<td>speed of P-waves</td>
<td>(r_s = 3 \text{ km/s})</td>
</tr>
<tr>
<td>(t_p)</td>
<td>travel time of P-waves</td>
<td>(d_p = d_s)</td>
</tr>
<tr>
<td>(d_s)</td>
<td>distance traveled by S-waves</td>
<td></td>
</tr>
<tr>
<td>(r_s)</td>
<td>speed of S-waves</td>
<td></td>
</tr>
<tr>
<td>(t_s)</td>
<td>travel time of S-waves</td>
<td></td>
</tr>
</tbody>
</table>

For each of the practice problems, assume that the speed of the P-waves will be 5 km/s and the speed of the S-waves will be 3 km/s. Also, because the P- and S-waves come from the same location, we can assume the distance traveled by both waves is the same.

\[
distance \text{ traveled by P-waves} = distance \text{ traveled by S-waves} \\
\quad d_p = d_s \\
\quad r_p \times t_p = r_s \times t_s
\]

Since the travel time for the S-waves is longer, we can say that,

\[
\text{travel time of S-waves} = (\text{travel time of P-waves}) + (\text{extra time}) \\
\quad t_s = t_p + (\text{extra time}) \\
\quad r_p \times t_p = r_s \times (t_p + \text{extra time})
\]
For each of the practice problems, assume that the speed of the P-waves is 5 kilometers per second, and the speed of the S-waves is 3 kilometers per second. The first problem is done for you. Show your work for all problems.

1. S-waves arrive to seismographic station A 85 seconds after the P-waves arrive. What is the travel time for the P-waves?

\[
\frac{5 \text{ km}}{s} \times t_p = \frac{3 \text{ km}}{s} \times (t_p + 85 \text{ s})
\]

\[
\left( \frac{5 \text{ km}}{s} \right) t_p = \left( \frac{3 \text{ km}}{s} \right) t_p + 255 \text{ km}
\]

\[
\left( \frac{2 \text{ km}}{s} \right) t_p = 255 \text{ km}
\]

\[
t_p = 128 \text{ s}
\]

2. S-waves arrive to another seismographic station B 80 seconds after the P-waves. What is the travel time for the P-waves to this station?

3. A third seismographic station C records that the S-waves arrive 120 seconds after the P-waves. What is the travel time for the P-waves to this station?

4. From the calculations in questions 1, 2, and 3, you know the travel times for P-waves to three seismographic stations (A, B, and C). Now, calculate the distance from the epicenter to each of the stations using the speed and travel time of the P-waves. Use the equation: distance = speed \times time.

5. Challenge question: You know that the travel time for P-waves to a seismographic station is 200 seconds.
   a. What is the difference between the arrival times of the P- and S-waves?
   b. What is the travel time for the S-waves to this station?

6. Table 3 includes data for three seismographic stations. Using this information, perform the calculations that will help you fill in the rest of the table, except for the scale distance row.

<table>
<thead>
<tr>
<th>Table 3: Calculating the distance to the epicenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Speed of P-waves</td>
</tr>
<tr>
<td>Speed of S-waves</td>
</tr>
<tr>
<td>Time between the arrival of P- and S-waves</td>
</tr>
<tr>
<td>Total travel time of P-waves</td>
</tr>
<tr>
<td>Total travel time of S-waves</td>
</tr>
<tr>
<td>Distance to epicenter in kilometers</td>
</tr>
<tr>
<td>Scale distance to epicenter in centimeters</td>
</tr>
</tbody>
</table>
Once you have determined the distance to the epicenter for three stations in kilometers, you can use a map to locate the epicenter. The steps are as follows:

**Step 1:** Determine the radius of a circle around each seismographic station on a map. The radius will be proportional to distance from the epicenter. Use the formula below to convert the distances in kilometers to distances in centimeters. For this situation, we will assume that 200 kilometers = 1 centimeter. Record the scale distances in centimeters in the last row of Table 3.

\[
\frac{1 \text{ cm}}{200 \text{ km}} = \frac{x}{\text{distance to epicenter in km}}
\]

**Step 2:** Draw circles around each seismic station. Use a geometric compass to make circles around each station. Remember that the radius of each circle is proportional to the distance to the epicenter.

**Step 3:** The location where the three circles intersect is the location of the epicenter.
20.2 Volcano Parts
As you read Section 20.3 of your student text, you will learn how basalt and granite form. You’ll learn about ways they are alike and ways that they are different. The Venn diagram below can help you organize this information. As you learn about these types of rock, place facts that apply to both in the space where the circles intersect. Place facts that apply to only one type of rock in its individual space. Use this diagram as a study aid.
21.2 Calculating Concentration of Solutions

What’s the difference between regular and extra-strength cough syrup? Is the rubbing alcohol in your parents’ medicine cabinet 70% isopropyl alcohol, or is it 90% isopropyl alcohol? The differences in these and many other pharmaceuticals is dependent upon the concentration of the solution. Chemists, pharmacists, and consumers often find it necessary to distinguish between different concentrations of solutions. Concentration is commonly expressed as of solute per mass of solution, known as *mass percent*.

\[
\text{Mass percent} = \frac{\text{Mass of solute}}{\text{Total mass of solution}} \times 100
\]

Remember that a solution is defined as a mixture of two or more substances that is homogenous at the molecular level. The solvent is the substance that is present in the greatest amount. All other substances in the solution are known as solutes.

**Examples**

- **What is the mass percent concentration of a solution made up of 12 grams of sugar and 300. grams of water?**

  **Solution:**

  In this case, the solute is sugar (12 g), and the total mass of the solution is the mass of the sugar plus the mass of the water, (12 g + 300. g).

  Substituting into the formula, where \( c \) = the percent concentration, we have:

  \[
  c = \frac{12 \text{ g}}{12 \text{ g} + 300 \text{ g}} \times 100 = \frac{12 \text{ g}}{312 \text{ g}} \times 100 = 3.8\%
  \]

  The concentration of a solution of 12 grams of sugar and 300. grams of water is 3.8%.

- **How many grams of salt and water are needed to make 150 grams of a solution with a concentration of 15% salt?**

  **Solution:**

  Here, we are given the concentration (15%) and the total mass of the solution (150 g). We are trying to find the mass of the solute (salt). Substituting into the same formula, where \( m \) is the mass of the salt, we have:

  \[
  15\% = \frac{m}{150 \text{ g}} \times 100, \text{ so } 0.15 = \frac{m}{150 \text{ g}}, \text{ and } 0.15 \times (150 \text{ g}) = m = 22.5 \text{ g}
  \]

  Since the total mass of the solution is 150 grams, and we now know that 22.5 grams are salt, that leaves:

  150 grams solution - 22.5 grams salt = 127.5 grams of water

  **To make 150 grams of a solution with a concentration of 15% salt, you would need 22.5 grams of salt and 127.5 grams of water.**
Find the mass percent concentration of each solution or mixture.

1. 5 grams of salt in 75 grams of water
2. 40 grams of cinnamon in 2,000 grams of flour
3. 1.5 grams of chocolate milk mix in 250 grams of 1% milk

Find the mass of the solute in each situation.

4. 1,000 grams of a 40% salt water solution
5. 30 grams of a 12.5% sugar water solution
6. 555 grams of a 25% sand and soil “solution”

Carefully read and answer each of the following questions.

7. Dawn is mixing 450 grams of dishwashing liquid with 600 grams of water to make a solution for her little brother to blow bubbles. What is the concentration of the dishwashing liquid?
8. How many grams of glucose are needed to prepare 250 grams of a 5% glucose and water solution?
9. Jill mixes 4 grams of vanilla extract into the 800 grams of cake batter she has prepared. What is the concentration of vanilla in her “solution” of cake batter?
10. **Challenge**: Find the amount of red food coloring (in grams) necessary to add to 50 grams of water to prepare a 15% solution of red food coloring in water.
21.2 Solubility

In this skill sheet you will practice solving problems about solubility. You will use solubility values to identify solutions that are saturated, unsaturated, or supersaturated. Finally, you will practice your skills in interpreting temperature-solubility graphs.

What is solubility?

A solution is defined as a mixture of two or more substances that is homogenous at the molecular level. The substance present in the greatest amount is called the solvent. The other substances are known as solutes. The degree to which a solute dissolved is described by its solubility value. This value is the mass in grams of the solute that can dissolve in a given volume of solvent under certain conditions.

For example, the solubility of table salt (NaCl) is 1 gram per 2.7 milliliters of water at 25 °C. Another way to state this solubility value is to say that 0.37 grams of salt will dissolve in one milliliter of water at 25 °C. Do you see that these values mean the same thing?

\[
\frac{1 \text{ gram NaCl}}{2.7 \text{ ml H}_2\text{O} \cdot 25 \circ \text{C}} = \frac{0.37 \text{ gram NaCl}}{2.7 \text{ ml H}_2\text{O} \cdot 25 \circ \text{C}}
\]

Information about the solubility of table salt and other substances is presented in the table below. Use these values to complete the questions that follow.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Solubility Value (grams/100 mL water 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table salt (NaCl)</td>
<td>37</td>
</tr>
<tr>
<td>Sugar (C\textsubscript{12}H\textsubscript{22}O\textsubscript{11})</td>
<td>200</td>
</tr>
<tr>
<td>Baking soda (NaHCO\textsubscript{3})</td>
<td>10</td>
</tr>
<tr>
<td>Chalk (CaCO\textsubscript{3})</td>
<td>insoluble</td>
</tr>
<tr>
<td>Talc (Mg silicates)</td>
<td>insoluble</td>
</tr>
</tbody>
</table>

1. Chalk and talc are listed as “insoluble” in the table. What do you think this term means? In your response, come up with a reason to explain why chalk and talc cannot dissolve in water.

2. Come up with a reason to explain why table salt, sugar, and baking soda dissolve in different amount for the same set of conditions (same volume and temperature).

3. How much table salt would dissolve in 540 mL of water if the water was 25 °C?

4. What volume of water would you need to dissolve 72 grams of salt at 25 °C?

5. What volume of water at 25 °C would you need to dissolve 50 grams of sugar?

6. How much baking soda will dissolve in 10 milliliters of water at 25 °C?
Saturated, unsaturated, and supersaturated solutions

The solubility value for a substance indicates how much solute is present in a saturated solution. When the amount of solute is less than the solubility value for a certain volume of water, we say the solution is unsaturated. When the amount of solute is more than the solubility value for a certain volume of water, we say the solution is supersaturated.

Use the table on the previous page to help you fill in the table below. In each situation, is the solution saturated, unsaturated, or supersaturated?

<table>
<thead>
<tr>
<th>Substance</th>
<th>Amount of substance in 200 mL of water at 25°C</th>
<th>Saturated, unsaturated, or supersaturated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table salt (NaCl)</td>
<td>37 grams</td>
<td></td>
</tr>
<tr>
<td>Sugar (C_{12}H_{22}O_{11})</td>
<td>500 grams</td>
<td></td>
</tr>
<tr>
<td>Baking soda (NaHCO_{3})</td>
<td>20 grams</td>
<td></td>
</tr>
<tr>
<td>Table salt (NaCl)</td>
<td>100 grams</td>
<td></td>
</tr>
<tr>
<td>Sugar (C_{12}H_{22}O_{11})</td>
<td>210 grams</td>
<td></td>
</tr>
<tr>
<td>Baking soda (NaHCO_{3})</td>
<td>25 grams</td>
<td></td>
</tr>
</tbody>
</table>
The influence of temperature on solubility

Have you noticed that sugar dissolves much easier in hot tea than in iced tea? The solubility of some substances increases greatly as the temperature of the solvent increases. For other substances, the dissolving rate changes very little. A solubility graph (sometimes called a solubility curve) can be used to show how temperature affects solubility.

Below is a table of some imaginary substances dissolved in water at different temperatures. Study the table and then answer the questions.

<table>
<thead>
<tr>
<th>Substance dissolved in 100 mL of water</th>
<th>Solubility values (grams per 100 mL of water) at different temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 °C</td>
</tr>
<tr>
<td>gas A</td>
<td>0.2</td>
</tr>
<tr>
<td>gas B</td>
<td>0.1</td>
</tr>
<tr>
<td>solid A</td>
<td>30</td>
</tr>
<tr>
<td>solid B</td>
<td>40</td>
</tr>
</tbody>
</table>

1. Use graph paper to make two solubility graphs of the data in the table. On one graph, plot the data for gases A and B. On the other graph, plot the data for solids A and B. Use two different colors to plot the data for A and for B. Label the x-axis, “Temperature (°C).” Label the y-axis, “Solubility value (grams/100 mL H₂O).”

2. How does the solubility of gases A and B differ from the solubility of solids A and B in water? Explain your response.

3. For which substance does temperature seem to have the greatest influence on solubility?

4. For which substance does temperature seem to have the least influence?

5. If you had 500 mL of water at 70°C and you made a saturated solution by adding 205 grams of a substance, which of the substances above would you be adding?

6. Organisms that live in ponds and lakes depend on dissolved oxygen to survive. Explain how the amount of dissolved oxygen in a pond or lake might vary with the seasons (winter, spring, summer, and fall). Justify your ideas.
21.2 Salinity and Concentration Problems

Bodies of water like ponds, lakes, and oceans contain solutions of dissolved substances. Often these substances are in small quantities, measured in parts per thousand (ppt), parts per million (ppm), and parts per billion (ppb). This skill sheet will provide you with practice in using these quantities and in doing calculations with them.

Unit conversions

Table 1 below provides unit conversions that will be helpful to you as you complete this skill sheet.

<table>
<thead>
<tr>
<th>Milligrams</th>
<th>= Grams</th>
<th>= Kilograms</th>
<th>= Liters of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.001</td>
<td>0.000001</td>
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<td>1</td>
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<td>1,000,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Review: working with small concentrations

When working with small concentrations, remember that the units of the numerator and denominator must match, as shown in the examples below.

A. Parts per thousand (ppt)

Example: 0.009 grams of phosphate in about 1000 grams of oxygenated water makes a solution that has a phosphate concentration of 0.009 ppt.

\[
\frac{0.009 \text{ grams}}{1,000 \text{ grams}} = 0.009 \text{ ppt}
\]

B. Parts per million (ppm)

Example: A good level of oxygen in a pond is 9 ppm. This means that there are 9 milligrams of oxygen for every one liter (1000 grams) of oxygenated water.

\[
\frac{9 \text{ milligrams}}{1 \text{ liter}} = \frac{9 \text{ milligrams}}{1,000 \text{ grams}} = \frac{9 \text{ milligrams}}{1,000,000 \text{ milligrams}} = 9 \text{ ppm}
\]

C. Parts per billion (ppb)

Example: The concentration of trace elements in seawater is very low. For example, the concentration of iron in seawater is 0.06 ppb. This means that there are 0.06 mg of iron in 1,000 liters of water. One thousand liters is equal to 1,000 times 1,000 grams of seawater.

\[
\frac{0.06 \text{ milligrams}}{1,000 \text{ liters}} = \frac{0.06 \text{ milligrams}}{1,000 \times 1,000 \text{ grams}} = \frac{0.06 \text{ milligrams}}{1,000,000 \text{ grams}} = \frac{0.06 \text{ milligrams}}{1,000,000,000 \text{ milligrams}} = 0.06 \text{ ppb}
\]
Work through these example problems and check your answers. Then you will be ready to try the practice problems on your own.

- There are 16 grams of salt in 984 grams of water. What is the salinity of this solution?
  
  **Solution:**

  \[
  \text{salinity} = \frac{16 \text{ grams salt}}{984 \text{ grams water} + 16 \text{ grams salt}} = \frac{16 \text{ grams salt}}{1,000 \text{ grams solution}} = 16 \text{ ppt}
  \]

- A liter of solution has a salinity of 40 ppt. How many grams of salt are in the solution? How many grams of pure water are in the solution?
  
  **Solution:**

  \[
  40 \text{ ppt} = \frac{40 \text{ grams salt}}{1,000 \text{ grams solution}} = \frac{40 \text{ grams salt}}{40 \text{ grams salt} + x \text{ grams water}}
  \]

  \[
  1,000 \text{ grams solution} = 40 \text{ grams salt} + x \text{ grams water}
  \]

  \[
  1,000 \text{ grams solution} - 40 \text{ grams salt} = 960 \text{ grams water}
  \]

- You measure the salinity of a seawater sample to be 34 ppt. How many grams of salt are in this sample if the mass is 2 kilograms?
  
  **Solution:** First, remember that there are 1,000 grams per kilogram. If a solution is given in parts per thousand, you can think of it as “grams per 1,000 grams” or “grams per kilogram.” Therefore, you can set up a proportion like this:

  \[
  \frac{34 \text{ grams salt}}{1 \text{ kilogram solution}} = \frac{x \text{ grams salt}}{2 \text{ kilograms solution}}
  \]

  Next, solve for \(x\).

  \[
  x = \frac{34 \text{ grams salt} \times 2 \text{ kilograms solution}}{1 \text{ kilogram solution}}
  \]

  \[
  x = 68 \text{ grams salt}
  \]
For each problem, show your work.

1. Complete Table 2 below:

Table 2: Salinity of Famous Places

<table>
<thead>
<tr>
<th>Place</th>
<th>Salinity (ppt)</th>
<th>Amount of salt in 1 liter (grams)</th>
<th>Amount of pure water in 1 liter (grams)</th>
</tr>
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<tbody>
<tr>
<td>Salton Sea</td>
<td>44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>California</td>
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<td>Great Salt Lake</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono Lake</td>
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</tr>
<tr>
<td>California</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pacific Ocean</td>
<td>87</td>
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<td></td>
</tr>
</tbody>
</table>

2. How many grams of salt are in 2 liters of seawater that has a salinity of 36 ppt?

3. A one-liter sample of seawater contains 10 grams of salt. What is the salinity of this sample?

4. You want to make a salty solution that has the same salinity as the Dead Sea. The salinity of the Dead Sea is 210 ppt. Write a recipe for how you would make 2 liters of this solution.

5. Five kilograms of seawater contains 30 grams of salt. What is the salinity of the volume of seawater?

6. You measure the salinity of a seawater sample to be 30 ppt. How many grams of salt are in this sample if the mass is 1.5 kilograms?

7. A solution has 2 grams of a substance in 1,000,000 grams of solution. Would you describe the concentration of the substance in solution as 2 parts per million or parts per billion?

8. A solution has 5 grams of a substance in 1,000,000,000 grams of solution. Would you describe the concentration of the substance as 5 ppb or 5 ppm?

9. Menthol is a substance that tastes sweet and minty and causes a cooling effect on your tongue. The taste threshold for menthol is 400 ppb. Could you taste menthol if there were 400 milligrams in 1,000,000 grams of menthol solution? Could you taste menthol if there were 400 milligrams in 1000 liters of menthol solution?

10. Above-ground pipelines are used to transport natural gas, an important energy source. Gas leaks are potential problems with the pipelines. German Shepherd dogs can be trained to detect the gas leaks. The dogs sniff along the pipeline and then indicate a leak by perking up their ears or pawing the ground. The most sensitive electronic devices can detect gas leaks as low as 50 ppm. A German Shepherd can detect a gas leak as low as 1 ppb. How many times more sensitive is the dog as compared to the electronic device?
21.3 Calculating pH

The pH of a solution is a measure of the concentration of hydrogen ions (H+) in the solution. The pH scale, which ranges from 0 to 14, provides a tool to assess the degree to which a solution is acidic or basic. As you may remember, solutions with low pH values are very acidic and contain high concentrations of hydrogen ions. Why does a low pH value mean a high concentration of H+? The answer has to do with what pH means mathematically. In this skill sheet, we will examine how pH values are calculated.

How do you calculate pH?

The pH value for any solution is equal to the negative logarithm of the hydrogen ion (H+) concentration in that solution. The formula is written this way:

\[
pH = -\log[H^+] \]

Concentration of hydrogen ions is implied by placing brackets (“[ ]”) around H+.

A term used by scientists to describe the concentration of a substance in a solution is molarity. Molarity (M) means how many moles of a substance are present in a given volume of solution.

For hydrogen ions in solutions, the concentration generally ranges from 10 to 10^{-14} M. The larger the molarity, the greater the concentration of H+ in the solution. If a solution had a H^+ concentration of 10^{-3} M, the corresponding pH value would be:

\[
\begin{align*}
\text{pH} & = -\log[10^{-3}] \\
10^{\text{pH}} & = -[10^{-3}] \\
\text{pH} & = -[-3] \\
\text{pH} & = 3
\end{align*}
\]

For a solution with an H^+ concentration of 10^{-5} M, the corresponding pH value would be:

\[
\begin{align*}
\text{pH} & = -\log[10^{-5}] \\
10^{\text{pH}} & = -[10^{-5}] \\
\text{pH} & = -[-5] \\
\text{pH} & = 5
\end{align*}
\]

The first solution has a higher H^+ concentration than the second solution (10^{-3} M versus 10^{-5} M); however, its pH value is a smaller number. Strong acids have small pH values. Larger pH values (like 14) have lower concentrations of H^+, and the solutions represent weaker acids.
1. Practice working with numbers that have exponents. In the blank provided, write greater than, less than, or equals.
   a. \(10^{-2} \quad \underline{} \quad 10^{-3}\)
   b. \(10^{-14} \quad \underline{} \quad 10^1\)
   c. \(10^{-7} \quad \underline{} \quad 0.0000001\)
   d. \(10^0 \quad \underline{} \quad 10^1\)

2. Solutions that range in pH from 0 to 7 are acidic. Solutions that range in pH from 7 to 14 are basic. Solutions that have pH of 7 are neutral. The hydrogen ion concentrations for some solutions are given below. Use the pH formula to determine which is an acid, which is a base, and which is neutral.
   a. Solution A: The hydrogen ion concentration is equal to \(10^{-1}\) M.
   b. Solution B: The hydrogen ion concentration is equal to 0.0000001 M.
   c. Solution C: The hydrogen ion concentration is equal to \(10^{-13}\) M.

3. Orange juice has a hydrogen ion concentration of approximately \(10^{-4}\) M. What is the pH of orange juice?

4. Black coffee has a hydrogen ion concentration of roughly \(10^{-5}\) M. Is black coffee a stronger or weaker acid than orange juice? Justify your answer and provide all relevant calculations for supporting evidence.

5. Pure water has a hydrogen ion concentration of \(10^{-7}\) M. What is the pH of water? Would you say water is an acid or a base? Explain your answer.

6. A solution has a pH of 11. What is the H\(^+\) concentration of the solution? Is this solution an acid or a base?

7. A solution has a pH of 8.4. What is the H\(^+\) concentration of this solution?

8. Acids are very good at removing hard water deposits from bathtubs, sinks, and glassware. Your father goes to the store to buy a cleaner to remove such deposits from your bathtub. He has a choice between a product containing lemon juice (H\(^+\) = \(10^{-2.5}\) M) and one containing vinegar (H\(^+\) = \(10^{-3.3}\) M). Which product would you recommend he purchase? Explain your answer.
22.1 Groundwater and Wells Project

When it rains, some of the water that falls on Earth seeps into the ground, while some water flows over the surface into local streams or lakes. Some water is absorbed by plants and some evaporates back into the atmosphere. The water that seeps into the ground flows downward, moving through empty spaces between soil, sand, or rocks. It continues its journey until it reaches rock through which it cannot easily move. Then, it starts to fill the spaces between the rock and soil above. The top of this wedge of water is called the water table.

The water that fills the empty spaces is called groundwater. Areas that groundwater easily moves through are called aquifers. Aquitards are bodies of rock where water can move through—but very slowly. If the aquitard does not allow any water to pass, it is called an aquiclude. Groundwater comes from precipitation (rain and snow melt), from lakes or rivers that leak water, and even from extra water not used by agricultural crops when they are irrigated.

Groundwater is a very important source of drinking water. According to the US Geological Survey, 51% of Americans get their drinking water from groundwater. 99% of the rural population in the US uses groundwater for drinking. 37% of agricultural water, which is mostly used for irrigation comes from groundwater. Groundwater is obtained by digging wells. The water fills the well underground and a pump inside pumps it up to the surface where it travels through pipes to bring it to our homes and businesses.

This project will help you learn more about groundwater movement and wells.

Materials:

- GeoBox
- ½” to ¾” white stone; rounded is better (approximately 1,800 mL total)
- ¼” plastic foam; one piece 7 ¾” x 13 ¾”; second piece 7 ¾” x 9”
- Caulk or plumbers putty (something that can be molded around the PVC wells for waterproofing)
- Plastic wrap
- Food dye - dark colors
- 8-10 cotton swabs
- Tape
- Wooden skewer or dowel with diameter less than ½”
- 3 wells (½” inside diameter PVC pipe with caps; 4 well holes near cap drilled with 13/64 drill bit)
- Watering can or beaker
Constructing the model:

1. Line the inside of the GeoBox with plastic wrap so that it comes up and over the edges of the box.

2. Hold well #2 in the middle of the GeoBox, with the cap end sitting directly on the bottom of the GeoBox. Add approximately 1,800 mL of the rock, surrounding the well. The rock should just cover the holes of the well and the well should stand on its own.

3. The larger plastic foam sheet will be layered next on top of the rock. In order to put it down, carefully poke the well through it so it fits over the well. Now place on top of it the plastic wrap that will come up and over the edges. Because you need to also make a hole in the plastic wrap through which to fit the well, use the caulk or putty to mold around the well and onto the plastic wrap to keep it water proof.

4. Once this is set, hold well #3 in place on the right side (diagram A) and add approximately 2,000 mL of stone down on the surface, so that it surrounds well #3 and holds it upright.

5. Now add approximately 1,300 mL of stone to the left side of the GeoBox to create a diagonal plane of stone that runs highest from the left edge to level just right of well #2.

6. Place well #1 in the built up area of stone on the left side of the GeoBox, just above, but not touching the first plastic foam layer (as well #3 is). Make sure that the stone is covering the holes in the well.

7. Place the smaller plastic foam sheet over well #1 and well #2, again poking holes in the plastic foam so that the sheet can sit on the rock layers below. This sheet will be slanted down towards the middle.

8. Again you will cover just the sheet with plastic wrap which will come up and over the edge on three sides. Caulk the two wells that poke through this sheet.

9. Use the remaining 3,000 mL of stone to fill the tray up to the top so that what is visible is just stone and three well tops. See photo at right.

10. Tape one cotton swab to the end of the skewer or wooden rod so that the cotton swab reaches out from the end of the wood. See diagram B at right.

11. Dye the water that you will be using for precipitation a dark color, such as blue, red, or green.

Making predictions:

a. Which well/s would you expect to collect water when it rains?

b. If contamination entered from the surface, what well would you expect to first show contaminated water?

c. Will well #2 get contaminated from surface contamination? Why?
Testing the model:

1. Watch the water flow closely as you do this experiment.

2. Sprinkle or pour the dyed water into the top layer of rock to simulate precipitation, without allowing the water to precipitate into the wells. The dye will make it easier to see the water as it travels.

3. Regularly check the wells with the cotton swab/dowel rods to see if water has entered the wells. In this way, you can also see which well collected water the quickest.

4. For a demonstration of the movement of surface pollution—dye water another color and allow this contaminated water to percolate through the layers. Use new cotton swabs attached to the wooden rods to visualize if and when the wells will get contaminated. The cotton swab should change color as the two dyes mix.

Thinking about what you observed:

a. Which wells collected water when it rained? Was your hypothesis correct?

b. Which well was first to be contaminated? Was your hypothesis correct?

c. What does the plastic wrap/plastic foam layer represent? Label diagram C appropriately.

d. What do the rock layers represent? Label diagram C appropriately.

e. Did well #2 get contaminated from surface contamination? Why? Was your hypothesis correct?

f. What effect would pumping from well #1 have on movement of surface contamination? Pumping from well #2?

g. What would happen if there was a dry spell and the water table and thus the groundwater was lowered to below well #1? Would any well be able to pump water?

h. If well #3 were located near the coast, what effect might pumping freshwater too quickly have on the water in the well?

i. When you dig a well, how might you decide how deep to dig it?
22.2 The Water Cycle

As you study Section 22.2 in your student text, you will learn about the processes that move water around our planet. Together, these processes form the water cycle. Use the word box to help you label the water cycle diagram below. Some words may be used more than once.

- condensation
- groundwater flow
- evaporation
- water vapor transport
- percolation
- transpiration
- precipitation

Answer the following questions. Use the diagram above and Section 22.2 of your text to help you.

1. Name two water cycle processes that are driven by the Sun. Explain the Sun’s role in each.

2. How is wind involved in the water cycle?

3. How does gravity affect the water cycle?
24.1 Period and Frequency

The **period** of a pendulum is the time it takes to move through one cycle. As the ball on the string is pulled to one side and then let go, the ball moves to the side opposite the starting place and then returns to the start. This entire motion equals one cycle.

**Frequency** is a term that refers to how many cycles can occur in one second. For example, the frequency of the sound wave that corresponds to the musical note “A” is 440 cycles per second or 440 hertz. The unit *hertz* (Hz) is defined as the number of cycles per second.

The terms period and frequency are related by the following equation:

\[
T = \frac{1}{f} \quad \text{and} \quad f = \frac{1}{T}
\]

**Practice**

1. A string vibrates at a frequency of 20 Hz. What is its period?
2. A speaker vibrates at a frequency of 200 Hz. What is its period?
3. A swing has a period of 10 seconds. What is its frequency?
4. A pendulum has a period of 0.3 second. What is its frequency?
5. You want to describe the harmonic motion of a swing. You find out that it take 2 seconds for the swing to complete one cycle. What is the swing’s period and frequency?
6. An oscillator makes four vibrations in one second. What is its period and frequency?
7. A pendulum takes 0.5 second to complete one cycle. What is the pendulum’s period and frequency?
8. A pendulum takes 10 seconds to swing through 2 complete cycles.
   a. How long does it take to complete one cycle?
   b. What is its period?
   c. What is its frequency?
9. An oscillator makes 360 vibrations in 3 minutes.
   a. How many vibrations does it make in one minute?
   b. How many vibrations does it make in one second?
   c. What is its period in seconds?
   d. What is its frequency in hertz?
24.1 Harmonic Motion Graphs

A graph can be used to show the amplitude and period of an object in harmonic motion. An example of a graph of a pendulum’s motion is shown below.

The distance to which the pendulum moves away from its center point is call the **amplitude**. The amplitude of a pendulum can be measured in units of length (centimeters or meters) or in degrees. On a graph, the amplitude is the distance from the x-axis to the highest point of the graph. The pendulum shown above moves 20 centimeters to each side of its center position, so its amplitude is 20 centimeters.

The **period** is the time for the pendulum to make one complete cycle. It is the time from one peak to the next on the graph. On the graph above, one peak occurs at 1.5 seconds, and the next peak occurs at 3.0 seconds. The period is $3.0 - 1.5 = 1.5$ seconds.

1. Use the graphs to answer the following questions

   a. What is the amplitude of each vibration?
   b. What is the period of each vibration?
2. Use the grids below to draw the following harmonic motion graphs. Be sure to label the $y$-axis to indicate the measurement scale.

a. A pendulum with an amplitude of 2 centimeters and a period of 1 second.

![Graph for pendulum with amplitude of 2 cm and period of 1 s]

b. A pendulum with an amplitude of 5 degrees and a period of 4 seconds.

![Graph for pendulum with amplitude of 5 degrees and period of 4 s]
24.2 Waves

A wave is a traveling oscillator that carries energy from one place to another. A high point of a wave is called a crest. A low point is called a trough. The amplitude of a wave is half the distance from a crest to a trough. The distance from one crest to the next is called the wavelength. Wavelength can also be measured from trough to trough or from any point on the wave to the next place where that point occurs.

![Diagram of a wave showing crest, trough, amplitude, and one wavelength.]

The speed of a wave can be calculated using the formula:

\[
v = f \lambda
\]

Where:
- \(v\) is the speed (m/sec)
- \(f\) is the frequency (hertz)
- \(\lambda\) is the wavelength (meters)

**EXAMPLE**

- The frequency of a wave is 40 Hz and its speed is 100 meters per second. What is the wavelength of this wave?

**Solution:**

\[
\frac{100 \text{ m/s}}{40 \text{ Hz}} = \frac{100 \text{ m/s}}{40 \text{ cycles/s}} = 2.5 \text{ meters per cycle}
\]

The wavelength is 2.5 meters.

**PRACTICE**

1. On the graphic at right label the following parts of a wave: one wavelength, half of a wavelength, the amplitude, a crest, and a trough.
   a. How many wavelengths are represented in the wave above?
   b. What is the amplitude of the wave shown above?
2. Use the grids below to draw the following waves. Be sure to label the y-axis to indicate the measurement scale.

a. A wave with an amplitude of 1 cm and a wavelength of 2 cm

b. A wave with an amplitude of 1.5 cm and a wavelength of 3 cm

3. A water wave has a frequency of 2 hertz and a wavelength of 5 meters. Calculate its speed.

4. A wave has a speed of 50 m/s and a frequency of 10 Hz. Calculate its wavelength.

5. A wave has a speed of 30 m/s and a wavelength of 3 meters. Calculate its frequency.

6. A wave has a period of 2 seconds and a wavelength of 4 meters. Calculate its frequency and speed. Note: Recall that the frequency of a wave equals 1/period and the period of a wave equals 1/frequency.

7. A sound wave travels at 330 m/s and has a wavelength of 2 meters. Calculate its frequency and period.

8. The frequency of wave A is 250 hertz and the wavelength is 30 centimeters. The frequency of wave B is 260 hertz and the wavelength is 25 centimeters. Which is the faster wave?

9. The period of a wave is equal to the time it takes for one wavelength to pass by a fixed point. You stand on a pier watching water waves and see 10 wavelengths pass by in a time of 40 seconds.
   a. What is the period of the water waves?
   b. What is the frequency of the water waves?
   c. If the wavelength is 3 meters, what is the wave speed?
Interference occurs when two or more waves are at the same location at the same time. For example, the wind may create tiny ripples on top of larger waves in the ocean. The superposition principle states that the total vibration at any point is the sum of the vibrations produced by the individual waves.

Constructive interference is when waves combine to make a larger wave. Destructive interference is when waves combine to make a wave that is smaller than either of the individual waves. Noise cancelling headphones work by producing a sound wave that perfectly cancels the sounds in the room.

This worksheet will allow you to find the sum of two waves with different wavelengths and amplitudes. The table below (and continued on the next page) lists the coordinates of points on the two waves.

1. Use coordinates on the table and the graph paper (see last page) to graph wave 1 and wave 2 individually. Connect each set of points with a smooth curve that looks like a wave. Then, answer questions 2–9.

2. What is the amplitude of wave 1?

3. What is the amplitude of wave 2?

4. What is the wavelength of wave 1?

5. What is the wavelength of wave 2?

6. How many wavelengths of wave 1 did you draw?

7. How many wavelengths of wave 2 did you draw?

8. Use the superposition principle to find the wave that results from the interference of the two waves.
   a. To do this, simply add the heights of wave 1 and wave 2 at each point and record the values in the last column. The first four points are done for you.
   b. Then use the points in last column to graph the new wave. Connect the points with a smooth curve. You should see a pattern that combines the two original waves.

9. Describe the wave created by adding the two original waves.

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<th>x-axis (blocks)</th>
<th>Height of wave 1 (y-axis blocks)</th>
<th>Height of wave 2 (y-axis blocks)</th>
<th>Height of wave 1 + wave 2 (y-axis blocks)</th>
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</tr>
<tr>
<td>25</td>
<td>-3.9</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>-3.7</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>-3.3</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>-2.8</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>-2.2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>-1.5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>-0.8</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
24.3 Decibel Scale

The loudness of sound is measured in decibels (dB). Most sounds fall between zero and 100 on the decibel scale making it a very convenient scale to understand and use. Each increase of 20 decibels (dB) for a sound will be about twice as loud to your ears. Use the following table to help you answer the questions.

<table>
<thead>
<tr>
<th>Decibels</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-15 dB</td>
<td>A quiet whisper 3 feet away</td>
</tr>
<tr>
<td>30-40 dB</td>
<td>Background noise in a house</td>
</tr>
<tr>
<td>65 dB</td>
<td>Ordinary conversation 3 feet away</td>
</tr>
<tr>
<td>70 dB</td>
<td>City traffic</td>
</tr>
<tr>
<td>90 dB</td>
<td>A jackhammer cutting up the street 10 feet away</td>
</tr>
<tr>
<td>100 dB</td>
<td>Listening to headphones at maximum volume</td>
</tr>
<tr>
<td>110 dB</td>
<td>Front row at a rock concert</td>
</tr>
<tr>
<td>120 dB</td>
<td>The threshold of physical pain from loudness</td>
</tr>
</tbody>
</table>

**Example**

- How many decibels would a sound have if its loudness was twice that of city traffic?

  **Solution:**

  City traffic = 70 dB
  Adding 20 dB doubles the loudness.
  70 dB + 20 dB = 90 dB
  90 dB is twice as loud as city traffic.

**Practice**

1. How many times louder than a jackhammer does the front row at a rock concert sound?
2. How many decibels would you hear in a room that sounds twice as loud as an average (35 dB) house?
3. You have your headphones turned all the way up (100 dB).
   a. If you want them to sound half as loud, to what decibel level must the music be set?
   b. If you want them to sound 1/4 as loud, to what decibel level must the music be set?
4. How many times louder than city traffic does the front row at a rock concert sound?
5. When you whisper, you produce a 10-dB sound.
   a. When you speak quietly, your voice sounds twice as loud as a whisper. How many decibels is this?
   b. When you speak normally, your voice sounds 4 times as loud as a whisper. How many decibels is this?
   c. When you yell, your voice sounds 8 times as loud as a whisper. How many decibels is this?
24.3 The Human Ear

Write the name of the part that corresponds to each letter in the diagram. Then write the function of each part in the spaces on the next page.

A _______________________
B _______________________
C _______________________
D _______________________
E _______________________
F _______________________
G _______________________
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
a. |   |
b. |   |
c. |   |
d. |   |
e. |   |
f. |   |
g. |   |
24.3 Standing Waves

A wave that is confined in a space is called a standing wave. Standing waves on the vibrating strings of a guitar produce the sounds you hear. Standing waves are also present inside the chamber of a wind instrument.

A string that contains a standing wave is an oscillator. Like any oscillator, it has natural frequencies. The lowest natural frequency is called the fundamental. Other natural frequencies are called harmonics. The first five harmonics of a standing wave on a string are shown to the right.

There are two main parts of a standing wave. The nodes are the points where the string does not move at all. The antinodes are the places where the string moves with the greatest amplitude.

The wavelength of a standing wave can be found by measuring the length of two of the “bumps” on the string. The first harmonic only contains one bump, so the wavelength is twice the length of the individual bump.

1. Use the graphic below to answer these questions.
   a. Which harmonic is shown in each of the strings below?
   b. Label the nodes and antinodes on each of the standing waves shown below.
   c. How many wavelengths does each standing wave contain?
   d. Determine the wavelength of each standing wave.
2. Two students want to use a 12-meter rope to create standing waves. They first measure the speed at which a single wave pulse moves from one end of the rope to another and find that it is 36 m/s. This information can be used to determine the frequency at which they must vibrate the rope to create each harmonic. Follow the steps below to calculate these frequencies.

a. Draw the standing wave patterns for the first six harmonics.

b. Determine the wavelength for each harmonic on the 12-meter rope. Record the values in the table below.

c. Use the equation for wave speed \( v = f \lambda \) to calculate each frequency.

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Speed (m/s)</th>
<th>Wavelength (m)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

d. What happens to the frequency as the wavelength increases?

e. Suppose the students cut the rope in half. The speed of the wave on the rope only depends on the material from which the rope is made and its tension, so it will not change. Determine the wavelength and frequency for each harmonic on the 6-meter rope.

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Speed (m/s)</th>
<th>Wavelength (m)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

f. What effect did using a shorter rope have on the wavelength and frequency?
24.3 Waves and Energy

A wave is an organized form of energy that travels. The amount of energy a wave has is proportional to its frequency and amplitude. Therefore, higher energy waves have a higher frequency and/or a higher amplitude. Remember that the frequency is measured in hertz. The frequency of 1 Hz equals one wave cycle per second.

For each set of diagrams, identify which of the standing waves has the highest energy and which has the lowest energy.

**Answers for frequency and energy:**

<table>
<thead>
<tr>
<th>Standing wave</th>
<th>Frequency</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>lowest</td>
<td>lowest</td>
</tr>
<tr>
<td>B</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>C</td>
<td>highest</td>
<td>highest</td>
</tr>
</tbody>
</table>

**Answers for amplitude and energy:**

<table>
<thead>
<tr>
<th>Standing wave</th>
<th>Frequency</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>lowest</td>
<td>lowest</td>
</tr>
<tr>
<td>B</td>
<td>highest</td>
<td>highest</td>
</tr>
</tbody>
</table>

1. When you drop a stone into a pool, water waves spread out from where the stone landed. Why?

2. Ian and Igor have opposite ends of a jump rope and perform the following demonstration. First they moved the rope up and down one time a second, then two times a second, and then three times a second. Describe the trend in frequency for the jump rope and the trend in energy used by Ian and Igor for this demonstration.

3. One wave has a frequency of 30 Hz and another has a frequency of 100 Hz. Both waves have the same amplitude. Which wave has more energy?

4. On a calm day ocean waves are about 0.1 meter high. However, during a hurricane, ocean waves might be as much as 14 meters high. If both waves have the same frequency, during which set of conditions do the waves have more energy?

5. Which wave has more energy: a wave that has an amplitude of 3 centimeters and a frequency of 2 Hz or a wave with an amplitude of 3 meters and a frequency of 2 Hz?

6. The loudness of sound is related to its amplitude. Which sound wave would have the least energy: a low-volume wave at 1,000 Hz or a high-volume (loud) wave at 1,000 Hz?

7. The frequency of microwaves is less than that of visible light waves. Which type of wave is likely to have greater energy?

8. Standing wave C in the first graphic above represents 1.5 wavelengths. Draw a standing wave that represents 2 wavelengths. Compare the energy and frequency of this standing wave to A, B, and C.
24.3 Palm Pipes Project

A palm pipe is a musical instrument made from a simple material—PVC pipe. To play a palm pipe, you hit an open end of the pipe on the palm of your hand, causing the air molecules in the pipe to vibrate. These vibrations create the sounds that you hear.

Materials:

- 1 standard 10-foot length of 1/2 inch PVC pipe for 180°F water.
- Flexible meter stick
- PVC pipe cutter or a hacksaw
- Sandpaper
- Seven different colors of permanent markers for labeling pipes
- Simple calculator

Directions:

1. Cut the PVC pipe into the lengths listed in the chart below. It works best if you measure one length, cut it, then make the next measurement. You may want to cut each piece a little longer than the given measurement so that you can sand out any rough spots and level the pipe without making it too short.

<table>
<thead>
<tr>
<th>Number</th>
<th>Note</th>
<th>Length of pipe (cm)</th>
<th>Frequency (Hertz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>23.60</td>
<td>349</td>
</tr>
<tr>
<td>2</td>
<td>G</td>
<td>21.00</td>
<td>392</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>18.75</td>
<td>440</td>
</tr>
<tr>
<td>4</td>
<td>B flat</td>
<td>17.50</td>
<td>446</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>15.80</td>
<td>523</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>14.00</td>
<td>587</td>
</tr>
<tr>
<td>7</td>
<td>E</td>
<td>12.50</td>
<td>659</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>11.80</td>
<td>698</td>
</tr>
<tr>
<td>9</td>
<td>G</td>
<td>10.50</td>
<td>748</td>
</tr>
<tr>
<td>10</td>
<td>A</td>
<td>9.40</td>
<td>880</td>
</tr>
<tr>
<td>11</td>
<td>B flat</td>
<td>9.20</td>
<td>892</td>
</tr>
<tr>
<td>12</td>
<td>C</td>
<td>7.90</td>
<td>1049</td>
</tr>
<tr>
<td>13</td>
<td>D</td>
<td>7.00</td>
<td>1174</td>
</tr>
<tr>
<td>14</td>
<td>E</td>
<td>6.25</td>
<td>1318</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>5.90</td>
<td>1397</td>
</tr>
</tbody>
</table>

2. Lightly sand the cut ends to smooth any rough spots.

3. Label each pipe with the number, note, and frequency using a different color permanent marker.

4. Hit one open end of the pipe on the palm of your hand in order to make a sound.
Activities:

1. Try blowing across the top of a pipe as if you were playing a flute. Does the pipe sound the same as when you tap it on your palm? Why or why not?
   **Safety note:** Wash the pipes with rubbing alcohol or a solution of 2 teaspoons household bleach per gallon of water before and after blowing across them.

2. Take one of the longer pipes and place it in a bottle of water so that the top of the pipe extends above the top of the bottle. Blow across it like a flute. What happens to the tone as you raise or lower the pipe in the bottle?

3. Try making another set of palm pipes out of 1/2-inch copper tubing. What happens when you strike these pipes against your palm? What happens when you blow across the top? How does the sound compare with the plastic pipes?

4. At a hardware store, purchase two rubber rings for each copper pipe. These rings should fit snugly around the pipes. Place one ring on each end of each pipe, then lay them on a table. Try tapping the side of each pipe with different objects—wooden and stainless steel serving spoons, for example. How does this sound compare with the other sounds you have made with the pipes?

5. Try playing some palm pipe music with your classmates. Here are two tunes to get you started:

<table>
<thead>
<tr>
<th>Happy Birthday</th>
<th>Twinkle Twinkle Little Star</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melody</td>
<td>C</td>
</tr>
<tr>
<td>Harmony</td>
<td>A</td>
</tr>
<tr>
<td>Melody</td>
<td>C</td>
</tr>
<tr>
<td>Harmony</td>
<td>F</td>
</tr>
</tbody>
</table>

| Melody        | F   | F   | C   | C   | D   | D   | C   | B♭  | B♭  | A   | A   | G   | G   | F   |
| Harmony       | C   | C   | A   | A   | B♭  | B♭  | A   | G   | G   | F   | F   | E   | E   | C   |

| Melody        | C   | C   | B♭  | B♭  | A   | A   | G   | C   | C   | B♭  | B♭  | A   | A   | G   |
| Harmony       | A   | A   | G   | G   | F   | F   | C   | A   | A   | G   | G   | F   | F   | C   |

| Melody        | F   | F   | C   | C   | D   | D   | C   | B♭  | B♭  | A   | A   | G   | G   | F   |
| Harmony       | C   | C   | A   | A   | B♭  | B♭  | A   | G   | G   | F   | F   | E   | E   | C   |
6. **Challenge:**

You can figure out the length of pipe needed to make other notes, too. All you need is a simple formula and your understanding of the way sound travels in waves.

To figure out the length of the pipe needed to create sound of a certain frequency, we start with the formula frequency = velocity of sound in air ÷ wavelength, or \( f = \frac{v}{\lambda} \). Next, we solve the equation for \( \lambda \): \( \lambda = \frac{v}{f} \).

The fundamental frequency is the one that determines which note is heard. You can use the chart below to find the fundamental frequency of a chromatic scale in two octaves. Notice that for each note, the frequency doubles every time you go up an octave.

Once you choose the frequency of the note you want to play, you need to know what portion of the fundamental frequency’s wavelength (S-shape) will fit inside the palm pipe.

To help you visualize the wave inside the palm pipe, hold the center of a flexible meter stick in front of you. Wiggle the meter stick to create a standing wave. This mimics a column of vibrating air in a pipe with two open ends. How much of a full wave do you see? If you answered one half, you are correct.

When a palm pipe is played, your hand closes one end of the pipe. Now use your meter stick to mimic this situation. Place the meter stick on a table top and use one hand to hold down one end of the stick. This represents the closed end of the pipe. Flick the other end of the meter stick to set it in motion. How much of a full wavelength do you see? Now do you know what portion of the wavelength will fit into the palm pipe? One-fourth of the wavelength of the fundamental frequency will fit inside the palm pipe. As a result the length of the pipe should be equal to \( \frac{1}{4} \lambda \), which is equal to \( \frac{1}{4}(\frac{v}{f}) \).

In practice, we find that the length of pipe needed to make a certain frequency is actually a bit shorter than this. Subtracting a length equal to \( 1/4 \) of the pipe’s inner diameter is necessary. The final equation, therefore, is: Length of pipe = \( \frac{v}{4f} - \frac{1}{4}D \) where D represents the inner diameter of the pipe.

Given that the speed of sound in air (at 20 °C) is 343 m/s and the inner diameter of the pipe is 0.0017 m, what is the length of pipe you would need to make the note B, with a frequency of 494 hertz? How about the same note one octave higher (frequency 988 hertz)? Make these two pipes so that you can play a C major scale.

| Chromatic scale in two octaves (frequencies rounded to nearest whole number) |
|-----------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Note | A | A# | B | C | C# | D | D# | E | F | F# | G | G# | A |
| Frequency (Hertz) | 220 | 233 | 247 | 262 | 277 | 294 | 311 | 330 | 349 | 370 | 392 | 415 | 440 |
| Frequency (Hertz) | 440 | 466 | 494 | 523 | 554 | 587 | 622 | 659 | 698 | 740 | 784 | 831 | 880 |

7. **What is the lowest note you could make with a palm pipe? What is the highest? Explain these limits using what you know about the human ear and the way sound is created by the palm pipe.**
Radio waves, microwaves, visible light, and x-rays are familiar kinds of electromagnetic waves. All of these waves have characteristic wavelengths and frequencies. Wavelength is measured in meters. It describes the length of one complete oscillation. Frequency describes the number of complete oscillations per second. It is measured in hertz, which is another way of saying “cycles per second.” The higher the wave’s frequency, the more energy it carries.

**Frequency, wavelength, and speed**

In a vacuum, all electromagnetic waves travel at the same speed: \(3.0 \times 10^8\) m/s. This quantity is often called “the speed of light” but it really refers to the speed of all electromagnetic waves, not just visible light. It is such an important quantity in physics that it has its own symbol, \(c\).

The speed of light is related to frequency \(f\) and wavelength \(\lambda\) by the formula to the right.

The different colors of light that we see correspond to different frequencies. The frequency of red light is lower than the frequency of blue light. Because the speed of both kinds of light is the same, a lower frequency wave has a longer wavelength. A higher frequency wave has a shorter wavelength. Therefore, red light’s wavelength is longer than blue light’s.

When we know the frequency of light, the wavelength is given by: \(\lambda = \frac{c}{f}\)

When we know the wavelength of light, the frequency is given by: \(f = \frac{c}{\lambda}\)
Answer the following problems. Don’t forget to show your work.

1. Yellow light has a longer wavelength than green light. Which color of light has the higher frequency?
2. Green light has a lower frequency than blue light. Which color of light has a longer wavelength?
3. Calculate the wavelength of violet light with a frequency of \(750 \times 10^{12}\) Hz.
4. Calculate the frequency of yellow light with a wavelength of \(580 \times 10^{-9}\) m.
5. Calculate the wavelength of red light with a frequency of \(460 \times 10^{12}\) Hz.
6. Calculate the frequency of green light with a wavelength of \(530 \times 10^{-9}\) m.
7. One light beam has wavelength, \(\lambda_1\), and frequency, \(f_1\). Another light beam has wavelength, \(\lambda_2\), and frequency, \(f_2\). Write a proportion that shows how the ratio of the wavelengths of these two light beams is related to the ratio of their frequencies.
8. The waves used by a microwave oven to cook food have a frequency of \(2.45\) gigahertz (\(2.45 \times 10^9\) Hz). Calculate the wavelength of this type of wave.
9. A radio station has a frequency of \(90.9\) megahertz (\(9.09 \times 10^7\) Hz). What is the wavelength of the radio waves the station emits from its radio tower?
10. An x-ray has a wavelength of 5 nanometers (\(5.0 \times 10^{-9}\) m). What is the frequency of x-rays?
11. The ultraviolet rays that cause sunburn are called UV-B rays. They have a wavelength of approximately 300 nanometers (\(3.0 \times 10^{-7}\) m). What is the frequency of a UV-B ray?
12. Infrared waves from the sun are what make our skin feel warm on a sunny day. If an infrared wave has a frequency of \(3.0 \times 10^{12}\) Hz, what is its wavelength?
13. Electromagnetic waves with the highest amount of energy are called gamma rays. Gamma rays have wavelengths of less than 10-trillionths of a meter (\(1.0 \times 10^{-11}\) m).
   a. Determine the frequency that corresponds with this wavelength.
   b. Is this the minimum or maximum frequency of a gamma ray?
14. Use the information from this sheet to order the following types of waves from lowest to highest frequency: visible light, gamma rays, x-rays, infrared waves, ultraviolet rays, microwaves, and radio waves.
15. Use the information from this sheet to order the following types of waves from shortest to longest wavelength: visible light, gamma rays, x-rays, infrared waves, ultraviolet rays, microwaves, and radio waves.
25.2 Color Mixing with Additive and Subtractive Processes

The way that color appears on a piece of paper and how your eyes interpret color involve two different color mixing processes. Your eyes see color using an additive color process. The RGB color model is the basis for how the additive process works and involves mixing colors of light. The CMYK color model is the basis for how the subtractive color process works and involves pigments of color which absorb colors of light.

- The human eye has photoreceptors for red, green, and blue light. Which of these photoreceptors are stimulated when looking at white paint?
  **Solution:** All three of these photoreceptors are stimulated equally.

- A laser printer prints a piece of paper that includes black lettering and a blue border. How are these colors made using the CMYK color model?
  **Solution:** Pure black pigment is used to make the black lettering. If you were to mix the other colors (magenta, yellow, and cyan), you would only get a muddy gray. The blue border was made by mixing cyan and magenta pigments.

### RGB color model

<table>
<thead>
<tr>
<th>Primary colors</th>
<th>Mixed colors</th>
<th>New color</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>red + green</td>
<td>yellow</td>
</tr>
<tr>
<td>green</td>
<td>green + blue</td>
<td>cyan</td>
</tr>
<tr>
<td>blue</td>
<td>blue + red</td>
<td>magenta</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How black is made</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Absence of light</td>
<td></td>
</tr>
</tbody>
</table>

### CMYK color model

<table>
<thead>
<tr>
<th>Primary colors</th>
<th>Mixed colors</th>
<th>New color</th>
</tr>
</thead>
<tbody>
<tr>
<td>magenta</td>
<td>magenta + yellow</td>
<td>red</td>
</tr>
<tr>
<td>yellow</td>
<td>yellow + cyan</td>
<td>green</td>
</tr>
<tr>
<td>cyan</td>
<td>cyan + magenta</td>
<td>blue</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How black is made</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure black pigment</td>
<td></td>
</tr>
</tbody>
</table>

### How white is made

<table>
<thead>
<tr>
<th>Primary colors</th>
<th>Mixed colors</th>
<th>New color</th>
</tr>
</thead>
<tbody>
<tr>
<td>red + green</td>
<td>red + green + blue</td>
<td></td>
</tr>
</tbody>
</table>

### How white is made

<table>
<thead>
<tr>
<th>Primary colors</th>
<th>Mixed colors</th>
<th>New color</th>
</tr>
</thead>
<tbody>
<tr>
<td>red + green + blue</td>
<td>How white is made</td>
<td>Absence of pigment or use of pure white pigment</td>
</tr>
</tbody>
</table>

### Example

- The human eye has photoreceptors for red, green, and blue light. Which of these photoreceptors are stimulated when looking at white paint?
  **Solution:** All three of these photoreceptors are stimulated equally.

### Practice

1. A friend asks you to describe the difference between the RGB color model and the CMYK color model. Give him three differences between these color models.

2. How would you see the following combinations of light colors?
   a. red only
   b. blue + red, both at equal intensity
   c. green only
   d. green + blue, both at equal intensity

3. The color orange is perceived by the eyes when both the red and green photoreceptors are stimulated and the red signal is stronger than the green. Given this information, what kind of signals would be received by the eye for the color purple?
4. You see a chair that is painted yellow. Most likely, pure yellow pigment was used to make the paint. However, explain how your eyes interpret the color yellow.

5. White paint purchased at a store is often made of a pure white pigment called titanium dioxide. This white paint reflects about 97% of the light that strikes it. Why might this property of the paint mean that you interpret its color as white?

6. The image you see on a color TV screen is made using the RGB color model. The image is made of thousands of pixels or dots of color. Describe how you could make the following pixels using the RGB color model.
   a. A white pixel
   b. A black pixel
   c. A cyan pixel
   d. A yellow pixel

7. What colors of light are reflected and/or absorbed by a red apple when:
   a. white light shines on it?
   b. only red light shines on it?
   c. only blue light shines on it?

8. The CMYK color model works because the combination of pigments absorb and reflect light. Imagine that white light containing a mixture of red, green, and blue light shines on the combination of CMYK pigments in the table below. Copy the table on your own paper. Indicate in the blank spaces which colors of light the pigments absorb and which color is reflected. Some parts of the table are filled in for you.

<table>
<thead>
<tr>
<th>Mixed colors</th>
<th>Reflected color</th>
<th>Which colors of light are absorbed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>magenta + yellow</td>
<td>red</td>
<td>blue is absorbed by yellow red is absorbed by cyan</td>
</tr>
<tr>
<td>yellow + cyan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cyan + magenta</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. If you mix magenta paint and cyan paint, what color will you achieve?

10. A laser printer’s ink only includes the colors cyan, magenta, yellow, and black.
    a. Explain how it makes the color green using these pigments.
    b. Then, explain what happens for your eye to interpret this color as green.
    c. This Venn diagram illustrates color mixing for the CMYK color model. Now, make a Venn diagram for the RGB color model. Use color when you make your diagram. Be sure to label the difference between the primary colors and the new colors made by mixing.
25.2 The Human Eye

Write the name of the part that corresponds to each letter in the diagram. Then write the function of each part in the spaces on the next page.
25.3 Measuring Angles with a Protractor

Measure each of these angles (A–Q) with a protractor. Record the angle measurements in the table below.
25.3 Using Ray Diagrams

This skill sheet gives you some practice using ray diagrams. A ray diagram helps you determine where an image produced by a lens will form and shows whether the image is upside down or right side up.

1. Of the diagrams below, which one correctly illustrates how light rays come off an object? Explain your answer.

2. Of the diagrams below, which one correctly illustrates how a light ray enters and exits a piece of thick glass? Explain your answer.

In your own words, explain what happens to light as it enters glass from the air. Why does this happen? Use the term *refraction* in your answer.

3. Of the diagrams below, which one correctly illustrates how parallel light rays enter and exit a converging lens? Explain your answer.

4. Draw a diagram of a converging lens that has a focal length of 10 centimeters. In your diagram, show three parallel lines entering the lens and exiting the lens. Show the light rays passing through the focal point of the lens. Be detailed in your diagram and provide labels.
25.3 Reflection

You have seen the law of reflection at work using light and the smooth surface of a mirror. Did you know you can apply this law to other situations? It can help you win a game of pool or pass a basketball to a friend on the court.

In this skill sheet you will review the law of reflection and work on practice problems that utilize this law. Use a protractor to make your angles correct in your diagrams.

The law of reflection states that when an object hits a surface, its angle of incidence will equal the angle of reflection. This is true when the object is light and the surface is a flat, smooth mirror. When the object and the surface are larger and lack smooth surfaces (like a basketball and a gym floor), the angles of incidence and reflection are nearly but not always exactly equal. The angles are close enough that understanding the law of reflection can help you improve your game.

A light ray strikes a flat mirror with a 30-degree angle of incidence. Draw a ray diagram to show how the light ray interacts with the mirror. Label the normal line, the incident ray, and the reflected ray.

Solution:

1. When we talk about angles of incidence and reflection, we often talk about the normal. The normal to a surface is an imaginary line that is perpendicular to the surface. The normal line starts where the incident ray strikes the mirror. A normal line is drawn for you in the sample problem above.
   a. Draw a diagram that shows a mirror with a normal line and a ray of light hitting the mirror at an angle of incidence of 60 degrees.
   b. In the diagram above, label the angle of reflection. How many degrees is this angle of reflection?
2. Light strikes a mirror’s surface at 20 degrees to the normal. What will the angle of reflection be?

3. A ray of light strikes a mirror. The angle formed by the incident ray and the reflected ray measures 90 degrees. What are the measurements of the angle of incidence and the angle of reflection?

4. In a game of basketball, the ball is bounced (with no spin) toward a player at an angle of 40 degrees to the normal. What will the angle of reflection be? Draw a diagram that shows this play. Label the angles of incidence and reflection and the normal.

Challenge Questions:

Use a protractor to figure out the angles of incidence and reflection for the following problems.

5. Because a lot of her opponent’s balls are in the way for a straight shot, Amy is planning to hit the cue ball off the side of the pool table so that it will hit the 8-ball into the corner pocket. In the diagram, show the angles of incidence and reflection for the path of the cue ball. How many degrees does each angle measure?

6. You and a friend are playing pool. You are playing solids and he is playing stripes. You have one ball left before you can try for the eight ball. Stripe balls are in the way. You plan on hitting the cue ball behind one of the stripe balls so that it will hit the solid ball and force it to follow the pathway shown in the diagram. Use your protractor to figure out what angles of incidence and reflection are needed at points A and B to get the solid ball into the far side pocket.
25.3 Refraction

When light rays cross from one material to another they bend. This bending is called **refraction**. Refraction is a useful phenomenon. All kinds of optics, from glasses to camera lenses to binoculars depend on refraction.

If you are standing on the shore looking at a fish in a stream, the fish appears to be in a slightly different place than it really is. That's because light rays that bounce off the fish are refracted at the boundary between water and air. If you are a hunter trying to spear this fish, you better know about this phenomenon or the fish will get away.

Why do the light rays bend as they cross from water into air?

A light ray bends because light travels at different speeds in different materials. In a vacuum, light travels at a speed of $3 \times 10^8$ m/s. But when light travels through a material, it is absorbed and re-emitted by each atom or molecule it hits. This process of absorption and emission slows the light ray’s speed. We experience this slowdown as a bend in the light ray. The greater the difference in the light ray’s speed through two different materials, the greater the bend in the path of the ray.

The **index of refraction** ($n$) for a material is the ratio of the speed of light in a vacuum to the speed of light in the material.

$$\text{Index of refraction} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in a material}}$$

The index of refraction for some common materials is given below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Index of refraction ($n$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum</td>
<td>1.0</td>
</tr>
<tr>
<td>Air</td>
<td>1.0001</td>
</tr>
<tr>
<td>Water</td>
<td>1.33</td>
</tr>
<tr>
<td>Glass</td>
<td>1.5</td>
</tr>
<tr>
<td>Diamond</td>
<td>2.42</td>
</tr>
</tbody>
</table>

1. Could the index of refraction for a material ever be less than 1.0? Explain.
2. Explain why the index of refraction for air (a gas) is smaller than the index of refraction for a solid like glass.
3. Calculate the speed of light in water, glass, and diamond using the index of refraction and the speed of light in a vacuum ($3 \times 10^8$ m/s).
4. When a light ray moves from water into air, does it slow down or speed up?
5. When a light ray moves from water into glass, does it slow down or speed up?
**Which way does the light ray bend?**

Now let’s look at some ray diagrams showing refraction. To make a refraction ray diagram, draw a solid line to show the boundary between the two materials (water and air in this case). Arrows are used to represent the incident and refracted light rays. The normal is a dashed line drawn perpendicular to the boundary between the surfaces. It starts at the point where the incident ray hits the boundary.

As you can see, the light ray is bent **toward** the normal as it crosses from air into water. Light rays always bend toward the normal when they move from a low-$n$ to a high-$n$ material. The opposite occurs when light rays travel from a high-$n$ to a low-$n$ material. These light rays bend away from the normal.

The amount of bending that occurs depends on the difference in the index of refraction of the two materials. A large difference in $n$ causes a greater bend than a small difference.

1. A light ray moves from water ($n = 1.33$) to a transparent plastic (polystyrene $n = 1.59$). Will the light ray bend toward or away from the normal?
2. A light ray moves from sapphire ($n = 1.77$) to air ($n = 1.0001$). Does the light ray bend toward or away from the normal?
3. Which light ray will be bent more, one moving from diamond ($n = 2.42$) to water ($n = 1.33$), or a ray moving from sapphire ($n = 1.77$) to air ($n = 1.0001$)?

4. The diagrams below show light traveling from water (A) into another material (B). Using the chart above, label material B for each diagram as helium, water, emerald, or cubic zirconia.

<table>
<thead>
<tr>
<th>Material</th>
<th>Index of refraction ($n$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>1.00004</td>
</tr>
<tr>
<td>Water</td>
<td>1.33</td>
</tr>
<tr>
<td>Emerald</td>
<td>1.58</td>
</tr>
<tr>
<td>Cubic Zirconia</td>
<td>2.17</td>
</tr>
</tbody>
</table>
25.3 Drawing Ray Diagrams

A ray diagram helps you see where the image produced by a lens appears. The components of the diagram include the lens, the principal axis, the focal point, the object, and three lines drawn from the tip of the object and through the lens. These light rays meet at a point and intersect on the other side of the lens. Where the light rays meet indicates where the image of the object appears.

A lens has a focal length of 2 centimeters. An object is placed 4 centimeters to the left of the lens. Follow the steps to make a ray diagram using this information. Trace the rays and predict where the image will form.

Steps:
- Draw a lens and show the principal axis.
- Draw a line that shows the plane of the lens.
- Make a dot at the focal point of the lens on the right and left sides of the lens.
- Place an arrow (pointing upward and perpendicular to the principle axis) at 4 centimeters on the left side of the lens.
- **Line 1**: Draw a line from the tip of the arrow that is parallel to the principal axis on the left, and that goes through the focal point on the right of the lens.
- **Line 2**: Draw a line from the tip of the arrow that goes through the center of the lens (where the plane and the principal axis cross).
- **Line 3**: Draw a line from the tip of the arrow that goes through the focal point on the left side of the lens, through the lens, and parallel to the principal axis on the right side of the lens.
- Lines 1, 2, and 3 converge on the right side of the lens where the tip of the image of the arrow appears.
- The image is upside down compared with the object.
1. A lens has a focal length of 4 centimeters. An object is placed 8 centimeters to the left of the lens. Trace the rays and predict where the image will form. Is the image bigger, smaller, or inverted as compared with the object?

2. **Challenge question:** An arrow is placed at 3 centimeters to the left of a converging lens. The image appears at 3 centimeters to the right of the lens. What is the focal length of this lens? (HINT: Place a dot to the right of the lens where the image of the tip of the arrow will appear. You will only be able to draw lines 1 and 2. Where does line 1 cross the principal axis if the image appears at 3 centimeters?)

3. What happens when an object is placed at a distance from the lens that is less than the focal length? Use the term *virtual image* in your answer.
Talking and writing about distances in our solar system can be cumbersome. The Sun and Neptune are on average 4,500,000,000 (or four billion, five hundred million) kilometers apart. Earth’s average distance from the Sun is 150,000,000 (one hundred fifty million) kilometers. It can be difficult to keep track of all the zeroes in such large numbers. And it’s not easy to compare numbers that large.

Astronomers often switch to astronomical units (abbreviated AU) when describing distances in our solar system. One astronomical unit is 150,000,000 km—the same as the distance from Earth to the Sun.

Neptune is 30 AU from the Sun. Not only is 30 an easier number to work with than 4,500,000,000; but using astronomical units allows us to see immediately that Neptune is 30 times as far from the Sun as Earth.

In this skill sheet, you will practice working with astronomical units.

**EXAMPLE**

- Jupiter is 778 million kilometers from the Sun, on average. Find this distance in astronomical units.
  
  **Solution:** Divide 778 million km by 150 million km: \( \frac{778,000,000}{150,000,000} = 5.19 \text{ AU} \)

- The average distance from Mars to the Sun is 1.52 AU. Find this distance in kilometers.
  
  **Solution:** Multiply 1.52 AU by 150 million km: \( 1.52 \times 150,000,000 = 228,000,000 \text{ km} \)

**PRACTICE**

1. The average distance from Saturn to the Sun is 1.43 billion kilometers. Find this distance in astronomical units.

2. The average distance from Venus to the Sun is 108 million kilometers. Find this distance in astronomical units.

3. Mercury’s average distance from the Sun is 0.387 astronomical units. How far is this in kilometers?

4. The average distance from Uranus to the Sun is 19.13 astronomical units. How far is this in kilometers?

5. Is the distance from Earth to the moon more or less than one astronomical unit? How do you know?

6. Which planet is almost 20 times as far away from the Sun as Earth?

7. Which planet is less than half as far away from the Sun as Earth?

8. Which planet is almost twice as far from the Sun as Jupiter?

9. An unmanned spacecraft launched from Earth has traveled 10 astronomical units in the direction away from the Sun. It most recently passed through the orbit of which planet?

10. An unmanned spacecraft launched from Earth has traveled 0.5 astronomical units toward the Sun. Has it passed through the orbit of Venus yet?
26.1 Gravity Problems

In this skill sheet, you will practice using proportions as you learn more about the strength of gravity on different planets.

Comparing the strength of gravity on the planets

Table 1 lists the strength of gravity on each planet in our solar system. We can see more clearly how these values compare to each other using proportions. First, we assume that Earth’s gravitational strength is equal to “1.” Next, we set up the proportion where \( x \) equals the strength of gravity on another planet (in this case, Mercury) as compared to Earth:

\[
\frac{1}{\text{Earth gravitational strength}} = \frac{x}{\text{Mercury gravitational strength}}
\]

\[
\frac{1}{9.8 \text{ N/kg}} = \frac{x}{3.7 \text{ N/kg}}
\]

\[
(1 \times 3.7 \text{ N/kg}) = (9.8 \text{ N/kg} \times x)
\]

\[
\frac{3.7 \text{ N/kg}}{9.8 \text{ N/kg}} = x
\]

\[
0.38 = x
\]

Note that the units cancel. The result tells us that Mercury’s gravitational strength is a little more than a third of Earth’s. Or, we could say that Mercury’s gravitational strength is 38% as strong as Earth’s.

Now, calculate the proportions for the remaining planets.

<table>
<thead>
<tr>
<th>Planet</th>
<th>Strength of gravity (N/kg)</th>
<th>Value compared to Earth’s gravitational strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>3.7</td>
<td>0.38</td>
</tr>
<tr>
<td>Venus</td>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td>9.8</td>
<td>1</td>
</tr>
<tr>
<td>Mars</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Jupiter</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td>Saturn</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>Uranus</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>Neptune</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Pluto</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>
26.1 How much does it weigh on another planet?
Use your completed Table 1 to solve the following problems.

Example:

• A bowling ball weighs 15 pounds on Earth. How much would this bowling ball weigh on Mercury?

\[
\frac{\text{Weight on Earth}}{\text{Weight on Mercury}} = \frac{1}{0.38}
\]

\[
\frac{1}{0.38} = \frac{15 \text{ pounds}}{x}
\]

\[0.38 \times 15 \text{ pounds} = x\]

\[x = 5.7 \text{ pounds}\]

1. A cat weighs 8.5 pounds on Earth. How much would this cat weigh on Neptune?

2. A baby elephant weighs 250 pounds on Earth. How much would this elephant weigh on Saturn? Give your answer in newtons (4.48 newtons = 1 pound).

3. On Pluto, a baby would weigh 2.7 newtons. How much does this baby weigh on Earth? Give your answer in newtons and pounds.

4. Imagine that it is possible to travel to each planet in our solar system. After a space “cruise,” a tourist returns to Earth. One of the ways he recorded his travels was to weigh himself on each planet he visited. Use the list of these weights on each planet to figure out the order of the planets he visited. On Earth he weighs 720 newtons. List of weights: 655 N; 1,699 N; 806 N; 43 N; and 662 N.

Challenge: Using the Universal Law of Gravitation

Here is an example problem that is solved using the equation for Universal Gravitation.

Example

What is the force of gravity between Pluto and Earth? The mass of Earth is \(6.0 \times 10^{24}\) kg. The mass of Pluto is \(1.3 \times 10^{22}\) kg. The distance between these two planets is \(5.76 \times 10^{12}\) meters.

\[
\text{Force of gravity between Earth and Pluto} = \left(\frac{6.67 \times 10^{-11} \text{N-m}^2}{\text{kg}^2}\right) \left(\frac{6.0 \times 10^{24} \text{kg}}{5.76 \times 10^{12} \text{m}}\right) \left(\frac{1.3 \times 10^{22} \text{kg}}{3.76 \times 10^{12} \text{m}}\right)
\]

\[
\text{Force of gravity} = \frac{52.0 \times 10^{35}}{33.2 \times 10^{24}} = 1.57 \times 10^{11} \text{N}
\]

Now use the equation for Universal Gravitation to solve this problem:

5. What is the force of gravity between Jupiter and Saturn? The mass of Jupiter is \(6.4 \times 10^{24}\) kg. The mass of Saturn is \(5.7 \times 10^{26}\) kg. The distance between Jupiter and Saturn is \(6.52 \times 10^{11}\) m.
26.1 Universal Gravitation

The law of universal gravitation allows you to calculate the gravitational force between two objects from their masses and the distance between them. The law includes a value called the gravitational constant, or “G.” This value is the same everywhere in the universe. Calculating the force between small objects like grapefruits or huge objects like planets, moons, and stars is possible using this law.

What is the law of universal gravitation?

The force between two masses $m_1$ and $m_2$ that are separated by a distance $r$ is given by:

$$ F = G \frac{m_1 m_2}{r^2} $$

So, when the masses $m_1$ and $m_2$ are given in kilograms and the distance $r$ is given in meters, the force has the unit of newtons. Remember that the distance $r$ corresponds to the distance between the center of gravity of the two objects.

For example, the gravitational force between two spheres that are touching each other, each with a radius of 0.300 meter and a mass of 1,000 kilograms, is given by:

$$ F = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \times \frac{1,000 \text{ kg} \times 1,000 \text{ kg}}{(0.300 \text{ m} + 0.300 \text{ m})^2} = 0.000185 \text{ N} $$

Note: A small car has a mass of approximately 1,000 kilograms. Try to visualize this much mass compressed into a sphere with a diameter of 0.500 meters (30.0 centimeters). If two such spheres were touching one another, the gravitational force between them would be only 0.000185 newtons. On Earth, this corresponds to the weight of a mass equal to only 18.9 milligrams. The gravitational force is not very strong!
Answer the following problems. Write your answers using scientific notation.

1. Calculate the force between two objects that have masses of 70. kilograms and 2,000. kilograms. Their centers of gravity are separated by a distance of 1.00 meter.

2. Calculate the force between two touching grapefruits each with a radius of 0.080 meters and a mass of 0.45 kilograms.

3. Calculate the force between one grapefruit as described above and Earth. Earth has a mass of $5.9742 \times 10^{24}$ kilograms and a radius of $6.3710 \times 10^6$ meters. Assume the grapefruit is resting on Earth’s surface.

4. A man on the moon with a mass of 90. kilograms weighs 146 newtons. The radius of the moon is $1.74 \times 10^6$ meters. Find the mass of the moon.

5. For $m = 5.9742 \times 10^{24}$ kilograms and $r = 6.3710 \times 10^6$ meters, what is the value given by: $\frac{G m}{r^2}$?
   a. Write down your answer and simplify the units.
   b. What does this number remind you of?
   c. What real-life values do $m$ and $r$ correspond to?

6. The distance between the centers of Earth and its moon is $3.84 \times 10^8$ meters. Earth’s mass is $5.9742 \times 10^{24}$ kilograms and the mass of the moon is $7.36 \times 10^{22}$ kilograms. What is the force between Earth and the moon?

7. A satellite is orbiting Earth at a distance of 35.0 kilometers. The satellite has a mass of 500. kilograms. What is the force between the planet and the satellite? Hint: Recall Earth’s mass and radius from earlier problems.

8. The mass of the sun is $1.99 \times 10^{30}$ kilograms and its distance from Earth is 150. million kilometers ($150. \times 10^9$ meters). What is the gravitational force between the sun and Earth?
26.1 Nicolaus Copernicus

Nicolaus Copernicus was a church official, mathematician, and influential astronomer. His revolutionary theory of a heliocentric (sun-centered) universe became the foundation of modern-day astronomy.

Wealth, education, and religion

Nicolaus Copernicus was born on February 19, 1473 in Torun, Poland. Copernicus’ father was a successful copper merchant. His mother also came from wealth. Being from a privileged family, young Copernicus had the luxury of learning about art, literature, and science.

When Copernicus was only 10 years old, his father died. Copernicus went to live with his uncle, Lucas Watzenrode, a prominent Catholic Church official who became bishop of Varmia (now part of modern-day Poland) in 1489. The bishop was generous with his money and provided Copernicus with an education from the best universities.

From church official to astronomer

Copernicus lived during the height of the Renaissance period when men from a higher social class were expected to receive well-rounded educations. In 1491, Copernicus attended the University of Krakow where he studied mathematics and astronomy. After four years of study, his uncle appointed Copernicus a church administrator. Copernicus used his church wages to help pay for additional education.

In January 1497, Copernicus left for Italy to study medicine and law at the University of Bologna. Copernicus’ passion for astronomy grew under the influence of his mathematics professor, Domenico Maria de Novara. Copernicus lived in his professor’s home where they spent hours discussing astronomy.

In 1500, Copernicus lectured on astronomy in Rome. A year later, he studied medicine at the University of Padua. In 1503, Copernicus received a doctorate in canon (church) law from the University of Ferrara.

Observations with his bare eyes

After his studies in Italy, Copernicus returned to Poland to live in his uncle’s palace. He resumed his church duties, practiced medicine, and studied astronomy. Copernicus examined the sky from a palace tower. He made his observations without any equipment. In the late 1500s, the astronomer Galileo used a telescope and confirmed Copernicus’ ideas.

A heliocentric universe

In the 1500s, most astronomers believed that Earth was motionless and the center of the universe. They also thought that all celestial bodies moved around Earth in complicated patterns. The Greek astronomer Ptolomy proposed this geocentric theory more than 1000 years earlier.

However, Copernicus believed that the universe was heliocentric (sun-centered), with all of the planets revolving around the sun. He explained that Earth rotates daily on its axis and revolves yearly around the sun. He also suggested that Earth wobbles like a top as it rotates.

Copernicus’ theory led to a new ordering of the planets. In addition, it explained why the planets farther from the sun sometimes appear to move backward (retrograde motion), while the planets closest to the sun always seem to move in one direction. This retrograde motion is due to Earth moving faster around the sun than the planets farther away.

Copernicus was reluctant to publish his theory and spent years rechecking his data. Between 1507 and 1515, Copernicus circulated his heliocentric principles to only a few astronomers. A young German mathematics professor, George Rheticus, was fascinated with Copernicus’ theory. The professor encouraged Copernicus to publish his ideas. Finally, Copernicus published The Revolutions of the Heavenly Orbs near his death in 1543.

Years later, several astronomers (including Galileo) embraced Copernicus’ sun-centered theory. However, they suffered much persecution by the church for believing such ideas. At the time, church law held great influence over science and dictated a geocentric universe. It wasn’t until the eighteenth century that Copernicus’ heliocentric principles were completely accepted.
Reading reflection

1. How did Copernicus’ privileged background help him become knowledgeable in so many areas of study?

2. Which people influenced Copernicus in his work as a church official and an astronomer?

3. How did Copernicus make his observations of the sky?

4. What did astronomers believe of the universe prior to the sixteenth century?

5. Describe Copernicus’ revolutionary heliocentric theory of the universe.

6. Why did so many astronomers face persecution by the church for their beliefs in a heliocentric universe?

7. Research: Using the library or Internet, find out which organizations developed the Copernicus Satellite (OAO-3) and why it was used.
26.1 Galileo Galilei

Galileo Galilei was a mathematician, scientist, inventor, and astronomer. His observations led to advances in our understanding of pendulum motion and free fall. He invented a thermometer, water pump, military compass, and microscope. He refined a Dutch invention, the telescope, and used it to revolutionize our understanding of the solar system.

An incurable mathematician

Galileo Galilei was born in Pisa, Italy, on February 15, 1564. His father, a musician and wool trader, hoped his son would find a more profitable career. He sent Galileo to a monastery school at age 11 to prepare for medical school. After four years there, Galileo decided to become a monk. The eldest of seven children, he had sisters who would need dowries in order to marry, and his father had planned on Galileo’s support. His father decided to take Galileo out of the monastery school.

Two years later, he enrolled as a medical student at the University of Pisa, though his interests were mathematics and natural philosophy. Galileo did not really want to pursue medical studies. Eventually, his father agreed to let him study mathematics.

Seeing through the ordinary

Galileo was extremely curious. At 20, he found himself watching a lamp swinging from a cathedral ceiling. He used his pulse like a stopwatch and discovered that the lamp’s long and short swings took the same amount of time. He wrote about this in an early paper titled “On Motion.” Years later, he drew up plans for an invention, a pendulum clock, based on this discovery.

Inventions and experiments

Galileo started teaching at the University of Padua in 1592 and stayed for 18 years. He invented a simple thermometer, a water pump, and a compass for accurately aiming cannonballs. He also performed experiments with falling objects, using an inclined plane to slow the object’s motion so it could be more accurately timed. Through these experiments, he realized that all objects fall at the same rate unless acted on by another force.

Crafting better telescopes

In 1609, Galileo heard that a Dutch eyeglass maker had invented an instrument that made things appear larger. Soon he had created his own 10-powered telescope. The senate in Venice was impressed with its potential military uses, and in a year, Galileo had refined his invention to a 30-powered telescope.

Star gazing

Using his powerful telescope, Galileo’s curiosity now turned skyward. He discovered craters on the moon, sunspots, Jupiter’s four largest moons, and the phases of Venus. His observations led him to conclude that Earth could not possibly be the center of the universe, as had been commonly accepted since the time of the Greek astronomer Ptolemy in the second century. Instead, Galileo was convinced that Polish astronomer Nicolaus Copernicus (1473-1543) must have been right: The Sun is at the center of the universe and the planets revolve around it.

House arrest

The Roman Catholic Church held that Ptolemy’s theory was truth and Copernican theory was heresy. Galileo had been told by the Inquisition in 1616 to abandon Copernican theory and stop pursuing these ideas.

Despite these threats, in February 1632, he published his ideas in the form of a conversation between two characters. He made the one representing Ptolemy’s view seem foolish, while the other, who argued Copernicus’s theory, seemed wise.

This angered the church, whose permission was needed for publishing books. Galileo was called to Rome before the Inquisition. He was given a formal threat of torture and so he abandoned his ideas that promoted Copernican theory. He was sentenced to house arrest, and lived until his death in 1642 watched over by Inquisition guards.
Reading reflection

1. What scientific information was presented in Galileo’s paper “On Motion”?

2. Research one of Galileo’s inventions and draw a diagram showing how it worked.

3. How were Galileo’s views about the position of Earth in the universe supportive of Copernicus’s ideas?

4. Imagine you could travel back in time to January 1632 to meet with Galileo just before he publishes his “Dialogue Concerning the Two Chief World Systems.” What would you say to him?

5. In your opinion, which of Galileo’s ideas or inventions had the biggest impact on history? Why?
26.1 Johannes Kepler

Johannes Kepler was a mathematician who studied astronomy. He lived at the same time as two other famous astronomers, Tycho Brahe and Galileo Galilei. Kepler is recognized today for his use of mathematics to solve problems in astronomy. Kepler explained that the orbit of Mars and other planets is an ellipse. In his most famous books he defended the sun-centered universe and his three laws of planetary motion.

Early years in Germany

Johannes Kepler was born December 27, 1571, in Weil der Stadt, Wurttemburg, Germany, now called the “Gate to the Black Forest.” He was the oldest of six children in a poor family. As a child he lived and worked in an inn run by his mother’s family. He was sickly, nearsighted, and suffered from smallpox at a young age. Despite his physical condition, he was a bright student.

The first school Kepler attended was a convent school in Adelberg monastery. Kepler’s original plan was to study to become a Lutheran minister. In 1589, Kepler received a scholarship to attend the University of Tubingen. There he spent three years studying mathematics, philosophy, and theology. His interest in math led him to take a mathematics teaching position at the Academy in Graz. There he began teaching and studying astronomy.

Influenced by Copernicus

At Tubingen, Kepler’s professor, Michael Mastlin, introduced Kepler to Copernican astronomy. Nicholas Copernicus (1473-1543), had published a revolutionary theory in, “On the Revolutions of Heavenly Bodies.” Copernicus’ theory stated that the sun was the center of the solar system. Earth and the planets rotated around the sun in circular orbits. At the time most people believed that Earth was the center of the universe.

Copernican theory intrigued Kepler and he wrote a defense of it in 1596, Mysterium Cosmographicum. Although Kepler’s original defense was flawed, it was read by several other famous European astronomers of the time, Tycho Brahe (1546–1601) and Galileo Galilei (1546–1642).

Kepler published many books in which he explained how vision, optics, and telescopes work. His most famous work, though, dealt with planetary motion.

Working with Tyco Brahe

In 1600, Brahe invited Kepler to join him. Brahe, a Danish astronomer, was studying in Prague, Czechoslovakia. Every night for years Brahe recorded planetary motion without a telescope from his observatory. Brahe asked Kepler to figure out a scientific explanation for the motion of Mars. Less than two years later, Brahe died. Kepler was awarded Brahe’s position as Imperial Mathematician. He inherited Brahe’s collection of planetary observations to use to write mathematical descriptions of planetary motion.

Kepler’s Laws of Planetary Motion

Kepler discovered that Mars’ orbit was an ellipse, not a circle, as Copernicus had thought. Kepler published his first two laws of planetary motion in Astronomia Nova in 1609. The first law of planetary motion stated that planets orbit the sun in an elliptical orbit with the sun in one of the foci. The second law, the law of areas, said that planets speed up as their orbit is closest to the sun, and slow down as planets move away from the sun. Kepler published a third law, called the harmonic law, in 1619. The third law shows how a planet’s distance from the sun is related to the amount of time it takes to revolve around the sun. His work influenced Isaac Newton’s later work on gravity. Kepler’s calculations were done before calculus was invented!

Other scientific discoveries

Kepler sent his book in 1609 to Galileo. Galileo’s theories did not agree with Kepler’s ideas and the two scientists never worked together. Despite his accomplishments, when Kepler died at age 59, he was poor and on his way to collect an old debt. It would take close to a century for his work to gain the recognition it deserved.
Reading reflection

1. Why was Copernicus’ idea of the sun at the center of the solar system considered revolutionary?

2. Explain how Brahe helped Kepler make important discoveries in astronomy.

3. How was Kepler’s approach to astronomy different than Brahe’s and Galileo’s?

4. Kepler discovered that Mars and other planets traveled in an ellipse around the sun. Does this agree with Copernicus’ theory?

5. Describe Kepler’s three laws of planetary motion.

6. Kepler observed a supernova in 1604. It challenged the way people at the time thought about the universe because people did not know the universe could change. When people have to change their beliefs about something because scientific evidence says otherwise, that is called a “paradigm shift.” Find three examples in the text of scientific discoveries that led to a “paradigm shift.”
26.1 Measuring the Moon’s Diameter

In this skill sheet you will explore how to measure the moon’s diameter using simple tools and calculations.

Materials

Here are the materials you will need to measure the moon’s diameter:

- A 3-meter piece of string
- A metric tape measure
- A small metric ruler
- A 3-meter piece of string
- Scissors
- Marker
- One-centimeter semi-circle card (Cut out from the bottom of the last page)

Proportions and geometry

The method you will use to measure the moon’s diameter depends on the properties of similar triangles. The following exercise demonstrates these properties.

Below is a large triangle. A line drawn from one side to the other of the large triangle results in a smaller triangle inside the larger one. The ends of each line are labeled with letters.

![Diagram of a triangle with labeled sides: A, B, C, D, E.]

1. Make the following measurements of the lines on the triangle:
   - Distance AC: _____________ cm
   - Distance AD: _____________ cm
   - Distance AB: _____________ cm
   - Distance AE: _____________ cm
   - Distance BE: _____________ cm
   - Distance CD: _____________ cm
2. How is the distance from AB related to AC?
3. How is the distance from BE related to CD?
4. Based on your measurements and your answers to questions (2) and (3), come up with a statement that explains the properties of similar triangles.

Finding the diameter of the moon

Now, you are ready to use your supplies to find the diameter of the moon. Follow these steps carefully and answer the questions as you go.

1. Locate a place where you can see the moon from a window. This is possible at night or early in the morning.
2. Use scissors to carefully cut out the semi-circle card found on the next page.
3. Tape this card to the window when you can see the full (or gibbous) moon through the window.
4. Tape one end of the 3-meter piece of string to the card directly underneath the semi-circle.
5. Now, slowly move backward from the window while holding on to the string. Watch your step! As you move backward, pay attention to the moon. You want to move back far enough so that the bottom half of the moon “sits” in the semi-circle cutout. You want the semi-circle to be the same size as the lower half to the moon.
6. When the lower half of the moon is the same size as the semi-circle cut out, stop moving backward and hold the string up to the side of one of your eyes. Have a friend carefully mark the string at this distance.
7. Now, measure the distance from the window to the mark on the string to the nearest millimeter. Convert this distance to meters. Write the string distance in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Finding the moon’s diameter data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-circle diameter</td>
</tr>
<tr>
<td>String distance</td>
</tr>
<tr>
<td>Diameter of the moon</td>
</tr>
<tr>
<td>Distance from Earth to the moon</td>
</tr>
</tbody>
</table>

Finding the moon’s diameter

1. You have three out of four measurements in Table 1. The only measurement you need is the moon’s diameter. You can find the moon’s diameter using proportions. Which calculation will help you?

   a. \[
   \frac{\text{semi-circle diameter}}{\text{moon diameter}} = \frac{\text{distance to semi-circle}}{\text{distance from Earth to the moon}}
   \]

   b. \[
   \frac{\text{semi-circle diameter}}{\text{distance to semi-circle}} = \frac{\text{moon diameter}}{\text{distance from Earth to the moon}}
   \]

   c. \[
   \frac{\text{moon diameter}}{\text{semi-circle diameter}} = \frac{\text{distance to semi-circle}}{\text{distance from Earth to the moon}}
   \]

   d. \[
   \frac{\text{moon diameter}}{\text{semi-circle diameter}} = \frac{\text{distance from Earth to the moon}}{\text{distance to semi-circle}}
   \]

2. Use the proportion that you selected in question (1) to calculate the moon’s diameter.
3. How is performing this calculation like the exercise you did in part 2?
Semi-Circle Card:

Diameter = 1 cm

Semi-circle card
(cut out along dotted lines)
26.2 Benjamin Banneker

Benjamin Banneker was a farmer, naturalist, civil rights advocate, self-taught mathematician, astronomer and surveyor who published his detailed astronomical calculations in popular almanacs. He was appointed by President George Washington as one of three surveyors of the territory that became Washington D.C.

Early times

Benjamin Banneker was born in rural Maryland in 1731. His family was part of a population of about two hundred free black men and women in Baltimore county. They owned a small farm where they grew tobacco and vegetables, earning a comfortable living.

A mathematician builds a clock

Benjamin’s grandmother taught him to read, and he briefly attended a Quaker school near his home. Benjamin enjoyed school and was especially fond of solving mathematical riddles and puzzles. When he was 22, Benjamin borrowed a pocket watch, took it apart, and made detailed sketches of its inner workings. Then he carved a large-scale wooden model of each piece, fashioned a homemade spring, and built his own clock that kept accurate time for over 50 years.

A keen observer of nature

Banneker was also a keen observer of the natural world and is believed to be the first person to document the cycle of the 17-year cicada, an insect that exists in the larval stage underground for 17 years, and then emerges to live for just a few weeks as a loud buzzing adult.

Banneker writes Thomas Jefferson

Banneker sent a copy of his first almanac to then-Secretary of State Thomas Jefferson, along with a letter challenging Jefferson’s ownership of slaves as inconsistent with his assertion in the Declaration of Independence that “all men are created equal.”

Jefferson sent a letter thanking Banneker for the almanac, saying that he sent it onto the Academy of Sciences of Paris as proof of the intellectual capabilities of Banneker’s race. Although Jefferson’s letter stated that he “ardently wishes to see a good system commenced for raising the condition both of [our black brethren’s] body and mind,” regrettably, he never freed his own slaves.

Designing Washington D.C.

In 1791, George Ellicott’s cousin Andrew Ellicott asked him to serve as an astronomer in a large surveying project. George Ellicott suggested that he hire Benjamin Banneker instead.

Banneker left his farm in the care of relatives and traveled to Washington, where he became one of three surveyors appointed by President George Washington to assist in the layout of the District of Columbia.

After his role in the project was complete, Banneker returned to his Maryland farm, where he died in 1806. Banneker Overlook Park, in Washington D.C., commemorates his role in the surveying project. In 1980, the U.S. Postal Service issued a stamp in Banneker’s honor.
Reading reflection

1. Benjamin Banneker built a working clock that lasted 50 years. Why would his understanding of mathematics have been helpful in building the clock?

2. Identify one of Banneker’s personal strengths. Justify your answer with examples from the reading.

3. Benjamin Banneker lived from 1731 to 1806. During his lifetime, he advocated equal rights for all people. Find out the date for each of the following “equal rights” events: (a) the Emancipation Proclamation, (b) the end of the Civil War, (c) women gain the right to vote, and (d) the desegregation of public schools (due to the landmark Supreme Court case, Brown versus the Board of Education).

4. Name three of Benjamin Banneker’s lifetime accomplishments.

5. What do you think motivated Banneker during his lifetime? What are some possible reasons that he was persistent in his scientific work?

6. **Research:** Find a mathematical puzzle written by Banneker. Try to solve it with your class.
26.3 Touring the Solar System

What would a tour of our solar system be like? How long would it take? How much food would you have to bring? In this skill sheet, you will calculate the travel times for an imaginary tour of the solar system. For our purposes, we will pretend that the planets form one straight line away from the Sun. Your mode of transportation will be a space vehicle travelling at 250 meters per second or 570 miles per hour.

Part 1: Planets on the tour

Starting from Earth, the tour itinerary is: Earth to Mars to Saturn to Neptune to Venus and then back to Earth. The distances between each planet of the tour are provided in Table 1. The space vehicle travels at 250 meters per second or 900 kilometers per hour. Using this rate and the speed formula, find out how long it will take to travel each leg of the itinerary. An example is provided below. For the table, also calculate the time in days and years.

**Example**

- How many days will it take to travel from Earth to Mars if the distance between the planets is 78 million kilometers?

**Solution:**

\[
\text{time} = \frac{\text{distance}}{\text{speed}}
\]

\[
\text{time to travel from Earth to Mars} = \frac{78 \text{ million km}}{900 \text{ km/hour}}
\]

\[
\text{time to travel from Earth to Mars} = \frac{78}{900} \times 24 = 86,666 \text{ hours}
\]

\[
86,666 \text{ hours} \times \frac{1 \text{ day}}{24 \text{ hours}} = 3,611 \text{ days}
\]

**Practice**

**Table 1: Solar System Trip**

<table>
<thead>
<tr>
<th>Legs of the trip</th>
<th>Distance traveled for each leg (km)</th>
<th>Hours traveled</th>
<th>Days traveled</th>
<th>Years traveled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth to Mars</td>
<td>78,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mars to Saturn</td>
<td>1,202,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturn to Neptune</td>
<td>3,070,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neptune to Venus</td>
<td>4,392,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venus to Earth</td>
<td>42,000,000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part 2: Provisions for the trip

A trip through the solar system is a science fiction fantasy. Answer the following questions as if such a journey were possible.

1. It is recommended that a person drink eight glasses of water each day. To keep yourself hydrated on your trip. How many glasses of water would you need to drink on the leg from Earth to Mars?

2. An average person needs 2,000 food calories per day. How many food calories will you need for the leg of the journey from Neptune to Venus?

3. Proteins and carbohydrates provide 4 calories per gram. Fat provides 9 calories per gram. Given this information, would it be more efficient to pack the plane full of foods that are high in fat or high in protein for the journey? Explain your answer.

4. You decide that you want to celebrate Thanksgiving each year of your travel. How many frozen turkeys will you need for the entire journey?

Part 3: Planning a trip to all eight planets

Section 26.3 of your student text presents a table that lists the properties of the eight planets. Use this table to answer the following questions.

1. On which planet would there be the most opportunities to visit a moon?

2. Which planets would require high-tech clothing to endure high temperatures? Which planets would require high-tech clothing to endure cold temperatures?

3. Which planet has the longest day?

4. Which has the shortest day?

5. On which planet would you have the most weight? How much would you weigh in newtons?

6. Which planet would take the longest time to travel around?

7. Which planet would require your spaceship to orbit with the fastest orbital speed? Explain your answer.
27.1 The Sun: A Cross-Section

- **D.** Outer atmosphere 2,000,000°C
- **E.** Inner atmosphere 5,000-10,000°C
- **F.** Visible “surface” 5,500°C

- **Heat transfer through motion of hot gas**
- **Heat transfer mainly through light energy**
- **Nuclear fusion**
27.1 Arthur Walker

Arthur Walker pioneered several new space-based research tools that brought about significant changes in our understanding of the sun and its corona. He was instrumental in the recruitment and retention of minority students at Stanford University, and he advised the United States Congress on physical science policy issues.

Not to be discouraged

Arthur Walker was born in Cleveland in 1936. His father was a lawyer and his mother a social worker. When he was 5, the family moved to New York. Arthur was an excellent student and his mother encouraged him to take the entrance exam for the Bronx High School of Science.

Arthur passed the exam, but when he entered school a faculty member told him that the prospects for a black scientist in the United States were bleak.

Rather than allow him to become dissuaded from his aspirations, Arthur’s mother visited the school and told them that her son would pursue whatever course of study he wished.

Making his mark in space

Walker went on to earn a bachelor’s degree in physics, with honors, from Case Institute of Technology in Cleveland and, by 1962, his master’s and doctorate from the University of Illinois.

Afterward, he spent three years’ active duty with the Air Force, where he designed a rocket probe and satellite experiment to measure radiation that affects satellite operation. This work sparked Walker’s lifelong interest in developing new space-based research tools.

After completing his military service, Walker worked with other scientists to develop the first X-ray spectrometer used aboard a satellite. This device helped determine the temperature and composition of the sun’s corona and provided new information about how matter and radiation interact in plasma.

Snapshots of the sun

In 1974, Walker joined the faculty at Stanford University. There he pioneered the use of a new multilayer mirror technology in space observations. The mirrors selectively reflected X rays of certain wavelengths, and enabled Walker to obtain the first high-resolution images showing different temperature regions of the solar atmosphere. He then worked to develop telescopes using the multilayer mirror technology, and launched them into space on rockets. The telescopes produced detailed photos of the sun and its corona. One of the pictures was featured on the cover of the journal Science in September 1988.

A model for student scientists

Walker was a mentor to many graduate students, including Sally Ride, who went on to become the first American woman in space. He worked to recruit and retain minority applicants to Stanford’s natural and mathematical science programs. Walker was instrumental in helping Stanford University graduate more black doctoral physicists than any university in the United States.

At work in other orbits

Public service was important to Walker, who served on several committees of the National Aeronautics and Space Administration (NASA), National Science Foundation, and National Academy of Science, working to develop policy recommendations for Congress. He was also appointed to the presidential commission that investigated the 1986 space shuttle Challenger accident.

Reading reflection

1. Use your textbook, an Internet search engine, or a dictionary to find the definition of each word in bold type. Write down the meaning of each word. Be sure to credit your source.

2. What have you learned about pursuing goals from Arthur Walker’s biography?

3. Why is a spectrometer a useful device for measuring the temperature and composition of something like the sun’s corona?

4. **Research:** Use a library or the Internet to find one of Walker’s revolutionary photos of the sun and its corona. Present the image to your class.

5. **Research:** Use a library or the Internet to find more about the commission that investigated the explosion of the space shuttle Challenger in 1986. Summarize the commission’s findings and recommendations in two or three paragraphs.
27.2 The Inverse Square Law

If you stand one meter away from a portable stereo blaring your favorite music, the intensity of the sound may hurt your ears. As you back away from the stereo, the sound’s intensity decreases. When you are two meters away, the sound intensity is one-fourth its original value. When you are ten meters away, the sound intensity is one-one hundredth its original value.

The sound intensity decreases according to the inverse square law. This means that the intensity decreases as the square of the distance. If you triple your distance from the stereo, the sound intensity decreases by nine times its original value.

Many fields follow an inverse square law, including sound, light from a small source (like a match or light bulb), gravity, and electricity. Magnetic fields are the exception. They decrease much faster because there are two magnetic poles.

Example 1: The light intensity one meter from a bulb is 2 W/m². What is the light intensity measured from a distance of four meters from the bulb?

Solution: The distance has increased to four times its original value. The light intensity will decrease by 4² or 16, times.

\[ 2 \times \frac{1}{16} = \frac{1}{8} \text{ or } 0.125 \text{ W/m}^2 \]

Example 2: Mercury has a gravitational force of 3.7 N/kg. Its radius is 2,439 kilometers. How far away from the surface of Mercury would you need to move in order to experience a gravitational force of 0.925 N/kg?

Solution: For the gravitational force to be reduced to one-fourth its original value, the distance from Mercury’s center must be doubled. Therefore you would have to move to a spot 2,439 kilometers away from Mercury’s surface or 4,878 meters from its center.

Practice

1. You stand 4 meters away from a light and measure the intensity to be 1 W/m². What will be the intensity if you move to a position 8 meters away from the bulb?

2. You are standing 1 meter from a squawking parrot. If you move to a distance three meters away, the sound intensity will be what fraction of its original value?

3. Venus has a gravitational force of 8.9 N/kg. Its radius is 6,051 kilometers. How far away from the surface of Mercury would you need to move in order to experience a gravitational force of 0.556 N/kg?

4. Earth’s radius is 6,378 kilometers. If you weigh 500 newtons on Earth’s surface, what would you weigh at a distance of 19,134 kilometers from Earth?

5. Compare the intensity of light 2 meters away from a lit match to the intensity 6 meters away from the match.

6. How does the strength of a sound field 1 meter from its source compare with its strength 4 meters away?
28.1 Scientific Notation

A number like 43,200,000,000,000,000,000 (43 quintillion, 200 quadrillion) can take a long time to write, and an even longer time to read. Because scientists frequently encounter very large numbers like this one (and also very small numbers, such as 0.000000012, or twelve trillionths), they developed a shorthand method for writing these types of numbers. This method is called scientific notation. A number is written in scientific notation when it is written as the product of two factors, where the first factor is a number that is greater than or equal to 1, but less than 10, and the second factor is an integer power of 10. Some examples of numbers written in scientific notation are given in the table below:

<table>
<thead>
<tr>
<th>Scientific Notation</th>
<th>Standard Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.32 \times 10^{19}</td>
<td>43,200,000,000,000,000,000</td>
</tr>
<tr>
<td>1.2 \times 10^{-8}</td>
<td>0.000000012</td>
</tr>
<tr>
<td>5.2777 \times 10^{7}</td>
<td>52,777,000</td>
</tr>
<tr>
<td>6.99 \times 10^{-5}</td>
<td>0.0000699</td>
</tr>
</tbody>
</table>

**Examples**

Rewrite numbers given in scientific notation in standard form.

- Express 4.25 \times 10^{6} in standard form: 4.25 \times 10^{6} = 4,250,000
  Move the decimal point (in 4.25) six places to the right. The exponent of the “10” is 6, giving us the number of places to move the decimal. We know to move it to the right since the exponent is a positive number.

  \[
  4.25 \times 10^{6} = 4.250,000
  \]

- Express 4.033 \times 10^{-3} in standard form: 4.033 \times 10^{-3} = 0.004033
  Move the decimal point (in 4.033) three places to the left. The exponent of the “10” is negative 3, giving the number of places to move the decimal. We know to move it to the left since the exponent is negative.

  \[
  4.033 \times 10^{-3} = 0.004033
  \]

Rewrite numbers given in standard form in scientific notation.

- Express 26,040,000,000 in scientific notation: 26,040,000,000 = 2.604 \times 10^{10}
  Place the decimal point in 2 6 0 4 so that the number is greater than or equal to one (but less than ten). This gives the first factor (2.604). To get from 2.604 to 26,040,000,000 the decimal point has to move 10 places to the right, so the power of ten is positive 10.

- Express 0.0001009 in scientific notation: 0.0001009 = 1.009 \times 10^{-4}
  Place the decimal point in 1 0 0 9 so that the number is greater than or equal to one (but less than ten). This gives the first factor (1.009). To get from 1.009 to 0.0001009 the decimal point has to move four places to the left, so the power of ten is negative 4.
1. Fill in the missing numbers. Some will require converting scientific notation to standard form, while others will require converting standard form to scientific notation.

<table>
<thead>
<tr>
<th>Scientific Notation</th>
<th>Standard Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $6.03 \times 10^{-2}$</td>
<td></td>
</tr>
<tr>
<td>b. $9.11 \times 10^{5}$</td>
<td></td>
</tr>
<tr>
<td>c. $5.570 \times 10^{-7}$</td>
<td>999.0</td>
</tr>
<tr>
<td>d.</td>
<td>264,000</td>
</tr>
<tr>
<td>e.</td>
<td>761,000,000</td>
</tr>
<tr>
<td>f.</td>
<td>$7.13 \times 10^{7}$</td>
</tr>
<tr>
<td>g.</td>
<td>0.00320</td>
</tr>
<tr>
<td>h.</td>
<td>0.000040</td>
</tr>
<tr>
<td>i.</td>
<td>$1.2 \times 10^{-12}$</td>
</tr>
<tr>
<td>j.</td>
<td>42,000,000,000,000</td>
</tr>
<tr>
<td>k.</td>
<td>12,004,000,000</td>
</tr>
<tr>
<td>l.</td>
<td>$9.906 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

2. Explain why the numbers below are not written in scientific notation, then give the correct way to write the number in scientific notation.

   Example: $0.06 \times 10^{5}$ is not written in scientific notation because the first factor (0.06) is not greater than or equal to 1. The correct way to write this number in scientific notation is $6.0 \times 10^{3}$.

   a. $2.004 \times 1^{11}$
   b. $56 \times 10^{-4}$
   c. $2 \times 100^{2}$
   d. $10 \times 10^{-6}$
3. Write the numbers in the following statements in scientific notation:
   a. The national debt in 2005 was about $7,935,000,000,000.
   b. In 2005, the U.S. population was about 297,000,000
   c. Earth's crust contains approximately 120 trillion (120,000,000,000,000) metric tons of gold.
   d. The mass of an electron is 0.000 000 000 000 000 000 000 000 000 000 91 kilograms.
   e. The usual growth of hair is 0.00033 meters per day.
   f. The population of Iraq in 2005 was approximately 26,000,000.
   g. The population of California in 2005 was approximately 33,900,000.
   h. The approximate area of California is 164,000 square miles.
   i. The approximate area of Iraq in 2005 was 169,000 square miles.
   j. In 2005, one right-fielder made a salary of $12,500,000 playing professional baseball.
28.1 Understanding Light Years

How far is it from Los Angeles to New York? Pretty far, but it can still be measured in miles or kilometers. How far is it from Earth to the Sun? It’s about one hundred forty-nine million, six hundred thousand kilometers (149,600,000, or $1.496 \times 10^8$ km). Because this number is so large, and many other distances in space are even larger, scientists developed bigger units in order to measure them. An Astronomical Unit (AU) is $1.496 \times 10^8$ km (the distance from Earth to the sun). This unit is usually used to measure distances within our solar system. To measure longer distances (like the distance between Earth and stars and other galaxies), the light year (ly) is used. A light year is the distance that light travels through space in one year, or $9.468 \times 10^{12}$ km.

**EXAMPLES**

1. **Converting light years (ly) to kilometers (km)**
   
   Earth’s closest star (Proxima Centauri) is about 4.22 light years away. How far is this in kilometers? 
   
   **Explanation/Answer:** Multiply the number of kilometers in one light year ($9.468 \times 10^{12}$ km/ly) by the number of light years given (in this case, 4.22 ly).
   
   $$\frac{9.468 \times 10^{12}}{1 \text{ ly}} \times 4.22 \text{ ly} \approx 3.995 \times 10^{13} \text{ km}$$

2. **Converting kilometers to light years**
   
   Polaris (the North Star) is about $4.07124 \times 10^{15}$ km from the earth. How far is this in light years? 
   
   **Explanation/Answer:** Divide the number of kilometers (in this case, $4.07124 \times 10^{15}$ km) by the number of kilometers in one light year ($9.468 \times 10^{12}$ km/ly).
   
   $$\frac{4.07124 \times 10^{15} \text{ km}}{9.468 \times 10^{12} \text{ km/ly}} = \frac{4.07124 \times 10^{15}}{9.468 \times 10^{12}} \approx 430 \text{ light years}$$

**PRACTICE**

Convert each number of light years to kilometers.

1. 6 light years
2. $4.5 \times 10^6$ light years
3. $4 \times 10^{-3}$ light years

Convert each number of kilometers to light years.

4. $5.06 \times 10^{16}$ km
5. 11 km
6. 11,003,000,000,000 km
Solve each problem using what you have learned.

7. The second brightest star in the sky (after Sirius) is Canopus. This yellow-white supergiant is about $1.13616 \times 10^{16}$ kilometers away. How far away is it in light years?

8. Regulus (one of the stars in the constellation Leo the Lion) is about 350 times brighter than the sun. It is 85 light years away from the earth. How far is this in kilometers?

9. The distance from earth to Pluto is about 28.61 AU from the earth. Remember that an AU = $1.496 \times 10^8$ km. How many kilometers is it from Pluto to the earth?

10. If you were to travel in a straight line from Los Angeles to New York City, you would travel 3,940 kilometers. How far is this in AU’s?

11. Challenge: How many AU’s are equivalent to one light year?
28.1 Parsecs

You have already learned about two units of measurement commonly used in astronomy:

- The astronomical unit (AU), which is the average distance between Earth and the Sun: $1.46 \times 10^8$ km
- The light year (ly), which is the distance light travels through space in one year: $9.468 \times 10^{12}$ km

Chapter 28 of your text introduces a third unit of distance, the parsec (pc). The word parsec stands for “parallax of one arcsecond” which refers to the geometric method used by astronomers to figure out distances between objects in space. For our purposes, we will define the parsec as equal to 3.26 light years, or 206,265 astronomical units. This means that you would have to make 206,265 trips from Earth to the Sun (or 103,132.5 round trips) in order to travel 1 parsec!

$1$ parsec $= 3.26$ light years or $206,265$ astronomical units

In this skill sheet, you will practice converting between parsecs, light years, astronomical units, and kilometers.

1. Converting light years (ly) to parsecs (pc)

   Earth’s closest star (Proxima Centauri) is about 4.22 light years away. How far is this in parsecs?

   **Explanation/Answer:** Divide the number of light years given (in this case, 4.22 ly) by the number of light years in one parsec (3.26 ly).

   \[
   4.22 \text{ ly} \div \frac{3.26 \text{ ly}}{1 \text{ pc}} = 4.22 \text{ ly} \times \frac{1 \text{ pc}}{3.26 \text{ ly}} = 1.29 \text{ ly}
   \]

2. Converting astronomical units (AU) to parsecs (pc)

   Polaris (the North Star) is about $2.789 \times 10^7$ astronomical units from Earth. How far is this in parsecs?

   **Explanation/Answer:** Divide the number of astronomical units (in this case, $2.789 \times 10^7$ AU) by the number of astronomical units in one parsec (206,265 AU).

   \[
   2.789 \times 10^7 \text{ AU} \div \frac{206,265 \text{ AU}}{1 \text{ pc}} = 2.789 \times 10^7 \text{ AU} \times \frac{1 \text{ pc}}{2.06265 \times 10^5 \text{ AU}} = 1.352 \times 10^2 \text{ or } 135.2 \text{ pc}
   \]
Convert each number of light years to parsecs.

1. 6.00 light years
2. \(4.50 \times 10^6\) light years
3. \(4.00 \times 10^{-3}\) light years

Convert each number of astronomical units to parsecs.

4. \(5.25 \times 10^6\) AU
5. 100. AU
6. 11,300,000 AU

Solve each problem using what you have learned.

7. The Milky Way galaxy is about 100,000 light years across. How large is this in parsecs?
8. The Andromeda galaxy is approximately 2,500,000 light years from Earth. How far is this in parsecs?
9. Regulus (one of the stars in the constellation Leo the Lion) is about 85 light years from Earth. How far is this in parsecs?
10. The average distance from the Sun to Pluto is approximately 29.6 astronomical units. How far is this in parsecs?
Edwin Hubble was an accomplished academic that many astronomers credit with “discovering the universe.”

A good student and even better athlete
Edwin Hubble was born on November 29, 1889, in Marshfield, Missouri. His family moved to Chicago when he was ten years old. Hubble was an active, imaginative boy. He was an avid reader of science fiction. Jules Verne’s adventure novels were among his favorite stories. Science fascinated Hubble, and he loved the way Verne wove futuristic inventions and scientific content into stories that took the reader on voyages to some strange and exotic destinations.

Hubble was a very good student and also an excellent athlete. In 1906 he set an Illinois state record for the high jump, and in that same season he took seven first place medals and one third place medal in a single high school track meet.

Focus turns to academics
Hubble continued his athletic success by participating in basketball and boxing at the University of Chicago. Eventually though, his studies became his primary focus. Hubble graduated with a bachelor's degree in Mathematics and Astronomy in 1910.

Hubble was selected as a Rhodes Scholar and spent the next three years at the University of Oxford, in England. Instead of continuing his studies in math and science, he decided to pursue a law degree. He completed the degree in 1913 and returned to the United States. He set up a law practice in Louisville, Kentucky. However, it was a short lived law career.

Returning to Astronomy
It took Hubble less than a year to become bored with his law practice, and he returned to the University of Chicago to study astronomy. He did much of his work at the Yerkes Observatory, and received his Ph.D. in astronomy in 1917.

Hubble joined the army at this time and served a tour of duty in World War I. He attained the rank of Major. When he returned in 1919, he was offered a job by George Ellery Hale, the founder and director of Carnegie Institution's Mount Wilson Observatory, near Pasadena, California.

The best tool for the job
The timing could not have been better. The 100-inch Hooker telescope, the world’s most powerful telescope at the time, had just been constructed. This telescope could easily focus images that were fuzzy, too dim, or too small to be seen clearly through other large telescopes.

The Hooker telescope enabled Hubble to make some astounding discoveries. Astronomers had believed that the many large fuzzy patches they saw through their powerful telescopes were huge gas clouds within our own Milky Way galaxy. They called these fuzzy patches “nebulae,” a Greek word meaning “cloud.” Hubble’s observations in 1923 and 1924 proved that while a few of these fuzzy objects were inside our galaxy, most were in fact entire galaxies themselves, not only separate from the Milky Way but millions of light years away. This greatly enlarged the accepted size of the universe, which many scientists at the time believed was limited to the Milky Way alone.

Another landmark discovery
Hubble also used spectroscopy to study galaxies. He observed that galaxies’ spectral lines were shifting toward the red end of the spectrum, which meant they were moving away from each other. He showed that the farther away a galaxy was, the faster it was moving away from Earth. In 1929, Hubble and fellow astronomer Milton Humason announced that all observed galaxies are moving away from each other with a speed proportional to the distance between them. This became known as Hubble’s Law, and it proved that the universe was expanding.

Albert Einstein visited Hubble and personally thanked him for this discovery, as it matched with Einstein’s calculations, providing observable evidence confirming his predictions.

Hubble worked at the Wilson Observatory until his death in 1953. He is considered the father of modern cosmology. To honor him, scientists have named a space telescope, a crater on the moon, and an asteroid after him.
Reading reflection

1. Look up the definition of each boldface word in the article. Write down the definitions and be sure to credit your source.

2. **Research:** What is a Rhodes Scholarship?

3. **Research:** Why does a larger telescope allow astronomers to see more?

4. Imagine you knew Edwin Hubble. Describe how you think he may have felt when Albert Einstein came to visit and thank him for his discoveries.

5. **Research:** Before Hubble’s discovery, people thought that the universe had always been about the same size. How did Hubble’s discovery that the universe is currently expanding change scientific thought about the size of the universe in the past?
28.2 Light Intensity Problems

Light is a form of energy. Light intensity describes the amount of energy per second falling on a surface, using units of watts per meter squared (W/m²). Light intensity follows an inverse square law. This means that the intensity decreases as the square of the distance from the source. For example, if you double the distance from the source, the light intensity is one-fourth its original value. If you triple the distance, the light intensity is one-ninth its original value.

Most light sources distribute their light equally in all directions, producing a spherical pattern. The area of a sphere is $4\pi r^2$, where $r$ is the radius or the distance from the light source. For a light source, the intensity is the power per area. The light intensity equation is:

$$ I = \frac{P}{A} = \frac{P}{4\pi r^2} $$

Remember that the power in this equation is the amount of light emitted by the light source. When you think of a “100 watt” light bulb, the number of watts represents how much energy the light bulb uses, not how much light it emits. Most of the energy in an incandescent light bulb is emitted as heat, not light. That 100-watt light bulb may emit less than 1 watt of light energy with the rest being lost as heat.

Solve the following problems using the intensity equation. The first problem is done for you.

1. For a light source of 60 watts, what is the intensity of light 1 meter away from the source?

   $$ I = \frac{P}{4\pi r^2} = \frac{60 \text{ W}}{4\pi (1 \text{ m})^2} = 4.8 \text{ W/m}^2 $$

2. For a light source of 60 watts, what is the intensity of light 10 meters away from the source?

3. For a light source of 60 watts, what is the intensity of light 20 meters away from the source?

4. If the distance from a light source doubles, how does light intensity change?

5. Answer the following problems for a distance of 4 meters from the different light sources.
   a. What is the intensity of light 4 meters away from a 1-watt light source?
   b. What is the intensity of light 4 meters away from a 10-watt light source?
   c. What is the intensity of light 4 meters away from a 100-watt light source?
   d. What is the intensity of light 4 meters away from a 1,000-watt light source?

6. What is the relationship between the watts of a light source and light intensity?
28.2 Henrietta Leavitt

Leavitt, although deaf, had a keen eye for observing the stars. Her ability to identify the magnitude of stars set the standard for determining a star's distance—hundreds or even millions of light years away.

**Star struck**

Henrietta Swan Leavitt was born on July 4, 1868 in Lancaster, Massachusetts. Henrietta's family lived in Cambridge, Massachusetts and later moved to Cleveland, Ohio. In Ohio, Leavitt attended Oberlin College for two years and was enrolled in the school's conservatory of music. She then moved back to Cambridge and attended Radcliffe College, which was then known as the Society for the Collegiate Instruction of Women.

In her last year of college, Henrietta took an astronomy course—then began her fascination with and love for the stars. She graduated in 1892 and later became a volunteer research assistant working at the Harvard College Observatory.

**Computing the stars**

In the 1880s, Harvard College established a goal to catalog the stars. Edward Pickering, a former professor at the Massachusetts Institute of Technology, became director of the Harvard Observatory. Pickering was an authority in photographic photometry—determining a star's magnitude from a photograph. He wanted to gather information about the brightness and color of stars.

In order to complete this work, Pickering needed people to perform the tedious task of examining photographs of stars. Men typically did not perform this type of work, but women were hired and known as “computers.” Leavitt was hired at a rate of $.30 per hour to complete this painstakingly detailed work.

Leavitt was not a healthy woman, struggling with complete hearing loss and other illnesses during college and throughout her career. Despite these setbacks, she became a super computer, devoting her life to studying the stars. She eventually became the head of the photographic stellar photometry department.

Leavitt catalogued variable stars that altered in brightness over the course of a few days, weeks, or even months. She studied Cepheid variable stars in the Magellanic Clouds, two galaxies near the Milky Way. Leavitt examined photographic plates, comparing the same regions on several plates taken at different times. Stars that had changed in brightness would look different in size. Leavitt continued to examine plates, discovering nearly 2,000 new variable stars in the Magellanic Clouds.

Leavitt found an inverse relationship between a star's brightness cycle and its magnitude. A stronger star took longer to cycle between brightness and dimness. Therefore, brighter Cepheid stars took longer to rotate between brightness and dimness. In 1912, Leavitt had established the Period-Luminosity relation.

These stars, all located within the Magellanic Clouds, were roughly the same distance from the Earth. This rule provided astronomers with the ability to measure distances within and beyond our galaxy.

**Astronomical findings**

Leavitt's discovery had a tremendous impact on future research in the field of astronomy. Astronomers could now determine distances to galaxies and within the universe overall. Ejnar Hertzsprung was able to plot the distance of Cepheid stars. Harlow Shapley, using Leavitt's findings, was able to map the Milky Way and determine its size. Edwin Hubble applied her rule to establish the age of the Universe.

**An unsung heroine**

In 1925, the Swedish Academy of Sciences wished to nominate Leavitt for a Nobel Prize. However, she had died of cancer nearly four years earlier at the age of 53. The Nobel Prize must be given during a recipient’s lifetime.

In addition to her discovery of numerous variable stars, Leavitt discovered four novas and developed the standard method for determining the magnitude of stars. An asteroid and crater on the moon are named in her honor.
Reading reflection

1. How did Henrietta Leavitt discover new variable stars?
2. What were Leavitt's two significant contributions to the field of astronomy?
3. Research: What is the name of the asteroid named in Leavitt's honor?
4. Research: When was the Harvard Observatory established and what does it do now?
5. Research: State three facts about each of these astronomers: Ejnar Hertzsprung, Harlow Shapley, and Edwin Hubble.
6. Research: What is the Nobel Prize?
28.2 Calculating Luminosity

You have learned that in order to understand stars, astronomers want to know their luminosity. *Luminosity* describes how much light is coming from the star each second. Luminosity can be measured in watts (W).

Measuring the luminosity of something as far away as a star is difficult to do. However, we can measure its brightness. *Brightness* describes the amount of the star’s light that reaches a square meter of Earth each second. Brightness is measured in watts/square meter (W/m²).

The brightness of a star depends on its luminosity and its distance from Earth. A star, like a light bulb, radiates light in all directions. Imagine that you are standing one meter away from an ordinary 100-watt incandescent light bulb. These light bulbs are about ten percent efficient. That means only ten percent of the 100 watts of electrical power is used to produce light. The rest is wasted as heat. So the luminosity of the bulb is about ten percent of 100 watts, or around 10 watts.

The brightness of this bulb is the same at all points one meter away from the bulb. All those points together form a sphere with a radius of one meter, surrounding the bulb.

If you want to find the brightness of that bulb, you take the luminosity (10 watts) and divide it by the amount of surface area it has to cover—the surface area of the sphere. So, the formula for brightness is:

\[
\text{brightness} = \frac{\text{luminosity}}{\text{surface area of sphere}} = \frac{\text{luminosity}}{4\pi(r)^2}
\]

The brightness of the bulb at a distance of one meter is:

\[
\frac{10 \text{ watts}}{4\pi(1 \text{ meter})^2} = \frac{10 \text{ watts}}{12.6 \text{ meter}^2} = 0.79 \text{ W/m}^2
\]

Notice that the radius in the equation is the same as the distance from the bulb to the point at which we’re measuring brightness. If you were standing 10 meters away from the bulb, you would use 10 for the radius in the equation. The surface area of your sphere would be \(4\pi(100)\) or 1, 256 square meters! The same 10 watts of light energy is now spread over a much larger surface. Each square meter receives just 0.008 watts of light energy. Can you see why distance has such a huge impact on brightness?
If we know the brightness and the distance, we can calculate luminosity by rearranging the equation:

\[
\text{luminosity} = \text{brightness} \times \text{surface area of sphere} = \text{brightness} \times 4\pi(\text{distance})^2
\]

This is the same formula that astronomers use to calculate the luminosity of stars.

**Example**

You are standing 5 meters away from another incandescent light bulb. Using a light-meter, you measure its brightness at that distance to be 0.019 watts/meter\(^2\). Calculate the luminosity of the bulb. Assuming this bulb is also about ten percent efficient, estimate how much electric power it uses (this is the wattage printed on the bulb).

**Step 1:** Plug the known values into the formula:

\[
\text{luminosity} = \frac{0.019 \text{ watts}}{\text{meter}^2} \times 4\pi(5 \text{ meters})^2
\]

**Step 2:** Solve for luminosity:

\[
\text{luminosity} = 0.019 \times 100\pi \text{ watts} = 6 \text{ watts}
\]

**Step 3:** If the bulb is only about ten percent efficient, the electric power used must be about ten times the luminosity. The bulb must use about \(10 \times 6\) watts, or 60 watts, of electric power.

**Practice**

1. Ten meters away from a flood lamp, you measure its brightness to be 0.024 W/m\(^2\). What is the luminosity of the flood lamp? What is the electrical power rating listed on the bulb, assuming it is ten percent efficient?

2. You hold your light-meter a distance of one meter from the light bulb in your refrigerator. You measure the brightness to be 0.079 W/m\(^2\). What is the luminosity of this light bulb? What is its power rating, assuming it is ten percent efficient?

3. **Challenge:** Finding the luminosity of the sun.

You can use the same formula to calculate the luminosity of the sun.

Astronomers have measured the average brightness of the sun at the top of Earth’s atmosphere to be 1,370 W/m\(^2\). This quantity is known as the *solar constant*.

We also know that the distance from Earth to the sun is 150 billion meters (or \(1.5 \times 10^{11}\) meters).

What is the luminosity of the sun?

**Hints:**

1. You may wish to rewrite the solar constant as \(1.370 \times 10^3\) W/m\(^2\).
2. \((10^{11})^2\) is the same as \(10^{11} \times 10^{11}\). To find the product, add the exponents.
3. Don’t forget to find the square of 1.5!
Doppler shift is an important tool used by astronomers to study the motion of objects, such as stars and galaxies, in space. For example, if an object is moving toward Earth, the light waves it emits are compressed, shifting them toward the blue end (shorter wavelengths, higher frequencies) of the visible spectrum. If an object is moving away from Earth, the light waves it emits are stretched, shifting them toward the red end (longer wavelengths, lower frequencies) of the visible spectrum. In this skill sheet, you will practice solving problems that involve doppler shift.

### Understanding Doppler Shift

You have learned that astronomers use a spectrometer to determine which elements are found in stars and other objects in space. When burned, each element on the periodic table produces a characteristic set of spectral lines. When an object in space is moving very fast, its spectral lines show the characteristic patterns for the elements it contains. However, these lines are shifted.

If the object is moving away from Earth, its spectral lines are shifted toward the red end of the spectrum. If the object is moving toward Earth, its spectral lines are shifted toward the blue end of the spectrum.

1. The graphic to the right shows two spectral lines from an object that is not moving. Use an arrow to indicate the direction that the spectrum would appear to shift if the object was moving toward you.

2. The graphic to the right shows the spectral lines emitted by four moving objects. The spectral lines for when the object is stationary are shown as dotted lines on each spectrum. The faster a star is moving, the greater the shift in wavelength. Use the graphic to help you answer the following questions.
   a. Which of the spectra show an object that is moving toward you?
   b. Which of the spectra show an object that is moving away from you?
   c. Which of the spectra show an object that is moving the fastest away from you?
   d. Which of the spectra show an object that is moving the fastest toward you?
Solving Doppler Shift Problems

By analyzing the shift in wavelength, you can also determine the speed at which a star is moving. The faster a star is moving, the larger the shift in wavelength. The following proportion is used to help you calculate the speed of a moving star. Remember that the speed of light is a constant value equal to $3 \times 10^8$ m/s.

\[
\frac{\text{The speed of a star}}{\text{The speed of light}} = \frac{\text{The difference in wavelength}}{\text{The stationary value for wavelength}}
\]

**EXAMPLE**

The spectral lines emitted by a distant galaxy are analyzed. One of the lines for hydrogen has shifted from 450 nm to 498 nm. Is this galaxy moving away from or toward Earth? What is the speed of galaxy?

\[
\frac{\text{The speed of a star}}{3 \times 10^8 \text{ m/s}} = \frac{498 \text{ nm} - 450 \text{ nm}}{450 \text{ nm}}
\]

The speed of a star = \[48 \text{ nm} \times 3 \times 10^8 \text{ m/s} = 0.11 \times 3 \times 10^8 \text{ m/s} = 3.3 \times 10^7 \text{ m/s}\]

The galaxy is moving away from Earth at a speed of 33 million meters per second.

**PRACTICE**

1. One of the spectral lines for a star has shifted from 535 nm to 545 nm. What is the speed of this star? Is the star moving away from or toward Earth?
2. One of the spectral lines for a star has shifted from 560 nm to 544 nm. What is the speed of the star? Is it moving away from or toward Earth?
3. An astronomer has determined that two galaxies are moving away from Earth. A spectral line for galaxy A is red shifted from 501 nm to 510 nm. The same line for galaxy B is red shifted from 525 nm to 540 nm. Which galaxy is moving the fastest? Justify your answer.
4. Does the fact that both galaxies in the question above are moving away from Earth support or refute the Big Bang theory? Explain your answer.
Skill Sheet 1.1: Lab Safety

Safety quiz answers:
1. Answers will vary.
2. Answers will vary.
3. Answers will vary. Example: (1) Be quite and listen, (2) locate your safety buddy, (3) in a safe and orderly manner, follow your teacher out of the lab to a designated safe location.
4. In many cases, investigations require the use of chemicals that may cause harm to your eyes or clothing if these are not protected. Gloves are also important when working with chemicals. For investigations that require heat, using a hot pad is very important.
5. Teamwork helps you to complete the lab efficiently, but keeping safe also requires teamwork. Sometimes, you may need someone to help you pour a chemical or perform a procedure that would be unsafe if you tried it by yourself. A team of people can also work together to keep everyone on the team safe. On your own, it is more difficult to be aware of all the possible dangers in a laboratory setting.
6. Cleaning up after an investigation prepares the work space for the next day’s investigation. A clean work space is safer because all chemicals and any sharp or dangerous objects are removed. Clean up also involves turning off any appliances that could heat up and cause a fire.
7. (1) Immediately tell my teacher, (2) listen carefully and follow any safety instructions provided by the teacher, and (3) follow the appropriate safety guidelines.
8. Answers are:
   a. First, I would make sure that my classmates know to stay away from the broken beaker and I would tell my teacher what had happened. Then, I would clean up the glass with a dust pan and a brush. I would not use my hands to clean up the glass. I would place the broken glass in a cardboard box, seal the box, and label it “sharps.”
   b. I would make sure my classmates know about the water so they don’t slip. I would tell my teacher as soon as possible. I would begin placing paper towels on the wet spot as soon as possible. Carefully, I would work with my classmates to clean up the spill. It would be best to use gloves during the clean up in case any chemicals are mixed in with the water.
   c. I would tell my teacher about the smell and follow any safety instructions given to me by the teacher. I would help to make sure that the lab is well ventilated (by helping to open windows and doors, for example). I would ask to leave the lab to get some fresh air if I needed to do so.
   d. I would stop talking and listen to any safety instructions from my teacher. I would follow the classroom plan for exiting the lab as soon as possible. I would not worry about removing my lab apron. I may remove my goggles if it seems unsafe to keep them on.
   e. I would take her hand and lead her to the eye wash station as soon as possible. I would tell a classmate to tell our teacher as soon as possible. When the teacher arrives, I would let her/him help my lab partner.
   f. I would stop talking and listen to any safety instructions from my teacher. I would follow the classroom plan for exiting the lab as soon as possible. I may need to use the nearest classroom fire extinguisher if my teacher is unable to do so.

Skill Sheet 1.1: Using Your Textbook

Part 1 answers:
1. Green
2. Correct answers include any four of the following vocabulary words:
   relief, elevation, sea level, topographic map, contour lines, slope
3. Blue
4. Hypotheses must be testable to be scientific.
5. Section reviews are found at the end of each section of each chapter.
6. Why does chocolate melt in your hand?
7. Answers are:
   1. looking for:
   2. Given
   3. Relationships
   4. Solution
8. The four parts are vocabulary, concepts, problems, and applying your knowledge.

Part 2 answers:
1. There are eight units:
   Science Skills
   Motion, Force, and Energy
   Matter, Energy, and Earth
   Matter and Its Changes
   Electricity and Magnetism
   Earth’s Structure
   Waves
   Matter and Motion in the Universe
2. Answers will vary according to student interest.
3. The glossary and index are found at the back of the book, after Unit 8. The glossary contains definitions; the index tells where to find information on specific topics.

Part 3 answers:
1. Velocity is a variable that tells you both speed and direction.
2. Pages 250 and 251
3. Page 347

Skill Sheet 1.1: SI Units

1. 10 g
2. 1000 mm
3. 600 mm
4. 420 g
5. 5 L
6. 0.1 m
7. 1,500,000 mg
8. 300 L
9. 6,500,000 cm
10. 120,000 mg
11. 7.2 L
12. 5.3 kL
13. A decimeter is 100 times larger than a millimeter.

14. A dekagram is 1000 times larger than a centigram.

15. A millimeter is 10 times smaller than a centimeter.

**Skill Sheet 1.1: Scientific Notation**

1. Answers are:
   a. 122,200
   b. 90,100,000
   c. 3,600
   d. 700.3
   e. 52,722

2. Answers are:
   a. $4.051 \times 10^6$
   b. $1.3 \times 10^9$
   c. $1.003 \times 10^6$
   d. $1.602 \times 10^4$
   e. $9.9999 \times 10^{12}$

**Skill Sheet 1.2: Measuring Length**

Stop and Think:

f. 10 millimeters = 1 centimeter

g. It is better to measure with the English system when you want to buy fabric for making curtains. Fabric is sold in yards and inches in the U.S. It is better to measure with the metric system when you are describing the length of something to your pen pal in Germany.

Example 1:
1. 63.0 mm
2. 6.30 cm
3. 0.063 m

Example 2:
1. 189.0 mm
2. 3 blocks
3. 7.44 inches

Example 3:
1. 42.5 mm
2. 7 dominoes

Practice with converting units for length:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Your multiplication factor</th>
<th>Your domino length in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>pico-</td>
<td>$10^{-9}$</td>
<td>$42.5 \times 10^9$ pm</td>
</tr>
<tr>
<td>nano-</td>
<td>$10^{-6}$</td>
<td>$42.5 \times 10^6$ nm</td>
</tr>
<tr>
<td>micro-</td>
<td>$10^{-3}$</td>
<td>$42.5 \times 10^3$ µm</td>
</tr>
<tr>
<td>milli</td>
<td>$10^{-3}$</td>
<td>$42.5 \times 10^3$ mm</td>
</tr>
<tr>
<td>centi-</td>
<td>$10^{-1}$</td>
<td>$42.5 \times 10^{-1}$ cm</td>
</tr>
<tr>
<td>deci-</td>
<td>$10^{-1}$</td>
<td>$42.5 \times 10^{-1}$ dm</td>
</tr>
<tr>
<td>deka-</td>
<td>$10^{1}$</td>
<td>$42.5 \times 10^1$ dm</td>
</tr>
<tr>
<td>hecto-</td>
<td>$10^{5}$</td>
<td>$42.5 \times 10^5$ hm</td>
</tr>
<tr>
<td>kilo-</td>
<td>$10^{6}$</td>
<td>$42.5 \times 10^6$ km</td>
</tr>
</tbody>
</table>

**Skill Sheet 1.2: Averaging**

1. Four gloves per household
2. On average, each person spent about $8.33.
3. $3.95; $31.60
4. $6$ points each
5. $5$ slices each ($5 \frac{1}{3}$ slices each)

**Skill Sheet 1.2: SQ3R Reading and Study Method**

No student responses are required.

**Skill Sheet 1.2: Stopwatch Math**

1. Answers are:
   a. 5, 5.05, 5.15, 5.2, 5.5
   b. 6:06, 6:06.004, 6:06.04, 6:06.4

2. Answers are:

<table>
<thead>
<tr>
<th>Time</th>
<th>9.88w</th>
<th>9.88w</th>
<th>9.91</th>
<th>9.95w</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>9.97w</th>
<th>10.01</th>
<th>10.08</th>
<th>10.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1999</td>
<td>2000</td>
<td>2005</td>
<td>2003</td>
</tr>
</tbody>
</table>

3. Answers are:

4. Infinitely many solutions possible.

Example: 26:15.21, 26:15.215, 26:15.22, 26:15.225, 26:15.23

**Skill Sheet 1.2: Understanding Light Years**

1. $5.7 \times 10^{13}$ km
2. $4.3 \times 10^{19}$ km
3. $3.8 \times 10^{10}$ km
4. 5,344 ly
5. $1.16 \times 10^{-12}$ ly
6. 1.16 ly
7. 1.200 ly
8. $8.0478 \times 10^{14}$ km
9. 4,280,056,000 km, or $4.28 \times 10^9$ km
10. $0.000026336$ AU, or $2.6 \times 10^{-5}$ AU
11. 63,288 AU

Page 2 of 57
Skill Sheet 1.2: Indirect Measurement

1. The tree is 3 meters tall.
2. The flagpole’s shadow is 12.8 meters.
3. Answers are:
   a. 2,200 feet
   b. 670 meters
4. The average mass is 0.1 kilogram or 100 grams.
5. Each staple is 0.0324 gram or 3.24 milligrams.
6. One business card is 0.034 centimeter thick.
7. The thickness of a CD is approximately 0.13 centimeter or 1.3 millimeters.
8. Answers are:
   a. 4.8 millimeters
   b. 9.6 millimeters
   c. 48 millimeters
   d. 9,600 millimeters or 9.6 meters
9. Answers are:
   a. Each cheesecake takes 0.85 hour or 51 minutes to make.
   b. Yvonne earns $12 per cheesecake.
   c. Yvonne earns $14.12 per hour.
10. The mass of the block of marble is 324,000 grams or 324 kilograms.
11. Sample answer:
    First fill the dropper with water from the glass. Then place drops of water one-by-one into the graduated cylinder. Count the number of drops it takes to reach the 5.0 mL mark on the graduated cylinder. To find the volume of one drop, divide the value 5.0 mL by the number of drops.
12. Sample answer:
    (1) Remove the newspaper from the recycling bin.
    (2) Unfold each sheet and smooth the paper.
    (3) Neatly stack the sheets of paper.
    (4) Place the newspaper on a flat surface.
    (5) Place something heavy, like a hardbound book, on the newspaper to remove excess space between the sheets of paper.
    (6) Measure the height of the stack of paper.
    (7) Divide the stack of paper by the number of sheets.

Note to teacher: This question is designed to prompt students to think about sources of experimental error. You may wish to ask the students what would happen if they divided the height of the recycle bin by the number of sheets of newsprint multiplied by four. Why wouldn’t this method yield an accurate result?

Skill Sheet 1.3: Dimensional Analysis

1. Answers are:
   a. $72/day
   b. 210 lbs/week
2. Answers are:
   a. 2.75 gal
   b. 2.20 m
   c. = 0.0947 mile
   d. 64 cups
3. Answers are:
   a. 126,144,000 s
   b. = 71.0 ft
   c. 4.5 qt
   d. 14 2/3 fields
   e. 48. km/gal
   f. = 13 km/l
   g. 95 ft/s

Skill Sheet 1.3: Fractions Review

Part 1 answers:
1. 13/12
2. 89/56
3. 19/6
4. 1.1, 1.6, 3.2

Part 2 answers:
1. -5/12
2. 9/56
3. -5/3
4. -0.42, 0.16, -1.67

Part 3 answers:
1. 1/4
2. 5/8

Part 4 answers:

Part 5 answers:
1. 1
2. 27/70
3. 1
4. 5/6
5. 1, 0.39, 1.83
### Skill Sheet 1.3: Significant Digits

#### Part 1 answers:
- a. 4
- b. 1
- c. 4
- d. 2
- e. 2
- f. 3
- g. infinitely many (# of students is counted)

#### Part 2 answers:
1. 34,000 cm²
2. 0.9 liters
3. 12.8 m²
4. 24.2°C
5. 40:32
6. Answers will vary.

### Skill Sheet 1.3: Study Notes
This skill sheet provides a note-taking grid for students. It can be used with reading assignments throughout the school year.

### Skill Sheet 1.3: Science Vocabulary

<table>
<thead>
<tr>
<th>Prefix is in bold and suffix is underlined:</th>
<th>4. Consisting of dissimilar ingredients</th>
</tr>
</thead>
<tbody>
<tr>
<td>thermometer</td>
<td>5. The emission of light (as by a chemical or physiological process)</td>
</tr>
<tr>
<td>electrolyte</td>
<td>6. An instrument for measuring spectra</td>
</tr>
<tr>
<td>volumetric</td>
<td></td>
</tr>
<tr>
<td>endothermic</td>
<td></td>
</tr>
<tr>
<td>spectroscopy</td>
<td></td>
</tr>
<tr>
<td>prototype</td>
<td></td>
</tr>
<tr>
<td>convex</td>
<td></td>
</tr>
<tr>
<td>super saturated</td>
<td></td>
</tr>
</tbody>
</table>

#### Student definitions:
Answers may vary. Correct answers include:
1. The study of water
2. Many units
3. The same kind
4. Different kinds
5. Existing light
6. An instrument for measuring the full range of something

#### Dictionary definitions:
1. The science dealing with the properties, distribution, and circulation of water
2. A chemical compound formed by the union of small molecules, usually consisting of repeating units
3. Of the same kind, having uniform structure

### Skill Sheet 1.3: SI Units Extra Practice

| 1. 12,756,000 m | 11. 1,200 mg to 2,700 mg |
| 2. 347,600,000 cm | 12. 158,000 kg |
| 3. 384,000 km | 13. 450,000,000 mg |
| 4. 200,000,000 m | 14. 23,000 g to 90,000 g |
| 5. 16,000,000 cm | 15. 40,000 mL |
| 6. 3,600,000 mm | 16. 1,000 mL |
| 7. 125,000 m long, 400 m deep, 1,500 m wide | 17. 26,600 kL |
| 8. 11.18 km/sec | 18. 1,558,000 L |
| 9. 5,400,000 g | 19. 60 mL |
| 10. 2 g | 20. 0.947 L |

### Skill Sheet 1.3: SI-English Conversions

| 1. = 4.3 mi | 11. = 4.3 mi |
| 2. = 4.11 oz | 12. = 4.11 oz |
| 3. = 896 kg | 13. = 896 kg |
| 4. = 2.1 qt | 14. = 2.1 qt |
| 5. = 2,400 g | 15. = 2,400 g |
| 6. = 33 mi | 16. = 33 mi |
| 7. 2830 in; 78.7 yd | 17. 2830 in; 78.7 yd |
| 8. = 1.74 mi | 18. = 1.74 mi |
| 9. = 3.77 L | 19. = 3.77 L |
| 10. = 0.379 lb | 20. = 0.379 lb |
Skill Sheet 1.4: Creating Scatterplots

1. Answers are:

<table>
<thead>
<tr>
<th>Data pair</th>
<th>Independent</th>
<th>Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td>Hours of heating</td>
<td>Hours of heating</td>
</tr>
<tr>
<td>Stopping distance</td>
<td>Speed of a car</td>
<td>Speed of a car</td>
</tr>
<tr>
<td>Number of people in family</td>
<td>Cost per week for groceries</td>
<td>Number of people in family</td>
</tr>
<tr>
<td>Stream flow</td>
<td>Rainfall</td>
<td>Amount of rainfall</td>
</tr>
<tr>
<td>Tree age</td>
<td>Average tree height</td>
<td>Tree age</td>
</tr>
<tr>
<td>Test score</td>
<td>Number of hours studying for a test</td>
<td>Number of hours studying</td>
</tr>
<tr>
<td>Population of a city</td>
<td>Number of schools needed</td>
<td>Population of a city</td>
</tr>
</tbody>
</table>

2. Answers are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Number of lines</th>
<th>Range ≥ No. of lines</th>
<th>Calculated scale (per line)</th>
<th>Adj. scale (per line)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>24</td>
<td>13 ≥ 24</td>
<td>0.54</td>
<td>1</td>
</tr>
<tr>
<td>83</td>
<td>43</td>
<td>83 ≥ 43</td>
<td>1.9</td>
<td>2</td>
</tr>
<tr>
<td>31</td>
<td>35</td>
<td>31 ≥ 35</td>
<td>0.88</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>33</td>
<td>100 ≥ 33</td>
<td>3.03</td>
<td>5</td>
</tr>
<tr>
<td>300</td>
<td>20</td>
<td>300 ≥ 20</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>900</td>
<td>15</td>
<td>900 ≥ 15</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

3. Answers are:

| 1000 | 20 | 1000 ≥ 20 | 50 | 50 |
| 547  | 15 | 547 ≥ 15  | 36.5 | 37 |
| 99   | 30 | 99 ≥ 30   | 3.3 | 4  |
| 35   | 12 | 35 ≥ 12   | 2.9 | 3  |

Skill Sheet 1.4: What's the Scale?

1. Answers are:

<table>
<thead>
<tr>
<th>Range from 0</th>
<th># of Lines</th>
<th>Range ≥ # of Lines</th>
<th>Calculated scale</th>
<th>Adj. scale (whole #)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>10</td>
<td>14 ≥ 10 =</td>
<td>1.4</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>8 ≥ 5</td>
<td>1.6</td>
<td>2</td>
</tr>
<tr>
<td>1000</td>
<td>20</td>
<td>1000 ≥ 20 =</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>547</td>
<td>15</td>
<td>547 ≥ 15 =</td>
<td>36.5</td>
<td>37</td>
</tr>
<tr>
<td>99</td>
<td>30</td>
<td>99 ≥ 30 =</td>
<td>3.3</td>
<td>4</td>
</tr>
<tr>
<td>35</td>
<td>12</td>
<td>35 ≥ 12 =</td>
<td>2.9</td>
<td>3</td>
</tr>
</tbody>
</table>

Skill Sheet 1.4: Interpreting Graphs

Practice set 1: Scatterplot
1. Graph title: “Money in cash box vs. hours washing cars.”
2. The two variables are number of hours washing cars and the amount of money in the cash box.
3. Hours

Skill Sheet 1.4: What's the Scale?

1. Answers are:

<table>
<thead>
<tr>
<th>Range</th>
<th>Number of lines</th>
<th>Range ≥ No. of lines</th>
<th>Calculated scale (per line)</th>
<th>Adj. scale (per line)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>24</td>
<td>13 ≥ 24</td>
<td>0.54</td>
<td>1</td>
</tr>
<tr>
<td>83</td>
<td>43</td>
<td>83 ≥ 43</td>
<td>1.9</td>
<td>2</td>
</tr>
<tr>
<td>31</td>
<td>35</td>
<td>31 ≥ 35</td>
<td>0.88</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>33</td>
<td>100 ≥ 33</td>
<td>3.03</td>
<td>5</td>
</tr>
<tr>
<td>300</td>
<td>20</td>
<td>300 ≥ 20</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>900</td>
<td>15</td>
<td>900 ≥ 15</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

2. The range is 30 and the scale is 1 per line.
3. The range is 25 and the scale is 3 per line.
4. Answers are:
   - Independent variable: Days; Dependent variable: Average Temperature (°F)
   - Range for x-axis = 11; Range for y-axis = 73
   - Scale for x-axis = 1 day/box; Scale for y-axis = 4 °F/box

5. Dollars
6. The data would be concentrated toward the bottom quarter of the graph. All the data would appear within first three grid boxes of the y-axis.
7. Yes, there is a relationship between the variables.
8. As the time spent washing cars increases, the money in the cash box increases.
9. If the theater club worked for five hours a Saturday for at least 14 Saturdays, they could earn $1050. This amount is based on earning $75 during the five hour period (assuming $20 is the starting amount of money in the cash box). Between April and the fall, there would be Saturdays in May, June, July, and August for doing the car wash; a total of about 16 Saturdays. This would be enough time to earn $1000.

**Practice set 2: Bar Graph**
1. Graph title: “Percentage of teenagers that are employed in four cities.”
2. The two variables are cities (four are represented) and gender (boys and girls). The variable represented on the y-axis is the percentage of teenagers that are employed. The range of values is from 0 to 80.
3. The highest percentages of boys and girls employed is in city C. The lowest percentages is in city D. The percentages of boys and girls employed is about the same in city A which has the second highest percentage of teenagers employed. Girls employed outnumber boys employed in cities B and D.
4. In cities A and C, the percentage of boys employed is greater than the percentage of girls employed. In cities B and D, the percentage of girls employed is greater than the percentage of boys employed.
5. Answers will vary. Sample Answer: The type of businesses in city C are suited to hiring workers that can only work in the afternoons or evenings for a pay rate that is suitable to teenagers. The type of jobs in city D are more suited to people who can work full time.
6. Answers will vary. Sample Answer: In city C, the kinds of jobs that are available to teenagers may be more suited for boys. The opposite is true for city B; there, the jobs may be more suitable and appealing to girls. By doing a survey of the teens in city C, this hypothesis could be tested.

**Practice set 3: Pie graph**
1. Graph title: “Percent distribution of jobs held by teenagers.”

**Skill Sheet 1.4: Recognizing Patterns on Graphs**
1. A, E, F
2. B, C
3. A, B, F
4. C, E
5. D
6. A

**Skill Sheet 2.1: Scientific Processes**
1. Maria and Elena’s question is: Does hot water in an ice cube tray freeze faster than cold water in an ice cube tray?
2. Maria’s hypothesis: Hot water will take longer to freeze into solid ice cubes than cold water, because the hot water molecules have to slow down more than cold water molecules to enter the solid state and become ice.
3. Examples of variables include: Amount of water in each ice cube tray “slot” must be uniform. Each ice cube tray must be made of same material, “slots” in all trays must be identical. Placement of trays in freezer must provide equal cooling. All “hot” water must be at the same initial temperature. All “cold” water must be at the same initial temperature.
4. Examples of measurements include: Initial temperature of hot water. Initial temperature of cold water. Volume of water to fill each ice cube tray “slot.”
5. Time taken for water to freeze solid.
6. Sample procedure in 9 steps:
   (1) Place 1 liter of water in a refrigerator to chill for 1 hour.
   (2) Boil water in pot on a stove (water will be 100°C).
   (3) Using pot holders, a kitchen funnel, and a medicine-measuring cup, carefully measure out 15 mL of boiling water into each slot in two labeled ice cube trays.
   (4) Remove chilled water from refrigerator, measure temperature.
   (5) Carefully measure 15 mL chilled water into each slot in two labeled ice cube trays.
   (6) Place trays on bottom shelf of freezer, along the back wall.
   (7) Start timer.
   (8) After 1/2 hour, begin checking trays every 15 minutes to see if solid ice has formed in any tray.
   (9) Stop timing when at least one tray has solid ice cubes in it.
7. The average time was 3 hours and 15 minutes.
7. Repeating experiments ensures the accuracy of your results. Each time you are able to repeat your results, you reduce the effect of sources of error in the experiment that may come from following a certain procedure, human error, or from the conditions in which the experiment is taking place.
8. The only valid conclusion that can be drawn is (d).
9. Maria and Elena could ask a few of their friends to repeat their experiment. This would mean that the experiment would be repeated in other places with other freezers. If their friends are able to repeat the girls’ results, then the kind of freezer used can be eliminated as a factor that influenced the results.
10. A new question could be: Do dissolved minerals in water affect how fast water freezes?
   For further study: Ask student to come up with a plan to test the validity of statements b and c. Encourage your students to research methods for measuring dissolved minerals and oxygen in water.

Skill Sheet 2.1: What’s Your Hypothesis?

1. Sample hypothesis: The water level in the cup is lower because the Sun heated the water in the cup and that caused evaporation of the water.
2. Sample hypothesis: The candle heats up the air above it. Warm air is less dense so it rises. The effect causes the air in the box to move in the area above the candle. When the smoke from moves above the candle, it gets heated and rises out of the chimney above the candle.
3. Sample hypothesis: Increasing the temperature of water will increase the rate at which evaporation occurs.
4. Sample hypothesis: If the river is flowing down a mountain, it will flow faster than if it is flowing along flat land. In other words, the force of gravity causes river water to flow faster if the water is moving from a high to a lower place.
5. Sample hypothesis: I think the flower bulbs have been dug up and eaten by squirrels.
6. Sample hypothesis: Since kelp is a food source for the sea urchins, the urchin population might die out. Without a sea urchin population as a food source, the sea otter population might die out.
7. Sample hypothesis: Snowshoe hares turn white in the winter so that they can blend in with the snow and avoid being caught by lynx. In the summertime, the brown coat of the hare blends in with the color of the ground.
8. Sample hypothesis: Yes, I think there would be animals like coyotes in other deserts. [Example: The jackal in the Kalahari Desert in Southwest Africa plays a similar ecological role as the coyote.]

Skill Sheet 2.2: Recording Observations in the Lab

Exercise 1:
1. c
2. a
3. c

Exercise 2:
1. c
2. a
3. c
4. Mass by year
5. Data/observations
6. answers vary.

Skill Sheet 2.2: Lab Report Format

This skill sheet can be used throughout the school year as a guide to writing a formal lab report.

Skill Sheet 2.2: Using Computer Spreadsheets

Example graph:

1. Time is the independent variable; temperature is the dependent variable.
2. The independent variable goes in the first column.
3. The temperature increases slowly for the first 90 seconds and then increases much more rapidly from 90-300 seconds.
4. The slope for the first 90 seconds is 0.02 degrees per second, and then it increases to 0.08 degrees per second for the period from 180 to 300 seconds.
5.
The slope is the same (2.0) until you get to the final segment, when it increases to 2.6.

**Skill Sheet 2.2: Identifying Control and Experimental Variables**

1. Experimental variable: antibacterial cleaner (antibacterial cleaner vs. no antibacterial cleaner). Control Variables: Petri dish, cotton swab, source of bacteria, length of experiment, incubation temperature, incubation light exposure

2. Experimental variable: amount of water each plant gets. Control variables: plant type, plant size, pot, soil, duration of experiment, amount of light exposure.

3. Experimental variable: bread type (preservatives vs. no preservatives). Control variables: plastic bag, damp paper towel, dark environment, duration of experiment.

4. Experimental variable: fertilizer (fertilizer vs. no fertilizer). Control variables: amount of water, algae sample, location of beakers (sunlight), duration of experiment.

**Skill Sheet 3.1: Position on the Coordinate Plane**

1.  

2.  

3. Yes the order does matter. The coordinate (2, 3) shows a point that is 2 to the right and 3 up, while the coordinate (3, 2) shows a point that is 3 to the right and 2 up.
Skill Sheet 3.1: Latitude and Longitude

Part 1 answers:
1. Answers are:
   a. Iceland
   b. Algeria
   c. Argentina
   d. Australia
   e. New Zealand
2. Answers are:
   a. Bay of Bengal
   b. Aegean Sea
   c. Red Sea
   d. Gulf of Mexico

Part 2 answers:
1. Answers are:
   a. 30.33°N
   b. 45.75°N
   c. 20.61°S
   d. 60.33°S
2. Answers are:
   a. 25.92°E
   b. 145.25°E
   c. 130.62°W
   d. 85.44°W

Skill Sheet 3.1: Map Scales

1. Answers are:
   a. Andora
   b. No. I need to know the scale to answer the question.
   c. Yes. They are both 1.5 cm.
   d. No. One centimeter could represent different distances on each island.
   e. Calypso is much bigger.
2. Answers are:
   (Note: Allow answers that are + or – 3 kilometers.)
   a. 40 km
   b. 128 km
   c. 50 km
   d. 110 km
   e. 80 km
   f. 185 km
   g. 125 km
   h. 170 km (50 + 120)
   i. 118 km (78 + 40)
   j. 298 km (120 + 50 + 128)

Bonus: Give credit for estimates between 850 – 950 km.

Skill Sheet 3.1: Vectors on a Map

1. (+60 km, –10 km)
2. (+1 km, +2 km)
3. (+1 km, +1 km)
4. 
5. Answers to student-designed problems will vary.

Skill Sheet 3.1: Navigation

Note to teacher: It is highly recommended that you do a trial run yourself before doing this activity with your students. This will enable you to help the students more efficiently during the activity, especially when it comes to finding locations on the maps.

Making predictions:
   a. I expect to find coral reefs.
   b. We will need to watch where we navigate our boat because coral reefs exist close to the surface and could be an obstruction for our boat.

It's time to go!
1. No student response required.
2. No student response required.
3. 1:326,856
4. It means that one unit on the map represents 326,856 of those units in real life.
5. There are six feet in a fathom.
6. There is a lighthouse with an occulting light, which means the period of darkness when the light is covered or obscured is less than the time period when the light is showing.
7. Two fathoms
8. Dump site of dredged material
9. Dredged material is material that was dug by machine (usually from another channel or river bed) and has been dumped here.
10. Yes
11. No
12. Yes
13. S Sh—Sand and shells on the bottom, Co Sh—coral shells on bottom, h S—hard sand on bottom, Co S—coral sand on bottom, bk SH—broken shells on bottom, bk Co—broken coral on bottom, Sh Co—shells and coral on bottom

14. It is a flashing lighthouse. The light is obscured for longer than it is showing (the opposite is true with an occulting light).

15. No student response required.

16. Explosive Dumping Area

17. A bad idea!

18. No. Lower the anchor and use the rowboat to get ashore.

19. Four

20. The fourth is aeronautical, which means that it displays flashes, in this case, of white and green, to indicate the location of an airport, a heliport, a landmark, a certain point of a federal airway in mountainous terrain, or an obstruction.

21. Seven nautical miles

22. Cables

23. Drop anchor

24. No

25. It means that the rocks on the isle are covered and uncovered by water and that they reach a height of 269 feet.

26. Fathoms

27. No student response required.

28. 1:100,000

29. You can see more detail on the second map.

30. National Response Center or the nearest US Coast Guard facility

Skill Sheet 3.2: Topographic Maps

1. Answer graphic:

![Topographic Map Diagram]

2. Answer graphic (at right):

![Topographic Map Diagram]

3. Answers are:
   a. 0 or sea level
   b. 400-499 feet
   c. 100 feet
   d. 300 feet
   e. between 0 and 100 feet.

4. Answers are:
   a. The island becomes two islands.
   b. The original island is now three islands.
   c. No, the storm wave would wash over the island.

Skill Sheet 3.3: Bathymetric Maps

1. Example answers:
   a. Mid-Atlantic Ridge
   b. East Pacific Rise
   c. Middle America Trench or Mariana Trench
   d. Falkland Plateau
   e. Mendocino Fracture Zone

2. Two tectonic plates move apart.

3. Answers are:
   a. East Pacific Rise
   b. Chile Rise; this rise looks like the Mid-Atlantic Ridge
   c. Chatham Rise; this feature seems to be a plateau on the sea floor

4. Subduction

5. A combination of two diverging plates at the East Pacific Rise and subduction zones in the northern part of the North Pacific Ocean. The plate movement associated with these features may have caused the fracture zone.

6. The ridge has a lot of faults. There is a thin, dark-blue line in the middle of the ridge. The white areas around the ridge are not very prominent.

7. This rise is less jagged. The white area near the rise is more prominent here than at the Mid-Atlantic Ridge.

8. Mid-Atlantic Ridge; the dark line indicates a valley in the middle of the ridge

9. Cross-sections of the Mid-Atlantic Ridge and the East Pacific Rise (Based on viewing the bathymetric map):
The Mid-Atlantic Ridge has a slow spreading rate, while the spreading rate of the East Pacific Rise is fast. Because the Mid-Atlantic Ridge is so slow, a valley has developed between the two separating plates.

Skill Sheet 3.3: Tanya Atwater

1. Tanya Atwater came from a family of scientists—her father was an engineer and her mother a botanist. Atwater recalls many dinner discussions about science and she eventually shared in her parents’ passion. Atwater and her family went on many vacations. The family often found the most remote places to explore. This explains Atwater’s deep love for the outdoors.

2. In 1967, Atwater began graduate school at the Scripps Oceanographic Institution in La Jolla, California. During this time, many exciting geological discoveries were being made. The concept of sea floor spreading was emerging, leading to the current theory of plate tectonics.

3. While at Scripps, Atwater joined a research group that used sophisticated equipment to study the sea floor off of northern California. It was her first close look at sea floor spreading. Atwater also took twelve trips down to the ocean floor in the tiny submarine Alvin. She collected samples nearly 2 miles down on the ocean floor using mechanical arms. Atwater’s firsthand view through Alvin’s portholes gave her a better understanding of the pictures and sonar records she had previously studied.

4. Propagating rifts are created when sea floor spreading centers realign themselves. This realignment is in response to changes in plate motion or uneven magma supplies. In the 1980s, Atwater was part of a team that researched propagating rifts near the Galapagos Islands off the coast of Ecuador. She has also discovered many propagating rifts on the sea floor off the northeast Pacific Ocean and evidence of propagating rifts in ancient sea floor records worldwide.

5. Atwater has been a geology professor at the University of California, Santa Barbara for over 25 years. Atwater also works with the media, museums, and teachers to educate them about the Earth. She has created presentations and an animated teaching film, “Continental Drift and Plate Tectonics,” that has been used by educators from the elementary school level through college.

6. Answers may vary. Some of Alvin’s noteworthy trips include locating a hydrogen bomb accidentally dropped in the Mediterranean Sea (1966), several trips to the Mid-Atlantic Ridge and Galapagos Rift, surveying the sunken ocean liner Titanic (1986), and IMAX filming off of the San Diego coast for a deep sea feature production (2002).

Skill Sheet 4.1: Solving Equations With One Variable

Part 1 answers:
1. \( w = 4.0 \text{ mm} \)
2. \( l = 0.8 \text{ m} \)
3. \( h = 8.00 \text{ cm} \)
4. \( d = 7.5 \text{ m} \)
5. \( s = 4.0 \text{ m/s} \)
6. \( t = 30 \text{ s} \)
7. \( t = 31.3 \text{ s} \)
8. \( D = 7.8 \text{ g/cm}^3 \)
9. \( m = 1.1 \text{ g} \)
10. \( m = 4.5 \text{ g} \)
11. \( V = 113 \text{ cm}^3 \)
12. \( V = 2.3 \text{ cm}^3 \)

Part 2 answers:
1. \( \text{Force} = 8 \text{ N} \)
2. \( p = 20 \text{ Pa} \)
3. \( p = 216 \text{ Pa} \)
4. \( p = 15,000 \text{ Pa} \)

Skill Sheet 4.1: Problem Solving Boxes

This skill sheet can be used throughout the school year to help students organize their work for questions or problems involving formulas and computation.

Skill Sheet 4.1: Problem Solving with Rates

1. \( 365 \text{ days} \)
   \( \frac{1 \text{ year}}{} \)
2. \( \frac{1 \text{ foot}}{12 \text{ inches}} \)
3. \( \frac{\$10.00}{3 \text{ small pizzas}} \)
4. \( \frac{3 \text{ boxes}}{36 \text{ pencils}} \)
5. \( \frac{360 \text{ miles}}{18 \text{ gallons of gasoline}} \)
6. \( \frac{2,100 \text{ calories}}{} \)
7. \( \frac{1,095 \text{ sodas}}{1 \text{ year}} \)
8. \( \frac{725,760 \text{ heartbeats}}{1 \text{ week}} \)
9. \( \frac{27.48}{\text{}} \)
10. 410 miles
11. $\frac{6.6 \text{ miles}}{\text{hour}}$
12. 22.2 lbs
13. 55 kg
14. 5.4977 miles
15. $280$
16. About 10 years
17. 53 grams
18. $\frac{0.11 \text{ miles}}{\text{hour}}$
19. 270 pills
20. 95 feet/sec

Skill Sheet 4.1: Percent Error

Table answers:

<table>
<thead>
<tr>
<th>Distance from A to B (cm)</th>
<th>Time from A to B (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.0050</td>
</tr>
<tr>
<td>20</td>
<td>1.8877</td>
</tr>
<tr>
<td>30</td>
<td>2.8000</td>
</tr>
<tr>
<td>40</td>
<td>3.7850</td>
</tr>
<tr>
<td>50</td>
<td>4.7707</td>
</tr>
<tr>
<td>60</td>
<td>5.6101</td>
</tr>
<tr>
<td>70</td>
<td>6.9078</td>
</tr>
<tr>
<td>80</td>
<td>7.9648</td>
</tr>
<tr>
<td>90</td>
<td>9.0140</td>
</tr>
</tbody>
</table>

1. $= 0.43\%$
2. $= 3.30\%$
3. $= 1.34\%$
4. $= 0.16\%$
5. $= 0.16\%$
6. Answers are:
   a. Avg. = 17.18 s; percent error = 5.06%
   b. Avg. = 38.39 s; percent error = 9.61%
   c. Avg. = 67.91 s; percent error = 0.68%

Skill Sheet 4.1: Speed

1. 17 km/hr
2. 55 mph
3. 4.5 seconds
4. 5.9 hours; 490 mph
5. 4.0 km
6. 2.5 miles
7. 4.5 meters
8. Answers are:
   a. 2.54 cm/inch
   b. 12 inches/min
9. 6 km/hr
10. Answers are:
    a. 600 seconds
    b. 10 minutes
11. 1,200 meters
12. Answers are:
    a. 42 km
    b. 9.3 km/hr
13. Answers are:
    a. 0.2 km/min
    b. 0.5 km/min
    c. 0.3 km/min faster by bicycle
14. 12.5 km
15. 40 minutes
16. 90 km/hr
17. 820 km/hr
18. 32.5 km or 33 km
19. 8 hours
20. 633 km/hr
21. 731 km/hr
22. 1.680 km
23. $3.84 \times 10^5$ km
24. $2.03 \times 10^4$ seconds
25. Answers for 25 (a)–(c) will vary. Having students write their own problems will further develop their understanding of how to solve speed problems.
Skill Sheet 4.1: Velocity

1. 420. km/hr, north
2. 0.30 seconds
3. 224 minutes
4. Answers are:
   a. 1.62 m/s, west
   b. 1.62 m/s, east
5. 16.0 hours
6. 3.0 m/s, west
7. Answers are:
   a. 4.5 m/s, south
   b. 4.5 m/s, north
8. 22 seconds
9. 0.36 miles/min, southwest or 22 mph, southwest
10. 116 kilometers
11. 3.9 km/hr, southeast
12. 9.39 kilometers

Skill Sheet 4.2: Calculating Slope from a Graph

Numbers correlate to graph numbers:

1. \( m = \frac{-3 \times 3}{6 \times 2} = \frac{-9}{12} = \frac{-3}{4} \)
2. \( m = \frac{-2 \times 3}{4 \times 2} = \frac{-6}{8} = \frac{-3}{4} \)
3. \( m = \frac{5}{9} \) Calculated using points (0,3) and (9,8)
4. \( m = \frac{4}{2} = 2 \)
5. \( m = \frac{3}{3} = 1 \)
6. \( m = \frac{-2}{2} = -1 \)
7. \( m = 0 \)
8. \( m = \frac{3}{4} \)
9. \( m = 2 \)
10. \( m = \frac{-1}{2} \)

Skill Sheet 4.2: Analyzing Graphs of Motion with Numbers

1. Answers are:
   a. The bicycle trip through hilly country.
   b. A walk in the park.
   c. Up and down the supermarket aisles.
2. Answers are:
   a. The honey bee among the flowers.
   b. Rover runs the street.
   c. The amoeba.
Skill Sheet 4.2: Analyzing Graphs of Motion without Numbers

1. Little Red Riding Hood. Graph Little Red Riding Hood:

2. The Tortoise and the Hare. Use two lines to graph both the tortoise and the hare:

3. The Skyrocket. Graph the altitude of the rocket:

4. Each student story will include elements that are controlled by the graphs and creative elements that facilitate the story. Only the graph-controlled elements are described here.
   a. The line begins and ends on the baseline, therefore Tim must start from and return to his house.
   b. The line rises toward the first peak as a downward curved line that becomes horizontal. This indicates that Tim’s pace toward Caroline’s house slowed to a stop.
   c. Then the line rises steeply to the first peak. This indicates that after his stop, Tim continues toward Caroline’s house faster than before.
   d. The first peak is sharp, indicating that Tim did not spend much time at Caroline’s house on first arrival.
   e. The line then falls briefly, turns to the horizontal, and then rises to a second peak. This indicates that Tim left, paused, and then returned quickly to Caroline’s house.
   f. The line then remains at the second peak for a long time, then drops steeply to the baseline. This indicates that after spending a long time at Caroline’s house, Tim probably ran home.

Skill Sheet 4.3: Acceleration

1. –0.75 m/s²
2. –8.9 m/s²
3. Answers are:

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (start)</td>
<td>0 (start)</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

The acceleration of the ball is 1.5 km/hr/s.

Skill Sheet 4.3: Acceleration and Speed-Time Graphs

1. Acceleration = 5 miles/hour/hour or 5 miles/hour²
2. Acceleration = –2 meters/minute/minute or –2 meters/minute²
3. Acceleration = 0 feet/minute/minute or 0 feet/minute² or no acceleration
4. Answers are:

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>Distance (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

Skill Sheet 4.3: Acceleration due to Gravity

1. velocity = –14.7 m/s
2. velocity = 11.3 m/s
3. velocity = –76.4 m/s
4. velocity = –16 m/s; depth = 86 meters
5. height = 11 meters; yes
6. time = 5.6 seconds
7. time = 7.0 seconds
Skill Sheet 5.1: Ratios and Proportions

1. 6 tablespoons; 2 eggs
2. \(\frac{3}{4}\) cup; \(\frac{1}{3}\) teaspoon
3. \(\frac{1}{4}\) teaspoon; \(\frac{3}{4}\) cup

4. Table answers:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>(\frac{3}{8}) cup</td>
</tr>
<tr>
<td>Butter</td>
<td>3 tablespoons</td>
</tr>
<tr>
<td>Milk</td>
<td>1 tablespoon</td>
</tr>
<tr>
<td>Chocolate chips</td>
<td>1 cup</td>
</tr>
<tr>
<td>Eggs</td>
<td>1 egg</td>
</tr>
<tr>
<td>Vanilla extract</td>
<td>(\frac{1}{2}) teaspoon</td>
</tr>
<tr>
<td>Baking soda</td>
<td>(\frac{1}{6}) teaspoon</td>
</tr>
<tr>
<td>Salt</td>
<td>(\frac{1}{8}) teaspoon</td>
</tr>
<tr>
<td>Confectioner’s sugar</td>
<td>1 tablespoon</td>
</tr>
</tbody>
</table>

5. To make 16 brownies, you need two eggs and 2 tablespoons of sugar. Therefore, to make 8 brownies, you only need 1 of each unit for each ingredient: 1 egg and 1 tablespoon of sugar.

6. Since 8 brownies requires 1 cup of chocolate chips, 3 cups of chocolate chips will make 24 brownies.

7. 1.5 teaspoons vanilla are needed to make 24 brownies.

Skill Sheet 5.1: Internet Research

Part 1 answers:
1. Example answer: “science museums” + “South Carolina” not “Columbia”
2. “dog breeds” + “inexpensive”
3. “producing electricity” not “coal” not “natural gas”

Part 2 answers:
1. Answers will vary. Sites that may be authoritative include non-profit sites (recognizable by having “org” as the extension in the web address) or government sites such as www.nasa.gov (recognizable by the “gov” extension address) or college/university websites (recognizable by the “edu” extension address). These sites often provide information to large, diverse groups and are not typically supported by advertising. Sites that are supported by advertising can be authoritative, but may be biased in the information presented. Another characteristic of authoritative sites are that they are actively updated on a regular basis.

2. Answers will vary. Reasons for why a source may not seem to be authoritative include: the author of the site is not affiliated with an organization and does not have obvious credentials, and the information seems to be one-sided. Many science topic searches will lead to student papers published on the Internet. These may contain mistakes, or they may have been written by a younger student.

3. Answers will vary. Intended audiences can be young children, pre-teens, teenagers, adults, or select groups of people (women, men, people who like dogs, etc.).

4. Answers will vary.

Skill Sheet 5.1: Bibliographies

No student responses are required.

Skill Sheet 5.1: Mass vs. Weight

1. 15 pounds
2. 2.6 pounds
3. 7.0 kilograms

4. Yes, a balance would function correctly on the moon. The unknown mass would tip the balance one-sixth as far as it would on Earth, but the masses of known quantity would tip the balance one-sixth as far in the opposite direction as they did on Earth. The net result is that it would take the same amount of mass to equalize the balance on the moon as it did on Earth. (In the free fall environment of the space shuttle, however, the masses wouldn’t stay on the balance, so the balance would not work).

5. Answers are:
   a. As the elevator begins to accelerate upward, the scale reading is greater than the normal weight. As the elevator accelerates downward, the scale reads less than the normal weight.
   b. When the elevator is at rest, the scale reads the normal weight.
   c. The weight appears to change because the spring is being squeezed between the top and the bottom of the scale. When the elevator accelerates upward, it is as if the bottom of the scale is being pushed up while the top is being pushed down. The upward force is what causes the spring to be compressed more than it is normally. When the elevator accelerates downward, the bottom of the scale provides less of a supporting force for the feet to push against. Therefore, the spring is not compressed as much and the scale reads less than the normal weight.

Page 15 of 57
Skill Sheet 5.1: Mass, Weight, and Gravity

1. Answers are:
   a. 22 newtons
   b. 8.1 newtons
   c. 8.9 N/kg
2. Answers are:
   a. 65 kilograms
   b. 640 newtons
   c. 240 newtons
3. Answers are:
   a. 23.10 N/kg
   b. 0.6 N/kg
   c. 4.9 newtons
4. Answers are:
   a. 195,700 newtons
   b. 19,970 kilograms
   c. 146,800 newtons
   d. weight of toy-filled boxes = 48,900 newtons.
      mass of toy-filled boxes = 4,990 kg

Skill Sheet 5.1: Gravity Problems

Table 1 answers:

<table>
<thead>
<tr>
<th>Planet</th>
<th>Force of gravity in Newtons (N)</th>
<th>Value compared to Earth’s gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>3.7</td>
<td>0.38</td>
</tr>
<tr>
<td>Venus</td>
<td>8.9</td>
<td>0.91</td>
</tr>
<tr>
<td>Earth</td>
<td>9.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Mars</td>
<td>3.7</td>
<td>0.38</td>
</tr>
<tr>
<td>Jupiter</td>
<td>23.1</td>
<td>2.36</td>
</tr>
<tr>
<td>Saturn</td>
<td>9.0</td>
<td>0.92</td>
</tr>
<tr>
<td>Uranus</td>
<td>8.7</td>
<td>0.89</td>
</tr>
<tr>
<td>Neptune</td>
<td>11.0</td>
<td>1.12</td>
</tr>
<tr>
<td>Pluto</td>
<td>0.6</td>
<td>0.06</td>
</tr>
</tbody>
</table>

1. 9.5 pounds on Neptune
2. 1,030 newtons on Saturn
3. The baby weighs 45 newtons on Earth which is equal to 10.04 pounds.
4. Venus, Jupiter, Neptune, Pluto, then Saturn
5. Answer:
   \[ \text{Gravity} = \left( \frac{6.67 \times 10^{-11} N \cdot m^2}{kg^2} \right) \left( \frac{6.4 \times 10^{24}}{kg} \right) \left( \frac{5.7 \times 10^{26}}{m^2} \right) \]
   \[ = 5.72 \times 10^7 N \]

Skill Sheet 5.1: Universal Gravitation

1. \( F = 9.34 \times 10^{-6} \text{ N} \). This is basically the force between you and your car when you are at the door.
2. \( 5.27 \times 10^{-10} \text{ N} \)
3. \( 4.42 \text{ N} \)
4. \( 7.36 \times 10^{22} \text{ kilograms} \)
5. Answers are:
   a. 9.8 N/kg = 9.8 kg-m/sec^2·kg = 9.8 m/sec^2
   b. Acceleration due to the force of gravity of Earth.
   c. Earth’s mass and radius.
6. \( 1.99 \times 10^{20} \text{ N} \)
7. \( 4.848 \text{ N} \)
8. \( 3.52 \times 10^{22} \text{ N} \)

Skill Sheet 5.2: Friction

1. Answers are:
   a. rolling friction
   b. Sliding friction is generally greater than rolling friction, so it would probably take more force to transport the blocks in the sled.
   c. The friction force would increase, because more blocks would mean more weight force squeezing the two surfaces together.
   d. static friction
2. Answers are:
   a. viscous friction
   b. The friction force would increase because the boat would sit lower in the water.
3. Answers are:
   a. rolling friction and air friction
4. Answers are:
   a. rolling friction
   b. Student responses will vary. Encourage students to look for a sports car rather than a professional racing car. Racing car spoilers may serve a different purpose.
   b. Sports car spoilers are generally designed to increase down force on the rear of the car, causing greater friction between the rear tires and the road.
   c. Spoilers on hybrid cars and sport utility vehicles are usually designed to create a smoother, less turbulent airflow over the rear of the vehicle. This reduces drag (air friction). Sports car spoilers are most often designed to increase rolling friction, not to decrease air friction. Spoilers on different types of cars serve different purposes.

Skill Sheet 5.3: Equilibrium

1. 142 N
2. A is 40 N; B is 8 N
3. 340 N
4. From the outside of a balloon, two forces act inward. The elastic membrane of the balloon and the pressure of Earth’s atmosphere work together to balance the outward force of the helium compressed inside. Together with the elastic force,
atmospheric pressure near Earth’s surface applies enough force to maintain this equilibrium, but as the balloon rises, atmospheric pressure decreases. Although the inward force supplied by the elastic membrane remains unchanged, the decreasing atmospheric pressure force causes an imbalance with the outward force of the contained helium and the balloon expands. At some point, the membrane of the balloon reaches its elastic limit and bursts.

Skill Sheet 6.1: Net Force and Newton’s First Law

1. When at rest, the cart experiences a normal force of 105 N and its weight of –105 N.
2. The net force on the cart is +20 N. While the cart is on the slippery margarine, it is not moving at constant velocity since it is experiencing a net force (acceleration).
3. The normal force on the cart after it is loaded with groceries is +180 N.
4. Gravity accelerates the cart down the ramp.
5. The friction force is greater on the rough blacktop than on the smooth tile.
6. The line of twenty empty carts has twenty times as much inertia, so it takes a much greater force to get it moving.

Skill Sheet 6.1: Isaac Newton

1. The isolation due to the Plague allowed Newton to focus on his scientific work, free from the distractions of university life. However, most scientists learn a great deal from discussing their ideas with peers. Collaboration also enables experimental scientists to test a greater number of hypotheses.
2. Newton was an active member of the scientific community at Cambridge for just under 30 years. In that time, he made great strides in understanding light and optics, planetary motion, universal gravitation, and calculus. He made extraordinary contributions to many scientific fields during those years.
3. Example answer: Newton’s first law says that unless you apply an unbalanced force to an object, the object will keep on doing what is was doing in the first place. So a rolling ball will keep on rolling until an unbalanced force changes its motion, while a ball that is not moving will stay still unless acted on by an unbalanced force.
4. Example answer: The law of universal gravitation says that the force of attraction between two objects is directly related to the masses of the objects and inversely related to the distance between them.
6. Newton claimed that 20 years earlier, he had invented the material that Leibnitz published. Newton accused Leibnitz of plagiarism. Most historians today agree that the two developed the material independently, and therefore they are known as co-discoverers.

Extra information: The famous legend of Newton’s apple tells of Newton sitting in his garden in Lincolnshire in 1666, watching an apple fall from a tree. He later noted that “In the same year, I began to think of gravity extending to the orb of the moon.” However, he did not make public his musings about gravity until the 1680’s, when he formulated his law of universal gravitation.

Skill Sheet 6.2: Newton’s Second Law

1. 2.100 m/s²
2. 83 m/s²
3. 82 N
4. 6 kg
5. 9800 N
6. 900 kg
7. 1.9 m/s²
Skill Sheet 6.3: Applying Newton’s Laws

Table answers are:

<table>
<thead>
<tr>
<th>Newton’s laws of motion</th>
<th>Write the law here in your own words</th>
<th>Example of the law</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first law</td>
<td>An object will continue moving in a straight line at constant speed unless acted upon by an outside force.</td>
<td>A seat belt in a car prevents you from continuing to move forward when your car suddenly stops. The seat belt provides the “outside force.”</td>
</tr>
<tr>
<td>The second law</td>
<td>The acceleration (a) of an object is directly proportional to the force (F) on an object and inversely proportional to its mass (m). The formula that represents this law is [ a = \frac{F}{m} ]</td>
<td>A bowling ball and a basketball, if dropped from the same height at the same time, will fall to Earth in the same amount of time. The resistance of the heavier ball to being moved due to its inertia is balanced by the greater gravitational force on this ball.</td>
</tr>
<tr>
<td>The third law</td>
<td>For every action force there is an equal and opposite reaction force.</td>
<td>When you push on a wall, it pushes back on you.</td>
</tr>
</tbody>
</table>

Skill Sheet 6.3: Momentum

1. \[ \text{momentum} = 4.000 \text{ kg} \times \frac{35 \text{ m}}{\text{s}} = 140,000 \text{ kg} \cdot \frac{\text{m}}{\text{s}} \]
2. \[ \text{momentum} = 1.000 \text{ kg} \times \frac{35 \text{ m}}{\text{s}} = 35,000 \text{ kg} \cdot \frac{\text{m}}{\text{s}} \]
3. \[ \text{mass} \times \text{speed} = 8 \text{ kg} \times \frac{2 \text{ m}}{\text{s}} = 16 \text{ kg} \cdot \frac{\text{m}}{\text{s}} \]
   \[ \text{speed} = \frac{2 \text{ m}}{\text{s}} \]
4. \[ \text{mass} \times \frac{0.5 \text{ m}}{\text{s}} = 0.25 \text{ kg} \cdot \frac{\text{m}}{\text{s}} \]
   \[ \text{mass} = 0.5 \text{ kg} \]
5. \[ 45.000 \text{ kg} \times \frac{\text{m}}{\text{s}} \]

Skill Sheet 6.3: Momentum Conservation

1. \[ m = p/v; \text{ mass} = (10.0 \text{ kg}/\text{m/s}) / (1.5 \text{ m/s}); \text{ mass} = 6.7 \text{ kg} \]
2. \[ v = p/m; \text{ speed} = (1000 \text{ kg}/\text{m/s}) / (2.5 \text{ kg}); \text{ speed} = 400 \text{ m/s} \]
3. \[ p = mv \]
   \[ \text{mass (is conventionally expressed in kilograms)} \]
   \[ p = (0.045 \text{ kg}) \times (75.0 \text{ m/s}) \]
   \[ p = 3.38 \text{ kg m/s} \]
4. \[ P = P; \text{ before firing) = P; (after firing)} \]
   \[ m_1v_1 + m_2v_2 = m_3v_3 \]
   \[ 400 \text{ kg}(0 \text{ m/s}) + 10 \text{ kg}(0 \text{ m/s}) = 400 \text{ kg}(v_2) + 10 \text{ kg}(20 \text{ m/s}) \]
   \[ 0 = 400 \text{ kg}(v_2) + 200 \text{ kg m/s} \]
   \[ v_2 = (–200 \text{ kg m/s})/400 \text{ kg} \]
   \[ v_2 = (–0.5 \text{ m/s}) \]
5. \[ P; \text{ before throwing) = P; (after throwing)} \]
   \[ m_1v_1 + m_2v_2 = m_3v_3 \]
   \[ 0 = m_1(0.05 \text{ m/s}) + 0.5 \text{ kg}(10.0 \text{ m/s}) \]
   \[ m_1 = (–0.5 \text{ kg})(10.0 \text{ m/s})/(0.05 \text{ m/s}) \]
   \[ \text{Eli’s mass} + \text{the skateboard (m_1)} = 100 \text{ kg} \]
6. \[ \frac{30 \text{ m}}{\text{s}} \]
7. \[ \text{The 4.0-kilogram ball requires more force to stop.} \]
8. \[ 980 \text{ kg} \]
9. \[ 4.2 \text{ kg} \cdot \frac{\text{m}}{\text{s}} \]
10. \[ 15 \text{ m/s} \]
11. \[ 0.01 \text{ kg} \cdot \frac{\text{m}}{\text{s}} \]

Answers are:

a. \[ p = mv + \Delta p; p = mv + F \Delta t \]

b. \[ p = (80 \text{ kg})(3.0 \text{ m/s}) + (800 \text{ N})(0.30 \text{ s}) \]

Answers are:

1. \[ p = mv; p = (2000 \text{ kg})(30 \text{ m/s}); p = 60,000 \text{ kg m/s} \]
b.  
\[ F\Delta t = m\Delta v \]
\[ F = (m_1 + m_2)\Delta v; F = (60,000 \text{ kg·m/s})/(0.72 \text{ s}) \]
\[ F = 83,000 \text{ N} \]

8. **Answers are:**

a. \( p = (\text{ (# of people)})(mv) \); \( p = (2.0 \times 10^9)(60 \text{ kg})(7.0 \text{ m/s}); p = 8.4 \times 10^{11} \text{ kg·m/s} \)

b. \( p \) (before jumping) = \( p \) (after jumping)
\[ m_1v_1 + m_2v_2 = m_3v_3 + m_4v_4 \]
\[ 0 = 8.4 \times 10^{11} \text{ kg·m/s} + 5.98 \times 10^{24}(v_4); \]
\[ (v_4) = (-8.4 \times 10^{11} \text{ kg·m/s}) / 5.98 \times 10^{24} \]

Earth moves beneath their feet at the speed
\[ v_4 = -1.4 \times 10^{-15} \text{ m/s} \]

---

### Skill Sheet 6.3: Collisions and Momentum Conservation

1. \( p = mv; p = (100 \text{ kg})(3.5 \text{ m/s}); p = 350 \text{ kg·m/s} \)
2. \( p = mv; p = (75 \text{ kg})(5.0 \text{ m/s}); p = 375 \text{ kg·m/s} \)
3. **Answer:**

\[ P \] (before coupling) = \( P \) (after coupling)
\[ m_1v_1 + m_2v_2 = (m_1 + m_2)(v_{3+4}) \]
\[ (2000 \text{ kg})(5 \text{ m/s}) + (6000 \text{ kg})(-3 \text{ m/s}) = (8000 \text{ kg})(v_{3+4}) \]
\[ v_{3+4} = -1 \text{ m/s or 1 m/s west} \]

4. **Answer:**

\[ P \] (before collision) = \( P \) (after collision)
\[ m_1v_1 + m_2v_2 = m_3v_3 + m_4v_4 \]
\[ (4 \text{ kg})(8 \text{ m/s}) + (1 \text{ kg})(0 \text{ m/s}) = (4 \text{ kg})(4.8 \text{ m/s}) + (1 \text{ kg})(v_4) \]
\[ v_4 = (32 \text{ kg·m/s} - 19.2 \text{ kg·m/s})/(1 \text{ kg}); v_4 = 12.8 \text{ m/s or 13 m/s} \]

5. **Answer:**

\[ P \] (before shooting) = \( P \) (after shooting)
\[ m_1v_1 + m_2v_2 = (m_1 + m_2)(v_{3+4}) \]
\[ (0.0010 \text{ kg})(50 \text{ m/s}) + (0.35 \text{ kg})(0 \text{ m/s}) = (0.351 \text{ kg})(v_{3+4}) \]
\[ (v_{3+4}) = (0.050 \text{ kg·m/s})/(0.351 \text{ kg}); (v_{3+4}) = 0.14 \text{ m/s} \]

6. **Answer:**

\[ P \] (before tackle) = \( P \) (after tackle)
\[ m_1v_1 + m_2v_2 = (m_1 + m_2)(v_{3+4}) \]
\[ (70 \text{ kg})(7 \text{ m/s}) + (100 \text{ kg})(-6 \text{ m/s}) = (170 \text{ kg})(v_{3+4}) \]
\[ (v_{3+4}) = (490 \text{ kg·m/s} - 600 \text{ kg·m/s})/(170 \text{ kg}) \]
\[ (v_{3+4}) = -0.65 \text{ m/s} \]

Terry is moved backwards at a speed of 0.65 m/s while Jared holds on.

7. **Answer:**

\[ P \] (before hand) = \( P \) (after hand)
\[ m_1v_1 + m_2v_2 = (m_1 + m_2)(v_{3+4}) \]
\[ (50 \text{ kg})(7 \text{ m/s}) + (100 \text{ kg})(-16 \text{ m/s}) = (150 \text{ kg})(v_{3+4}) \]
\[ (v_{3+4}) = (350 \text{ kg·m/s} + 1600 \text{ kg·m/s})/150 \text{ kg} \]
\[ (v_{3+4}) = 13 \text{ m/s} \]

---

### Skill Sheet 6.3: Rate of Change of Momentum

1. **Force = 200,000 N.** At this level of force, after a couple of hits with a wrecking ball, any impressive-looking wall crumbles to pieces.

3. **2 seconds**

5. **250 N**

5. **75 million N**

6. **The answers are:**

a. The force created on the egg by the person is:
\[ \frac{0.05 \text{ kg} \times 10 \text{ m/s}}{0.001 \text{ sec}} = 500 \text{ N} \]

b. The force created on the egg by the person is:
\[ 50 \text{ kg} \times 9.8 \text{ m/s}^2 = 490 \text{ N} \]

c. The force created by the person is close to the amount of force that broke the egg. Therefore, if the person fell on the egg, it would probably break.

d. As a result the force will be 500 times smaller:
\[ \frac{0.05 \text{ kg} \times 10 \text{ m/s}}{0.5 \text{ s}} = 1 \text{ N} \]

e. The egg would probably not break if it fell on the pillow because the force is 500 times smaller than if it fell on the hard floor.
Skill Sheet 7.1: Mechanical Advantage

1. 4
2. 0.4
3. 100 newtons
4. 25 newtons
5. 300 newtons
6. 26 newtons
7. 3
8. 150 newtons
9. 1.5
10. Answers are:
    a. 1,500 newtons
    b. 2 meters

Skill Sheet 7.1: Mechanical Advantage of Simple Machines

1. 5
2. 1.5
3. 0.5 meters
4. 4.8 meters
5. 0.4
6. 0.8 meters
7. 0.25 meters
8. 6.7
9. 2 meters
10. 12 meters
11. 2.4
12. 6 newtons
13. 560 newtons
14. 4 meters

Skill Sheet 7.1: Work

1. Work is force acting upon an object to move it a certain distance. In scientific terms, work occurs ONLY when the force is applied in the same direction as the movement.
2. Work is equal to force multiplied by distance.
3. Work can be represented in joules or newton-meters.
4. Answers are:
   a. No work done
   b. Work done
   c. No work done
   d. Work done
   e. Work done
5. 100 N·m or 100 joules
6. 180 N·m or 180 joules
7. 100,000 N·m or 100,000 joules
8. 50 N·m to lift the sled; no work is done to carry the sled
9. No work was done by the mouse. The force on the ant was upward, but the distance was horizontal.
10. 10,000 joules
11. Answers are:
    a. 1.25 meters
    b. 27 pounds
12. 2.500 N or 562 pounds
13. 1,500 N
14. 54 N·m or 54 joules
15. 225 N·m or 225 joules
16. 0.50 meters
17. Answers are:
    a. No work was done.
    b. 100 N·m or 100 joules
18. Answers are:
    a. No work is done
    b. 11 N·m or 11 joules
    c. 400 N·m or 400 joules (Henry did the most work.)

Skill Sheet 7.1: Types of Levers

Part 1 and 2 answers:

1. 2nd class lever
2. 1st class lever
3. 3rd class lever
4. Two examples:

Skill Sheet 7.1: Gear Ratios

1. 9 turns
2. 1 turn
3. 4 turns
4. 10 turns
5. 6 turns
6. Answers for the table are:

Table 1: Using the gear ratio to calculate number of turns

<table>
<thead>
<tr>
<th>Input Gear (# of teeth)</th>
<th>Output Gear (# of teeth)</th>
<th>Gear ratio (Input Gear: Output Gear)</th>
<th>How many turns does the output gear make if the input gear turns 3 times?</th>
<th>How many turns does the input gear make if the output gear turns 2 times?</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>24</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>36</td>
<td>12</td>
<td>3</td>
<td>9</td>
<td>0.67, or 2/3 of a turn</td>
</tr>
<tr>
<td>24</td>
<td>36</td>
<td>0.67, or 2/3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>48</td>
<td>36</td>
<td>1.33, or 4/3</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>24</td>
<td>48</td>
<td>0.5, or 1/2</td>
<td>1.5</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2: Setup for three gears

<table>
<thead>
<tr>
<th>Set up</th>
<th>Gears</th>
<th>Number of teeth</th>
<th>Ratio 1 (top gear: middle gear)</th>
<th>Ratio 2 (middle gear: bottom gear)</th>
<th>Total gear ratio (Ratio 1 × Ratio 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top gear</td>
<td>12</td>
<td>$\frac{1}{2}$</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{1}{3}$</td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Top gear</td>
<td>24</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{3}{2}$</td>
<td>$\frac{2}{3}$</td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Top gear</td>
<td>12</td>
<td>$\frac{1}{4}$</td>
<td>$\frac{4}{2}$</td>
<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Top gear</td>
<td>24</td>
<td>$\frac{1}{2}$</td>
<td>$\frac{4}{3}$</td>
<td>$\frac{2}{3}$</td>
</tr>
<tr>
<td></td>
<td>Middle gear</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bottom gear</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. The middle gear turns left. The bottom gear turns right.
9. 3 times
10. 4 times
11. 1/2 time
12. 6 times

Skill Sheet 7.1: Levers in the Human Body

Lever A:

1. Type of lever: Third-class lever.
2. This lever is used to lift objects.
Lever B:

3. Type of lever: First-class lever.
4. This lever is used to chew food.
Lever C:

5. Type of lever: Second-class lever.
6. This lever is used to raise and lower the heel of the foot while standing.

Skill Sheet 7.1: Bicycle Gear Ratios Project

Students evaluate the gear ratios of their own bicycles to complete this project. Answers will vary.

Skill Sheet 7.2: Potential and Kinetic Energy

1. First shelf: 5.0 newton-meters
   Second shelf: 7.5 newton-meters
   Third shelf: 10. newton-meters
2. Answers are:
   a. 588 newtons
   b. 1.7 meters
   c. 5.8 m/s
3. Answers are:
   a. 450 joules
   b. 450 joules
   c. 46 meters
4. 25,000 joules
5. 4 m/s
6. 75 kilograms

Skill Sheet 7.2: Identifying Energy Transformations

1. (1) Chemical energy from food to kinetic energy to elastic energy; (2) chemical energy from food to kinetic energy; (3) elastic energy to kinetic energy.
2. Electrical energy to radiant (microwave) energy to kinetic energy (increased movement of molecules in the soup, which increases the soup's temperature).
3. Chemical energy from food to kinetic energy (as Dmitri operates the pump) to pressure energy.
4. Chemical energy from the battery in controller to radiant energy (radio waves). Radio waves to electrical signal in car; chemical energy from car battery to kinetic energy as car moves.
5. Chemical energy from food is transformed to kinetic energy which is transformed to potential energy as Adeline moves toward the top of the hill. As she coasts down the other side, potential energy is transformed to kinetic energy.
Skill Sheet 7.2: Energy Transformations—Extra Practice

Part 1 answers:
1. The potential energy of the stretched bungee cord is changed into the kinetic energy of the person bouncing back up.
2. The potential energy of the football from its high point is changed into kinetic energy as it spirals down.
3. In this case, radiant energy is converted to chemical energy in the battery, which is then converted to the electrical energy needed to run the calculator. Mechanical energy (kinetic or potential, is not being used in this case.

Part 2 answers:
1. The chemical potential energy of the wood is changed to radiant energy in the form of heat. Radiant energy is changed into mechanical energy as the water boils, changes to steam, and makes the whistle vibrate, which causes vibrations in air molecules that we experience as sound.
2. Nuclear energy is changed into electrical energy, which is changed into radiant energy (light to make the television picture) and mechanical energy (vibration of speakers) that causes vibration of air molecules that we experience as sound.
3. The chemical potential energy of food is changed into mechanical energy of the bicyclist, which is changed into electrical energy of the generator, which is changed into radiant energy from the light.

Skill Sheet 7.2: Conservation of Energy

1. 0.20 meters
2. 3.5 m/s
3. 39.6 m/s
4. 196,000 joules
5. 10. meters
6. 30. meters
7. Answers will vary.

Skill Sheet 7.2: James Joule

1. Perhaps because he thought that the pursuit of science was worthwhile.
2. His father hired one of the most famous scientists of his time to tutor his sons.
3. His interest was based upon his desire to improve the brewery. He wanted to make a more efficient electric motor to replace the old steam engines that they had at the time.
4. His goal had been to replace the old steam engines with more efficient electric motors. He was not able to do that, however, he learned a great deal about electromagnets, magnetism, heat, motion, electricity, and work.
5. Electricity produces heat when it travels through a wire because of the resistance of the wire. Joule’s Law also provided a formula so that scientists could calculate the exact amount of heat produced.
6. Joule believed that heat was a state of vibration caused by the collision of molecules. This contradicted the beliefs of his peers who thought that heat was a fluid.
7. Joule knew that the temperature of the water at the bottom of the waterfall was warmer than the water at the top of the waterfall. He thought that this was true because the energy produced by the falling water was converted into heat energy. He wanted to measure how far water had to fall in order to raise the temperature of the water by one degree. Joule used a large thermometer to measure the temperature at the top of the waterfall and the temperature at the bottom of the waterfall. The experiment failed because the water did not fall the right distance for his calculations and there was too much spray from the waterfall to read the instruments accurately.
8. Refrigeration
9. The joule is the international measurement for a unit of energy.
10. Answers will vary.

Skill Sheet 7.3: Efficiency

1. 27.1 percent
2. 92 joules
3. 100,000 joules
4. 94.2 kilojoules
5. Answers are:
   a. 2,025 million watts
   b. b. 39.5 percent
6. 59 percent

Skill Sheet 7.3: Power

1. 250 watts
2. 50 watts
3. 1,200 watts
4. 1,500 watts
5. 741 watts
6. 720 watts
7. work = 500 joules; power = 33 watts
8. 1,800 seconds or 30 minutes
9. 2,160,000 joules
10. 2,500 watts
11. 90,000 joules
12. work = 1,500 joules; time = 60 seconds
13. force = 25 newtons; power = 250 watts
14. distance = 100 meters; power = 1,000 watts
15. force = 333 newtons, work = 5,000 joules
Skill Sheet 7.3: Power in Flowing Energy

1. Answers are given in table below:

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Distance (m)</th>
<th>Time (sec)</th>
<th>Work (J)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>2</td>
<td>5</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>10</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
<td>10</td>
<td>400</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>5</td>
<td>25</td>
<td>500</td>
<td>20</td>
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<tr>
<td>50</td>
<td>20</td>
<td>20</td>
<td>1000</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>30</td>
<td>10</td>
<td>600</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>3</td>
<td>180</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>15</td>
<td>75</td>
<td>5</td>
</tr>
</tbody>
</table>

2. Answers are:
   a. 1,800 J
   b. 450 watts

3. Answers are:
   a. 60,000 J
   b. 2,000 W; 2.68 hp

4. Answers are:
   a. 36,750 J (37,000 J with correct significant figures)
   b. 20.4 W (20 W with correct significant figures)

5. 200 W

6. Answers are:
   a. 5,000 seconds or 1.4 hours
   b. 8,640,000 J
   c. 17.3 apples

7. Answers are:
   a. 98,000 J
   b. 98,000 W; 131 hp

8. 3.3 W

Skill Sheet 7.3: Efficiency and Energy

1. 55%

2. 12%

3. Answers are:
   a. 91%
   b. Energy is lost due to friction with the track (which creates heat), air resistance, and the sound made by the track and wheels.
   c. The first hill is the tallest because a roller coaster loses energy as it moves along the track. No roller coaster is 100% efficient. Unless there is a motor to give it additional energy, it will never be able to make it back up to a height as high as the first hill.

4. 80%

5. 278 m

Skill Sheet 8.2: Measuring Temperature

Stop and Think:
   a. 15°C
   b. 21°C
   c. 23.0°C, 30.0°C, 30.0°C, 31.5°C, 31.5°C
   d. At 0°C, water changes from liquid to solid. At 100°C, water changes from liquid to gas.
   e. The liquid will expand so the level in the tube will increase.

Answers to the “Reading the temperature” sections will vary.

Skill Sheet 8.2: Temperature Scales

1. Answers are:
   a. 100°C
   b. 37°C
   c. 4.4°C
   d. –12.2°C
   e. 32°F
   f. 77°F
   g. 167°F
   h. 7.2°C
   i. 177°C
   j. 107°C
   k. 374°F
   l. 450°F

2. The table shows that the friend in Europe thinks that the temperature is on the Celsius scale because 15°C is equal to 59°F, a relatively warm air temperature. However, 15°F is a relatively cold air temperature, equivalent to –9.4°C.

<table>
<thead>
<tr>
<th>°F</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>15°F</td>
<td>–9.4°C</td>
</tr>
<tr>
<td>59°F</td>
<td>15°C</td>
</tr>
</tbody>
</table>

8. Answers are:
   a. –283°F
   b. The melting point for this liquid is 35°F which is equal to 1.7°C. The melting point for mercury is –38.9°C (–38.0°F). The unknown substance is not mercury, since its boiling point is not the same as that of mercury.

Extension Answers:
1. 184K to 242K
2. –108°C
3. –139°C
4. –223°C
5. 5,273K to 8,273K
6. 10,273K
7. 1,000,273K
8. 15,000,273K
9. 622K
10. 900°F

Skill Sheet 8.2: Reading a Heating/Cooling Curve

1. The iron changed from liquid to gas between points D and E.

2. The heat added to the iron was used to break the intermolecular forces between the iron atoms.

3. The melting temperature of iron is about 1,500°C.
4. The freezing temperature of iron is about 1,500°C. The melting and freezing temperatures of a substance are the same.

5. The boiling temperature of iron is about 2,800°C.

6. The boiling temperature of iron is about 2,700°C higher than the boiling temperature of water. That means it takes a lot more heat energy to break the intermolecular forces between iron atoms than those between water molecules. Iron’s intermolecular forces are much stronger than water’s.

7. Freezing occurred between points B and C.

8. The freezing and melting temperatures are the same—69°C.

9. The melting temperature of stearic acid is higher than water’s melting temperature. The intermolecular forces between stearic acid molecules are stronger than those between water molecules. That’s why it would take more heat energy to melt stearic acid.

10. Yes, a substance can definitely be cooled below its freezing temperature. The ice in the first graph started at –20°C. The iron started 1,500°C below its freezing temperature, and the stearic acid continued to cool well below its freezing temperature. The molecules in a solid have some kinetic energy at their freezing temperatures. Their kinetic energy slowly decreases as they cool down further. Absolute zero (–273°C) is the point at which molecules have the minimum possible kinetic energy.

Skill Sheet 9.1: Specific Heat

1. Gold would heat up the quickest because it has the lowest specific heat.
2. Pure water is the best insulator because it has the highest specific heat.
3. Silver is a better conductor of heat than wood because its specific heat is lower than that of wood.

4. Aluminum, because it has the higher specific heat.
5. 5°C × 4,184 J/kg °C = 20,920 J
6. At the same temperature, the larger mass of water contains more thermal energy.

Skill Sheet 9.1: Using the Heat Equation

1. 323 J
2. 588 J
3. 2,243 J
4. The gold would cool down fastest. It has to release only 323 J of energy to return to its original temperature.

5. 711,280 J
6. 440,000 J
7. 5.6 °C
8. 4,393,200 J

Skill Sheet 9.2: Heat Transfer

Definitions:
- Heat conduction: The transfer of heat by the direct contact of particles of matter.
- Convection: The transfer of heat by the motion of matter, such as by moving air or water.
- Thermal radiation: Heat transfer by electromagnetic waves, including light.

1. Conduction. The water molecules collide with the frozen shrimp, transferring thermal energy by direct contact.

2. Radiation and heat conduction. Heat from the Sun is radiated to Earth. The black asphalt absorbs more of this radiation than the light-colored sidewalk. Heat is transferred from the sidewalk and the asphalt to Juan’s feet by the process of heat conduction. Since the sidewalk absorbed more heat, it can transfer more heat to Juan’s feet.

3. Convection. A thermal is a convection current in the atmosphere.

4. Radiation and convection. The hot space heater emits thermal radiation, and convection currents distribute the heat throughout the room.

5. Conduction. The mother duck is in direct contact with the eggs so the heat is transferred from her body directly to the eggs.

6. Radiation. Thermal energy from the Sun is absorbed by the car.

7. Conduction. The molecules of hot coffee collide with the molecules of cold milk. The average kinetic energy of the coffee molecules decreases, and the average kinetic energy of the milk molecules increases until thermal equilibrium is reached. The equilibrium temperature is lower than the initial temperature of the coffee.

8. Convection. A sea breeze is a convection current in the atmosphere, created when air over the land is heated and rises. Then cool air from over the water rushes in to take its place, creating the sea breeze.

9. Conduction. The heat from the water is transferred directly to the pipes, then to the marble floor, then to the feet.

10. Conduction and convection. First the heat from the water is transferred to the pipes and then to the floor. Then convection currents circulate the heat from the floor to all parts of the room.

Skill Sheet 10.1: Measuring Mass With a Triple-Beam Balance

Answers will vary.

Skill Sheet 10.1: Measuring Volume

Stop and Think:
- a. Sample student answer: The water level will rise so that it spills out of the spout.
- b. A fist-sized rock will displace more water because it is bigger and will sink (an acorn may float).
- c. The volume of spilled water equals the amount of water that is displaced by the object.
- d. Water is added to the displacement tank until it can hold no more without the water spilling out of the spout. Then an object is placed in the tank and the spilled water is volume of the object.
Skill Sheet 10.1: Calculating volume

**Stop and Think:**
- a. cm³ or centimeters cubed
- b. 64 in³
- c. Area is calculated using two dimensions (length and width). Volume is calculated using three dimensions (length, width, and height).
- d. 64 cubes each 1 cm³ would fit

Calculating volume of a rectangular prism:
1. 24 cm²
2. 48 cm³
3. 90 cm³

Calculating volume of a triangular prism:
1. 3 cm²
2. 18 cm³
3. 100 cm³

Calculating volume of a cylinder:
1. 28.3 cm²
2. 170 cm³
3. 402 cm³

Calculating volume of a cone:
1. 78.5 cm²
2. 628 cm³
3. 134 cm³; this volume is one-third the value of the volume of the cylinder with similar dimensions.

Calculating volume of a rectangular pyramid:
1. 20 cm²
2. 40 cm³
3. 66.7 cm³
4. About 6.25 cm

Calculating volume of a triangular pyramid:
1. 6 cm²
2. 14 cm³
3. 50 cm³
4. 12.6 cm

Calculating volume of a sphere:
1. 268 cm³
2. 33.5 cm³
3. 523 cm³ (assume 3.14 for π)

Skill Sheet 10.1: Density

1. 1.10 g/cm³
2. 0.870 g/cm³
3. 2.7 g/cm³
4. 920,000 grams or 920 kilograms
5. 2,420 grams or 2.42 kilograms
6. 1,025 grams or 1.025 kilograms
7. 1,200 cm³
8. 29.8 cm³
9. 11.4 mL

10. Answers are:
   a. density = 960. kg/m³, HDPE
   b. 76,000 grams or 76 kilograms
   c. The volume needed is 0.11 m³; 11 10-liter containers would be needed to hold the plastic
   d. HDPE, LDPE, PP (PS would probably be suspended in seawater)

Skill Sheet 10.3: Pressure in Fluids

1. 50,000 Pa
2. 157,000 N
3. 0.0015 m²
4. 5 m²
5. If the area of the input piston is doubled, the pressure transmitted by the system is cut in half.
6. If the area of the input piston is doubled (and no other variables are changed), the output force is cut in half.
7. No, the output distance must be less than the input distance. Output work (output force × output distance) can never be greater than input work (input force × input distance).
8. The woman's force (540 N) remains constant whether she's wearing high heels or snowshoes. But the area over which the force is applied is much greater with snowshoes than high heels. Since pressure = force ÷ area, the pressure applied to the floor by high heeled shoes is much greater than the pressure applied to the snow by the snowshoes.

Skill Sheet 10.3: Boyle's Law

1. 3.25 atm
2. 36 m³
3. 563 kPa
4. 570 liters
5. 25 liters

Skill Sheet 10.4: Buoyancy

1. Sink
2. Float
3. 0.12 N
4. 0.10 N
5. The light corn syrup has greater buoyant force than the vegetable oil.
6. 0.13 N
7. The buoyant force would be smaller if the gold cube were suspended in water. Student explanations may vary. A simple observation, such as “The water is thinner than the molasses” is acceptable, as well as the more sophisticated “The displaced water would weigh less than the displaced molasses” or “The water is less dense than the molasses.”
Skill Sheet 10.4: Charles’s Law

1. 25.4 liters
2. 22.8 liters

3. Answers are:

<table>
<thead>
<tr>
<th></th>
<th>(V_1)</th>
<th>(T_1)</th>
<th>(V_2)</th>
<th>(T_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>6,114 mL</td>
<td>838 K</td>
<td>1,070 mL</td>
<td>147 K</td>
</tr>
<tr>
<td>b.</td>
<td>3,250 mL</td>
<td>475°C (748 K)</td>
<td>1,403 mL</td>
<td>50°C (323 K)</td>
</tr>
<tr>
<td>c.</td>
<td>10 L</td>
<td>(-58°C (215 K))</td>
<td>15 L</td>
<td>50°C (323 K)</td>
</tr>
</tbody>
</table>

Skill Sheet 13.2: Pressure-Temperature Relationship

1. 0.27 atmospheres
2. 1,000 K

3. Answers are:

<table>
<thead>
<tr>
<th></th>
<th>(P_1)</th>
<th>(T_1)</th>
<th>(P_2)</th>
<th>(T_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>30.0 atm</td>
<td>(-100°C (173 K))</td>
<td>134 atm</td>
<td>500°C (773 K)</td>
</tr>
<tr>
<td>b.</td>
<td>15.0 atm</td>
<td>25.0°C (298 K)</td>
<td>18.0 atm</td>
<td>85°C (360 K)</td>
</tr>
<tr>
<td>c.</td>
<td>5.00 atm</td>
<td>488 K</td>
<td>3.00 atm</td>
<td>293 K</td>
</tr>
</tbody>
</table>

Skill Sheet 10.4: Archimedes

1. Density: a property that describes the relationship between a material’s mass and volume. Buoyancy: A measure of the upward force a fluid exerts on an object.
2. Sample answer: I, Archimedes, have a wide variety of skills to offer. First, I am an inventor of problem-solving devices, including a device for transporting water upward. I have also worked as a crime scene investigator for the king, uncovering fraud through scientific testing of materials. Furthermore, I am a writer with several treatises already published. I also have advanced skills in mathematics and can even estimate for you the number of grains of sand needed to fill the entire universe.
3. In the treatise entitled “The Sand Reckoner,” Archimedes devised a system of exponents that allowed him to represent large numbers on paper—up to \(8 \times 10^{63}\) in modern scientific notation. This was large enough, he said, to count the grains of sand that would be needed to fill the universe. His assessment of the universe’s size was an underestimate, but he was the first to think of the universe being so large.
4. A helium balloon floats in air because the air it displaces weighs more than the filled balloon. A balloon filled with air from someone’s lungs sinks because the combined weight of the latex balloon and the air inside is greater than the weight of the air it displaces.
5. Inventions attributed to Archimedes include war machines (such as a lever used to turn enemy boats upside down), the Archimedes screw, compound pulley systems, and a planetarium. There is some debate about whether he invented a water organ and a system of mirrors and/or lenses to focus intense, burning light on enemy ships. Students can use the Internet or library to find more information and diagrams of the inventions.

Skill Sheet 10.4: Narcís Monturiol

1. Monturiol was motivated by the suffering of the coral divers he saw along the coast of Spain. The divers performed dangerous work to retrieve pieces of coral. They could drown, hurt themselves on rocks and coral, or be attacked by sharks. A submarine would provide a safer means of gathering coral.
2. Ictineo I relied on human power to turn the propellers. It had a spherical inner chamber to withstand water pressure and an egg-shaped outer chamber for ease of movement. It also had a ventilator, two sets of propellers, and several portholes. Monturiol even created a backup system to ensure that the submarine could be raised to the surface in case of emergency. Ictineo I could dive to 20 meters and stayed underwater for nearly two hours. Ictineo II used steam power instead of human power to turn the propellers. Monturiol developed a chemical reaction to power the engine. This reaction also added oxygen to the submarine. Ictineo II was longer than Ictineo I, had two engines, dove to 30 meters, and remained underwater for nearly seven hours.
3. A replica of Ictineo I is located at the Marine Museum in Barcelona. A replica of Ictineo II can be found at Barcelona harbor.
4. In 1862, Ictineo I was destroyed by a freight ship while anchored in Barcelona Harbor.
5. Monturiol developed the following: A process to speed up the manufacturing of adhesive paper, a machine to copy letters, a stone cutter, and a meat preservative.
6. Spain created a postage stamp in Monturiol’s honor.
7. The Narcís Monturiol medal is an award given for “distinction in science and technology and for contributions to the scientific development of Catalonia.”

Skill Sheet 10.4: Archimedes’ Principle

1. If they are both submerged, then they both displace the same amount of water and have the same buoyant force acting on them.

2. Answers are:
   a. 100 cm³
   b. 0.98 N
   c. 0.98 N
   d. sink
3. Answers are:
   a. 100 cm³
   b. 13 N
   c. 13 N
   d. float

4. In both cases, a material sinks in a fluid if it is more dense than the fluid. A material floats in a fluid if it is less dense than the fluid.

Skill Sheet 11.1: Layers of the Atmosphere

<table>
<thead>
<tr>
<th>Layer</th>
<th>Distance from Earth’s surface</th>
<th>Thickness</th>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Troposphere</td>
<td>0–11 km</td>
<td>11 km</td>
<td>• Most of Earth’s water vapor, carbon dioxide, dust, airborne pollutants, and terrestrial life forms are found in this layer.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• The temperature drops as you go higher into the troposphere.</td>
</tr>
<tr>
<td>Stratosphere</td>
<td>11–50 km</td>
<td>39 km</td>
<td>• The ozone layer is located here.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• The temperature increases as you go higher into the stratosphere.</td>
</tr>
<tr>
<td>Mesosphere</td>
<td>50–80 km</td>
<td>30 km</td>
<td>• “Shooting stars” occur when meteors burn up in this layer.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• The mesosphere is the coldest layer of the atmosphere.</td>
</tr>
<tr>
<td>Thermosphere</td>
<td>80—approx. 500 km</td>
<td>420 km</td>
<td>• Very low density of air molecules in this layer.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Very high temperatures because sun’s rays hit here first.</td>
</tr>
<tr>
<td>Exosphere</td>
<td>500 km—no specific outer limit</td>
<td>undefined</td>
<td>• Lightweight atoms and molecules escape into space.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Many man-made satellites orbit in this region, about 36,000 km above the equator.</td>
</tr>
</tbody>
</table>

Skill Sheet 11.2: Gustave-Gaspard Coriolis

1. Coriolis attended one of the best-known engineering schools in France. His exceptional ability coupled with great schooling provided him with a solid foundation for his thoughts, research, and studies.
2. His first book presented mechanics in a way that could easily be applied. It was the foundation and establishment of applying the concept of work to the field of mechanics. Coriolis was intent on using and applying proper terms. He was the first to derive formulas expressing kinetic energy and mechanical work.
3. As you are flying overhead, Earth is rotating from west to east beneath you. By the time you are ready to land, Earth has rotated far enough that Little Rock is east of your current position.
4. In the northern hemisphere, the Coriolis effect bends winds to the right. In the southern hemisphere it bends winds to the left.
5. Answers will vary, but should include the following:
   Trade winds are surface wind currents that move between 30 degrees North latitude and the equator. The Coriolis effect bends the trade winds moving across the surface so they flow from northeast to southwest in the northern hemisphere and from southwest to northeast in the southern hemisphere.
   Polar easterlies form when the air over the poles cools and sinks, and spreads along the surface to about the 60 degree latitude. The polar wind is bent by the Coriolis effect and the air flows from northeast to southwest in the northern hemisphere, and from southeast to northwest in the southern hemisphere. Bands of cold air move away from the poles. Prevailing westerlies are created when air bends to the right due to the Coriolis effect. These winds blow towards the poles from the west and are bent to the right in the northern hemisphere and to the left in the southern hemisphere.
6. His work was not accepted outside the field of mechanics until 1859 when the French Academy of Science arranged for a discussion on Earth’s rotation and its effects on water currents. His work on Earth’s rotation was discussed and linked to the field of meteorology in the late 1800’s early 1900’s.
7. Coriolis was able to connect theory with application in each of these books. The billiard book was published in 1835 and provided the mathematical theory of spin, friction, and collision in the game of billiards. Coriolis discussed how physics determines and explains the game of billiards. The Treatise book was published after his death in 1944.

Skill Sheet 11.2: Degree Days

Part 1 answers:
1. Cooling degree day value = 88 – 65 = 23.
2. Heating degree day value = 65 – 14 = 51.
3. On July 22, 2002 the heating degree day value was zero. On January 22, 2003 the cooling degree day value was zero.
Part 2 answers:
1. Answers:
   - St. Louis residents were more likely to use heating systems on six days and more likely to cool their homes on seven days. However, many of these days had such small degree day values that residents may have used either system only rarely. The most likely day to use energy for heating or cooling was May 9, with a cooling degree day value of 15.

Part 3 answers:
1. Total heating degree day value: 33
2. Total cooling degree day value: 39
3. The monthly total heating degree day value for May 2003 was 33 + 31, or 64. The monthly total cooling degree day value was 39 + 32, or 71.
4. May 2003’s total heating degree day value was 15 less than normal, and its total cooling degree day value was 43 less than normal. With average temperatures closer to 65°F, St. Louis residents probably used less energy for heating and cooling in May than is usually needed.

Part 4 answers:
1. Graph:
   - Two week totals: 33 39

   *St. Louis residents were more likely to use heating systems on six days and more likely to cool their homes on seven days. However, many of these days had such small degree day values that residents may have used either system only rarely. The most likely day to use energy for heating or cooling was May 9, with a cooling degree day value of 15.*

   *Total heating degree day value: 33
   - Total cooling degree day value: 39

   *The monthly total heating degree day value for May 2003 was 33 + 31, or 64. The monthly total cooling degree day value was 39 + 32, or 71.*

   *May 2003’s total heating degree day value was 15 less than normal, and its total cooling degree day value was 43 less than normal. With average temperatures closer to 65°F, St. Louis residents probably used less energy for heating and cooling in May than is usually needed.*

   *Skill Sheet 11.3: Joanne Simpson*

1. Simpson is the first woman to earn a Ph.D. in meteorology, the first person to create a computerized cloud model, and the first woman to have served as president of the American Meteorological Society.
2. Simpson faced discrimination based on the fact that she was a woman. At the end of the war, most women returned home after temporarily filling the roles of men away during the war. Simpson was not one of those women. She continued on with her studies after teaching meteorology to aviation cadets. She earned a master’s degree and was so interested in meteorology that she wanted to go on for a Ph.D. Her advisor and the all-male faculty at her university did not support a woman going on for an advanced degree. They felt that women were unable to do the work which included shifts and flying planes. Simpson did finally find an advisor to support her Ph.D., but even he had negative comments about her topic. Simpson did have difficulty finding a job, but eventually landed a position as an assistant professor of physics. She continued to move into numerous positions and did not let others’ opinions and comments stop her career pursuits.
3. Students should comment on Simpson’s determination despite the obstacles she faced along her journey to complete her degree and to work in the field of meteorology. Students will understand that if you really want to achieve a goal, you need to stay focused, work hard, and not be discouraged by negative opinions along the way.

4. A slide rule is a mechanical tool used to calculate complicated mathematical problems involving multiplication, divisions, square roots, cube roots, and trigonometry. The invention of the slide rule dates back to the 16th century. The slide rule, a handheld tool, was used commonly in science and engineering. The scientific calculator and computers made the slide rule obsolete.

5. This is the highest award given by the American Meteorological Society for atmospheric science including meteorology, climatology, atmospheric physics, and atmospheric chemistry. It is named after Carl-Gustaf Rossby, a leader in the fields of oceanography and meteorology. He was also the 2nd recipient of this award.

6. Woods Hole Oceanographic Institute (WHOI) is located in Woods Hole, Massachusetts on Cape Cod. Scientists at WHOI study oceans, their function, and their interaction with the Earth. WHOI provides opportunities for research and higher education. Students can visit the WHOI website on the Internet for more information.

7. Students can locate hot tower clouds in scientific articles or websites. Hot towers are commonly associated with hurricanes. The NASA website provides some specific information about hot towers.
Skill Sheet 11.3: Weather Maps

Sample table with answers:

<table>
<thead>
<tr>
<th>City</th>
<th>High</th>
<th>Low</th>
<th>Temp difference</th>
<th>Sky cover</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle</td>
<td>72</td>
<td>54</td>
<td>18</td>
<td>Partly cloudy</td>
<td>High</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>85</td>
<td>68</td>
<td>17</td>
<td>Sunny</td>
<td>High</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>108</td>
<td>81</td>
<td>27</td>
<td>Pcldy</td>
<td>High</td>
</tr>
<tr>
<td>Phoenix</td>
<td>108</td>
<td>86</td>
<td>22</td>
<td>Pcldy</td>
<td>High</td>
</tr>
<tr>
<td>Atlanta</td>
<td>89</td>
<td>66</td>
<td>23</td>
<td>Pcldy</td>
<td>Low</td>
</tr>
<tr>
<td>Tampa</td>
<td>88</td>
<td>74</td>
<td>14</td>
<td>T-storms</td>
<td>Low</td>
</tr>
<tr>
<td>San Francisco</td>
<td>76</td>
<td>56</td>
<td>20</td>
<td>Sunny</td>
<td>Low</td>
</tr>
<tr>
<td>Oklahoma City</td>
<td>101</td>
<td>74</td>
<td>27</td>
<td>Pcldy</td>
<td>High</td>
</tr>
<tr>
<td>New Orleans</td>
<td>94</td>
<td>76</td>
<td>18</td>
<td>T-storms</td>
<td>Low</td>
</tr>
<tr>
<td>Kansas City</td>
<td>91</td>
<td>70</td>
<td>21</td>
<td>Pcldy</td>
<td>Low</td>
</tr>
<tr>
<td>Tucson</td>
<td>103</td>
<td>76</td>
<td>27</td>
<td>Pcldy</td>
<td>High</td>
</tr>
<tr>
<td>Denver</td>
<td>94</td>
<td>62</td>
<td>32</td>
<td>Pcldy</td>
<td>Low</td>
</tr>
<tr>
<td>Dallas</td>
<td>105</td>
<td>78</td>
<td>27</td>
<td>Sunny</td>
<td>High</td>
</tr>
<tr>
<td>Houston</td>
<td>98</td>
<td>76</td>
<td>22</td>
<td>Pcldy</td>
<td>High</td>
</tr>
<tr>
<td>Minneapolis</td>
<td>86</td>
<td>64</td>
<td>22</td>
<td>Sunny</td>
<td>High</td>
</tr>
<tr>
<td>Memphis</td>
<td>94</td>
<td>73</td>
<td>21</td>
<td>Sunny</td>
<td>High</td>
</tr>
<tr>
<td>Chicago</td>
<td>85</td>
<td>66</td>
<td>19</td>
<td>T-storms</td>
<td>Low</td>
</tr>
<tr>
<td>Miami</td>
<td>93</td>
<td>75</td>
<td>18</td>
<td>T-storms</td>
<td>Low</td>
</tr>
<tr>
<td>New York</td>
<td>73</td>
<td>63</td>
<td>10</td>
<td>T-storms</td>
<td>Low</td>
</tr>
<tr>
<td>Baltimore</td>
<td>78</td>
<td>70</td>
<td>8</td>
<td>T-storms</td>
<td>Low</td>
</tr>
</tbody>
</table>

1. The highest temperatures (daily high over 95°F) are in the lower latitudes such as Las Vegas, Phoenix, Tucson, Dallas, and Houston. The coolest temperatures (daily high under 82°F) are found in Seattle, Chicago, and New York. These cities are at higher latitudes. The Sun is more directly overhead in lower latitude regions, and it is lower on the horizon and therefore less intense at midday in the higher latitude regions.

2. Even though Los Angeles is the southern part of the continent, its high temperature was only 85°F. This is due to the cooling effect of the Pacific Ocean. Chicago is farther south than Minneapolis, but it is cooler because it sits on the shore of Lake Michigan. Denver, with its Rocky Mountain location, cools down to a nighttime low of 62°F in the summer.

3. On the map, the thickest cloud cover is in the Northeast, where it cools Baltimore and New York. Baltimore and Kansas City are nearly the same latitude, but Kansas City (with less cloud cover) was 13°F warmer. During the day, the clouds reflect some of the sun’s heat away.

4. Sample answers: The high-pressure regions center on Oregon, New Mexico, and Quebec. The low-pressure regions center on Wyoming, North Dakota, and North Carolina.

5. See the table for answers.

6. High pressure regions tend to have sunny weather, since less air is rising, cooling, and condensing. Humidity is much lower in these regions.

7. Low-pressure regions tend to be overcast and/or stormy. The humidity is higher.

8. Fronts are associated with low pressure regions. Fronts tend to bring precipitation.

9. Cold fronts are associated with stormy areas. Warm fronts tend to be accompanied by bands of light precipitation.

10. The air in a low-pressure region rises. The air in a high pressure region sinks.

11. In a low pressure region, warm, moist air can be carried upward by convection. As the air cools, water condenses into clouds and precipitation.

12. A low-pressure region is a good place for a volume of air to reach the dew point temperature because the warm, moist air in this region rises. As this air rises, it cools to the dew point temperature. The result is that the water in the air mass condenses, clouds form, and eventually precipitation occurs.

Skill Sheet 11.3: Tracking a Hurricane

Map answers:

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
<th>Action</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/22/1992</td>
<td>1500</td>
<td>Hurricane watch</td>
<td>Northwest Bahamas</td>
</tr>
<tr>
<td>8/22/1992</td>
<td>2100</td>
<td>Hurricane warning</td>
<td>Northwest Bahamas</td>
</tr>
<tr>
<td>8/22/1992</td>
<td>2100</td>
<td>Hurricane watch</td>
<td>Florida east coast from Titusville through the Florida keys</td>
</tr>
<tr>
<td>8/23/1992</td>
<td>0600</td>
<td>Hurricane warning</td>
<td>Central Bahamas</td>
</tr>
<tr>
<td>8/23/1992</td>
<td>1200</td>
<td>Hurricane warning</td>
<td>Florida east coast from Vero Beach southward through the Florida keys</td>
</tr>
<tr>
<td>8/23/1992</td>
<td>1200</td>
<td>Hurricane watch</td>
<td>Florida west coast south of Bayport including greater Tampa area to north of Flamingo</td>
</tr>
</tbody>
</table>

Part 2 answers:

2. Students may mention Florida or Cuba as likely hurricane watch areas. The Bahamas should be mentioned as a hurricane warning area. Here are the actual watches and warnings issued by the Tropical Prediction Center for this time period:

3.2 The Bahamas islands. Note: The National Hurricane Center reported that landfall occurred at the northern Eleuthera Island, Bahamas.

4.2 Southern Florida. Note: The National Hurricane Center reported that landfall occurred at Homestead Air Force Base, Florida.

5.2 Louisiana. Note: The National Hurricane Center reported that landfall occurred at Point Chevreuil, Louisiana.
Skill Sheet 12.1: Structure of the Atom

1. Answers are:

<table>
<thead>
<tr>
<th>What is this element?</th>
<th>How many electrons does the neutral atom have?</th>
<th>What is the mass number?</th>
</tr>
</thead>
<tbody>
<tr>
<td>lithium</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>carbon</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>hydrogen</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>hydrogen (a radioactive isotope, 3H, called tritium)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>beryllium</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>

2. Answers are:
   a. hydrogen-2: 1 proton, 1 neutron
   b. scandium-45: 21 protons, 24 neutrons
   c. aluminum-27: 13 protons, 14 neutrons
   d. uranium-235: 92 protons, 143 neutrons
   e. carbon-12: 6 protons, 6 neutrons

3. Most of an atom’s mass is concentrated in the nucleus. The number of electrons and protons is the same but electrons are so light they contribute very little mass. The mass of the proton is 1,835 times the mass of the electron. Neutrons have a bit more mass than protons, but the two are so close in size that we usually assume their masses are the same.

4. Yes, it has a proton (+1) and no electrons to balance charge. Therefore, the overall charge of this atom (now called an ion) is +1.

5. This sodium atom has 10 electrons, 11 protons, and 12 neutrons.

Skill Sheet 12.1: Atoms and Isotopes

Part 1 answers:
1. protium has 0 neutrons; deuterium has 1 neutron; tritium has 2 neutrons
2. Answers are:
   a. 3
   b. Lithium
   c. 7
   d. $^7\text{Li}$

Part 2 answers:
1. Bromine-80
2. Potassium-39 has 20 neutrons.
3. Lithium-7
4. Neon-20 has 10 neutrons.

Skill Sheet 12.1: Ernest Rutherford

1. Alpha particle: a particle that has two protons and two neutrons (also known as a helium nucleus). Beta particle: An electron emitted by an atom when a neutron splits into a proton and an electron.

2. For one atom to turn into another kind of atom, the number of protons in the nucleus must change. This can happen when an alpha particle is ejected (two protons are lost then) or when a neutron splits into a proton and an electron (in that case the number of protons increases by one).

3. Diagram:

   ![Alpha decay and Beta decay diagrams](image)

4. Rutherford’s planetary model suggested that an atom consists of a tiny nucleus surrounded by a lot of empty space in which electrons orbit in fixed paths. Subsequent research has shown that electrons don’t exist in fixed orbitals. The Heisenberg uncertainty principle tells us that it is impossible to know both an electron’s position and its momentum at the same time. Scientists now discuss the probability that an electron will exist in a certain position. Computer models predict where an electron is most likely to exist, and three-dimensional shapes can be drawn to show the most likely positions. The sum of these shapes produces the charge-cloud model of the electron.

5. In the game of marbles, players “shoot” one marble at a group of marbles and then watch the deflection as collisions occur. This is a lot like what Rutherford was doing on a much, much smaller scale. Rutherford’s comment is reflective of his typical self-deprecating humor. While “playing with marbles,” he discovered the proton.

6. Answers will vary. Students may wish to write about one of the following discoveries: Rutherford first described two different kinds of particles emitted from radioactive atoms, calling them alpha and beta particles. He also proved that radioactive decay is possible. He developed the planetary model of the atom, and was the first to split an atom.

Skill Sheet 12.2: Electrons and Energy Levels

1. Danish physicist Niels Bohr

2. Energy levels can be thought of as similar to steps on a staircase. Electrons can exist only in one energy level or another and cannot remain between energy levels, just as a person can be on one step or another but not between steps except in passing.

3. Energy levels are filled from the lowest (innermost) energy level outward.

4. answers are:
Skill Sheet 12.2: Neils Bohr

1. Both Rutherford and Bohr described atoms as having a tiny dense core (the nucleus) surrounded by electrons in orbit. Bohr described the nature of the electrons' orbits in much greater detail.

2. Niels Bohr described electrons as existing in specific orbital pathways, and explained how atoms emit light.

3. In Bohr's model of the atom, the electrons are in different energy levels. Bohr's model of the atom at right:

4. An electron absorbs energy as it jumps from an inner orbit to an outer one. When the electron falls back to the inner orbit, it releases the absorbed energy in the form of visible light.

5. Answers will vary. You may wish to ask students to research world events from the end of World War II to Bohr's death in 1962. Students should look for events that may have raised concerns in Bohr's mind about the potential use/misuse of nuclear weapons. They might also choose to research Bohr's own comments on the subject.

Skill Sheet 12.3: The Periodic Table

1. Fluorine
2. Argon
3. Manganese
4. Phosphorous
5. Technetium
6. The atomic number tells the number of protons in an atom of the element.
7. Iron, 55.8 amu
8. Cesium, 132.9 amu
9. Silicon, 28.1 amu
10. Sodium, 23.0 amu
11. Bismuth, 209.0 amu
12. The atomic mass tells the average mass of all known isotopes of an element, expressed in amu.
13. The atomic mass isn't always a whole number because it is an average mass of all known isotopes.
14. The mass of an electron is too small to be significant.
15. Alkali metals

16. Any two of the following: soft, silvery, highly reactive, combines in 2:1 ratio with oxygen
17. Any three of the following: F, Cl, Br, I, At
18. They are toxic gases or liquids in pure form, highly reactive, and form salts with alkali metals.
19. In the far right column
20. They rarely form chemical bonds with other atoms.
21. See figure 12.20, student text.
Skill Sheet 13.1: Dot Diagrams

Part 1 answers:

<table>
<thead>
<tr>
<th>Element</th>
<th>Chemical Symbol</th>
<th>Total Electrons</th>
<th>No. of Valence Electrons</th>
<th>Dot Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium</td>
<td>K</td>
<td>19</td>
<td>1</td>
<td>K·</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>7</td>
<td>5</td>
<td>N·</td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
<td>6</td>
<td>4</td>
<td>C·</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Be</td>
<td>4</td>
<td>2</td>
<td>Be·</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>10</td>
<td>8</td>
<td>Ne·</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>16</td>
<td>6</td>
<td>S·</td>
</tr>
</tbody>
</table>

Part 2 answers:

<table>
<thead>
<tr>
<th>Elements</th>
<th>Dot Diagram for Each Element</th>
<th>Dot Diagram for Compound Formed</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na and F</td>
<td>Na· · · · · · · · · · · · · ·</td>
<td>Na· · · · · · · · · · · · · ·</td>
<td>NaF</td>
</tr>
<tr>
<td>Br and Br</td>
<td>· Br· · Br· · Br· · Br· · Br·</td>
<td>· Br· · Br· · Br· · Br· · Br·</td>
<td>Br2</td>
</tr>
<tr>
<td>Mg and O</td>
<td>Mg· · · · · · · · · · · · · ·</td>
<td>Mg· · · · · · · · · · · · · ·</td>
<td>MgO</td>
</tr>
</tbody>
</table>

Skill Sheet 13.2: Finding the Least Common Multiple

1. 21
2. 24
3. 45
4. 50
5. 80
6. 147
7. 108
8. 315
9. 880
10. 192

Skill Sheet 13.2: Chemical Formulas

Answers:

<table>
<thead>
<tr>
<th>Element</th>
<th>Oxidation No.</th>
<th>Element</th>
<th>Oxidation No.</th>
<th>Chemical Formula for Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium (K)</td>
<td>1+</td>
<td>Chlorine (Cl)</td>
<td>1−</td>
<td>KCl</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>2+</td>
<td>Chlorine (Cl)</td>
<td>1−</td>
<td>CaCl2</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>1+</td>
<td>Oxygen (O)</td>
<td>2−</td>
<td>Na2O</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>3+</td>
<td>Phosphorus (P)</td>
<td>3−</td>
<td>BP</td>
</tr>
<tr>
<td>Lithium (Li)</td>
<td>1+</td>
<td>Sulfur (S)</td>
<td>2−</td>
<td>Li2S</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>3+</td>
<td>Oxygen (O)</td>
<td>2−</td>
<td>Al2O3</td>
</tr>
<tr>
<td>Beryllium (Be)</td>
<td>2+</td>
<td>Iodine (I)</td>
<td>1−</td>
<td>BeI2</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>2+</td>
<td>Nitrogen (N)</td>
<td>3−</td>
<td>Ca3N2</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>1+</td>
<td>Bromine (Br)</td>
<td>1−</td>
<td>NaBr</td>
</tr>
</tbody>
</table>

Skill Sheet 13.2: Naming Compounds

<table>
<thead>
<tr>
<th>Combination</th>
<th>Compound Name</th>
<th>Compound Name</th>
<th>Chemical Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al + Br</td>
<td>aluminum bromide</td>
<td>Si + C2H3O21−</td>
<td>silicon acetate</td>
</tr>
<tr>
<td>Be + O</td>
<td>beryllium oxide</td>
<td>Lipase</td>
<td>enzymes</td>
</tr>
<tr>
<td>K + N</td>
<td>potassium nitride</td>
<td>Methanol</td>
<td>alcohols</td>
</tr>
<tr>
<td>Ba + CrO42−</td>
<td>barium chromate</td>
<td>Formic Acid</td>
<td>organic acids</td>
</tr>
<tr>
<td>Cs + F</td>
<td>cesium fluoride</td>
<td>Butane</td>
<td>alkanes</td>
</tr>
<tr>
<td>NH4+ + S</td>
<td>ammonium sulfide</td>
<td>Sucrose</td>
<td>sugars</td>
</tr>
<tr>
<td>Mg + Cl</td>
<td>magnesium chloride</td>
<td>Acetone</td>
<td>ketones</td>
</tr>
<tr>
<td>B + I</td>
<td>boron iodide</td>
<td>Acetic Acid</td>
<td>organic acids</td>
</tr>
<tr>
<td>Na + SO42−</td>
<td>sodium sulfate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Skill Sheet 14.1: Chemical Equations

Part 1 answers:

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
<th>Unbalanced Chemical Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric acid HCl and Sodium hydroxide NaOH</td>
<td>Water H₂O and Sodium chloride NaCl</td>
<td>HCl + NaOH → NaCl + H₂O</td>
</tr>
<tr>
<td>Calcium carbonate CaCO₃ and Potassium iodide KI</td>
<td>Potassium carbonate K₂CO₃ and Calcium iodide CaI₂</td>
<td>CaCO₃ + KI → K₂CO₃ + CaI₂</td>
</tr>
<tr>
<td>Aluminum fluoride AlF₃ and Magnesium nitrate Mg(NO₃)₂</td>
<td>Aluminum nitrate Al(NO₃)₃ and Magnesium fluoride MgF₂</td>
<td>AlF₃ + Mg(NO₃)₂ → Al(NO₃)₃ + MgF₂</td>
</tr>
</tbody>
</table>

Part 2 answers:
1. 4Al + 3O₂ → 2Al₂O₃
2. CO + 3H₂ → H₂O + CH₄
3. 2HgO → 2Hg + O₂
4. CaCO₃ → CaO + CO₂
5. 3C + 2Fe₂O₃ → 4Fe + 3CO₂
6. N₂ + 3H₂ → 2NH₃
7. 2K + 2H₂O → 2KOH + H₂
8. 4P + 5O₂ → 2P₂O₅
9. Ba(OH)₂ + H₂SO₄ → 2H₂O + BaSO₄
10. CaF₂ + H₂SO₄ → CaSO₄ + 2HF
11. 3C + 2Fe₂O₃ → 4Fe + 3CO₂
12. BaCl₂ formula mass: 208.22
13. NaHCO₃ formula mass: 84.01
14. Mg(OH)₂ formula mass: 58.33
15. NH₄NO₃ formula mass: 80.06
16. Sr₃(PO₄)₂ formula mass: 452.80

Skill Sheet 14.1: The Avogadro Number

<table>
<thead>
<tr>
<th>Substance</th>
<th>Elements in substance</th>
<th>Atomic masses of elements (amu)</th>
<th>No. of atoms of each element</th>
<th>Formula mass (amu)</th>
<th>Molar mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr</td>
<td>Sr</td>
<td>87.6</td>
<td>1</td>
<td>87.6</td>
<td>87.6</td>
</tr>
<tr>
<td>Ne</td>
<td>Ne</td>
<td>20.2</td>
<td>1</td>
<td>20.2</td>
<td>20.2</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>Ca, O, H</td>
<td>Ca, 40.1 0, 16.0 H, 1.01</td>
<td>1 2</td>
<td>74.1</td>
<td>74.1</td>
</tr>
<tr>
<td>NaCl</td>
<td>Na, Cl</td>
<td>Na, 23.0 Cl, 35.5</td>
<td>1 1</td>
<td>58.5</td>
<td>58.5</td>
</tr>
<tr>
<td>O₃</td>
<td>O</td>
<td>16.0</td>
<td>3</td>
<td>48.0</td>
<td>48.0</td>
</tr>
<tr>
<td>C₆H₁₂O₇</td>
<td>C, H, O</td>
<td>C, 12.0 H, 1.01 O, 16.0</td>
<td>6 12 1</td>
<td>100 100</td>
<td></td>
</tr>
</tbody>
</table>

Skill Sheet 14.1: Formula Mass

Part 1 answers:
1. First ion: Ca⁺²; Second ion: PO₄³⁻
2. Ca₃(PO₄)₂
3. MgCl₂
4. The formula mass for Ca₃(PO₄)₂: 120.24 g + 61.94 g + 128.00 g = 310.18 g

Part 2 answers:
1. BaCl₂ formula mass: 208.23
2. NaHCO₃ formula mass: 84.01
3. Mg(OH)₂ formula mass: 58.33
4. NH₄NO₃ formula mass: 80.06
5. Sr₃(PO₄)₂ formula mass: 452.80

Skill Sheet 14.2: Classifying Reactions

1. Synthesis. Two substances combine to make a new compound.
3. Decomposition. A single compound is broken into two substances.
4. Decomposition. A single compound is broken into two substances.
5. Combustion. A carbon compound reacts with oxygen to produce carbon dioxide and water.
6. Double displacement. Two solutions are mixed and a solid is one of the products.
7. Double displacement. Two solutions are mixed and a solid is one of the products.
11. This is a double displacement reaction because a solid forms from two solutions.
12. A combustion reaction.
13. Synthesis reaction because two substances form a single compound.
14. The reaction is similar to a combustion reaction because a substance (hydrogen) reacts with oxygen and energy is produced. So is water. It is different because carbon is not involved in the reaction.
Skill Sheet 14.2: Predicting Chemical Equations

1. Ca
2. K
3. Al
4. Al + LiCl
5. Ca + K₂O
6. I₂ + KF
7. Ca + K₂S → 2K + CaS
8. 3Mg + Fe₂O₃ → 3MgO + 2Fe
9. Li + NaCl → Na + LiCl

Skill Sheet 14.2: Percent Yield

1. 110.98 g
2. 87.9%
3. 104.3 g
4. 63.55 g
5. 88.0%
6. 61.0 g
7. 119.06 g
8. 84%
9. 107.2 g
10. Experimental error, such as not measuring reactants or products carefully, spilling a reactant or product, or introducing a contaminant can affect the actual yield. Also, it may be impossible to measure every last bit of a reactant or product.

Skill Sheet 14.4: Lise Meitner

1. Ludwig Boltzmann was a pioneer of statistical mechanics. He used probability to describe how properties of atoms (like mass, charge, and structure) determine visible properties of matter (like viscosity and thermal conductivity).
2. They discovered protactinium. Its atomic number is 91 and atomic mass is 231.03588. It has 20 isotopes. All are radioactive.
3. The graphic at right illustrates fission (n = a neutron):
4. Some topics students may research and describe include nuclear power plants, nuclear weapons, nuclear-powered submarines or aircraft carriers.
5. Meitner’s honors included the Enrico Fermi award, and element 109, meitnerium, named in her honor.
6. Students should include the following pieces of evidence in their letters:
   - Meitner suggested tests to perform on the product of uranium bombardment.
   - Meitner proved that splitting the uranium atom was energetically possible.
   - Meitner explained how neutron bombardment caused the uranium nucleus to elongate and eventually split.

Skill Sheet 14.4: Marie and Pierre Curie

1. Sample answer: Marie (or Marya, as she was called) had a strong desire to learn and had completed all of the schooling available to young women in Poland. She was part of an illegal “underground university” that helped young women prepare for higher education. Perhaps her own thirst for knowledge fueled her empathy for the peasant children, who were also denied the right to an education.
2. Marie Curie proposed that uranium rays were an intrinsic part of uranium atoms, which encouraged physicists to explore the possibility that atoms might have an internal structure.
3. Marie and Pierre worked with uranium ores, separating them into individual chemicals. They discovered two substances that increased the conductivity of the air. They named the new substances polonium and radium.
4. Answers include nuclear physics, nuclear medicine, and radioactive dating.
5. Marie Curie thought carefully about how to balance her scientific career and the needs of her children. When the children were young, Pierre’s father lived with the family and took care of the children while their parents were working. Marie spent a great deal of time finding schools that best fit the individual needs of her children and at one point set up an alternative school where she and several friends took turns tutoring their children. When her daughters were in their teens, Marie included them in her professional activities when possible. Irene, for example, helped her mother set up mobile x-ray units for wounded soldiers during the war.

Skill Sheet 14.4: Rosalyn Yalow

1. There are some striking similarities in the lives of Rosalyn Yalow and Marie Curie. As young women, both were outstanding math and science students. Even though Yalow was 54 years younger than Marie Curie, both faced limited higher education opportunities because they were women. Undaunted, each earned a doctorate degree in physics. Both Yalow and Curie’s research focused on radioactive materials. Curie’s work was at the forefront of discovery of how radiation works, while Yalow’s work was to develop a new application of radiation. Both women were particularly interested in the medical uses of radiation. Each was committed to using their scientific discoveries to promote humanitarian causes. Both women won Nobel Prizes for their work (Marie Curie won two!).
2. RIA is a technique that uses radioactive molecules to measure tiny amounts of biological substances (like hormones) or certain drugs in blood or other body fluids.
3. Using RIA, they showed that adult diabetics did not always lack insulin in their blood, and that, therefore, something
must be blocking their insulin’s normal action. They also studied the body’s immune system response to insulin injected into the bloodstream.

4. The issue of patents in medical research remains a hotly debated issue in our society. Proponents of patents, especially for new drugs, claim that because very few new drugs make it through the extensive safety and effectiveness trials required for FDA approval, research costs are very high. Patents, they claim, are the only means of recouping these research costs.

On the other side of the issue, critics say that the profit motive drives research into certain types of medicines—tending to be drugs for chronic illnesses, so that patients will take the drugs for a long time. Research into drugs (like new antibiotics) that are generally taken only for a short period of time tends to be less of a priority. You may wish to have students research the pros and cons of the patent system and write a position paper or hold a class discussion or debate on the topic.

Skill Sheet 14.4: Chien-Shiung Wu

1. **Weak nuclear force**: One of the fundamental forces in the atom that governs certain processes of radioactive decay. It is weaker than both the electric force and the strong nuclear force. If you leave a solitary neutron outside the nucleus, the weak force eventually causes it to break into a proton and an electron. The weak force does not play an important role in a stable atom, but comes into action in certain cases when atoms break apart.

   **Beta decay**: a radioactive transformation in which a neutron splits into a proton and an electron. The electron is emitted as a beta particle and the proton stays in the nucleus, increasing the atomic number by one.

   **Isotope**: Forms of the same element that have different numbers of neutrons and different mass numbers.

2. When Enrico Fermi was having difficulty with a fission experiment, he turned to Wu for assistance. She recognized the cause of the problem: a rare gas she had studied in graduate school. Because she was familiar with the behavior of the gas she was able to help Fermi get on with his work.

3. The law of conservation of parity stated that in nuclear reactions, there should be no favoring of left or right. In beta decay, for example, electrons should be ejected to the left and to the right in equal numbers.

4. Cobalt-60 has 27 protons and 33 neutrons. There is only one stable isotope of cobalt, cobalt-59.

5. Wu cooled cobalt-60 to less than one degree above absolute zero, then placed the material in a strong magnetic field so that all the cobalt nuclei lined up and spun along the same axis. As the radioactive cobalt broke down and gave off electrons, Wu observed that far more electrons flew off in the direction opposite the spin of the nuclei. She proved that the law of conservation of parity does not hold true in all cases.

6. Margaret Burbidge, professor of astronomy, UCLA-awarded the National Medal of Science in the physical sciences in 1983. Citation: “For leadership in observational astronomy. Her spectroscopic investigations have provided crucial information about the chemical composition of stars and the nature of quasi-stellar objects.”

Vera C. Rubin, staff member, astronomer, Carnegie Institute of Washington-awarded the National Medal of Science in the physical sciences in 1993. Citation: “For her pioneering research programs in observational cosmology which demonstrated that much of the matter in the universe is dark and for significant contributions to the realization that the universe is more complex and more mysterious than had been imagined.”

7. Answers may vary. Some interesting questions to research include:

   - What are some other experiments or projects Wu undertook during the course of her career?
   - Did she ever return to her home country?
   - What advice would she give young people who wish to become scientists?

8. Unfortunately, the contributions of women to science were often overlooked. When the prize was awarded to Lee and Yang, playwright Clare Booth Luce commented, “When Dr. Wu knocked out that principle of parity, she established the principle of parity between men and women.”

Skill Sheet 14.4: Radioactivity

1. In the answers below, “a” is alpha decay and “b” is beta decay.

   **a. Answers are:**
   
   \[
   \begin{align*}
   ^{238}_{92}\text{U} & \rightarrow ^{234}_{90}\text{Th} \quad \text{b}\rightarrow ^{234}_{92}\text{Pa} & \rightarrow ^{234}_{92}\text{U} & \rightarrow ^{230}_{90}\text{Th} & \rightarrow ^{226}_{88}\text{Ra} \rightarrow ^{222}_{86}\text{Rn} & \rightarrow ^{218}_{84}\text{Po} & \rightarrow ^{214}_{82}\text{Bi} & \rightarrow ^{210}_{82}\text{Pb} \rightarrow ^{210}_{82}\text{Po} & \rightarrow ^{206}_{82}\text{Pb}
   \end{align*}
   \]

   **b. Answers are:**
   
   \[
   \begin{align*}
   ^{240}_{94}\text{Pu} & \rightarrow ^{240}_{95}\text{Am} & \rightarrow ^{236}_{93}\text{Np} & \rightarrow ^{232}_{91}\text{Pa} & \rightarrow ^{232}_{92}\text{U} \rightarrow ^{228}_{88}\text{Ra} & \rightarrow ^{224}_{86}\text{Ac} & \rightarrow ^{220}_{87}\text{Fr} & \rightarrow ^{216}_{85}\text{At} & \rightarrow ^{212}_{83}\text{Bi}
   \end{align*}
   \]

Skill Sheet 15.2: Svante Arrhenius

1. Arrhenius studied what happens when electricity is passed through solutions. He proposed that molecules in solutions could break up into electrically charged fragments called ions.

2. Arrhenius had always been a strong student. However, his doctoral thesis was not well understood and he was given a
barely passing grade. This made it difficult for him to find work in a university after graduation.

3. Arrhenius was interested in physical chemistry, biology, astronomy, and meteorology.

4. Arrhenius suggested that life may have spread from one part of the universe to another when living spores from one planet escaped their atmosphere and were then pushed along by radiation pressure to other places in the universe until they landed on another hospitable planet.

5. Arrhenius was one of the first to explain the role of “greenhouse gases” in warming the surface of the planet. He also proposed that humans could change Earth’s average temperature by adding carbon dioxide to the atmosphere.

Skill Sheet 16.1: Open and Closed Circuits

1. Answers are:
   a. A, B
   b. A, C, D
   c. A, B, C
   d. no current
   e. A, B, D
   f. B, C, D
   g. A, C
   h. A
   i. A
   j. no current

2. Answers are:
   a. A, B, C, D, E
   b. A, B, C, D, E, F, G
   c. A, B, C, D, E
   d. A, B, C, D, F, G
   e. A, B, C
   f. B, C, D, E, F, G
   g. no current
   h. B, C, D, F, G
   i. A, B, C, D, F, G
   j. A, B, C
   k. A, B, C, D, E
   l. B, C
   m. A, B, C
   n. no current
   o. B, C

3. Diagrams:

4. diagram #1: 4 paths; diagram #2: 8 paths

5. Student drawings will vary. If time permits, allow students to build and test their circuits

Skill Sheet 16.1: Benjamin Franklin

1. Franklin learned through reading, writing, discussing, and experimenting.

2. Franklin’s hypothesis was that lightning is an example of a large-scale discharge of static electricity.

3. Franklin’s reported results were that the loose threads of the hemp stood up and that touching the key resulted in a static electric shock. He concluded that the results were consistent with other demonstrations of static electricity; therefore, lightning was a large-scale example of the same phenomenon.

4. If the kite had been struck by lightning, the amount of charge coming down the hemp string would most likely have electrocuted Franklin.

Skill Sheet 16.2: Using an Electrical Meter

1. Sample diagram:

2. First battery: 1.553 volts; second battery: 1.557 volts

3. First bulb: 1.514 volts; second bulb: 1.586 volts

4. 3.113 volts

5. 3.108 volts

6. The two voltages are approximately equal.

7. post #1: 0.0980 amps
   post #2: 0.0981 amps
   post #3: 0.0978 amps
   post #4: 0.0980 amps
   post #5: 0.0980 amps
8. The current is approximately the same at all points.
9. First bulb: 15.4 ohms; second bulb: 16.2 ohms
10. Measuring resistance: First, set the meter dial to measure resistance. Remove the bulb from its holder. Then place one lead on the side of the metal portion of the light bulb (where the bulb is threaded to fit into the socket). Place the other lead on the “bump” at the base of the light bulb. The meter will display the bulb’s resistance.
Measuring voltage: First, set the meter dial to measure DC voltage. Locate the device (battery, bulb, etc.) that you wish to measure the voltage across. Then place one meter lead on one of the posts next to the device. Put the other meter lead on the post on the other side of the device. The meter will display the device’s voltage. If it shows a negative voltage, switch the two leads.
Measuring current: First, set the meter to measure DC current. Then break the circuit at the location where you wish to measure the current. Connect one of the meter leads at one side of the break. Connect the other lead at the other side of the break. The meter will display the current. If it shows a negative current, switch the two leads.

Skill Sheet 16.3: Voltage, Current, and Resistance

Reading section answers:
1. A battery with a larger voltage can create a greater energy difference. A 9-volt battery gives a greater “push” to the charges and creates a larger current.
2. You could increase the number of batteries, which would increase the total voltage in the circuit. You could replace the light bulb with a bulb of lower resistance. You could also use thicker wires, shorter wires, or wires made from a material with a higher conductivity. These changes to the wires would decrease the total amount of resistance in the circuit.
3. If the circuit used a 9-volt battery, you could try replacing it with five (or less than five) 1.5-volt batteries to lower the voltage in the circuit. You could replace the bulb with a bulb of higher resistance. Or, you could use thinner wires, longer wires, or wires made from a material with a lower conductivity. These changes to the wires would increase the total resistance in the circuit. To stop the current completely, you could simply open the switch.
4. You could simply cut each piece of wire in the circuit as short as possible. A shorter wire has less resistance than a longer wire. To make a more significant decrease in resistance, you would need to replace the wire with a thicker gauge wire or a wire made from a material with greater conductivity.
5. Ohm’s law states that, in a circuit, the amount of current is directly related to voltage, and inversely related to the resistance in the circuit.

Problem section answers:
1. 1.5 amps
2. 0.75 amps
3. 50 volts
4. 12 ohms

Skill Sheet 16.3: Ohm’s Law

1. 3 amps
d. It is brighter in circuit B because there is a greater voltage and greater current (and more power is consumed since power equals current times voltage).
2. 0.75 amp
3. 0.5 amp
4. 1 amp
5. 120 volts
6. 8 volts
7. 50 volts
8. 12 ohms
9. 240 ohms
10. 1.5 volts
11. 3 ohms
12. Answers are:
   a. Circuit A: 6 V; Circuit B: 12 V
   b. Circuit A: 1 A; Circuit B: 2 A
   c. Circuit: A 0.5 A; Circuit B: 1 A
13. The current becomes 4 times as great.
14. If resistance increases, the current decreases. The two are inversely proportional.
15. If voltage increases, current increases. The two are directly proportional.
16. Remove one of the light bulbs. This decreases the resistance and increases the current.
17. Remove one of the batteries. This decreases the voltage and decreases the current.
18. Answers are:
   a. 2 batteries and a 3 ohm bulb (or 4 batteries and all 3 bulbs)
   b. 4 batteries and a 3 ohm bulb
   c. 2 batteries and a 1 ohm bulb (or 4 batteries and a 2 ohm bulb)
   d. 4 batteries and a 1 ohm bulb

Skill Sheet 16.4: Series Circuits

1. Answers are:
   a. 6 volts
c. 3 amps
   b. 2 ohms
d. 3 volts
   c. Diagram:

2. Answers are:
a. 6 volts
c. 2 amps
b. 3 ohms
d. 2 volts
   c. Diagram:
3. The current decreases because the resistance increases.
4. The brightness decreases because the voltage across each bulb decreases and the current decreases. Since power equals voltage times current, the power consumed also decreases.
5. Answers are:
   a. 3 ohms
   b. 2 amps
   c. 1 ohm bulb: 2 volts; 2 ohm bulb: 4 volts
6. Answers are:
   a. 12 volts
   b. 4 ohms
   c. 3 amps
   d. 6 volts
   e. Diagram:

   ![Diagram of parallel circuit]
7. Answers are:
   a. 2 ohms
   b. 1 volt
   c. Diagram:

   ![Diagram of circuit with 6V, 1.5V, 0.5A]
8. Answers are:
   a. 6 ohms
   b. 1.5 amps
   c. 2 ohm resistor: 3 volts; 3 ohm resistor: 4.5 volts; 1 ohm resistor: 1.5 volt
   d. The sum is 9 volts, the same as the battery voltage.
9. Answers are:
   a. Diagram A: 0.5 amps; Diagram B: 1.0 amps
   b. Diagram A: 0.25 amps; Diagram B: 0.5 amps
   c. The amount of current increases.

**Skill Sheet 16.4: Parallel Circuits**

**Practice set 1:**
1. Answers are:
   a. 12 volts
   b. 6 amps
   c. 12 amps
   d. 1 ohm
2. Answers are:
   a. 12 volts
   b. 4 amps
   c. 8 amps
   d. 1.5 ohms
3. Answers are:
   a. 12 volts
   b. 2 ohm branch: 6 amps; 3 ohm branch: 4 amps
   c. 10 amps
   d. 1.2 ohms
4. Answers are:
   a. 9 volts
   b. 2 ohm branch: 4.5 amps; 3 ohm branch: 3 amps; 1 ohm branch: 9 amps
   c. 16.5 amps

**Practice set 2:**
1. Answers are:
   a. 4 ohms
   b. 6 ohms
   c. 2.67 ohms
   d. 2.4 ohms
2. Answers are:
   a. 2.67 ohms
   b. 1.2 ohms
   c. 0.545 ohms

**Skill Sheet 16.4: Thomas Edison**

1. Edison’s education included one-on-one tutoring from his mother, reading lots of books, and performing experiments in laboratories that he set up.
2. Edison learned that in order to sell an invention, not only does it have to be a technical success, it also has to be something that people want to buy.
3. Edison’s research facility at Menlo Park had workshops, laboratories, offices, and a library. Edison hired a team of assistants with various specialties to work there.
4. The tin foil phonograph and a practical, safe, and affordable incandescent light were developed at Menlo Park.
5. Edison’s invention process was to brainstorm as many ideas as possible, try everything that seems even remotely workable, record everything, and use failed experiments to redirect the project.
6. Edison was not easily discouraged by failure. Instead, he saw failed projects as providing useful information to narrow down the possibilities of what does work.
7. Students can find information about Edison’s tin foil phonograph using the Internet. Here’s a summary of how it worked:
Edison set up a membrane that vibrated when exposed to sound waves. The membrane (called a diaphragm) had an embossing needle attached. When someone spoke, the diaphragm would vibrate and the embossing needle would make indentations on tin foil wrapped around a metal cylinder. The cylinder was turned by a hand-crank at around 60 revolutions per minute. There was a second diaphragm-and-needle apparatus for playback. When the needle followed the “tracks” made in the tin foil, it made the diaphragm vibrate which reproduced the recorded sounds.

8. Answers will vary. Some of Edison’s interesting inventions include paraffin paper, an “electric pen” (the forerunner of the mimeograph machine) a carbon rheostat, a fluoroscope, and sockets, switches, and insulating tape.

Skill Sheet 16.4: George Westinghouse

1. Westinghouse first developed his talents as an inventor in his father’s agricultural machine shop.
2. Westinghouse enabled trains to travel more safely at higher speeds in two ways: He invented an air brake which allowed the engineer to stop all the cars at once, and he developed signaling and switching systems which reduced the likelihood of collisions.
3. Westinghouse promoted alternating current because it could be transmitted over longer distances.
4. Westinghouse demonstrated the potential of alternating current by lighting the streets of Philadelphia and then the entire Chicago World’s Fair using this technology.
5. Direct current occurs when charge flows in one direction. Batteries provide direct current. Alternating current, in contrast, switches directions. Household circuits in the United States run on alternating current that reverses direction 60 times each second. The diagrams below compare direct and alternating current.

<table>
<thead>
<tr>
<th>DC circuit</th>
<th>AC circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="DC_circuit.png" alt="Diagram" /></td>
<td><img src="AC_circuit.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

Skill Sheet 16.4: Lewis Latimer

1. Lewis Latimer did not attend college, but learned how to be a draftsman by studying the drawings of draftsmen while working as an office boy for a patent law firm. He was self-motivated and used any available books and tools to learn the skills needed to become an outstanding draftsman. He was also a self-taught electrical engineer. He learned all that he could about electricity while working for Hiram Maxim at U.S. Electric Lighting.
2. Latimer invented the following:
   • Mechanical improvements for railroad train water closets (also known as toilets)
   • Carbon filaments to replace paper filaments in light bulbs
   • An improved manufacturing process for carbon filaments
   • An early version of the air conditioner
   • A locking rack for hats, coats, and umbrellas
   • A book support
His most important inventions are the development of carbon fibers and improved manufacturing process to produce those filaments. The light bulb invented by Thomas Edison used a paper filament. As a result, it had a very short life span. With carbon filaments, light bulbs lasted longer, were more affordable, and could be used in a variety of ways. Latimer improved the technology so that light bulbs would become commonplace in both industry and homes.
3. A “Renaissance man” is a scholar with a depth of knowledge in a variety of areas. During the Renaissance, there were men who were accomplished in multiple disciplines including math, engineering, art, and music. Leonardo da Vinci was one of the great Renaissance men. Lewis Latimer can be called a Renaissance man because he, too, excelled in a variety of areas including science, literature, music, and art.
4. Two of Latimer’s poems were titled *Friends* and *Ebon Venus*.
5. The Edison Pioneers first met on February 11, 1918. This was Thomas Edison’s 71st birthday.

Excerpt from obituary:
“He was of the colored race, the only one in our organization, and was one of those to respond to the initial call that led to the formation of the Edison Pioneers, January 24, 1918. Broadmindedness, versatility in the accomplishment of things intellectual and cultural, a linguist, a devoted husband and father, all were characteristic of him, and his genial presence will be missed from our gatherings.”
Skill Sheet 17.1: Magnetic Earth

1. Students learn in Chapter 17 that Earth’s magnetic field comes from its core. For those who desire a more detailed explanation, scientists believe that the motion of molten metals in Earth’s outer core create its magnetic field.
2. Seven percent of 0.5 gauss is 0.035 gauss. In 100 years, Earth’s strength could be 0.465 gauss.
3. Student answers will vary but may include responses such as: devices that depend on magnets would work differently or not at all. Earth science experts tell us that the poles could reverse within the next 2,000 years. During a reversal, the field would not completely disappear. The main magnetic field that we use for navigation would be replaced by several smaller fields with poles in different locations.
4. Rock provides a good record because as the rock is made, atoms in the rock align with the magnetic field of Earth. (Actually, oceanic rock is made of a substance called magnetite!) Rock that was made 750,000 years ago would have a north-south orientation that is exactly opposite the north-south orientation of rock that is made today. Therefore, we can use the north-south orientation of bands of rock on the sea floor to understand how many times the poles have reversed over geologic time.
5. NOTE: In many references, magnetic south pole is referred to as “magnetic north pole” because it is located at the geographic north pole. This terminology can be confusing to students who know that opposite poles attract. The north pole of a compass needle is in fact the north end of a bar magnet. This is why we think it is best to use the term magnetic south pole as the point to which the north end of a compass needle is attracted. For more information about Earth’s magnetism see http://www.ngdc.noaa.gov/. 

Answers are:
   a. Both the magnetic south pole and geographic north are located near the Arctic.

Skill Sheet 17.2: Maglev Train Model Project

Students build a model to complete this skill sheet. No written responses are required.

Skill Sheet 17.4: Michael Faraday

1. Faraday took careful notes during lectures given by Davy, then bound his notes and sent them to Davy along with a request for a job. Faraday had little formal training in science, so this was a means of proving his capabilities.
2. Benzene is used in cleaning solvents, herbicides, insecticides, and varnishes. Note: Benzene is a known carcinogen and highly flammable. Safety precaution must be taken whenever it is used.
3. Electromagnetic induction is the use of a moving magnet to create an electric current.
4. Sample answer: When light is polarized (vibrating in one plane), a strong magnetic field can change the orientation of that plane.
5. Faraday instituted the Friday Evening Discourses and the Christmas Lectures for Children, which gave non-scientists the opportunity to learn about the scientific community and about recent advances in science.
6. The electric motor, invented by Faraday, is used in all sorts of household appliances including electric fans, hair dryers, food processors, and vacuum cleaners. Electromagnetic induction is used by local power plants to generate the electricity that is used every day.
7. Faraday had a reputation as an engaging speaker who used exciting demonstrations to catch his audience’s interest. He had a knack for communicating scientific knowledge in terms that non-scientists understood. It also would be interesting to see who else might be in attendance at the lecture!
8. Iron filings are available from many science supply catalogs. Place some iron filings on a piece of clear plastic (such as an overhead transparency). Place the plastic over a magnet to observe the field lines.

Skill Sheet 17.4: Transformers

1. 25 turns
2. 230 volts
3. 220 volts
4. 100 volts
5. 440 turns
6. 131 turns
Skill Sheet 17.4: Electrical Power

1. Answers are:
   a. 5 kW
   b. 10 kWh
   c. $1.50
2. Answers are:
   a. 300 minutes
   b. 5 hours
   c. 1.2 kW
   d. 6 kW
   e. $0.90
3. 960 W
4. 24 W
5. Answers are:
   a. 60 W
   b. 0.06 kW
   c. 525.6 kWh
   d. $78.84
6. 0.625 A
7. Answers are:
   a. 3 V
   b. 1 A
   c. 3 W
8. Answers are:
   a. 24 ohms
   b. 600 W
   c. 0.6 kW
9. Answers are:
   a. 20.5 A
   b. 10.8 ohms
   c. 18 kWh
   d. $140.40
10. Answers are:
    a. 6 ohms
    b. 2 A
    c. 12 W
    d. 24 W
11. Answers are:
    a. 12 V
    b. 4 A
    c. 48 W
    d. 8 A
    e. 96 W

Skill Sheet 18.1: Andrew Douglass

1. Douglass originally started as an astronomer. He helped to set-up observatories and also studied Mars with Percival Lowell. He noticed a possible relationship between sunspot cycles and the climate and wished to study this further. He noted that tree rings held information about weather patterns and hoped he could find a link between periods of drought and sunspot activity. This marked his move away from astronomy and toward tree ring analysis.
2. Douglass created the science of dendrochronology or tree ring dating. He specifically developed cross-dating as a technique to match tree ring samples with ancient ruins.
3. Douglass, in 1929, was able to date with accuracy Native American ruins in Arizona. He studied pine tree rings dating back to the time of Native American dwellings. He matched wooden beam samples against pine tree rings to determine a precise date for the ancient ruins. This cross-dating technique provided a tool for all archaeologists to date prehistoric remains and ruins.
4. The second asteroid is called Minor Planet or Asteroid (15420) Aedouglass.
5. The Boyden Observatory is now located in Bloemfontein, South Africa.
6. The Spacewatch Project is located at the University of Arizona’s Lunar and Planetary Laboratory. Scientists at Spacewatch study and explore small objects in the solar system including asteroids and comets. The Project was founded by Professor Tom Gehrels and Dr. Robert S. McMillan in 1980.

Skill Sheet 18.2: Relative Dating

1. A thunderstorm began. A child ran through a mud puddle leaving footprints. Hail began to fall. Finally, the mud puddle dried and cracked.
2. One April afternoon, a thunderstorm began. A child was outside playing. When the rain began to fall hard, the child ran home. Her footprints were left in a mud puddle. Fortunately, she made it home just in time because small hailstones suddenly began to fall. The hailstorm lasted for a few minutes and then the clouds cleared. The next morning was bright and sunny. The mud puddle dried and then cracked in many places.
3. C
4. E (This is the term that will be new to students.)
5. A
6. F
7. B
8. D
9. There is no matching picture for this concept. The name of this concept is faunal succession.
10. The rock bodies formed in this order: H, G, F, D, C, B, E, and A.
11. The fault formed after layer F and before both layer D and the intrusion.
12. The stream formed after layer A. Like an intrusion, the stream cut across the rock bodies.

Extension
13. The set of clues includes three layers of colored sand in a clear tank. The layers were made while a small pencil was held upright. The sand filled in around the pencil. After the layers were created, a second, longer pencil was pushed through the layers.
14. The concepts of original horizontality and lateral continuity are demonstrated here. Pencil E represents cross-cutting relationships. Pencil D represents the idea of inclusions.

15. The order of the events is D, A, B, C, and E. My classmates successfully figured out the correct order of the events.

**Skill Sheet 18.2: Nicolas Steno**

1. Steno is responsible for the following three principles of geology:
   - The principle of superposition states that layers of sedimentary rock settle on top of each other. The oldest layers are at the bottom and the younger layers are on top. The bottom layers are formed first with younger layers sitting above. Geologists use this principle to determine the relative ages of layers.
   - The principle of original horizontality states that sedimentary rock layers form horizontally.
   - The principle of lateral continuity states that rock layers spread out until they reach something that stops this spreading. The layers will continue to move out in all directions horizontally until they are stopped.

2. People did not understand how fossils formed and what fossils truly were. Common misconceptions included the following: fossils grew inside rocks, fossils fell from the sky, and fossils fell from the moon. People did not consider extinction or have an understanding of geological principles to understand fossils and fossil formation.

3. Steno identified tongue stones as ancient shark teeth. He understood that particles settled in sediment. The shark teeth had settled into soft sediment that eventually hardened. Sharks had once lived in the mountains that at one time had been covered by the sea. Shark teeth became buried in mud and rock layers formed around the teeth. These layers became buried under new layers of rock.

4. As an anatomist, Steno developed keen observation skills. He was comfortable examining something in depth and trying to understand how something worked. He was not merely satisfied with viewing something. He liked to take things apart. His medical background and work in anatomy made him a hands-on researcher. He took his observation and interest in understanding structure and applied those skills to geology. Unlike many of his counterparts who simply read scholarly works, Steno was a true field scientist. He traveled, observed, and touched.

5. Answers will vary. Students might suggest observations they have made in a science lab, at the beach, or on a field trip. In general, observation often teaches us that things are not what they may initially appear. Observation means paying attention to the details, even if minute or mundane.

6. A goldsmith is a metalworker who often makes jewelry. A goldsmith will solder, file, and polish. A goldsmith does not work only with gold, but will handle a variety of metals. Most work by a goldsmith is done by hand. Steno’s father’s goldsmith shop was a laboratory providing him with the opportunity to use his hands to handle various tools and materials.
   - Alchemy is the early ancestor of chemistry. This ancient form of chemistry included herbs and metals. Alchemists often looked for cures for illnesses. Goldsmith work and alchemy both took place in a laboratory-like setting providing Steno exposure to scientific concepts and materials. Alchemists liked to experiment and tried to understand the world around them. Steno used observation and his hands throughout his career as a scientist to make sense of the world around him.

**Skill Sheet 18.3: The Rock Cycle**

![Rock Cycle Diagram](image_url)

**Skill Sheet 19.1: Earth’s Interior**

A. Crust  
B. Upper mantle  
C. Asethenosphere  
D. Lower mantle  
E. Outer core  
F. Inner core
Skill Sheet 19.1: Charles Richter

1. Answers are:
   - theoretical physics—a branch of physics that attempts to understand the world by making a model of reality, used for rationalizing, explaining, and predicting physical phenomena through a "physical theory."
   - seismology—The study of earthquakes and of the structure of the Earth by natural and artificial seismic waves.
   - seismograms—A written record of an earthquake, recorded by a seismograph.
   - magnitude—the property of relative size or extent (whether large or small)
   - seismographs—An instrument for automatically detecting and recording the intensity, direction, and duration of a movement of the ground, especially of an earthquake.

2. Richter responded by taking on routine tasks and making something extraordinary out of something ordinary.

3. Dr. Beno Gutenberg

Skill Sheet 19.2: Alfred Wegener

1. He developed an interest in Greenland when he was a young boy. As an adult scientist, he went there on several scientific expeditions to study the movement of air masses over the polar ice cap. He studied the movement of air masses long before the common acceptance of the jet stream. He died there during a blizzard on one of his expeditions just a few days after his fiftieth birthday.

2. He and his brother set the world record for staying aloft in a hot air balloon for the longest period of time, 52 hours.

3. Wegener studied and used several different fields of science in his work. His main areas of expertise were astronomy and meteorology, however, he also explored paleontology (fossils), geology, and climatology as he gathered evidence for his drifting continent theory.

4. Fossils of the small reptile were found only on the eastern coast of Brazil and the western coast of Africa. Since there was no way that the reptile could have crossed the Atlantic Ocean, Wegener figured that those two continents must have been connected when that reptile was alive.

5. Coal can only be formed under certain conditions. It can be formed only from plants that grow in warm, wet climates. Those type of plants could not grow in either England or Antarctica today. That means that at some time, England and Antarctica must have been located somewhere around the equator where those type of plants could survive, and they must have moved away from the equator to their present locations.

6. Wegener was a relatively unknown scientist at the time, and geology wasn't even his field of expertise, yet he was proposing a theory that went against everything that scientists at the time believed about geology. The most famous scientists alive at that time attacked him viciously and called his theory utter rot! Also, even though he had gathered what appeared to be a lot of evidence to show that the continents had indeed moved over millions of years, he could never explain what driving force could be powerful enough to move continents. He could never explain what driving force could be powerful enough to move continents.

7. Richter responded by taking on routine tasks and making something extraordinary out of something ordinary.

8. Answers will vary.
Skill Sheet 19.2: Harry Hess

1. Hess used his time in the Navy to further his geological research. Between battles, Hess and his crew gathered data about the structure of the ocean floor using the ship’s sounding equipment. They recorded thousands of miles worth of depth recordings.

2. While in the Navy, Hess measured the deepest point of the ocean ever recorded—nearly 7 miles deep. He also discovered hundreds of flat-topped mountains lining the Pacific Ocean floor. He named these unusual mountains “guyouts”.

3. Hess explained that sea floor spreading occurs when molten rock (or magma) oozes up from inside the Earth along the mid-oceanic ridges. This magma creates new sea floor that spreads away from the ridge and then sinks into the deep oceanic trenches where it is destroyed.

4. Hess explained that the ocean floor is continually being recycled and that sediment has been accumulating for more than 300 million years. This is the amount of time needed for the ocean floor to spread from the ridge crest to the trenches. Therefore, the oldest fossils found on the sea floor are no more than 180 million years old.

5. In 1962, President John F. Kennedy appointed Hess as Chairman of the Space Science Board—an advisory group for the National Aeronautics and Space Administration (NASA). During the late 1960s, Hess helped plan the first landing of humans on the moon. He was part of a committee assigned to analyze rock samples brought back from the moon by the Apollo 11 crew.

6. In 1984, the American Geophysical Union established the Harry H. Hess medal in recognition of “outstanding achievements in research in the constitution and evolution of Earth and sister planets.”

Skill Sheet 19.2: John Tuzo Wilson

1. Wilson’s adventurous parents helped to expand Canada’s frontiers. Wilson’s mother, Henrietta Tuzo, was a famous mountaineer who had Mount Tuzo in western Canada named in her honor. Wilson’s father, also named John, helped plan the Canadian Arctic Expedition of 1913 to 1918. He also helped develop airfields throughout Canada.

2. Wilson is sometimes called an adventurous scholar because he enjoyed traveling to unusual locations. He became the first person to scale Mount Hague in Montana. Wilson also led an expedition called Exercise Musk-Ox in which ten army vehicles traveled 3,400 miles through the Canadian Arctic. While a professor, Wilson mapped glaciers in Northern Canada and became the second Canadian to fly over the North Pole during his search for unknown Arctic islands.

3. Volcanic islands, like the Hawaiian Islands, are found thousands of kilometers away from plate boundaries. In 1963, Wilson published a paper that explained how plates move over stationary “hotspots” in the earth’s mantle and form volcanic islands.

4. In 1965, Wilson proposed that a type of plate boundary must connect ocean ridges and trenches. He suggested that a plate boundary ends abruptly and transforms into major faults that slip horizontally. Wilson called these boundaries “transform faults”.

5. In 1967, Wilson published an article that described the repeated process of ocean basins opening and closing—a process later named the Wilson Cycle. Geologists believe that the Atlantic Ocean basin closed millions of years ago and caused the formation of the Appalachian and Caledonian mountain systems. The basin later re-opened to form today’s Atlantic Ocean.

6. Antarctica

Skill Sheet 19.3: Earth’s Largest Plates

A. Pacific Plate
B. North American Plate
C. Eurasian Plate
D. African Plate
E. Indo-Australian Plate
F. Antarctic Plate

Skill Sheet 19.4: Continental U.S. Geology

No student responses are required.

Skill Sheet 20.1: Finding an Earthquake Epicenter

Practice 1:
Table 1 answers:

<table>
<thead>
<tr>
<th>Station name</th>
<th>Arrival time difference between P- and S-waves</th>
<th>Distance to epicenter in kilometers</th>
<th>Scale distance to epicenter in centimeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15 seconds</td>
<td>130 km</td>
<td>1.3 cm</td>
</tr>
<tr>
<td>2</td>
<td>24 seconds</td>
<td>200 km</td>
<td>2.0 cm</td>
</tr>
<tr>
<td>3</td>
<td>42 seconds</td>
<td>350 km</td>
<td>3.5 cm</td>
</tr>
</tbody>
</table>
Practice 2:
1. First problem is done for students.
   Station A: \[ t_p = 128 \text{ seconds} \]
2. Station B:
   \[ 5 \text{ km/sec} \times t_p = 3 \text{ km/sec} \times (t_p + 80 \text{ sec}) \]
   \[ (2 \text{ km/sec}) \times t_p = 240 \text{ km} \]
   \[ t_p = 120 \text{ seconds} \]
3. Station C: \[ t_p = 180 \text{ seconds} \]
4. Station A: distance = \[ 5 \text{ km/s} \times 128 \text{ sec} = 640 \text{ km} \]
   Station B: distance = \[ 5 \text{ km/s} \times 120 \text{ sec} = 600 \text{ km} \]
   Station C: distance = \[ 5 \text{ km/s} \times 180 \text{ sec} = 900 \text{ km} \]
5. Answers are:
   (a) \[ 5 \text{ km/s} \times 200 \text{ s} = 3 \text{ km/s} \times (200 \text{ s} + x) \]
   \[ 1000 \text{ km} = 600 \text{ km} + (3 \text{ km/s})x \]
   \[ 400 \text{ km} = (3 \text{ km/s})x \]
   \[ x = 133 \text{ s} = \text{time between the P-waves and S-waves} \]
   (b) \[ 133 \text{ s} + 200 \text{ s} = 333 \text{ s} = t_s \]

6. Table 3 answers:

<table>
<thead>
<tr>
<th></th>
<th>Variables</th>
<th>Station 1</th>
<th>Station 2</th>
<th>Station 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of P-waves</td>
<td>( r_p )</td>
<td>5 km/s</td>
<td>5 km/s</td>
<td>5 km/s</td>
</tr>
<tr>
<td>Speed of S-waves</td>
<td>( r_s )</td>
<td>3 km/s</td>
<td>3 km/s</td>
<td>3 km/s</td>
</tr>
<tr>
<td>Time between the</td>
<td>( t_s - t_p )</td>
<td>70 seconds</td>
<td>115 seconds</td>
<td>92 seconds</td>
</tr>
<tr>
<td>arrival of P- and</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-waves</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total travel time</td>
<td>( t_p )</td>
<td>105 seconds</td>
<td>173 seconds</td>
<td>138 seconds</td>
</tr>
<tr>
<td>of P-waves</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total travel time</td>
<td>( t_s )</td>
<td>175 seconds</td>
<td>288 seconds</td>
<td>230 seconds</td>
</tr>
<tr>
<td>of S-waves</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to epicenter</td>
<td>( d_p, d_s )</td>
<td>525 km</td>
<td>865 km</td>
<td>690 km</td>
</tr>
<tr>
<td>Scale distance to</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>epicenter</td>
<td></td>
<td>2.6 cm</td>
<td>4.3 cm</td>
<td>3.5 cm</td>
</tr>
</tbody>
</table>

Skill Sheet 20.2: Volcano Parts

A. Vent
B. Layers of lava and ash
C. Volcano
D. Magma
E. Conduit
F. Magma chamber
G. Vent
H. Lava

Skill Sheet 20.3: Basalt and Granite

Sample student answer:

Basalt
- forms oceanic crust
- fine crystals
- made from lava that’s NOT silica-rich
- cooled quickly

Granite
- forms continental crust
- large visible crystals
- made from silica-rich magma
- cooled slowly

Skill Sheet 21.2: Concentration of Solutions

1. 6.7%
2. 2.0%
3. 0.6%
4. 400 g salt
5. 3.75 g sugar
6. 139 g sand
7. 43%
8. 12.5 g
9. 0.5%
10. 8.8 g red food coloring
Skill Sheet 21.2: Solubility

Part 1 answers:
1. Insoluble means that no amount of this substance will dissolve in water at this temperature under these conditions. Chalk and talc are substances that do not interact with water molecules. It is possible that the bonds in chalk and talc molecules are nonpolar.
2. The degree to which a substance is soluble depends on the nature of the bonds and the size of the molecules in the substance. Molecules of sugar, salt, and baking soda are different with respect to the nature of the bonds and sizes of these molecules. Therefore, these molecules will each dissolve in water in different ways and to different degrees.
3. 205 g
4. 190 mL
5. 25 mL
6. 1 g

Part 2 answers:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Amount of substance in 200 mL of water at 25°C</th>
<th>Saturated, unsaturated, or supersaturated?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table salt (NaCl)</td>
<td>38 grams</td>
<td>unsaturated</td>
</tr>
<tr>
<td>Sugar (C₁₂H₂₂O₁₁)</td>
<td>500 grams</td>
<td>supersaturated</td>
</tr>
<tr>
<td>Baking soda (NaHCO₃)</td>
<td>20 grams</td>
<td>saturated</td>
</tr>
<tr>
<td>Table salt (NaCl)</td>
<td>100 grams</td>
<td>supersaturated</td>
</tr>
<tr>
<td>Sugar (C₁₂H₂₂O₁₁)</td>
<td>210 grams</td>
<td>unsaturated</td>
</tr>
<tr>
<td>Baking soda (NaHCO₃)</td>
<td>25 grams</td>
<td>supersaturated</td>
</tr>
</tbody>
</table>

Part 3 answers:
1. Graphs:

Skill Sheet 21.2: Salinity and Concentration problems

1. Answers are:

<table>
<thead>
<tr>
<th>Place</th>
<th>Salinity</th>
<th>Salt in 1 L</th>
<th>Pure water in 1 L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salton Sea California</td>
<td>44</td>
<td>44</td>
<td>956</td>
</tr>
<tr>
<td>Great Salt Lake Utah</td>
<td>280</td>
<td>280</td>
<td>720</td>
</tr>
<tr>
<td>Mono Lake California</td>
<td>210</td>
<td>210</td>
<td>790</td>
</tr>
<tr>
<td>Pacific Ocean</td>
<td>87</td>
<td>87</td>
<td>913</td>
</tr>
</tbody>
</table>

2. 72 grams
3. 10 ppt
4. Add 420 grams of salt to 1,580 grams of water. If the dissolved salt does not bring the volume up to 2,000 mL, make a second batch of solution. Add the second batch to the first until you have two liters of solution.
5. 6 ppt
6. 45 grams
7. 2 ppm
8. 5 ppb
9. yes; yes
10. 50,000 times more sensitive
Skill Sheet 21.3: Calculating pH

1. Answers:
   a. $10^{-2} > 10^{-3}$
   b. $10^{-14} < 10^1$
   c. $10^{-7} = 0.0000001$
   d. $10^0 < 10^1$

2. Answers:
   a. acid
   b. neutral
   c. base

3. pH = 4
4. pH 5; weaker acid
5. pH 7; Water is neutral and has an equal number of H+ and OH- ions.
6. $10^{-11}$; base
7. $1 \times 10^{-8.4}$
8. The product with lemon juice contains a greater concentration of acid which would mean that it might be a better cleaning solution than the cleaner with the weaker acid, vinegar.

Skill Sheet 22.1: Groundwater and Wells

Making predictions:
   a. 1, 3
   b. 3
   c. No, because water can’t pass through the cling wrap/foam layer.

Thinking about what you observed:
   a. 1, 3; yes
   b. 3; yes
   c. Aquiclude
   d. Aquifer
   e. No, because the well is below the aquiclude. Yes, hypothesis was correct.

   f. The surface contamination would move toward well #1. If well #2 was being pumped, it would not have an effect on the movement of surface contamination because it is located below the aquiclude.
   g. Well #3 would possibly be able to provide water. It depends on how low the water table became.
   h. It might pull in salt water from the ocean. That is a form of contamination.
   i. Answers will vary. Sample answer: Look up how low the water table got during the worst drought of the last 100 years. Dig the well a little lower than that level.

Skill Sheet 22.2: The Water Cycle

Part 1 answers:
A. condensation
B. precipitation
C. percolation
D. groundwater flow
E1. evaporation
E2. evaporation
F. transpiration
G. water vapor transport.

Part 2 answers:
1. evaporation—The Sun’s heat provides energy to enable water molecules to enter the atmosphere in the gas phase; transpiration—The Sun’s energy makes photosynthesis possible, which in turn causes plants to release water into the atmosphere in a process known as transpiration.
2. Wind pushes water in the atmosphere to new locations, so that the water doesn’t always fall back to Earth as precipitation in the same spot from which it evaporated.
3. Gravity causes water to run down a mountain toward the coast, and causes water droplets to fall to Earth as precipitation. Gravity is also the primary force that moves water from Earth’s surface through the ground to become groundwater.

Skill Sheet 24.1: Period and Frequency

1. 0.05 sec
2. 0.005 sec
3. 0.1 Hz
4. 3.33 Hz
5. period = 2 sec; frequency = 0.5 Hz
6. period = 0.25 sec; frequency = 4 Hz
7. period = 0.5 sec; frequency = 2 Hz

8. Answers are:
   a. 5 sec
   b. 5 sec
   c. 0.2 Hz

9. Answers are:
   a. 120 vibrations
   b. 2 vibrations
   c. 0.5 sec
   d. 2 Hz
Skill Sheet 24.1: Harmonic Motion Graphs

1. Answers are:
   a. A = 5 degrees; B = 100 cm
   b. A = 1 second; B = 2 seconds

2. Answers are:
   a. Diagram:

![Position vs Time Graph](image)

b. Diagram:

![Angle vs Time Graph](image)

Skill Sheet 24.2: Waves

1. Diagram:

![Wave Diagram](image)

a. Two wavelengths

b. The amplitude of a wave is the distance that the wave moves beyond the average point of its motion. In the graphic, the amplitude of the wave is 5 centimeters.

2. Answers are:
   a. Diagram:

![Wave Diagram](image)

3. 10 m/s
4. 5 m
5. 10 Hz
6. frequency = 0.5 Hz; speed = 2 m/s
7. frequency = 165 Hz; period = 0.006 s
8. A’s speed is 75 m/s, and B’s speed is 65 m/s, so A is faster.

9. Answers are:
   a. 4 s
   b. 0.25 Hz
   c. 0.75 m/s

Skill Sheet 24.2: Wave Interference

1. Diagram:

![Wave Interference Diagram](image)

2. 4 blocks
3. 2 blocks
4. 32 blocks
5. 4 blocks
6. 1 wavelength
7. 8 wavelengths

8. A portion of the table and a graphic of the new wave are shown below. The values for the third column of the table are found by added the heights for wave 1 and wave 2.

<table>
<thead>
<tr>
<th>x (blocks)</th>
<th>Height wave 1 (blocks)</th>
<th>Height wave 2 (blocks)</th>
<th>Height of wave 1 +2 (blocks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0.8</td>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>2.2</td>
<td>-2</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>2.8</td>
<td>0</td>
<td>2.8</td>
</tr>
<tr>
<td>5</td>
<td>3.3</td>
<td>2</td>
<td>5.3</td>
</tr>
<tr>
<td>6</td>
<td>3.7</td>
<td>0</td>
<td>3.7</td>
</tr>
<tr>
<td>7</td>
<td>3.9</td>
<td>-2</td>
<td>-1.9</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>
9. The new wave looks like the second wave, but it vibrates about the position of the first wave, rather than about the zero line.

Skill Sheet 24.3: Decibel Scale

1. Twice as loud.
2. 55 dB
3. Answers are:
   a. 80 dB
   b. 60 dB
4. Four times louder
5. Answers are:
   a. 30 dB
   b. 50 dB
   c. 70 dB

Skill Sheet 24.3: Human Ear

a. Ear canal—leads to the middle ear.
b. Eardrum—vibrates as the sound waves reach it.
c. Semicircular canals—balance.
d. Cochlea—a spiral-shaped, fluid-filled cavity that contains nerve endings and is essential to interpreting sound waves.
e. Malleus—transfers vibrations from the eardrum.
f. Incus—between the malleus and stapes; transmits vibrations from malleus to stapes.
g. Stapes—vibrates against the cochlea.

Skill Sheet 24.3: Waves and Energy

1. Most of the stone’s kinetic energy is converted into water waves and the waves carry that energy away from where the stone landed.
2. The frequency of the jump rope increases and the energy expended by Ian and Igor increases for this demonstration.
3. The 100-hertz wave has more energy.
4. During a hurricane, waves have more energy as indicated by their higher amplitude.
5. A wave that has a 3-meter amplitude has more energy than a wave that has a 0.03 meter (3 centimeter) amplitude.
6. The low-volume sound has the least amount of energy.
7. Visible light waves are likely to have greater energy.
8. This wave has more energy and a higher frequency than the other waves. Sketch:

Skill Sheet 24.3: Standing Waves

1. Answers are:
   a. A = 2nd; B = 3rd; C = 1st or fundamental; D = 4th (You can easily determine the harmonics of a vibrating string by counting the number of “bumps” on the string. The first harmonic (the fundamental) has one bump. The second harmonic has two bumps and so on.)
   b. Diagram:

   ![Diagram of standing waves]

c. A = 1 wavelength, B = 1.5 wavelengths, C = half a wavelength, D = 2 wavelengths
   d. A = 3 meters, B = 10 meters, C = 6 meters, D = 7.5 meters
2. Answers are:
   a. Diagram:

   ![Diagram of standing waves]

   b. See answer for (c).
c. See table below:

d. The frequency decreases as the wavelength increases. They are inversely proportional.

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Speed (m/sec)</th>
<th>Wavelength (m)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>24</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>8</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>4.8</td>
<td>7.5</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>

e. See table below.

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Speed (m/sec)</th>
<th>Wavelength (m)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>2.4</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>2</td>
<td>18</td>
</tr>
</tbody>
</table>

f. The shorter rope resulted in harmonics with shorter wavelengths. The second harmonic on the short rope is equivalent in terms of wavelength and frequency to the 4th harmonic on the longer rope.

**Skill Sheet 25.1: The Electromagnetic Spectrum**

1. Green
2. Green
3. $400 \times 10^{-9}$ m or $4.0 \times 10^{-7}$ m
4. $517 \times 10^{12}$ Hz or $5.17 \times 10^{14}$ Hz
5. $652 \times 10^{-9}$ m or $6.52 \times 10^{-7}$ m
6. $566 \times 10^{12}$ Hz or $5.66 \times 10^{14}$ Hz

$$\frac{\lambda_1}{\lambda_2} = \frac{f_2}{f_1}$$

7. The answer is: $\frac{\lambda_1}{\lambda_2} = \frac{f_2}{f_1}$
8. $\lambda = 0.122$ meter or $1.22 \times 10^{-1}$ m
9. $\lambda = 3.3$ meters

**Skill Sheet 25.2: Color Mixing**

1. The differences include: (1) for RGB the primary colors are red, green, and blue and for CMYK the primary colors are cyan, magenta, and yellow, (2) for RGB black is the absence of light but for CMYK black is an added pigment, and (3) to make white with RGB you mix the three primary colors and to make white in CMYK you omit pigment (or you need a special white pigment to make white, as in making white paint).

2. (a) Your eye sees red. (b) Your eye sees magenta. (c) Your eye sees green. (d) Your eye sees cyan.

3. The blue and red photoreceptors would be stimulated to see purple. For purple, the signal for blue would be stronger. Note: This can be tested for purple or any color by adjusting the RGB intensity for font color in a word processing program.

4. To see yellow, the red and green photoreceptors of your eyes are stimulated.

5. By reflecting most of the light that strikes it, all the colors of visible light reach your eyes and all three photoreceptors (red, green, and blue) are stimulated so that your brain interpret the color as being white.

6. (a) All three colors of light would be mixed, (b) There would be an absence of light, (c) green and blue light would be mixed in equal amounts, (d) red and green light would be mixed in equal amounts.

7. (a) red light is reflected and all the other colors are absorbed, (b) red light is reflected and no colors of light are absorbed (c) blue light is absorbed and no light is reflected so that the apple appears black.

8. Table answers:

<table>
<thead>
<tr>
<th>Mixed colors</th>
<th>Reflected color</th>
<th>Which colors of light are absorbed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>magenta + yellow</td>
<td>red</td>
<td>green absorbed by magenta</td>
</tr>
<tr>
<td>yellow + cyan</td>
<td>green</td>
<td>blue absorbed by yellow</td>
</tr>
<tr>
<td>cyan + magenta</td>
<td>blue</td>
<td>red absorbed by cyan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>green absorbed by magenta</td>
</tr>
</tbody>
</table>

9. If magenta and cyan paint are mixed, you get blue paint.

10. (a) The color green is made by mixing yellow and cyan.
    (b) The green photoreceptors in your eyes are stimulated by this color combination and the brain interprets the color as green.
    (c) Sample diagram:

![The additive primary colors](https://via.placeholder.com/150)

The additive primary colors are red, green, and blue.
Skill Sheet 25.2: The Human Eye

a. Cornea—refracts and focuses light.

b. Iris—pigmented part of the eye that opens or closes to change the size of the pupil.

c. Ciliary muscles—contract to change the shape of the lens.

d. Sclera—outer protective covering.

e. Vitreous humor—liquid inside of the eye.

f. Optic nerve—transmits signals from the retina to the brain.

g. Retina—thin layer of cells in the back of the eye that converts light into nerve signals.

h. Choroid—provides oxygen and nutrients to the retina.

i. Lens—refracts and focuses light.

j. Aqueous humor—liquid in the front part of the eye.

k. Pupil—opening in the iris that controls the amount of light entering the eye.

Skill Sheet 25.3: Measuring Angles

Answers are:

<table>
<thead>
<tr>
<th>Letter</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>56°</td>
</tr>
<tr>
<td>B</td>
<td>110°</td>
</tr>
<tr>
<td>C</td>
<td>10°</td>
</tr>
<tr>
<td>D</td>
<td>96°</td>
</tr>
<tr>
<td>E</td>
<td>167°</td>
</tr>
<tr>
<td>F</td>
<td>122°</td>
</tr>
<tr>
<td>G</td>
<td>34°</td>
</tr>
<tr>
<td>H</td>
<td>45°</td>
</tr>
<tr>
<td>I</td>
<td>19°</td>
</tr>
<tr>
<td>J</td>
<td>153°</td>
</tr>
<tr>
<td>K</td>
<td>131°</td>
</tr>
<tr>
<td>L</td>
<td>148°</td>
</tr>
<tr>
<td>M</td>
<td>81°</td>
</tr>
<tr>
<td>N</td>
<td>90°</td>
</tr>
<tr>
<td>O</td>
<td>73°</td>
</tr>
<tr>
<td>P</td>
<td>27°</td>
</tr>
<tr>
<td>Q</td>
<td>139°</td>
</tr>
</tbody>
</table>

Skill Sheet 25.3: Using Ray Diagrams

1. A is the correct answer. Light travels in straight lines and reflects off objects in all directions. This is why you can see something from different angles.

2. C is the correct answer. In this diagram, when light goes from air to glass it bends about 13 degrees from the path of the light ray in air. The light bends toward the normal to the air-glass surface because air has a lower index of refraction compared to glass. When the light re-enters the air, it bends about 13 degrees away for the light path in the glass and away from the normal.

   As a ray of light approaches glass at an angle, it bends (refracts) toward the normal. As it leaves the glass, it bends away from the normal. However, if a ray of light enters a piece of glass perpendicular to the glass surface, the light ray will slow, but not bend because it is already in line with the normal. This happens because the index of refraction for air is lower than the index of refraction for glass. The index of refraction is a ratio that tells you how much light is slowed when it passes through a certain material.

3. A is the correct answer. Light rays that approach the lens that are in line with a normal to the surface pass right through, slowing but not bending. This is what happens at the principal axis. However, due to the curvature of the lens, the parallel light rays above and below the principal axis, hit the lens surface at an angle. These rays bend toward the normal (this bending occurs toward the fat part of the lens) and are focused at the lens’ focal point. The rays diverge (move apart) past the focal point.

4. Diagram:

Skill Sheet 25.3: Reflection

1. Diagram at right:

2. The angle of reflection will be 20 degrees.

3. Each angle will measure 45 degrees.

4. Diagram at right:

5. The angle is 72 degrees. Therefore, the angles of incidence and reflection will each be 36 degrees.

6. The angles of incidence and reflection at point A are each 70 degrees; the angles of incidence and reflection at point B are each 21 degrees.
Skill Sheet 25.3: Refraction

Part 1 answers:
1. The index of refraction will never be less than one because that would require the speed of light in a material to be faster than the speed of light in a vacuum. Nothing in the universe travels faster than that.
2. The index of refraction for air is less than that of glass because a gas like air is so much less dense than a solid like glass. The light rays are slowed each time they bump into an atom or molecule because they are absorbed and re-emitted by the particle. A light ray in a solid bumps into many more particles than a light ray traveling through a gas.
3. Water: \(2.26 \times 10^8\); glass: \(2.0 \times 10^8\); diamond; \(1.24 \times 10^8\)
4. speed up
5. slow down

Part 2 answers:
1. The light ray is moving from low-\(n\) to high-\(n\) so it will bend toward the normal.
2. The light ray is moving from high-\(n\) to low-\(n\) so it will bend away from the normal.
3. The difference in \(n\) from diamond to water is 1.09 while the difference from sapphire to air is 0.770. The ray traveling from diamond to water experiences the greater change in \(n\) so it would bend more.
4. From left to right, material B is water, emerald, helium, cubic zirconia.

Skill Sheet 25.3: Drawing Ray Diagrams

1. Diagram:
   - The image is inverted as compared with the object.

2. Diagram:

3. A lens acts like a magnifying glass if an object is placed to the left of a converging lens at a distance less than the focal length. The lens bends the rays so that they appear to be coming from a larger, more distant object than the real object. These rays you see form a virtual image. The image is virtual because the rays appear to come from an image, but don’t actually meet.

Skill Sheet 26.1: Astronomical Units

1. 9.53 AU
2. 0.72 AU
3. 58 million kilometers
4. 2.87 billion kilometers
5. Less. The moon is not nearly as far from Earth as the Sun.
6. Uranus
7. Mercury
8. Saturn
9. Saturn
10. yes

Skill Sheet 26.1: Gravity Problems

Table 1 answers:

<table>
<thead>
<tr>
<th>Planet</th>
<th>Force of gravity in Newtons (N)</th>
<th>Value compared to Earth’s gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>3.7</td>
<td>0.38</td>
</tr>
<tr>
<td>Venus</td>
<td>8.9</td>
<td>0.91</td>
</tr>
<tr>
<td>Earth</td>
<td>9.8</td>
<td>1</td>
</tr>
<tr>
<td>Mars</td>
<td>3.7</td>
<td>0.38</td>
</tr>
<tr>
<td>Jupiter</td>
<td>23.1</td>
<td>2.36</td>
</tr>
<tr>
<td>Saturn</td>
<td>9.0</td>
<td>0.92</td>
</tr>
<tr>
<td>Uranus</td>
<td>8.7</td>
<td>0.89</td>
</tr>
<tr>
<td>Neptune</td>
<td>11.0</td>
<td>1.12</td>
</tr>
<tr>
<td>Pluto</td>
<td>0.6</td>
<td>0.06</td>
</tr>
</tbody>
</table>

1. 9.5 pounds on Neptune
2. 1,029 newtons on Saturn
3. The baby weighs 44.1 Newtons on Earth which is equal to 9.8 pounds.
4. Venus, Jupiter, Neptune, Pluto, then Saturn
5. Answer:
   \[
   \text{Gravity} = \left( \frac{6.67 \times 10^{-11} \text{N} \cdot \text{m}^2}{\text{kg}^2} \right) \left( \frac{6.4 \times 10^{24} \text{m}^2}{(5.7 \times 10^{26})} \right) \left( \frac{9.8 \text{ m/s}^2}{(6.52 \times 10^{11})^2} \right) = 5.72 \times 10^{17} \text{ N} 
   \]

Skill Sheet 26.1: Universal Gravitation

1. \(F = 9.34 \times 10^{-6} \text{ N}\). This is basically the force between you and your car when you are at the door.
2. \(5.28 \times 10^{-10} \text{ N}\)
3. \(4.42 \text{ N}\)
4. \(7.33 \times 10^{22} \text{ kilograms}\)
5. Answers are:
   a. \(9.8 \text{ N/kg} = 9.8 \text{ kg-m/sec}^2 \cdot \text{kg} = 9.8 \text{ m/sec}^2\)
   b. Acceleration due to the force of gravity of Earth.
   c. Earth’s mass and radius.
   6. \(1.99 \times 10^{20} \text{ N}\)
   7. \(4.848 \text{ N}\)
   8. \(3.52 \times 10^{22} \text{ N}\)
### Skill Sheet 26.1: Johannes Kepler

1. Copernicus’ idea that the sun was at the center of the solar system was revolutionary because people believed Earth was the center of the universe.

2. Brahe helped Kepler make his important discoveries in several ways. Brahe invited Kepler to come and work with him. He asked Kepler to solve the problem of Mars’ orbit. When Brahe died, Kepler gained all of his observational records. Kepler also got Brahe’s job.

3. Kepler used mathematics to solve problems in astronomy. For this reason, Kepler is considered a theoretical positional astronomer. Brahe was an observational astronomer. He made and recorded the motion of planets and the stars in the night sky without a telescope. Galileo was also an observational astronomer. He used and improved the telescope, but he was not a mathematician.

4. Kepler’s discovery that Mars traveled in an elliptical orbit was different than Copernicus’ theory which said planets traveled in circular orbits.

5. Kepler’s three laws of planetary motion are:
   - Planets orbit the sun in an elliptical orbit with the sun in one of the foci.
   - The law of areas says that planets speed up as they travel in their orbit closer to the sun and they slow down as they travel in their orbit farther away from the sun.
   - The harmonic law says that a planet’s distance from the sun is mathematically related to the amount of time it takes the planet to revolve around the sun.

6. Three examples of a paradigm shift:
   - Copernicus’ theory that the sun and not Earth was the center of the solar system.
   - Kepler’s discovery that planets orbit the sun in an elliptical and not a circular path.
   - Newton’s laws of gravitational attraction.
Skill Sheet 26.1: Measuring the Moon’s Diameter

Part 1 answers:
There are no questions to answer for Part 1.

Part 2 answers:
1. AC = 6 cm
   AD = 6 cm
   AB = 2 cm
   AE = 2 cm
   BE = 2 cm
   CD = 6 cm
2. Distance AB is 1/3 of the distance AC
3. Distance BE is 1/3 of the distance CD
4. If a triangle is drawn inside a larger triangle so that they share the same vertex and have bases that are parallel, then the sides and base of the small triangle will be proportional to the sides and base of the large triangle.

Part 3 answers:
Answers will vary. A string distance of about 1 meter will yield good results.

Part 4 answers:
1. A and D are the same, but D is most helpful because it is set up with the unknown in the numerator.
2. Answers will vary. A string distance of about 1 meter should give a value close to the accepted moon diameter; 3,476,000 meters.
3. The semi-circle diameter is the base of the small triangle; the base of the large triangle is what we are solving for: the

Skill Sheet 26.2: Benjamin Banneker

1. An understanding of gear ratios was necessary for building the clock. He used geometry skills to figure out how to create a large-scale model of each tiny piece of the watch he examined.
2. Personal strengths identified from the reading include strong spacial skills (building the clock), creativity and problem solving skills (irrigation system), curiosity and attention to detail (astronomical observations, cicada observations, and almanac), concern for others (letter to Jefferson).
3. Dates are as follows:
   a. 1863
   b. 1865
   c. 1920
   d. 1954
4. Any three of the following answers is correct. Banneker’s accomplishments include:
   a. Designed an irrigation system
   b. Documented cycle of 17-year cicada
   c. Published detailed astronomical calculations in popular almanacs
   d. Served as surveyor of territory that became Washington D.C.
   e. Banneker evidently had a strong innate curiosity about the natural world. He was passionate about improving the welfare of the black men and women in the United States and his letter to Jefferson stated that he hoped his scientific work would be seen as proof that people of all races are created equal.
   f. Banneker’s puzzles can be found on several web sites. Using an Internet search engine, look for “Benjamin Banneker” + puzzle. Some of the sites publish the answers while others do not. Here is one of Banneker’s puzzles taken from the web site www.thefriendsofbanneker.org. Note that the puzzle was written in the 1700’s and is from Banneker’s personal journals.

THE PUZZLE ABOUT TRIANGLES
“Suppose ladder 60 feet long be placed in a Street so as to reach a window on the one side 37 feet high, and without moving it at bottom, will reach another window on the other side of the Street which is 23 feet high, requiring the breadth of the Street.” [No solution recorded in historic records.]

Skill Sheet 26.3: Touring the Solar System

Part 1 answers:

<table>
<thead>
<tr>
<th>Legs of the trip</th>
<th>Distance travelled for each leg (km)</th>
<th>Hours travelled</th>
<th>Days travelled</th>
<th>Years travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth to Mars</td>
<td>78,000,000</td>
<td>86,666</td>
<td>3,611</td>
<td>9.9</td>
</tr>
<tr>
<td>Mars to Saturn</td>
<td>1,202,000,000</td>
<td>1,335,600</td>
<td>55,648</td>
<td>152</td>
</tr>
<tr>
<td>Saturn to Neptune</td>
<td>3,070,000,000</td>
<td>3,411,100</td>
<td>142,130</td>
<td>389</td>
</tr>
<tr>
<td>Neptune to Venus</td>
<td>4,392,000,000</td>
<td>4,880,000</td>
<td>203,330</td>
<td>557</td>
</tr>
<tr>
<td>Venus to Earth</td>
<td>42,000,000</td>
<td>46,667</td>
<td>1,944</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Part 2 answers:
1. \(\frac{8 \text{ glasses}}{1 \text{ day}} \times 3,611 \text{ days} = 28,888 \text{ glasses of water}\)
2. \(\frac{2,000 \text{ food calories}}{1 \text{ day}} \times 203,330 \text{ days} = 406,660,000 \text{ food calories}\)
3. Pack foods high in fat for the journey because you get more calories per gram than from proteins and carbohydrates and you want a payload minimum.
4. Your entire trip will take 1,113 years, so you will need that many turkeys.

Part 3 answers:
1. Jupiter; it has 39 moons.
2. Venus has the hottest surface temperature; Neptune has the coldest surface temperature.
3. Venus; it takes 243 Earth days to rotate once around its axis.
4. Jupiter has the shorter day; it takes 0.41 Earth days to rotate.
5. Jupiter; it has the strongest gravitational force. You will weigh 2.36 times your Earth weight in Newtons.
6. Jupiter; it has the largest diameter of 142,796 km.
7. Jupiter; it has the strongest gravitational force, therefore the spaceship must orbit at a fast speed to balance the gravitational force pulling the spaceship towards Jupiter’s surface.

Skill Sheet 27.1: The Sun: A Cross-Section

A. Corona
B. Chromosphere
C. Photosphere
Skill Sheet 27.1: Arthur Walker

1. You may wish to have students compare and contrast their definitions with those of a student who used a different source. Discuss with the class the value of using a variety of sources and the importance of crediting these sources.

2. Walker didn’t allow prejudice to dissuade him from pursuit of his goals. As a result he made important contributions to science and society. He also spent time and energy helping other members of minority groups achieve their own goals.

3. A spectrometer separates light into spectral lines. Each element has its own unique pattern of lines, so scientists use the patterns to identify the ions in the corona. Temperature can be determined by the colors seen in the corona. For example, red indicates cooler areas, while bluish light indicates a very hot area.

4. Magazines and journals that may have one of Walker’s photographs can be found at public and university libraries. You might suggest that students contact a reference librarian for assistance.

5. The committee found that the accident was caused by a failure in a seal of the right solid rocket booster. They also made nine specific recommendations of changes to be made to the space shuttle program prior to another flight. These steps included:
   a. Redesign the solid rocket boosters.
   b. Upgrade the space shuttle landing system.
   c. Create a crew escape system that would allow astronauts to parachute to safety in certain situations.
   d. Improve quality control in both NASA and contractor manufacturing.
   e. Reorganize the space shuttle program to place astronauts in key decision-making roles.
   f. Revoke any waivers to current safety standards, especially those related to launches in poor weather conditions.
   g. Open the review of a mission’s technical issues to independent government agencies.
   h. Set up an extensive open review system to evaluate issues related to each particular mission.
   i. Provide a means of anonymous, reprisal-free reporting of space shuttle safety concerns by any NASA employee or contractor.

Skill Sheet 27.2: The Inverse Square Law

1. 0.25 W/m²
2. one-ninth
3. 24,204 km (four times the original distance)
4. 55.6 N
5. It is 9 times more intense 2 meters away.
6. It is 16 times more intense at 1 meter than at 4 meters away.

Skill Sheet 28.1: Scientific Notation

1. Answers are:
   a. 122,200
   b. 90,100,000
   c. 3,600
   d. 700.3
   e. 52,722

2. Answers are:
   a. \(4.051 \times 10^6\)
   b. \(1.3 \times 10^9\)
   c. \(1.003 \times 10^6\)
   d. \(1.602 \times 10^4\)
   e. \(9.9999 \times 10^{12}\)

Skill Sheet 28.1: Understanding Light Years

1. \(5.7 \times 10^{13}\) km
2. \(4.3 \times 10^{19}\) km
3. \(3.8 \times 10^{10}\) km
4. 5,344 ly
5. \(1.16 \times 10^{-12}\) ly
6. 1.16 ly
7. 1.200 ly
8. \(8.0478 \times 10^{14}\) km
9. \(4,280,056,000\) km, or \(4.28 \times 10^9\) km
10. \(0.000026336\) AU, or \(2.6 \times 10^{-5}\) AU
11. 63,288 AU
12. \(0.000026336\) AU, or \(2.6 \times 10^{-5}\) AU
13. 63,288 AU
14. \(8.0478 \times 10^{14}\) km

Skill Sheet 28.1: Parsecs

1. 1.84 pc
2. \(1.38 \times 10^6\) pc
3. \(1.23 \times 10^3\) pc
4. \(2.55 \times 10^1\) pc or 25.5 pc
5. \(4.85 \times 10^4\) pc
6. 54.8 pc
7. 30,000 pc
8. 770,000 pc
9. 26 pc
10. \(1.44 \times 10^{-4}\) pc

Skill Sheet 28.1: Edwin Hubble

1. Answers are:
   - spectroscopy—a method of studying an object by examining the visible light and other electromagnetic waves it creates.
   - cosmology—the astrophysical study of the history, structure, and constituent dynamics of the universe.
2. Outstanding students from around the world are nominated for the prestigious Rhodes scholarship. Rhodes Scholars are invited to study at the University of Oxford in England. Only about 90 students are selected each year. This scholarship is awarded by the Rhodes Trust, a foundation set up by Cecil Rhodes in 1902.
3. A larger telescope allows more light to be collected by the mirrors and/or lenses of the telescope. More light allows for a clearer image, which can then be magnified to show greater detail.
4. Example answer: Edwin was incredibly excited today. Albert Einstein came to visit him, and he even thanked him for all of his hard work. It’s almost unbelievable! The most celebrated scientist of our lifetime came to visit him. Just to be associated with Einstein is an honor, let alone be thanked by him. Edwin works very hard, and he must be very proud of his new discoveries that have changed the world of astronomy.

5. The fact that the universe is expanding implies that it must have been smaller in the past than it is today. The expanding universe implies that the universe must have had a beginning. This idea led to the development of the Big Bang theory, which says that the universe exploded outward from a single point smaller than an atom into the vast expanse of today’s universe.

Skill Sheet 28.2: Light Intensity

1. Example problem: 4.8 W/m²
2. 0.0478 W/m²
3. 0.0119 W/m²
4. If distance from a light source doubles, then light intensity decreases by a factor of 4. Example: 4 × 0.0119 W/m² approximately equals 0.0478 W/m² (see questions 2 and 3).
5. Answers are:
   a. 0.005 W/m²
   b. 0.05 W/m²
   c. 0.5 W/m²
   d. 5 W/m²

Skill Sheet 28.2: Henrietta Leavitt

1. Leavitt discovered new variable stars by comparing photographic plates. The photographs showed the same regions in the sky, but at different times. This allowed Leavitt to examine the photos and identify stars that had changed in size over time.
2. Leavitt studied Cepheid stars and found an inverse relationship between a star’s brightness cycle and its magnitude. A stronger star took longer to cycle between brightness and dimness. As a result, she developed the Period-Luminosity relation.
3. The asteroid is called 5383 Leavitt.
4. The observatory was founded in 1839 and currently conducts research in astronomy and astrophysics.
5. Example Answers:
   Ejnar Hertzsprung:
   • Danish astronomer born October 8, 1873
   • Found the distance to the Small Magellan Cloud located outside of the Milky Way Galaxy in 1913.
   Harlow Shapley:
   • Astronomer born November 2, 1885 in Nashville, Missouri
   • In addition to being an astronomer, Shapley was a writer.
   • Shapley determined the size of the Milky Way Galaxy.
   Edwin Hubble:
   • Astronomer born November 29, 1889 in Marshfield, Missouri.
   • Earned an undergraduate degree in math and astronomy, and went on to study law.
   • Developed a classification system for galaxies and created Hubble’s Law which helped astronomers determine the age of the universe.

Skill Sheet 28.2: Calculating Luminosity

1. luminosity = 30 watts
   power rating on bulb = 300 watts
2. luminosity = 1 watt
   power rating on bulb = 10 watts
3. Challenge: luminosity = 1.370 \times 10^3(4\pi)(1.5 \times 10^{11})^2
   = 1.370 \times 10^3(4\pi)(2.25 \times 10^{22})
   = 39 \times 10^{25}
   = 3.9 \times 10^{26} \text{ watts}

Skill Sheet 28.3: Doppler Shift

Part 1 answers:
1. Graphic, right
2a. B and D
2b. A and C
2c. C
2d. B

Part 2 answers:
1. The star is moving away from Earth at a speed of 5.6 \times 10^6 \text{ m/s}.
2. The star is moving toward Earth at a speed of 8.6 \times 10^6 \text{ m/s}.
3. Galaxy B is moving fastest because it has shifted farther toward the red (15 nm) than Galaxy A (9 nm).
4. It supports the Big Bang. This theory states that the universe began from a single point and has been expanding ever since.