CONTENTS IN BRIEF

TABLE OF CONTENTS

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Your eStudentEdition, found at **connectED.mcgraw-hill.com,** includes interactive features to improve your understanding of the physics content presented in each chapter.

Concepts in Motion include animations and interactive diagrams to help explain topics and eliminate misconceptions. BrainPOP **Videos** connect physics to your world. **Virtual Investigations** are online laboratory experiences, and **Personal Tutors** provide video demonstrations of solutions to various example problems.

iLab Station

Throughout each chapter, you will see references to laboratory experiences from the **iLabStation,** your online resource for lab activities and worksheets.

Each chapter begins with a **LaunchLAB,** an introductory laboratory investigation designed to introduce the concepts in that chapter. **MiniLABs** are short investigations that can improve your understanding of physics content. You will also find one or more **PhysicsLABs** in each chapter, providing opportunities for more in-depth investigations.

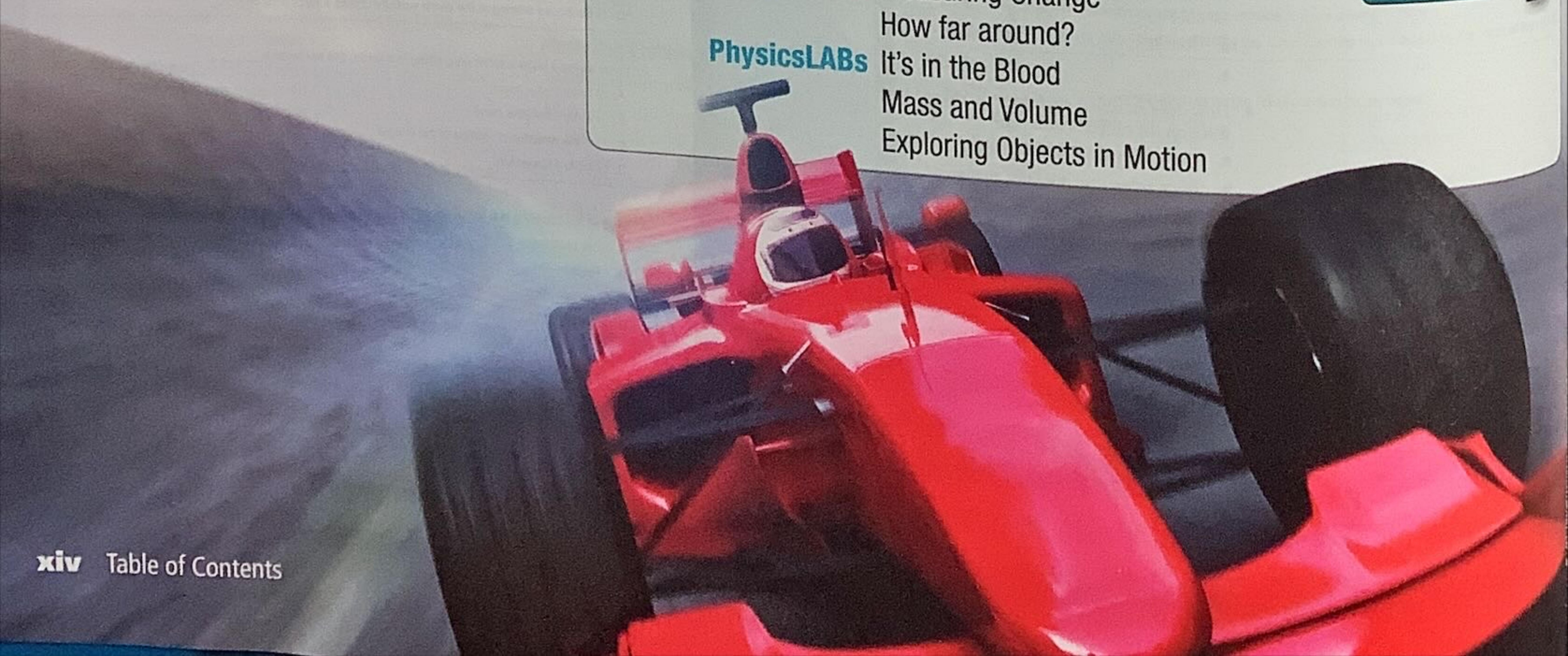
CHAPTER 1

Go online!

Concepts in Motion Precision and Accuracy
Graphing Data
BrainPOPs Scientific Methods
Measuring Matter

iLab Station

LaunchLAB Mass and Falling Objects
MiniLABs Measuring Change
How far around?
PhysicsLABs It's in the Blood
Mass and Volume
Exploring Objects in Motion



Mechanics

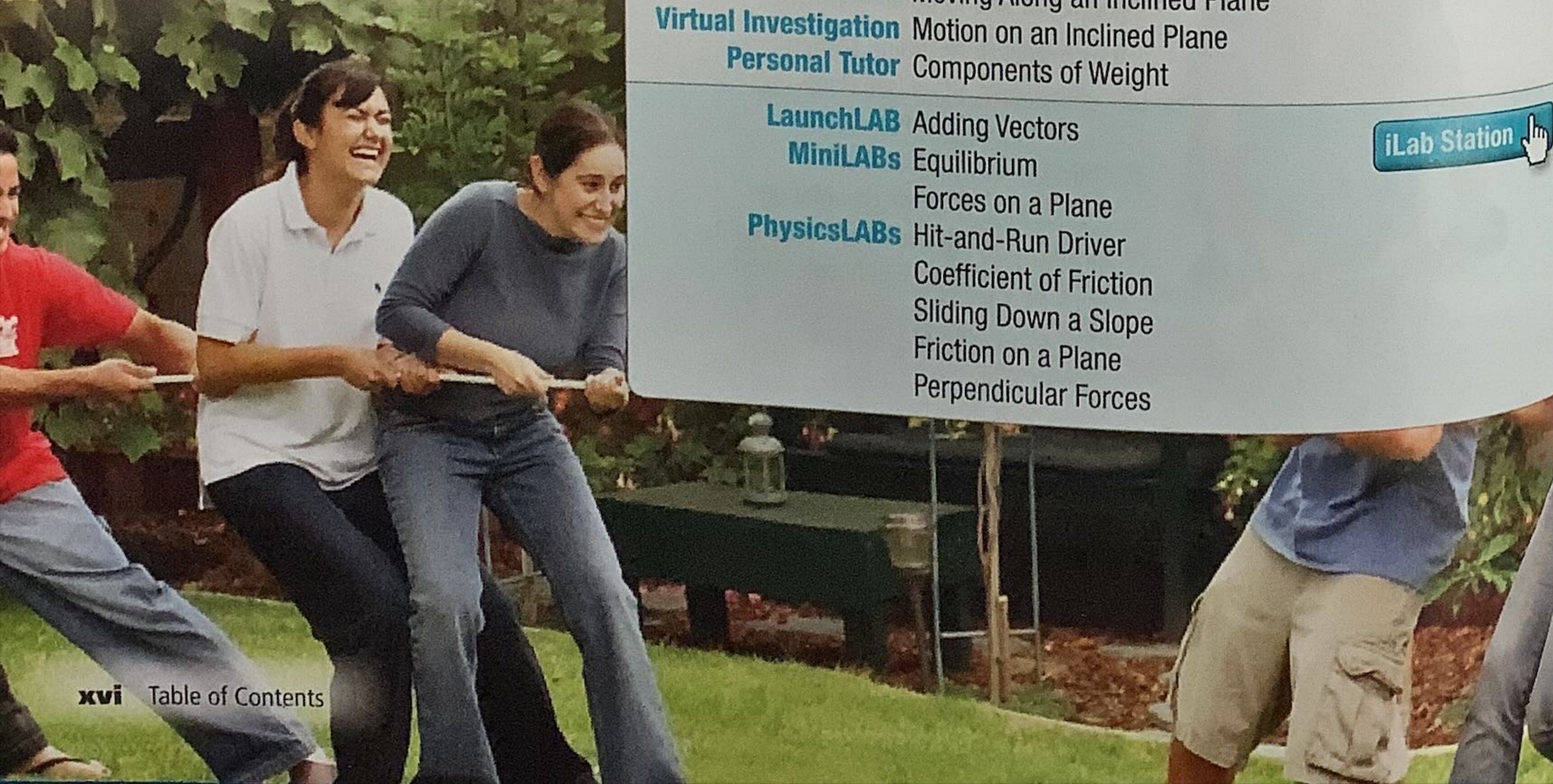
CHAPTER 2

CHAPTER 3

Mechanics

CHAPTER 4

CHAPTER 5



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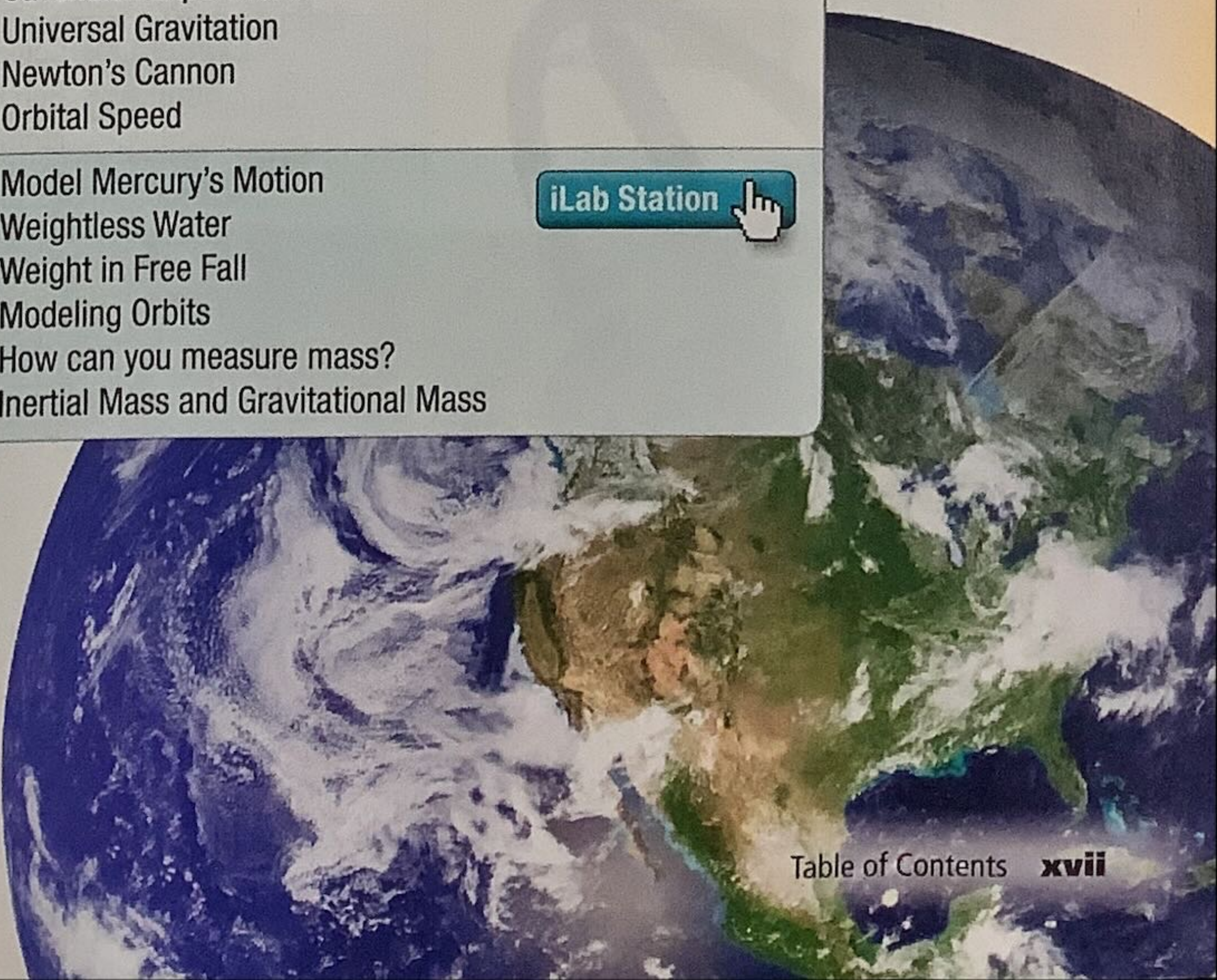
CHAPTER 6

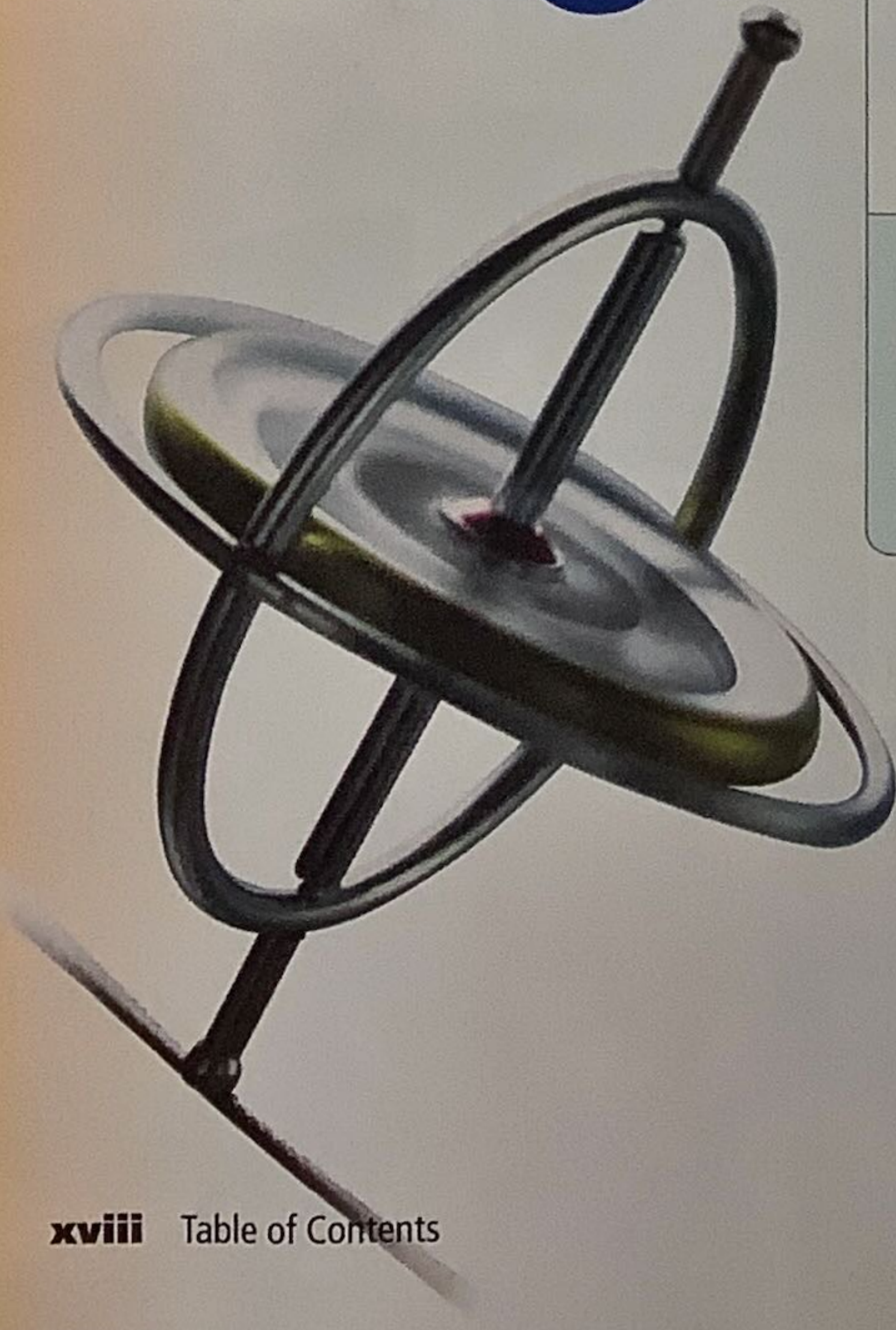
CHAPTER 7



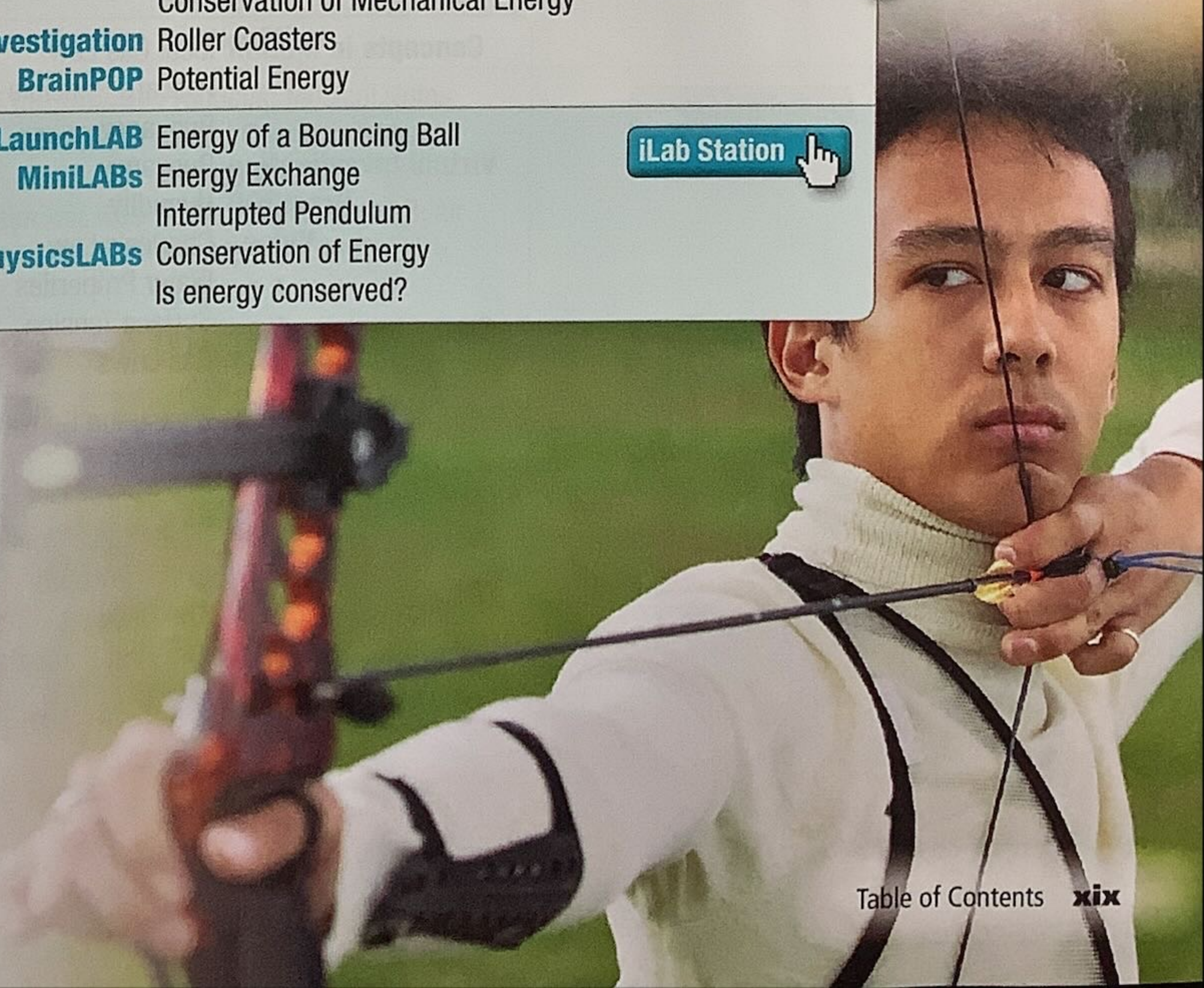
Mechanics

CHAPTER 8

CHAPTER 9



Energy



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Energy

CHAPTER 12

Go online!

Concepts in Motions Using Calorimetry to Determine Specific Heat
Changes of States
Heat Engine
Virtual Investigations Phase Changes
Kinetic Theory and How Energy Spreads Out
BrainPOP How Matter Changes States
Personal Tutor Amount of Heat

iLab Station

LaunchLAB Thermal Energy Transfer
MiniLABs Melting
Convert Energy
PhysicsLABs Solar Collectors
Heating and Cooling
How many calories are there?
Heat of Fusion

CHAPTER 13

Go online!

Concepts in Motion Ideal Gas Law
Pascal's Principle
Buoyancy
Virtual Investigation Buoyancy
BrainPOP Humidity
Videos Charles's Law
Water Properties
Surface Tension
Personal Tutor Gas Laws

iLab Station

LaunchLAB Measuring Buoyancy
MiniLABs Pressure
Jumpers
PhysicsLABs Evaporative Cooling
Under Pressure
The Buoyant Force of Water
The First Forensic Scientist

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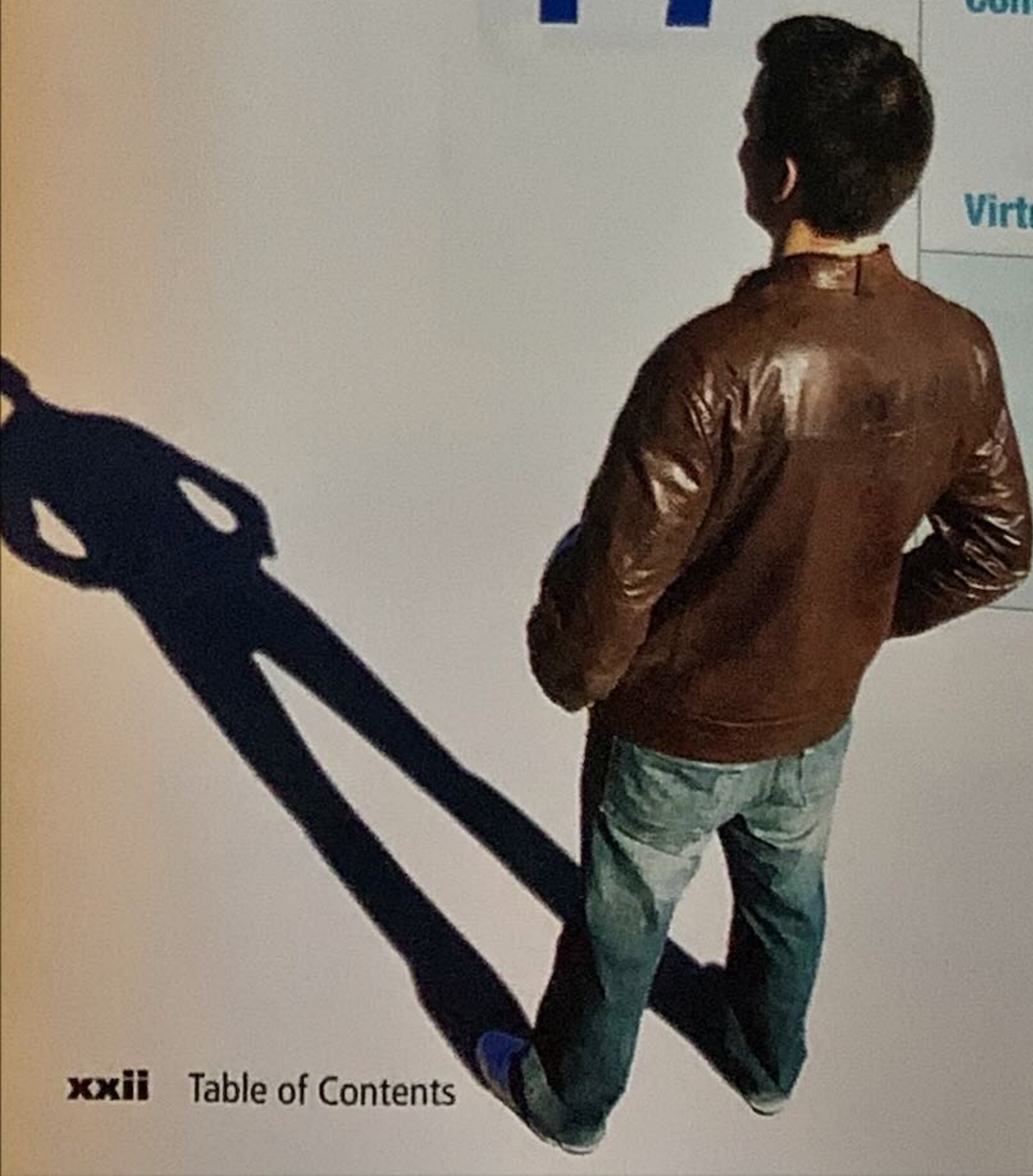
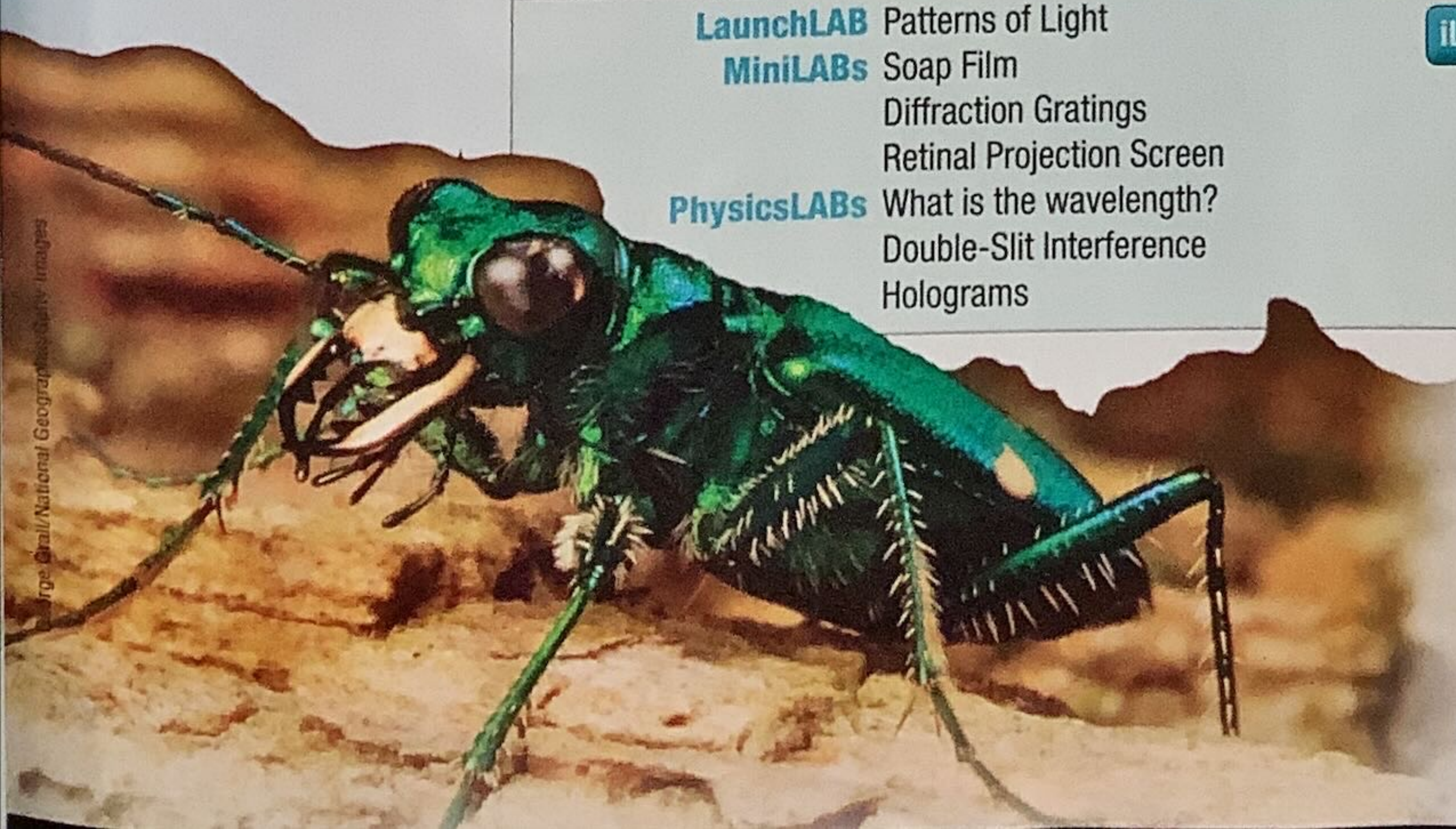
Waves and Light

Waves and Light

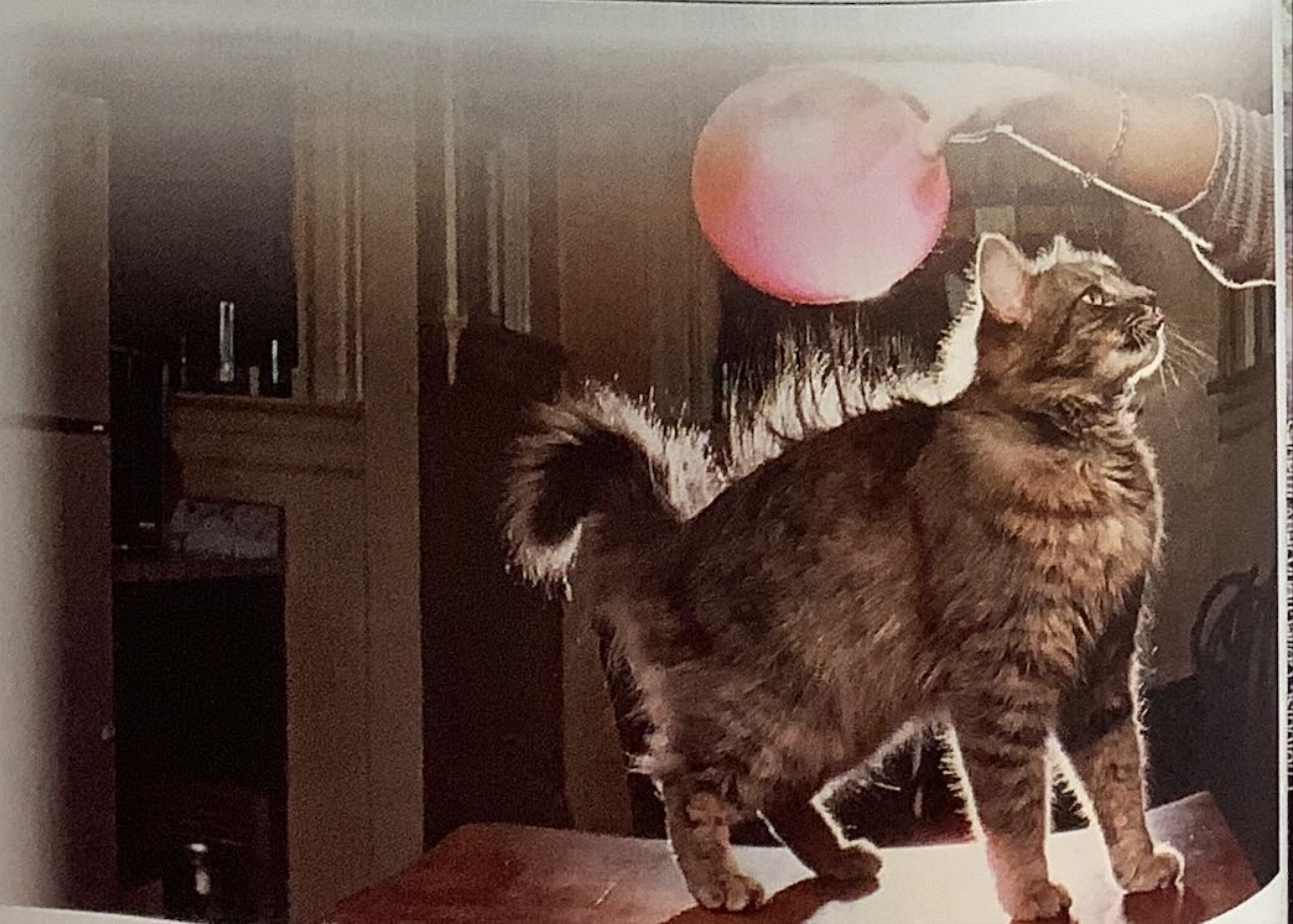




Electricity and Magnetism

CHAPTER 20

CHAPTER 21



Electricity and Magnetism

CHAPTER 22

Electric Current

Go online!

Concepts in Motion Current and Circuits; Electric Circuits

Virtual Investigations Circuits and Ohm's Law

BrainPOP Current Electricity

Personal Tutor Electric Heat

iLab Station

LaunchLAB Light the Bulb

MiniLABs Current Affairs; Making Electrical Energy

PhysicsLABs Voltage, Current, and Resistance; Variables in Circuits; Energy Conservation

CHAPTER 23

Series and Parallel Circuits

Go online!

Concepts in Motion Circuit Lab

Virtual Investigation Electric Circuits

Video Electric Circuits

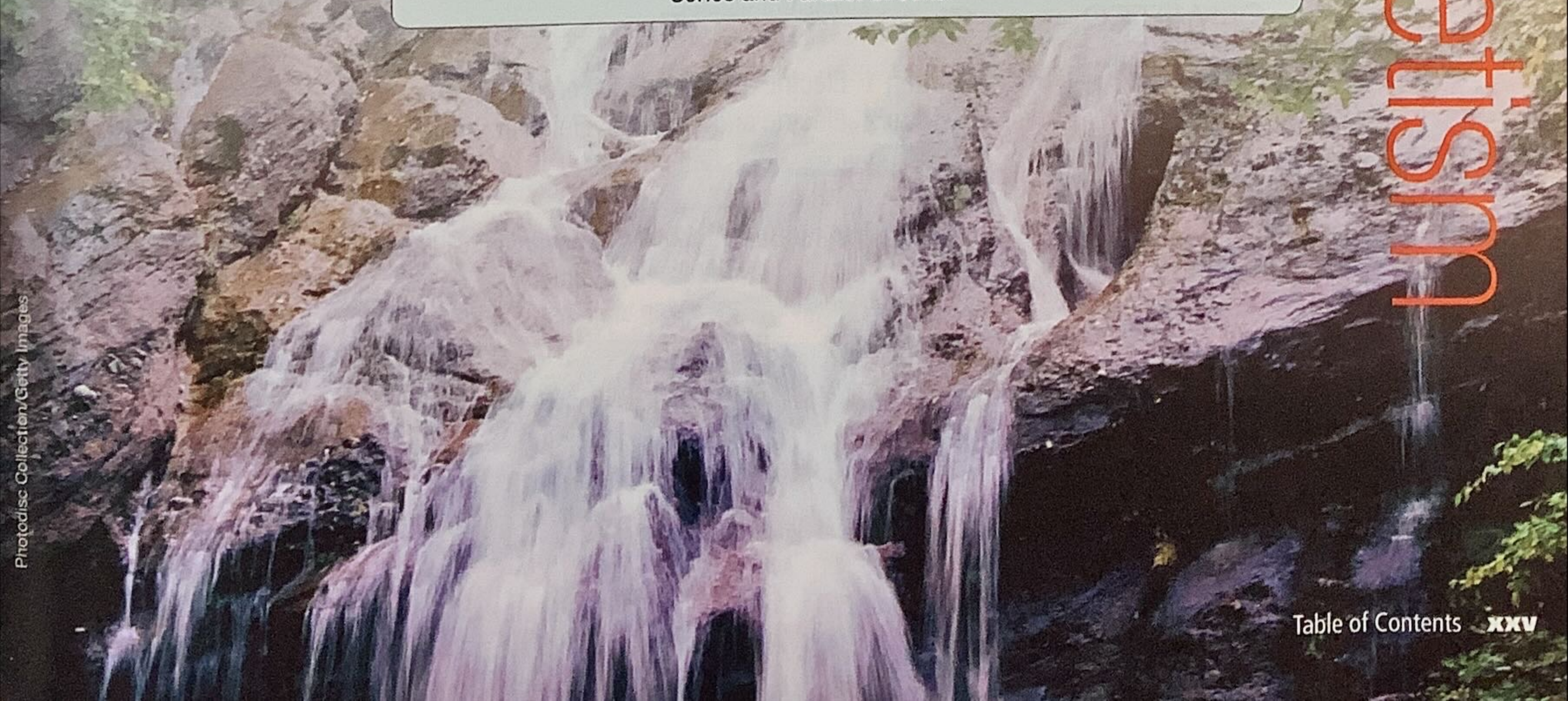
Personal Tutor Resistance and Current

iLab Station

LaunchLAB Fuses and Electric Circuits

MiniLABs Parallel Resistance; Parallel Circuit Measurements

PhysicsLABs Resistors in Series Circuits; Circuit Configurations; How do parallel resistors work?; Series and Parallel Circuits



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Electricity and Magnetism

Subatomic Physics

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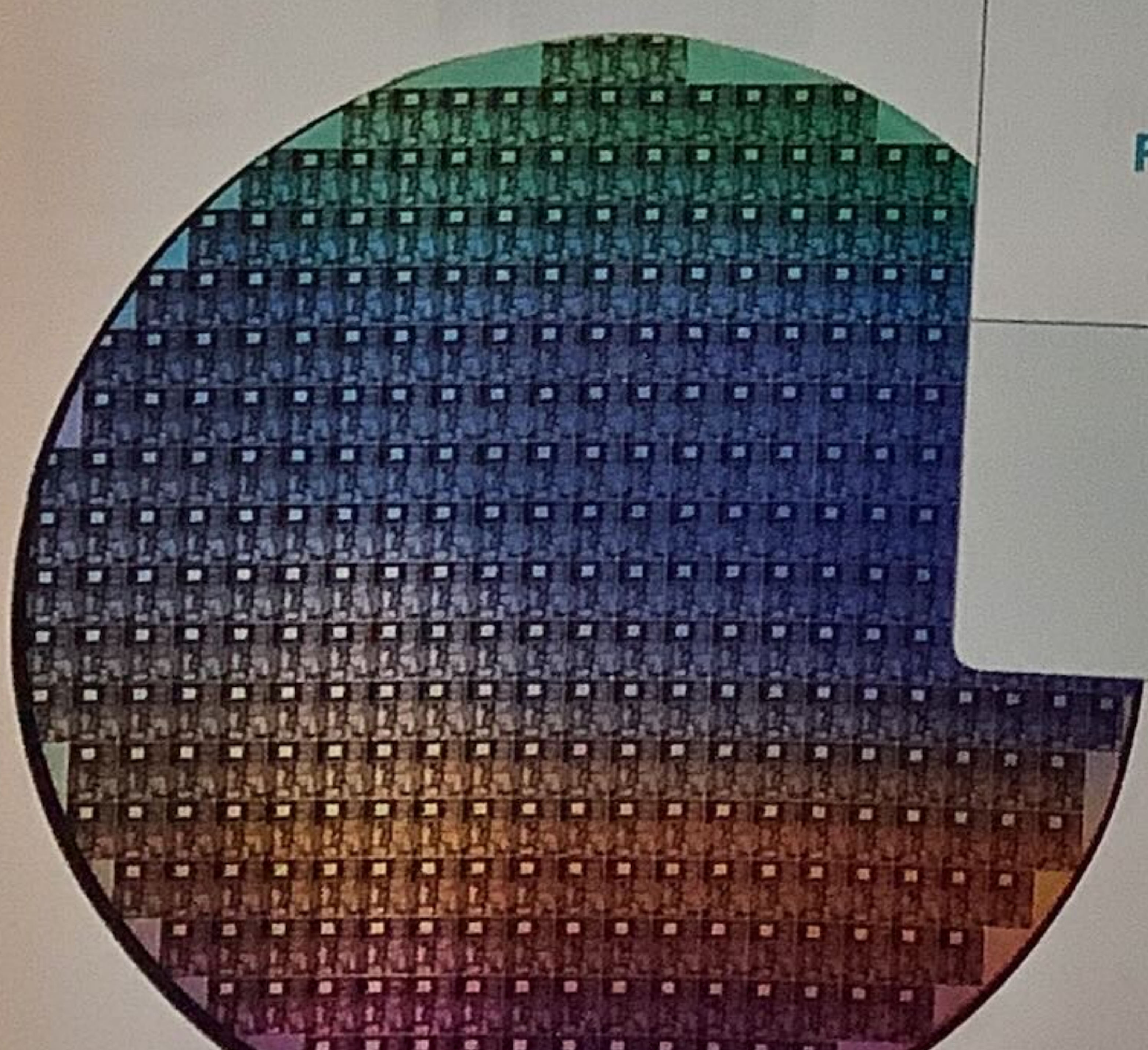
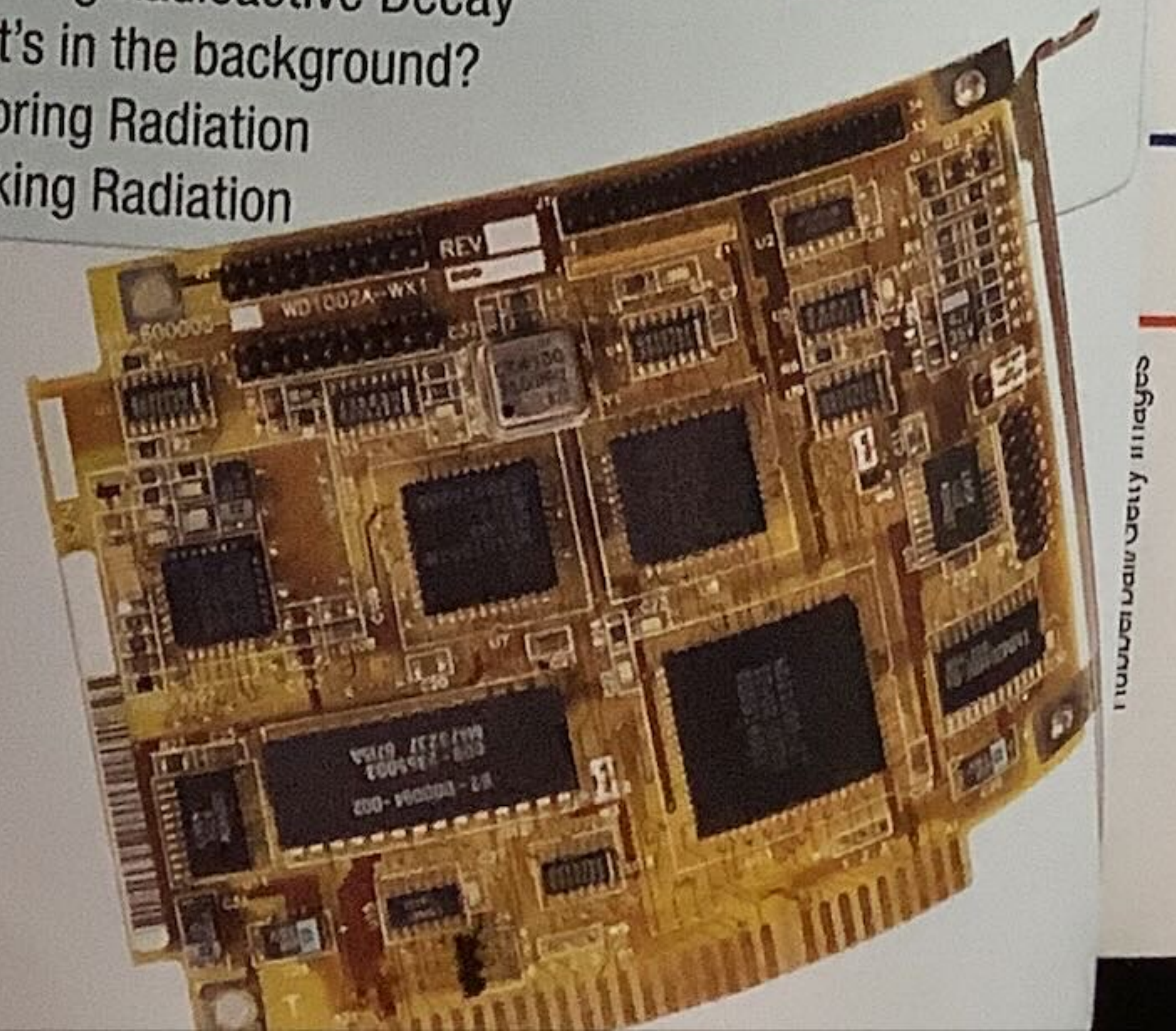
Subatomic Physics





STUDY GUIDE

BIGIDEA Physicists use scientific methods to investigate energy and matter.

SECTION 1 Methods of Science

VOCABULARY
- **physics** *(p. 4)*
- **scientific methods** *(p. 5)*
- **hypothesis** *(p. 6)*
- **model** *(p. 7)*
- **scientific theory** *(p. 8)*
- **scientific law** *(p. 8)*

MAINIDEA Scientific investigations do not always proceed with identical steps but do contain similar methods.

- Scientific methods include making observations and asking questions about the natural world.
- Scientists use models to represent things that may be too small or too large, processes that take too much time to see completely, or a material that is hazardous.
- A scientific theory is an explanation of things or events based on knowledge gained from observations and investigations. A scientific law is a statement about what happens in nature, which seems to be true all the time.
- Science can't explain or solve everything. Questions about opinions or values can't be tested.

SECTION 2 Mathematics and Physics

VOCABULARY
- **dimensional analysis** *(p. 11)*
- **significant figures** *(p. 12)*

MAINIDEA We use math to express concepts in physics.

- Using the metric system helps scientists around the world communicate more easily.
- Dimensional analysis is used to check that an answer will be in the correct units.
- Significant figures are the valid digits in a measurement.

SECTION 3 Measurement

VOCABULARY
- **measurement** *(p. 14)*
- **precision** *(p. 15)*
- **accuracy** *(p. 16)*

MAINIDEA Making careful measurements allows scientists to repeat experiments and compare results.

- Measurements are reported with uncertainty because a new measurement that is within the margin of uncertainty confirms the old measurement.
- Precision is the degree of exactness with which a quantity is measured. Accuracy is the extent to which a measurement matches the true value.
- A common source of error that occurs when making a measurement is the angle at which an instrument is read. If the scale of an instrument is read at an angle, as opposed to at eye level, the measurement will be less accurate.

SECTION 4 Graphing Data

VOCABULARY
- **independent variable** *(p. 18)*
- **dependent variable** *(p. 18)*
- **line of best fit** *(p. 18)*
- **linear relationship** *(p. 20)*
- **quadratic relationship** *(p. 21)*
- **inverse relationship** *(p. 22)*

MAINIDEA Graphs make it easier to interpret data, identify trends, and show relationships among a set of variables.

- Graphs contain information about the relationships among variables. Patterns that are not immediately evident in a list of numbers are seen more easily when the data are graphed.
- Common relationships shown in graphs include linear relationships, quadratic relationships, and inverse relationships. In a linear relationship the dependent variable varies linearly with the independent variable. A quadratic relationship occurs when one variable depends on the square of another. In an inverse relationship, one variable depends on the inverse of the other variable.
- Scientists use models and relationships between variables to make predictions.

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Vocabulary Practice

STUDY GUIDE

BIG IDEA You can use displacement and velocity to describe an object's motion.

SECTION 1 Picturing Motion

VOCABULARY
- **motion diagram** *(p. 36)*
- **particle model** *(p. 36)*

MAIN IDEA You can use motion diagrams to show how an object's position changes over time.

- A motion diagram shows the position of an object at successive equal time intervals.
- In a particle model motion diagram, an object's position at successive times is represented by a series of dots. The spacing between dots indicates whether the object is moving faster or slower.

SECTION 2 Where and When?

VOCABULARY
- **coordinate system** *(p. 37)*
- **origin** *(p. 37)*
- **position** *(p. 37)*
- **distance** *(p. 37)*
- **magnitude** *(p. 38)*
- **vector** *(p. 38)*
- **scalar** *(p. 38)*
- **time interval** *(p. 38)*
- **displacement** *(p. 39)*
- **resultant** *(p. 40)*

MAIN IDEA A coordinate system is helpful when you are describing motion.

- A coordinate system gives the location of the zero point of the variable you are studying and the direction in which the values of the variable increase.
- A vector drawn from the origin of a coordinate system to an object indicates the object's position in that coordinate system. The directions chosen as positive and negative on the coordinate system determine whether the objects' positions are positive or negative in the coordinate system.
- A time interval is the difference between two times.

$$\Delta t = t_f - t_i$$

- Change in position is displacement, which has both magnitude and direction.

$$\Delta \mathbf{x} = \mathbf{x}_f - \mathbf{x}_i$$

- On a motion diagram, the displacement vector's length represents how far the object was displaced. The vector points in the direction of the displacement, from $\mathbf{x}_i$ to $\mathbf{x}_f$.

SECTION 3 Position-Time Graphs

VOCABULARY
- **position-time graph** *(p. 41)*
- **instantaneous position** *(p. 43)*

MAIN IDEA You can use a position-time graph to determine an object's position at a certain time.

- Position-time graphs provide information about the motion of objects. They also might indicate where and when two objects meet.
- The line on a position-time graph describes an object's position at each time.
- Motion can be described using words, motion diagrams, data tables, or graphs.

SECTION 4 How Fast?

VOCABULARY
- **average velocity** *(p. 47)*
- **average speed** *(p. 47)*
- **instantaneous velocity** *(p. 49)*

MAIN IDEA An object's velocity is the rate of change in its position.

- An object's velocity tells how fast it is moving and in what direction it is moving.
- Speed is the magnitude of velocity.
- Slope on a position-time graph describes the average velocity of the object.

$$\bar{\mathbf{v}} \equiv \frac{\Delta \mathbf{x}}{\Delta t} = \frac{\mathbf{x}_f - \mathbf{x}_i}{t_f - t_i}$$

- You can represent motion with pictures and physical models. A simple equation relates an object's initial position ($\mathbf{x}_i$), its constant average velocity ($\bar{\mathbf{v}}$), its position ($\mathbf{x}$), and the time (t) since the object was at its initial position.

$$\mathbf{x} = \bar{\mathbf{v}}t + \mathbf{x}_i$$

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Acceleration is the rate of change in an object's velocity.

VOCABULARY
- **acceleration** *(p. 61)*
- **velocity-time graph** *(p. 63)*
- **average acceleration** *(p. 64)*
- **instantaneous acceleration** *(p. 64)*

SECTION 1 Acceleration

MAINIDEA An object accelerates when its velocity changes—that is, when it speeds up, slows down, or changes direction.

- Acceleration is the rate at which an object's velocity changes.
- Velocity and acceleration are not the same thing. An object moving with constant velocity has zero acceleration. When the velocity and the acceleration of an object are in the same direction, the object speeds up; when they are in opposite directions, the object slows down.
- You can use a velocity-time graph to find the velocity and the acceleration of an object. The average acceleration of an object is the slope of its velocity-time graph.

$$\bar{\boldsymbol{a}} \equiv \frac{\Delta \boldsymbol{v}}{\Delta t} = \frac{\boldsymbol{v}_f - \boldsymbol{v}_i}{t_f - t_i}$$

SECTION 2 Motion with Constant Acceleration

MAINIDEA For an object with constant acceleration, the relationships among position, velocity, acceleration, and time can be described by graphs and equations.

- If an object is moving with constant acceleration, its position-time graph is a parabola, and its velocity-time graph is a straight line.
- The area under an object's velocity-time graph is its displacement.
- In motion with constant acceleration, position, velocity, acceleration, and time are related:

$$\boldsymbol{v}_f = \boldsymbol{v}_i + \bar{\boldsymbol{a}}\Delta t$$

$$\boldsymbol{x}_f = \boldsymbol{x}_i + \boldsymbol{v}_i t_f + \frac{1}{2}\bar{\boldsymbol{a}} t_f^2$$

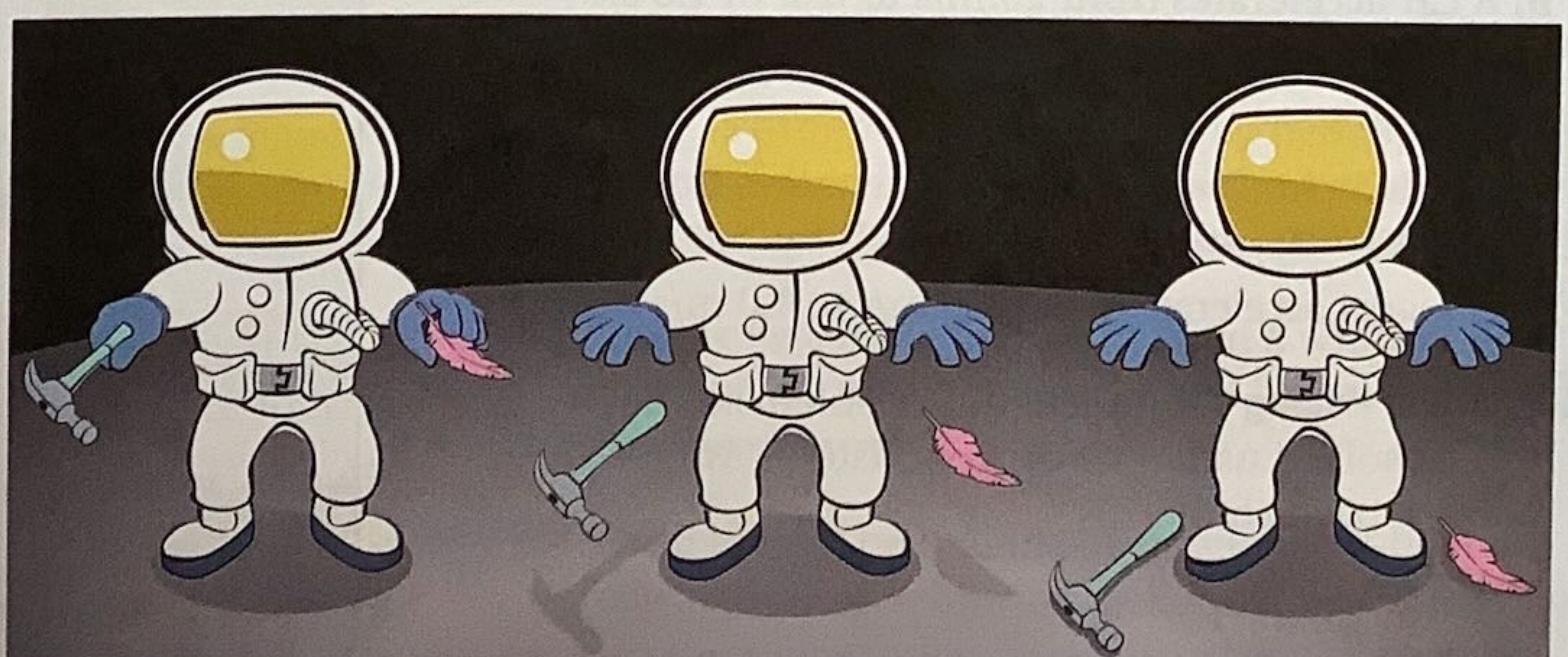
$$v_f^2 = v_i^2 + 2\bar{a}(x_f - x_i)$$

VOCABULARY
- **free fall** *(p. 75)*
- **free-fall acceleration** *(p. 75)*

SECTION 3 Free Fall

MAINIDEA The acceleration of an object in free fall is due to gravity alone.

- Free-fall acceleration on Earth is about 9.8 m/s² downward. The sign associated with free-fall acceleration in equations depends on the choice of the coordinate system.
- When an object is in free fall, gravity is the only force acting on it. Equations for motion with constant acceleration can be used to solve problems involving objects in free fall.



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Vocabulary Practice

STUDY GUIDE

BIGIDEA Net forces cause changes in motion.

SECTION 1 Force and Motion

VOCABULARY
- **force** *(p. 90)*
- **system** *(p. 91)*
- **free-body diagram** *(p. 92)*
- **net force** *(p. 93)*
- **Newton's second law** *(p. 96)*
- **Newton's first law** *(p. 98)*
- **inertia** *(p. 98)*
- **equilibrium** *(p. 99)*

MAINIDEA A force is a push or a pull.

- A force is a push or a pull. Forces have both direction and magnitude. A force might be either a contact force or a field force.
- Newton's second law states that the acceleration of a system equals the net force acting on it divided by its mass.

$$a = \frac{F_{net}}{m}$$

- Newton's first law states that an object that is at rest will remain at rest and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero. An object with zero net force acting on it is in equilibrium.

SECTION 2 Weight and Drag Force

VOCABULARY
- **weight** *(p. 100)*
- **gravitational field** *(p. 100)*
- **apparent weight** *(p. 102)*
- **weightlessness** *(p. 102)*
- **drag force** *(p. 104)*
- **terminal velocity** *(p. 105)*

MAINIDEA Newton's second law can be used to explain the motion of falling objects.

- The object's weight (F_g) depends on the object's mass and the gravitational field at the object's location.

$$F_g = mg$$

- An object's apparent weight is the magnitude of the support force exerted on it. An object with no apparent weight experiences weightlessness.
- A falling object reaches a constant velocity when the drag force is equal to the object's weight. The constant velocity is called the terminal velocity. The drag force on an object is determined by the object's weight, size, and shape as well as the fluid through which it moves.

SECTION 3 Newton's Third Law

VOCABULARY
- **interaction pair** *(p. 106)*
- **Newton's third law** *(p. 106)*
- **tension** *(p. 109)*
- **normal force** *(p. 111)*

MAINIDEA All forces occur in interaction pairs.

- Newton's third law states that the two forces that make up an interaction pair of forces are equal in magnitude, but opposite in direction and act on different objects. In an interaction pair, $F_{A\ on\ B}$ does not cause $F_{B\ on\ A}$. The two forces either exist together or not at all.

$$F_{A\ on\ B} = -F_{B\ on\ A}$$

- The normal force is a support force resulting from the contact between two objects. It is always perpendicular to the plane of contact between the two objects.

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Vocabulary Practice

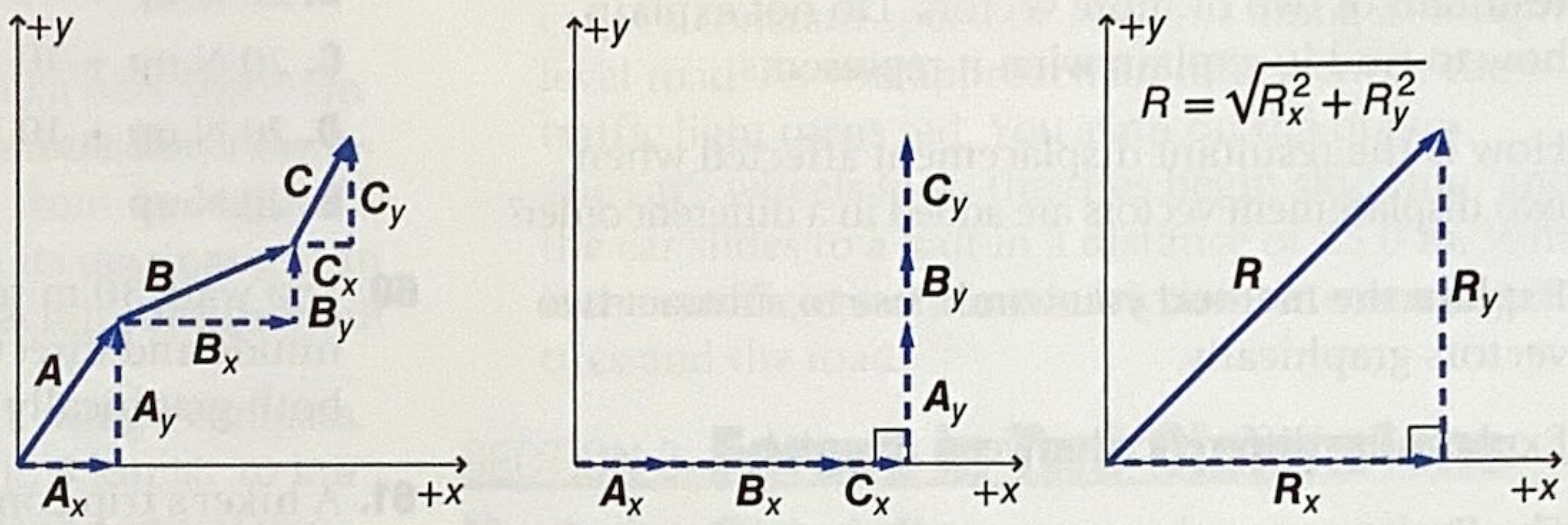
BIGIDEA Forces in two dimensions can be described using vector addition and vector resolution.

VOCABULARY
- **components** *(p. 125)*
- **vector resolution** *(p. 125)*

SECTION 1 Vectors

MAINIDEA All vectors can be broken into *x*- and *y*-components.

- Vectors are added graphically by placing the tail of the second vector on the tip of the first vector. The resultant is the vector pointing from the tail of the first vector to the tip of the final vector.
- The components of a vector are projections of the component vectors onto axes. Vectors can be summed by separately adding the *x*- and *y*-components.



- When two vectors are at right angles, you can use the Pythagorean theorem to determine the magnitude of the resultant vector. The law of cosines and the law of sines can be used to find the resultant of any two vectors.

VOCABULARY
- **kinetic friction** *(p. 130)*
- **static friction** *(p. 130)*
- **coefficient of kinetic friction** *(p. 131)*
- **coefficient of static friction** *(p. 132)*

SECTION 2 Friction

MAINIDEA Friction is a type of force between two touching surfaces.

- Friction is a force that acts parallel to the surfaces when two surfaces touch.
- The kinetic friction force is equal to the coefficient of kinetic friction times the normal force. The static friction force is less than or equal to the coefficient of static friction times the normal force.

$$F_{\text{f,kinetic}} = \mu_k F_N$$

$$F_{\text{f,static}} \le \mu_s F_N$$

VOCABULARY
- **equilibrant** *(p. 137)*

SECTION 3 Forces in Two Dimensions

MAINIDEA An object is in equilibrium if the net forces in the *x*-direction and in the *y*-direction are zero.

- The equilibrant is a force of the same magnitude but opposite direction as the sum of all the other forces acting on an object.
- Friction forces are parallel to an inclined plane but point up the plane if the motion of the object is down the plane. An object on an inclined plane has a component of the force of gravity parallel to the plane; this component can accelerate the object down the plane.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA You can use vectors and Newton's laws to describe projectile motion and circular motion.

SECTION 1 Projectile Motion

VOCABULARY
- **projectile** *(p. 152)*
- **trajectory** *(p. 152)*

MAINIDEA A projectile's horizontal motion is independent of its vertical motion.

- The vertical and horizontal motions of a projectile are independent. When there is no air resistance, the horizontal motion component does not experience an acceleration and has constant velocity; the vertical motion component of a projectile experiences a constant acceleration under these same conditions.
- The curved flight path a projectile follows is called a trajectory and is a parabola. The height, time of flight, initial velocity, and horizontal distance of this path are related by the equations of motion. The horizontal distance a projectile travels before returning to its initial height depends on the acceleration due to gravity and on both components of the initial velocity.

SECTION 2 Circular Motion

VOCABULARY
- **uniform circular motion** *(p. 159)*
- **centripetal acceleration** *(p. 160)*
- **centripetal force** *(p. 161)*

MAINIDEA An object in circular motion has an acceleration toward the circle's center due to an unbalanced force toward the circle's center.

- An object moving in a circle at a constant speed has an acceleration toward the center of the circle because the direction of its velocity is constantly changing.
- Acceleration toward the center of the circle is called centripetal acceleration. It depends directly on the square of the object's speed and inversely on the radius of the circle.

$$a_c = \frac{v^2}{r}$$

- A net force must be exerted by external agents toward the circle's center to cause centripetal acceleration.

$$\mathbf{F}_{net} = m\mathbf{a}_c$$

SECTION 3 Relative Velocity

VOCABULARY
- **reference frame** *(p. 164)*

MAINIDEA An object's velocity depends on the reference frame chosen.

- A coordinate system from which you view motion is called a reference frame. Relative velocity is the velocity of an object observed in a different, moving reference frame.
- You can use vector addition to solve motion problems of an object in a moving reference frame.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Gravity is an attractive field force that acts between objects with mass.

SECTION 1 Planetary Motion and Gravitation

VOCABULARY
- **Kepler's first law** *(p. 179)*
- **Kepler's second law** *(p. 179)*
- **Kepler's third law** *(p. 180)*
- **gravitational force** *(p. 182)*
- **law of universal gravitation** *(p. 182)*

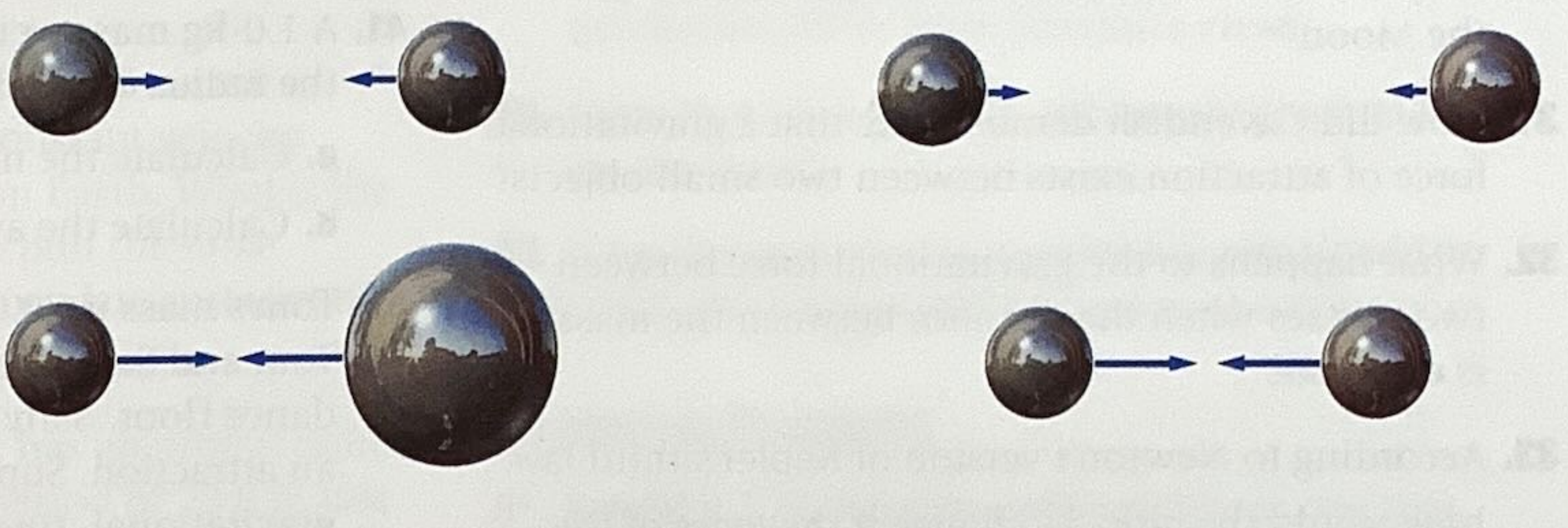
MAINIDEA The gravitational force between two objects is proportional to the product of their masses divided by the square of the distance between them.

- Kepler's first law states that planets move in elliptical orbits, with the Sun at one focus, and Kepler's second law states that an imaginary line from the Sun to a planet sweeps out equal areas in equal times. Kepler's third law states that the square of the ratio of the periods of any two planets is equal to the cube of the ratio of the distances between the centers of the planets and the center of the Sun.

$$\left(\frac{T_A}{T_B}\right)^2 = \left(\frac{r_A}{r_B}\right)^3$$

- Newton's law of universal gravitation can be used to rewrite Kepler's third law to relate the radius and period of a planet to the mass of the Sun. Newton's law of universal gravitation states that the gravitational force between any two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers. The force is attractive and along a line connecting the centers of the masses.

$$F = \frac{Gm_1m_2}{r^2}$$



- Cavendish's investigation determined the value of G, confirmed Newton's prediction that a gravitational force exists between two objects, and helped calculate the mass of Earth.

SECTION 2 Using the Law of Universal Gravitation

VOCABULARY
- **inertial mass** *(p. 191)*
- **gravitational mass** *(p. 191)*

MAINIDEA All objects are surrounded by a gravitational field that affects the motions of other objects.

- The speed and period of a satellite in circular orbit describe orbital motion. Orbital speed and period for any object in orbit around another are calculated with Newton's second law.
- Gravitational mass and inertial mass are two essentially different concepts. The gravitational and inertial masses of an object, however, are numerically equal.
- All objects have gravitational fields surrounding them. Any object within a gravitational field experiences a gravitational force exerted on it by the gravitational field. Einstein's general theory of relativity explains gravitational force as a property of space itself.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Applying a torque to an object causes a change in that object's angular velocity.

SECTION 1 Describing Rotational Motion

VOCABULARY
- radian *(p. 204)*
- angular displacement *(p. 204)*
- angular velocity *(p. 205)*
- angular acceleration *(p. 206)*

MAINIDEA Angular displacement, angular velocity, and angular acceleration all help describe angular motion.

- Angular displacement is the change in the angle (θ) as an object rotates. It is usually measured in degrees or radians.
- Average angular velocity is the object's angular displacement divided by the time taken to make the angular displacement. Average angular velocity is represented by the Greek letter omega (ω) and is determined by the following equation:

$$\omega = \frac{\Delta\theta}{\Delta t}$$

- Average angular acceleration is the change in angular velocity divided by the time required to make the change.

$$\alpha = \frac{\Delta\omega}{\Delta t}$$

SECTION 2 Rotational Dynamics

VOCABULARY
- lever arm *(p. 209)*
- torque *(p. 209)*
- moment of inertia *(p. 213)*
- Newton's second law for rotational motion *(p. 216)*

MAINIDEA Torques cause changes in angular velocity.

- Torque describes the combination of a force and a lever arm that can cause an object to rotate. Torque is represented by the Greek letter tau (τ) and is determined by the following equation:

$$\tau = Fr \sin\theta$$

- The moment of inertia is a point object's resistance to changes in angular velocity. The moment of inertia is represented by the letter I and for a point mass, it is represented by the following equation:

$$I = mr^2$$

- Newton's second law for rotational motion states that angular acceleration is directly proportional to the net torque and inversely proportional to the moment of inertia.

$$\alpha = \frac{\tau_{net}}{I}$$

SECTION 3 Equilibrium

VOCABULARY
- center of mass *(p. 219)*
- centrifugal "force" *(p. 224)*
- Coriolis "force" *(p. 224)*

MAINIDEA An object in static equilibrium experiences a net force of zero and a net torque of zero.

- The center of mass of an object is the point on the object that moves in the same way that a point particle would move.
- An object is stable against rollover if its center of mass is above its base.
- An object in equilibrium has no net force exerted on it and there is no net torque acting on it.
- Centrifugal "force" and the Coriolis "force" are two apparent, but nonexistent, forces that seem to exist when a object is analyzed from a rotating frame of reference.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA If the net force on a closed system is zero, the total momentum of that system is conserved.

VOCABULARY
- **impulse** *(p. 236)*
- **momentum** *(p. 237)*
- **impulse-momentum theorem** *(p. 237)*
- **angular momentum** *(p. 240)*
- **angular impulse-angular momentum theorem** *(p. 240)*

SECTION 1 Impulse and Momentum

MAINIDEA An object's momentum is equal to its mass multiplied by its velocity.

- The impulse on an object is the average net force exerted on the object multiplied by the time interval over which the force acts.

$$\textit{impulse} = \mathbf{F}\Delta t$$

- The momentum of an object is the product of its mass and velocity and is a vector quantity.

$$\mathbf{p} = m\mathbf{v}$$

When solving a momentum problem, first define the objects in the system and examine their momentum before and after the event. The impulse on an object is equal to the change in momentum of the object.

$$\mathbf{F}\Delta t = \mathbf{p}_f - \mathbf{p}_i$$

- The angular momentum of a rotating object is the product of its moment of inertia and its angular velocity.

$$L = I\omega$$

The angular impulse-angular momentum theorem states that the angular impulse on an object is equal to the change in the object's angular momentum.

$$\tau\Delta t = L_f - L_i$$

VOCABULARY
- **closed system** *(p. 245)*
- **isolated system** *(p. 245)*
- **law of conservation of momentum** *(p. 245)*
- **law of conservation of angular momentum** *(p. 251)*

SECTION 2 Conservation of Momentum

MAINIDEA In a closed, isolated system, linear momentum and angular momentum are conserved.

- According to Newton's third law of motion and the law of conservation of momentum, the forces exerted by colliding objects on each other are equal in magnitude and opposite in direction.
- Momentum is conserved in a closed, isolated system.

$$\mathbf{p}_f = \mathbf{p}_i$$

- The law of conservation of momentum relates the momentums of objects before and after a collision. Use vector analysis to solve momentum-conservation problems in two dimensions. The law of conservation of angular momentum states that if there are no external torques acting on a system, then the angular momentum is conserved.

$$L_f = L_i$$

Because angular momentum is conserved, the direction of rotation of a spinning object can be changed only by applying a torque.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Doing work on a system changes the system's energy.

VOCABULARY

- **work** (p. 264)
- **joule** (p. 264)
- **energy** (p. 270)
- **work-energy theorem** (p. 270)
- **kinetic energy** (p. 270)
- **translational kinetic energy** (p. 270)
- **power** (p. 271)
- **watt** (p. 271)

SECTION 1 Work and Energy

MAINIDEA Work is the transfer of energy that occurs when a force is applied through a displacement.

- Work is done when a force is applied through a displacement. Work is the product of the force exerted on a system and the component of the distance through which the system moves that is parallel to the force.

$$W = Fd\cos\theta$$

The work done can be determined by calculating the area under a force-displacement graph.

- Energy is the ability of a system to produce a change in itself or its environment. A moving object has kinetic energy. Objects that are changing position have translational kinetic energy.

$$KE_{trans} = \frac{1}{2}mv^2$$

- The work done on a system is equal to the change in energy of the system. This is called the work-energy theorem.

$$W = \Delta E$$

- Power is the rate at which energy is transformed. When work causes the change in energy, power is equal to the rate of work done.

$$P = \frac{\Delta E}{t} = \frac{W}{t}$$

VOCABULARY

- **machine** (p. 274)
- **effort force** (p. 274)
- **resistance force** (p. 274)
- **mechanical advantage** (p. 274)
- **ideal mechanical advantage** (p. 275)
- **efficiency** (p. 276)
- **compound machine** (p. 277)

SECTION 2 Machines

MAINIDEA Machines make tasks easier by changing the magnitude or the direction of the force exerted.

- Machines, whether powered by engines or humans, do not change the amount of work done, but they do make the task easier by changing the magnitude or direction of the effort force.
- The mechanical advantage (*MA*) is the ratio of resistance force to effort force.

$$MA = \frac{F_r}{F_e}$$

- The ideal mechanical advantage (IMA) is the ratio of the distances moved.

$$IMA = \frac{d_e}{d_r}$$

- The efficiency of a machine is the ratio of output work to input work.

$$e = \left(\frac{W_o}{W_i}\right) \times 100$$

The efficiency of a machine can be found from the real and ideal mechanical advantages. In all real machines, *MA* is less than *IMA*, and *e* is less than 100 percent.

$$e = \left(\frac{MA}{IMA}\right) \times 100$$

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Within a closed, isolated system, energy can change form, but the total energy is constant.

SECTION 1 The Many Forms of Energy

VOCABULARY
- **rotational kinetic energy** *(p. 294)*
- **potential energy** *(p. 294)*
- **gravitational potential energy** *(p. 295)*
- **reference level** *(p. 295)*
- **elastic potential energy** *(p. 298)*
- **thermal energy** *(p. 300)*

MAINIDEA Kinetic energy is energy due to an object's motion, and potential energy is energy stored due to the interactions of two or more objects.

- The translational kinetic energy of an object is proportional to its mass and the square of its velocity. The rotational kinetic energy of an object is proportional to the object's moment of inertia and the square of its angular velocity.
- The gravitational potential energy of an object-Earth system depends on the object's weight and that object's distance from the reference level. The reference level is the position where the gravitational potential energy is defined to be zero ($h = 0$).

$$GPE = mgh$$

- Elastic potential energy is energy stored due to stretching, compressing, or bending an object.
- Albert Einstein recognized that mass itself is a form of energy. This energy is called rest energy.

$$E_0 = mc^2$$

SECTION 2 Conservation of Energy

VOCABULARY
- **law of conservation of energy** *(p. 301)*
- **mechanical energy** *(p. 301)*
- **elastic collision** *(p. 306)*
- **inelastic collision** *(p. 306)*

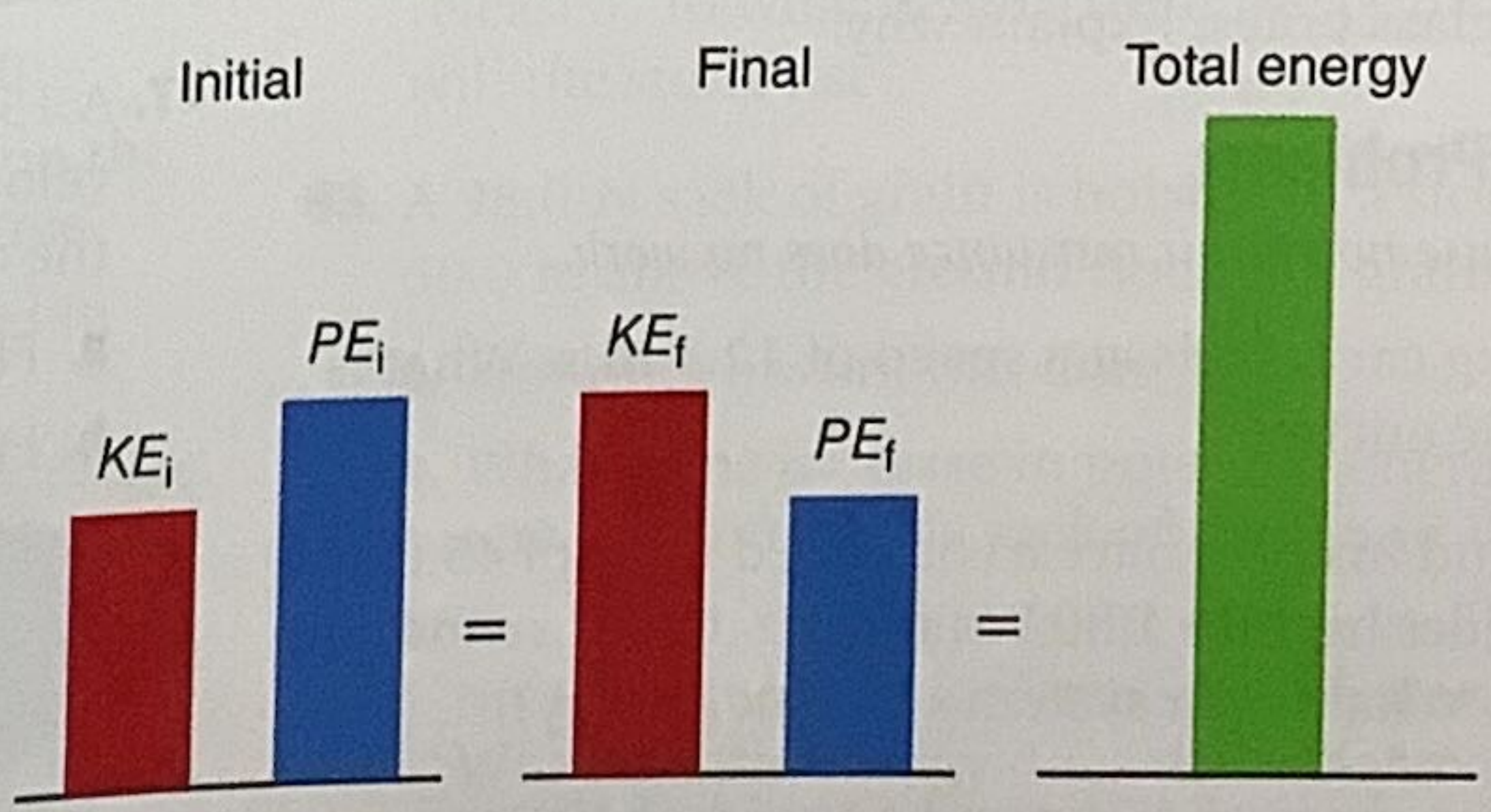
MAINIDEA In a collision in a closed, isolated system, the total energy is conserved, but kinetic energy might not be conserved.

- The total energy of a closed, isolated system is constant. Within the system, energy can change form, but the total amount of energy does not change. Thus, energy is conserved.
- The sum of kinetic and potential energy is called mechanical energy.

$$ME = KE + PE$$

In a closed, isolated system where the only forms of energy are kinetic energy and potential energy, mechanical energy is conserved. The mechanical energy before an event is the same as the mechanical energy after the event.

$$KE_{before} + PE_{before} = KE_{after} + PE_{after}$$



- Momentum is conserved in collisions if the external force is zero. The kinetic energy may be unchanged or decreased by the collision, depending on whether the collision is elastic or inelastic. The type of collision in which the kinetic energy before and after the collision is the same is called an elastic collision. The type of collision in which the kinetic energy after the collision is less than the kinetic energy before the collision is called an inelastic collision.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Thermal energy is related to the motion of an object's particles and can be transferred and transformed.

VOCABULARY
- thermal conduction *(p. 322)*
- thermal equilibrium *(p. 322)*
- heat *(p. 324)*
- convection *(p. 325)*
- radiation *(p. 325)*
- specific heat *(p. 325)*

SECTION 1 Temperature, Heat, and Thermal Energy

MAINIDEA Heat is a transfer of thermal energy that occurs spontaneously from a warmer object to a cooler object.

- Thermal energy is the sum of the kinetic and potential energies of an object's particles. An object's temperature is a measure of the average kinetic energy of its particles.
- When two objects are in thermal equilibrium, there is no net transfer of thermal energy between the objects and the two objects are at the same temperature. A thermometer measures temperature by reaching thermal equilibrium with its surroundings. When an object's temperature is at absolute zero, the average kinetic energy of its particles is zero and that object cannot transfer thermal energy.
- Heat is the transfer of thermal energy. Thermal energy is spontaneously transferred from a warm object to a cool object. Thermal energy is transferred by three processes: conduction, convection, and radiation.
- Substances heat differently, based on their specific heats. Specific heat (C) is the heat required to raise the temperature of 1 kg of a substance 1 K.

$$Q = mC\Delta T = mC(T_f - T_i)$$

A calorimeter is a closed system used to measure changes in thermal energies. Specific heat is calculated by using measurements from a calorimeter.

VOCABULARY
- heat of fusion *(p. 331)*
- heat of vaporization *(p. 331)*
- first law of thermodynamics *(p. 334)*
- heat engine *(p. 335)*
- second law of thermodynamics *(p. 337)*
- entropy *(p. 338)*

SECTION 2 Changes of State and Thermodynamics

MAINIDEA When thermal energy is transferred, energy is conserved and the total entropy of the universe will increase.

- Thermal energy transferred during a change of state does not change the temperature of a substance. The heat of fusion is the quantity of heat needed to change 1 kg of a substance from a solid state to a liquid state at its melting point.

$$Q = mH_f$$

The heat of vaporization is the quantity of heat needed to change 1 kg of a substance from a liquid state to a gaseous state at its boiling point.

$$Q = mH_v$$

- The first law of thermodynamics states that the change in the thermal energy of an object is equal to the heat added to the object minus the work done by the object.

$$\Delta U = Q - W$$

- A heat engine converts thermal energy to mechanical energy. A heat pump and a refrigerator use mechanical energy to transfer thermal energy from a region of lower temperature to one of higher temperature.
- The second law of thermodynamics states that whenever there is an opportunity for energy dispersal, the energy always spreads out. Entropy (S) is a measure of the energy dispersal of a system. The second law of thermodynamics indicates that natural processes go in a direction that maintains or increases the total entropy of the universe. The change in entropy of an object is defined as the heat added to the object divided by the object's temperature.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA The thermal energy of a material and the forces between the material's particles determine its properties.

SECTION 1 Properties of Fluids

VOCABULARY
- fluid (p. 348)
- pressure (p. 349)
- pascal (p. 349)
- combined gas law (p. 351)
- ideal gas law (p. 352)
- thermal expansion (p. 354)
- plasma (p. 355)

MAINIDEA Fluids flow, have no definite shape, and include liquids, gases, and plasmas.

- Matter in the fluid state flows and has no definite shape of its own.
- The combined gas law represents the relationships among the pressure, volume, and temperature of gases.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

- The ideal gas law represents the relationship among pressure, volume, temperature, and the number of moles of a gas.
- Plasma is a gaslike state of negatively charged electrons and positively charged ions.

SECTION 2 Forces Within Liquids

VOCABULARY
- cohesive forces (p. 356)
- adhesive forces (p. 357)

MAINIDEA Cohesive forces occur between the particles of a substance, while adhesive forces occur between particles of different substances.

- Surface tension is the tendency of the surface of a liquid to contract to the smallest possible area. Surface tension results from the attractive forces that like particles exert on one another.
- Capillary action occurs when a liquid rises in a thin tube because the adhesive forces between the tube and the liquid are stronger than the cohesive forces between liquid's molecules.
- Clouds form when water vapor in the atmosphere cools and condenses, forming droplets around dust particles.

SECTION 3 Fluids at Rest and in Motion

VOCABULARY
- Pascal's principle (p. 359)
- buoyant force (p. 361)
- Archimedes' principle (p. 361)
- Bernoulli's principle (p. 364)
- streamlines (p. 366)

MAINIDEA Hydraulic lifts, floating objects, and carburetors rely on the forces exerted by fluids.

- Pascal's principle states that an applied pressure change is transmitted undiminished throughout a fluid.
- According to Archimedes' principle, the buoyant force equals the weight of the fluid displaced by an object.
- Bernoulli's principle states that the pressure exerted by a fluid decreases as its velocity increases.

SECTION 4 Solids

VOCABULARY
- crystal lattice (p. 367)
- amorphous solid (p. 367)
- coefficient of linear expansion (p. 369)
- coefficient of volume expansion (p. 369)

MAINIDEA Solids usually expand when heated.

- A crystalline solid has a regular pattern of particles, and an amorphous solid has an irregular pattern of particles. Malleability and ductility depend on structure type.
- As the temperature of a solid changes, the kinetic energy of its particles changes accordingly. As the vibrations of the particles change, a solid expands as temperature increases and contracts as temperature decreases.
- Expansion rates of different materials must be considered when designing structures.

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Vocabulary Practice

BIGIDEA Waves and simple harmonic motion are examples of periodic motion.

SECTION 1 Periodic Motion

VOCABULARY
- periodic motion (p. 382)
- period (p. 382)
- amplitude (p. 382)
- simple harmonic motion (p. 382)
- Hooke's law (p. 383)
- simple pendulum (p. 386)
- resonance (p. 386)

MAINIDEA Periodic motion repeats in a regular cycle.

- Simple harmonic motion results when the restoring force on an object is directly proportional to the object's displacement from equilibrium.
- The elastic potential energy of a spring that obeys Hooke's law is expressed by the following equation:

$$PE_{sp} = \frac{1}{2}kx^2$$

- The period of a pendulum depends on the pendulum's length and the gravitational field strength at the pendulum's location. The period can be found using the following equation:

$$T = 2\pi\sqrt{\frac{\ell}{g}}$$

SECTION 2 Wave Properties

VOCABULARY
- wave (p. 388)
- wave pulse (p. 388)
- transverse wave (p. 388)
- periodic wave (p. 388)
- longitudinal wave (p. 388)
- surface wave (p. 389)
- trough (p. 390)
- crest (p. 390)
- wavelength (p. 390)
- frequency (p. 391)

MAINIDEA Waves transfer energy without transferring matter.

- Waves are disturbances that transfer energy without transferring matter.
- In transverse waves, the displacement of the medium is perpendicular to the direction the wave travels. In longitudinal waves, the displacement is parallel to the direction the wave travels.
- The velocity of a continuous wave is equal to the wave's frequency times its wavelength.

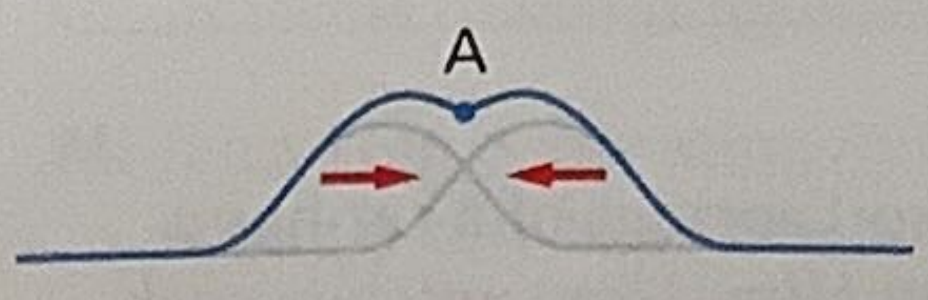
$$v = f\lambda$$

SECTION 3 Wave Behavior

VOCABULARY
- incident wave (p. 394)
- reflected wave (p. 394)
- principle of superposition (p. 395)
- interference (p. 395)
- node (p. 396)
- antinode (p. 396)
- standing wave (p. 397)
- wavefront (p. 397)
- ray (p. 397)
- normal (p. 398)
- law of reflection (p. 398)
- refraction (p. 399)

MAINIDEA Waves can interfere with other waves.

- When two-dimensional waves are reflected from boundaries, the angles of incidence and reflection are equal. The change in direction of waves at the boundary between two different mediums is called refraction.
- Interference occurs when two or more waves travel through the same medium at the same time. The principle of superposition states that the displacement of a medium resulting from two or more waves is the algebraic sum of the displacements of the individual waves.



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Vocabulary Practice

STUDY GUIDE

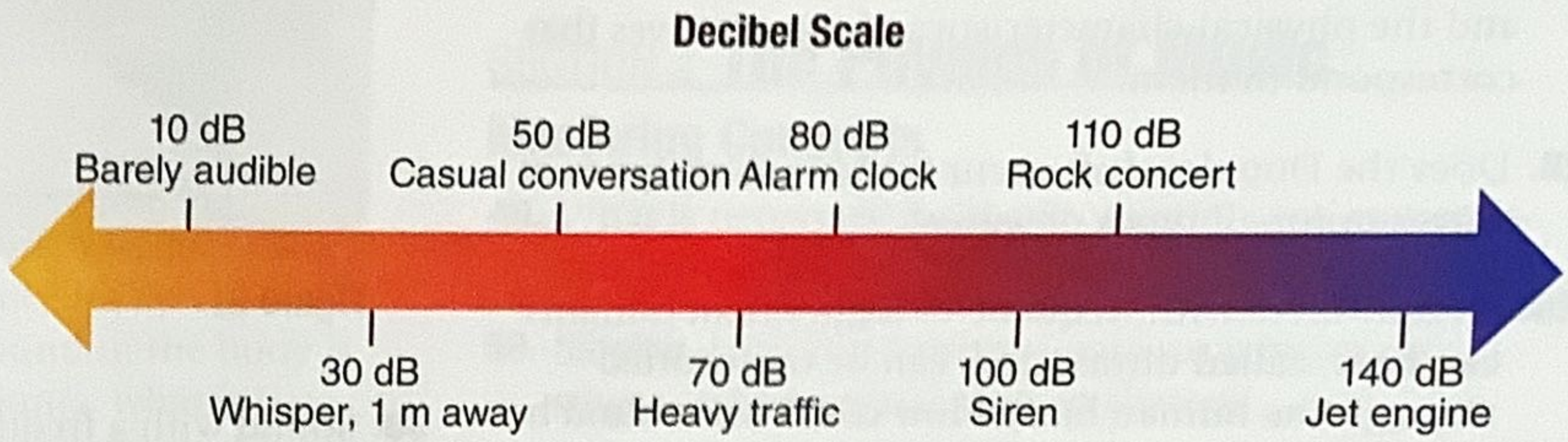
BIGIDEA Sound waves are pressure variations, and many can be detected by the human ear.

SECTION 1 Properties and Detection of Sound

VOCABULARY
- sound wave (p. 411)
- pitch (p. 413)
- loudness (p. 413)
- sound level (p. 413)
- decibel (p. 413)
- Doppler effect (p. 414)

MAINIDEA Our perception of a sound wave depends on that wave's physical properties.

- Sound is a pressure variation transmitted through matter as a longitudinal wave. A sound wave has frequency, wavelength, speed, and amplitude. Sound waves reflect and interfere.
- Sound detectors convert the energy carried by a sound wave into another form of energy. The human ear is a highly efficient and sensitive detector of sound waves. The frequency of a sound wave is heard as its pitch. The loudness of sound as perceived by the ear and brain depends mainly on its amplitude. The pressure amplitude of a sound wave can be measured in decibels (dB).



- The Doppler effect is the change in frequency of sound caused by the motion of either the source or the detector.
- The Doppler effect is used in radar detectors, in medical ultrasound machines, and by astronomers. Bats also use the Doppler effect to detect and catch flying insects.

SECTION 2 The Physics of Music

VOCABULARY
- closed-pipe resonator (p. 419)
- open-pipe resonator (p. 420)
- fundamental (p. 425)
- harmonics (p. 425)
- dissonance (p. 426)
- consonance (p. 426)
- beat (p. 426)

MAINIDEA Music consists of complex sound waves produced by vibrating objects.

- Sound is produced by a vibrating object in a medium.
- An air column can resonate with a sound source, thereby increasing the amplitude of its resonant frequency. A closed pipe resonates when its length is $\frac{\lambda}{4}$, $\frac{3\lambda}{4}$, $\frac{5\lambda}{4}$, and so on. Its resonant frequencies are odd-numbered multiples of the fundamental. An open pipe resonates when its length is $\frac{\lambda}{2}$, $\frac{2\lambda}{2}$, $\frac{3\lambda}{2}$, and so on. Its resonant frequencies are whole-number multiples of the fundamental.
- A clamped string has a node at each end and resonates when its length is $\frac{\lambda}{2}$, $\frac{2\lambda}{2}$, $\frac{3\lambda}{2}$, and so on, just as with an open pipe. The string's resonant frequencies are also whole-number multiples of the fundamental.
- The frequencies and intensities of the complex waves produced by a musical instrument determine the timbre that is characteristic of that instrument.
- Two waves with almost the same frequency interfere to produce beats.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Light behaves like a wave and can be detected by the human eye.

VOCABULARY
- ray model of light (p. 439)
- luminous source (p. 439)
- opaque (p. 440)
- translucent (p. 440)
- transparent (p. 440)
- luminous flux (p. 440)
- illuminance (p. 441)

SECTION 1 Illumination

MAINIDEA Light rays travel in straight lines and can only change direction when they encounter a boundary.

- Light can be modeled as a ray that travels in a straight path until it encounters a boundary. Mediums can be characterized as being transparent, translucent, or opaque, depending on how light interacts with them.
- The luminous flux of a light source is the rate at which light is emitted. It is measured in lumens (lm). Illuminance is the luminous flux per unit area. Illuminance is measured in lux (lx), or lumens per square meter (lm/m^2). For a point source, illuminance follows an inverse-square relationship with distance and a direct relationship with luminous flux.

$$E = \frac{P}{4\pi r^2}$$

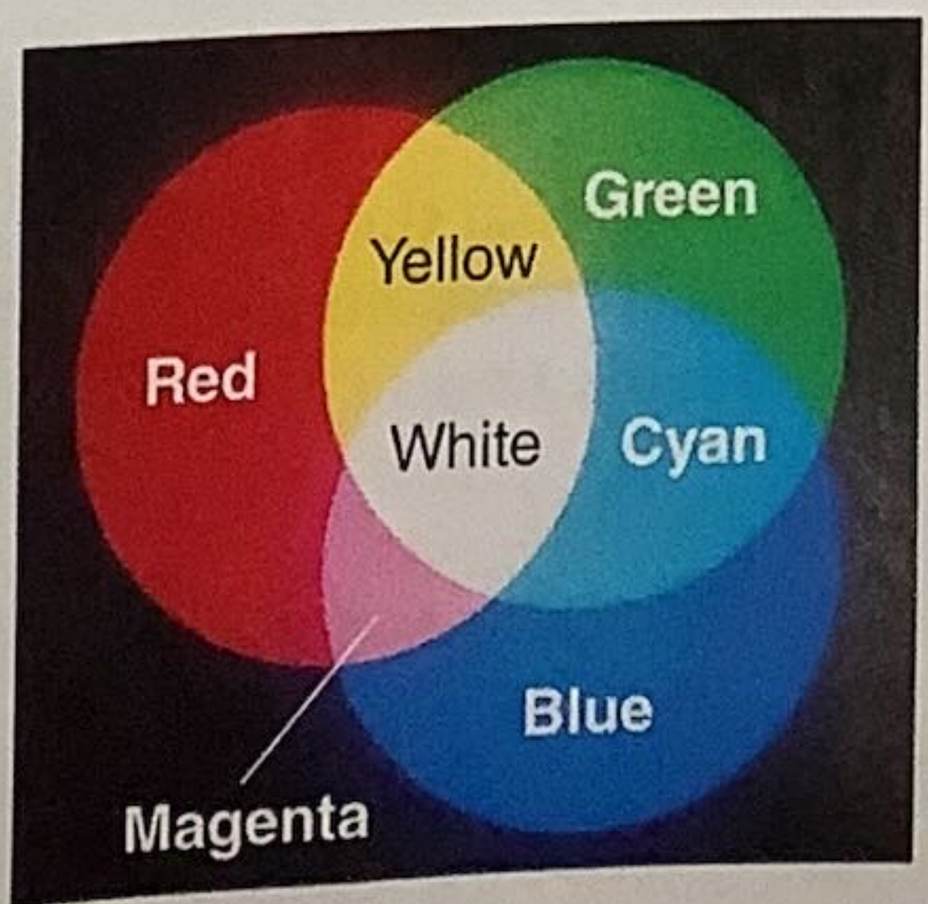
- Early measurements of the speed of light involved measurement of the time it takes for light to reach Earth from Jupiter's moon Io. Michelson used a land-based technique that involved the distance between two mountains and a set of rotating mirrors. In a vacuum, light has a constant speed of $c = 3.00\times10^8$ m/s.

VOCABULARY
- diffraction (p. 447)
- primary color (p. 449)
- secondary color (p. 449)
- complementary color (p. 449)
- primary pigment (p. 449)
- secondary pigment (p. 450)
- polarization (p. 451)
- Malus's law (p. 452)

SECTION 2 The Wave Nature of Light

MAINIDEA Like all waves, light diffracts around objects, has a wavelength and frequency, and can be Doppler shifted.

- In the wave model of light, all the points in a wavefront can be thought of as sources of smaller waves. As light travels past an edge, the wavefront is cut and each new wavelet generates a new circular wave.
- Visible light can have wavelengths between 400 and 700 nm. White light is a combination of the spectrum of colors, each color having a different wavelength. Combining the primary colors—red, blue, and green—forms white light. Combinations of two primary colors form the secondary colors, yellow, cyan, and magenta.



The primary pigments, cyan, magenta, and yellow, are used in combinations of two to produce the secondary pigments, red, blue, and green.

- Polarized light consists of waves whose electric fields oscillate with a specific pattern. Often, the oscillation is in a single plane. Light can be polarized with a polarizing filter or by reflection. Light waves traveling through a vacuum can be characterized in terms of frequency, wavelength, and the speed of light. Light waves are Doppler shifted based on the relative speed of the observer and light source along the axis of the observer and the light source.

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Vocabulary Practice

CHAPTER 17 STUDY GUIDE

BIGIDEA All surfaces reflect light, but smooth surfaces can produce images.

VOCABULARY
- **specular reflection** *(p. 466)*
- **diffuse reflection** *(p. 466)*
- **plane mirror** *(p. 468)*
- **object** *(p. 468)*
- **image** *(p. 468)*
- **virtual image** *(p. 468)*

SECTION 1 Plane Mirrors

MAINIDEA The angle of incidence of a light ray is equal to the angle of reflection.

- According to the law of reflection, the angle that an incident ray makes with the normal equals the angle that the reflected ray makes with the normal.

$$\theta_r = \theta_i$$

- The law of reflection applies to both smooth and rough surfaces. A rough surface has normals that are not parallel; therefore, parallel incident rays are not reflected in parallel. A rough surface produces diffuse reflection. A smooth surface has parallel normals; therefore, parallel incident rays are reflected in parallel. A smooth surface produces specular reflection. Specular reflection results in the formation of images that appear to be behind plane mirrors.
- An image produced by a plane mirror is always virtual, is the same size as the object, has the same orientation, and is the same distance from the mirror as the object.

$$x_i = -x_o \qquad h_i = h_o$$

VOCABULARY
- **concave mirror** *(p. 471)*
- **principal axis** *(p. 471)*
- **focal point** *(p. 472)*
- **focal length** *(p. 472)*
- **real image** *(p. 472)*
- **spherical aberration** *(p. 474)*
- **convex mirror** *(p. 476)*
- **magnification** *(p. 478)*

SECTION 2 Curved Mirrors

MAINIDEA Curved mirrors can produce real and virtual images and can magnify or reduce the image size.

- A spherical concave mirror is shaped as if it were a section of a hollow sphere with the same geometric center (C) and radius of curvature (r) as a sphere of radius r. The focal point (F) of a spherical concave mirror is the point where rays parallel to the principal axis of the mirror converge after reflection. Concave mirrors are used in flashlights, spotlights, and telescopes.
- You can locate the image created by a spherical mirror by drawing two rays from a point on the object to the mirror. The intersection of the two reflected rays or sight lines of the two reflected rays is the location of the image of the object point. A concave mirror produces a real image that is inverted when the object position is greater than the focal length. A concave mirror produces a virtual image that is upright when the object position is less than the focal length. A convex mirror always produces a virtual image that is upright and smaller compared to the object.
- By forming images smaller than the objects, convex mirrors make images seem farther away and produce a wide field of view, which is useful for rearview mirrors and security mirrors. Mirrors can be used in combinations to produce images of any size, orientation, and location desired. The most common use of combinations of mirrors is in telescopes.
- The mirror equation gives the relationship among image position, object position, and focal length of a spherical mirror.

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

The magnification of a mirror image is given by equations relating either the positions or the heights of the image and the object.

$$m \equiv \frac{h_i}{h_o} = \frac{-x_i}{x_o}$$

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Lenses refract light and create images.

VOCABULARY
- index of refraction (p. 493)
- critical angle (p. 496)
- total internal reflection (p. 496)
- dispersion (p. 498)

SECTION 1 Refraction of Light

MAINIDEA The amount of refraction at a boundary depends on the indices of refraction of the two mediums and the angle of incidence.

- A beam of light refracts when it travels across a boundary from one medium with an index of refraction (n_1) into a medium with a different index of refraction (n_2). Refraction is described by Snell's law of refraction.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

- The speed of light in a medium is slower than the speed of light in a vacuum. The ratio of the speed of light in a vacuum (c) to the speed of light in a medium (v) is the index of refraction (n) of the medium.
- When light traveling through a medium hits a boundary with a medium of a smaller index of refraction, if the angle of incidence exceeds the critical angle (θ_c) the light will be reflected back into the original medium by total internal reflection. The indices of refraction for the mediums determine the critical angle.
- Optical effects such as mirages and rainbows are the result of refraction. Mirages occur due to the effect of temperature on n and rainbows occur because refracted white light is dispersed.

VOCABULARY
- lens (p. 500)
- convex lens (p. 500)
- concave lens (p. 500)
- thin lens equation (p. 503)
- chromatic aberration (p. 506)
- achromatic lens (p. 506)

SECTION 2 Convex and Concave Lenses

MAINIDEA Lenses can be used to enlarge and reduce images.

- A single convex lens produces a real image, formed by converging light rays, when the object is farther from the lens than its focal point. A single convex lens produces a virtual image, formed by diverging light rays, when the object is between the lens and the focal point. A single concave lens always produces a virtual image, formed by diverging light rays.
- Ray diagrams use two rays to determine the position, magnification, and orientation of an image formed by a lens. The thin lens equation provides the relationship between focal length (f), object position (x_o), and image position (x_i).

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

The magnification (m) of an image by a lens is defined by the magnification equation.

- All simple lenses have chromatic aberration. Chromatic aberration is reduced by using a combination of lenses with different indices of refraction.

VOCABULARY
- nearsightedness (p. 509)
- farsightedness (p. 509)

SECTION 3 Applications of Lenses

MAINIDEA People see objects that they could not otherwise see by using lenses.

- Differences in indices of refraction between air and the cornea are primarily responsible for focusing light in the eye.
- Nearsightedness is the inability to focus clearly on distant objects. A concave lens corrects nearsightedness. Farsightedness is the inability to focus clearly on nearby objects. A convex lens corrects farsightedness.
- Optical instruments use combinations of lenses to obtain clear images of small or distant objects.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Light waves can diffract and interfere with each other.

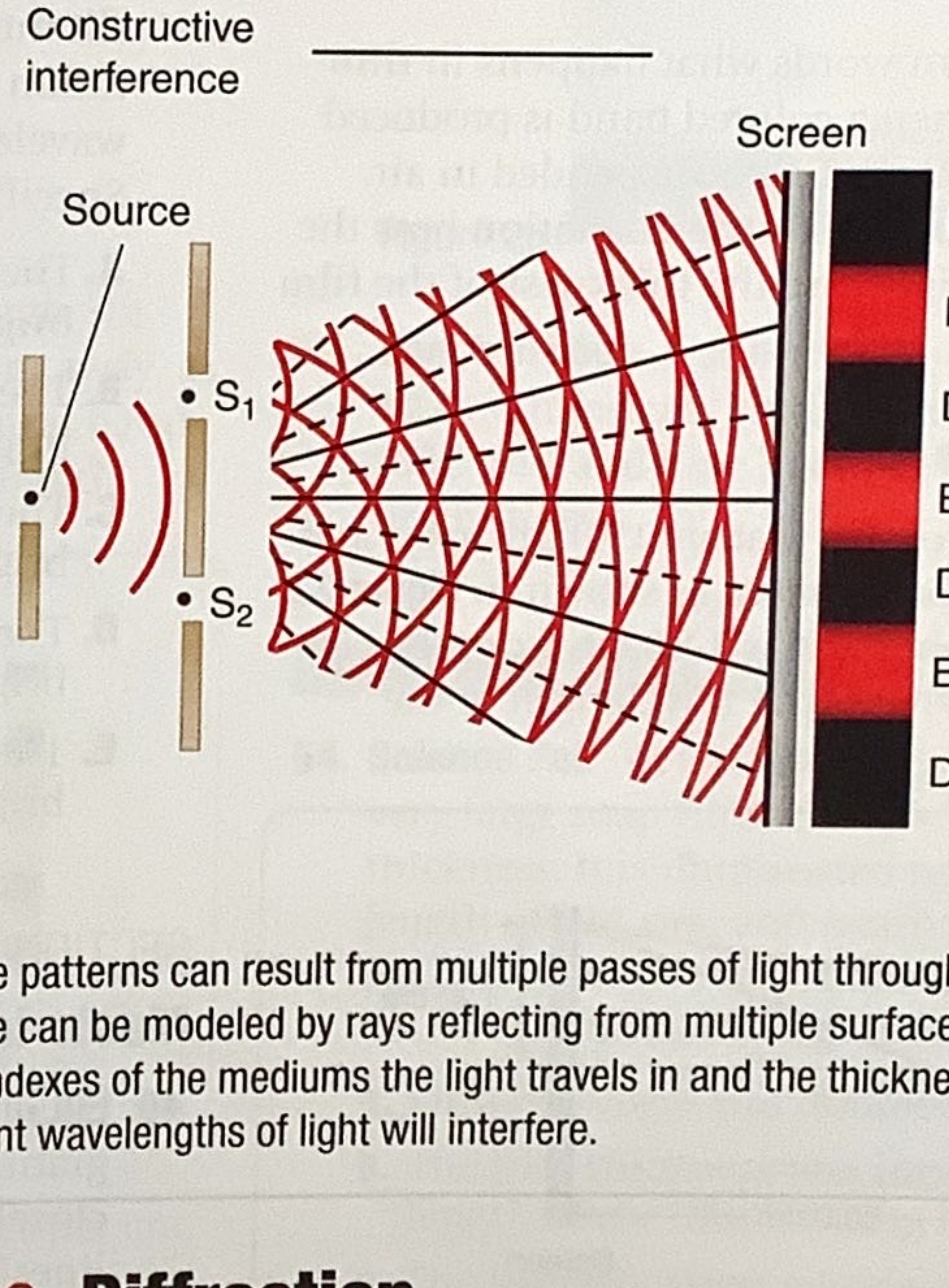
SECTION 1 Interference

VOCABULARY
- **incoherent light** *(p. 522)*
- **coherent light** *(p. 522)*
- **interference fringes** *(p. 523)*
- **monochromatic light** *(p. 523)*
- **thin-film interference** *(p. 527)*

MAINIDEA Light can interfere when passing through narrow slits or reflecting from a thin film.

- The superposition of light waves from coherent light sources can produce an interference pattern. Light passing through two closely spaced, narrow slits produces a pattern of dark and light bands on a screen called interference fringes.
- Interference patterns can be used to measure the wavelength of light.

$$\lambda = \frac{xd}{L}$$



- Interference patterns can result from multiple passes of light through a thin film. Thin-film interference can be modeled by rays reflecting from multiple surfaces of a thin film. The refractive indexes of the mediums the light travels in and the thickness of the film determine how different wavelengths of light will interfere.

SECTION 2 Diffraction

VOCABULARY
- **diffraction pattern** *(p. 531)*
- **diffraction grating** *(p. 534)*
- **Rayleigh criterion** *(p. 538)*

MAINIDEA Light waves diffract when they pass through a single slit and diffract and interfere when they encounter a diffraction grating.

- Light passing through a narrow slit is diffracted, which means spread out from a straight-line path, producing a diffraction pattern on a screen. The width of the bright central band of a single-slit diffraction pattern is related to the wavelength of light used.
- Diffraction gratings consist of large numbers of slits that are very close together and produce narrow spectral lines that result from interference of light diffracted by all the slits.
- Diffraction gratings can be used to measure the wavelength of light precisely or to separate light composed of different wavelengths.

$$\lambda = d \sin \theta$$

- Diffraction limits the ability of an aperture to distinguish two closely spaced objects, because the resulting image contains a diffuse central bright spot. If two bright spots are closer than the limit of resolution, they will overlap and the objects cannot be distinguished.

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Vocabulary Practice

STUDY GUIDE

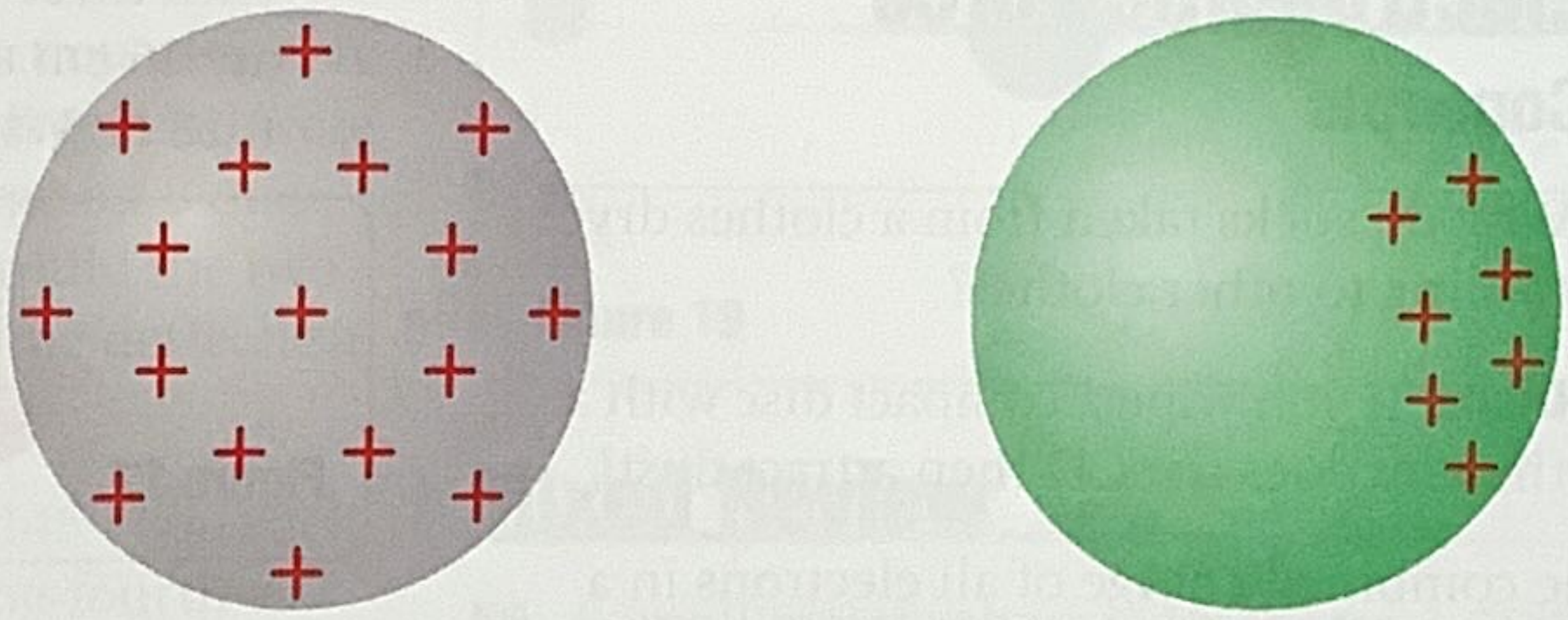
BIGIDEA Separated positive and negative charges exert forces on one another.

VOCABULARY
- electrostatics *(p. 548)*
- neutral *(p. 550)*
- insulator *(p. 551)*
- conductor *(p. 551)*

SECTION 1 Electric Charge

MAINIDEA Like electric charges repel, and unlike electric charges attract.

- There are two kinds of electric charge, positive and negative. Interactions of these charges explain the attraction and repulsion you observed using strips of tape.
- Electric charge is not created or destroyed; it is conserved. Charging is the separation, not creation, of electric charges. Objects are charged by the transfer of electrons. An area with excess electrons has a net negative charge; an area with a deficit of electrons has a net positive charge.
- Charges added to one part of an insulator remain on that part. Insulators include glass, dry wood, most plastics, and dry air. Charges added to a conductor quickly spread throughout the conductor. Some examples of conductors are graphite, metals, and matter in the plasma state. Under certain conditions, charges can move through a substance that is ordinarily an insulator. Lightning moving through air is one example.



VOCABULARY
- electroscope *(p. 554)*
- charging by conduction *(p. 554)*
- charging by induction *(p. 555)*
- grounding *(p. 556)*
- Coulomb's law *(p. 557)*
- coulomb *(p. 558)*
- elementary charge *(p. 558)*

SECTION 2 Electrostatic Force

MAINIDEA Forces between charged particles are mathematically related to charge and distance.

- Electrostatic force acts over a distance and decreases as the distance between charges increases.
- Charging by conduction charges a neutral object by touching that object with a charged object. Conduction requires the transfer of electrons between the charging object and the object being charged. Charging by induction charges a neutral object by bringing a charged object near the neutral object without the two objects touching. Induction makes use of separation of charge or grounding to charge a neutral object. Charging by induction enables the charging object to be used multiple times.
- Coulomb's law states that the force between two charged particles varies directly with the product of their charges and inversely with the square of the distance between them. It is used to find the magnitude of the force two charged particles exert on each other.

$$F = K\frac{q_A q_B}{{r_{AB}}^2}$$

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Electric charges are surrounded by electric fields that exert a force on other charged objects.

SECTION 1 Measuring Electric Fields

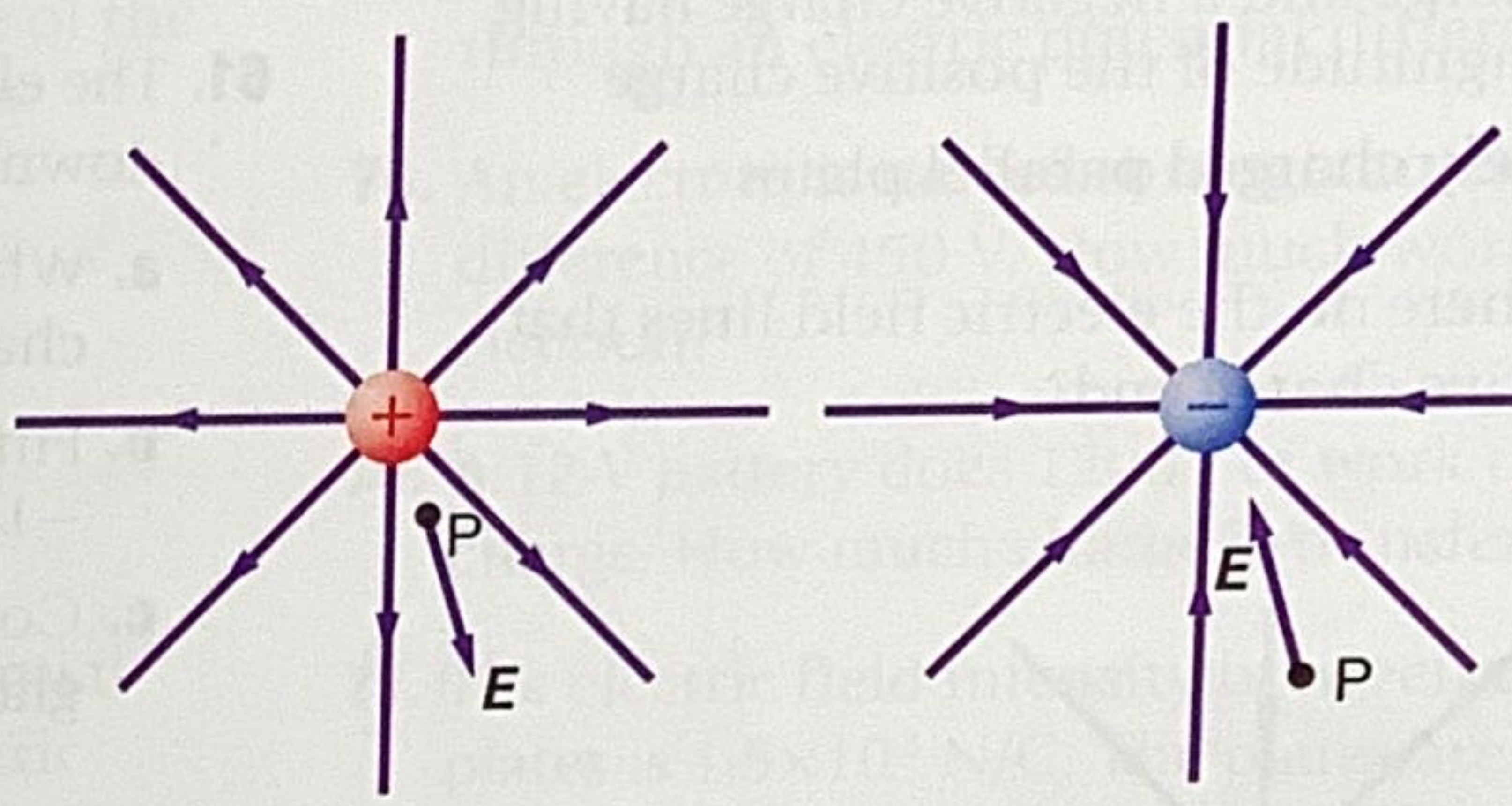
VOCABULARY
- electric field *(p. 570)*
- electric field line *(p. 574)*

MAINIDEA An electric field is a property of the space around a charged object that exerts forces on other charged objects.

- An electric field exists around any charged object. The field produces forces on other charged objects.
- Quantities relating to charge, electric fields, and forces are related and can be calculated using these formulas:

$$E = \frac{F}{q'} \qquad E = \frac{Kqq'}{r^2q'} = \frac{Kq}{r^2}$$

- Electric field lines provide a pictorial model of the electric field. They are directed away from positive charges and toward negative charges. They never cross, and their density is related to the strength of the field. The direction of the electric field is the direction of the force on a tiny, positive test charge.



SECTION 2 Applications of Electric Fields

VOCABULARY
- electric potential difference *(p. 578)*
- volt *(p. 578)*
- equipotential *(p. 579)*
- capacitor *(p. 585)*
- capacitance *(p. 585)*

MAINIDEA Electric potential (sometimes called voltage) is electric potential energy per unit charge.

- Electric potential difference is the change in potential energy per unit charge in an electric field. Electric potential differences are measured in volts.
- Potential difference is related to the work required to move a charge and is represented by the following equation:

$$\Delta V = \frac{W}{q'}$$

- Capacitors are used to store electrical energy. A capacitor consists of two conducting plates separated by an insulator. The capacitance C depends only on the geometry of these plates and insulator. It can be calculated by the following equation.

$$C = \frac{q}{\Delta V}$$

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Vocabulary Practice

CHAPTER 22 STUDY GUIDE

BIGIDEA Electric currents carry electrical energy that can be transformed into other forms of energy.

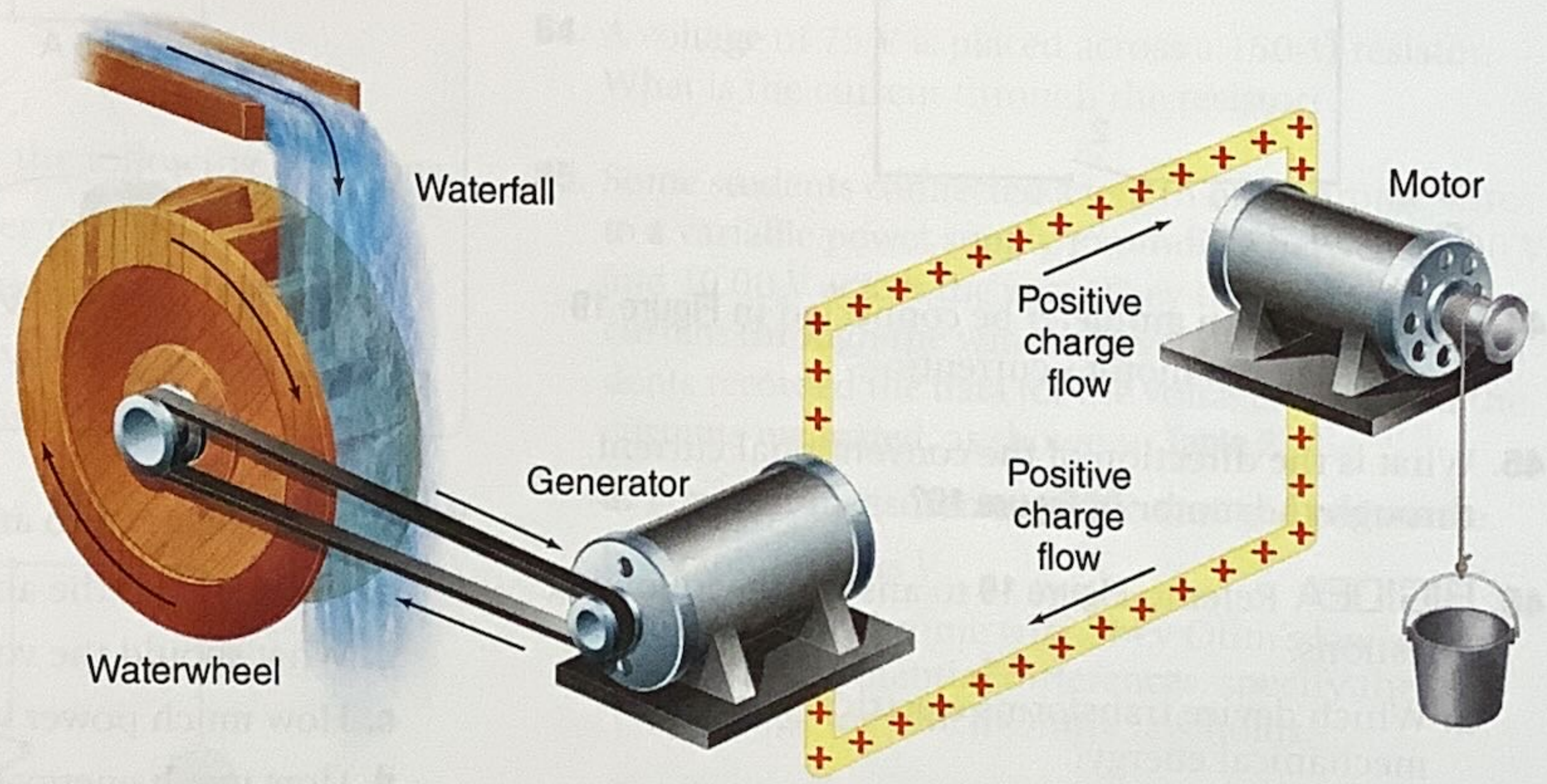
VOCABULARY
- **electric current** *(p. 598)*
- **conventional current** *(p. 598)*
- **battery** *(p. 598)*
- **electric circuit** *(p. 599)*
- **ampere** *(p. 600)*
- **resistance** *(p. 604)*
- **resistor** *(p. 605)*
- **parallel connection** *(p. 608)*
- **series connection** *(p. 608)*

SECTION 1 Current and Circuits

MAINIDEA Electric current is the flow of electric charges.

- Electric current is a flow of charged particles. By convention, current direction is the direction in which a positive test charge moves.
- A circuit transforms electrical energy to thermal energy, radiant energy, or some other form of energy.
- Ohm's law states that the ratio of potential difference to current is a constant for a given conductor. Any resistance that does not change with potential difference or the direction of charge flow obeys Ohm's law.
- The following equations show how power, current, potential difference, and resistance are mathematically related.

$$P = I\Delta V \qquad R = \frac{\Delta V}{I}$$



VOCABULARY
- **superconductor** *(p. 611)*
- **kilowatt-hour** *(p. 612)*

SECTION 2 Using Electrical Energy

MAINIDEA Electrical energy can be transformed to radiant energy, thermal energy, and mechanical energy.

- Electrical energy is transformed into thermal energy whenever moving charges transfer energy to other particles.
- If energy is transformed at a uniform rate, the total energy transformed equals power multiplied by time. Power also can be represented by I^2R and $\frac{(\Delta V)^2}{R}$ to give the last two equations.

$$E = Pt$$
$$E = I^2Rt$$
$$E = \left(\frac{(\Delta V)^2}{R}\right)t$$

- The unwanted transformation of electrical energy to thermal energy during transmission is called the joule heating loss, or I^2R loss. The best way to minimize the Joule heating loss is to minimize the current in the transmission wires. Transmitting at higher voltages enables current to be reduced without power being reduced.

Review vocabulary with translations.
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CHAPTER 23 STUDY GUIDE

BIGIDEA Circuit components can be placed in series, in parallel, or in a combination of series and parallel.

SECTION 1 Simple Circuits

VOCABULARY
- **series circuit** *(p. 625)*
- **equivalent resistance** *(p. 626)*
- **voltage divider** *(p. 627)*
- **parallel circuit** *(p. 630)*

MAINIDEA In a series circuit, current follows a single path; in a parallel circuit, current follows more than one path.

- The current is the same everywhere in a simple series circuit. If any branch of a parallel circuit is opened, there is no current in that branch. The current in the other branches is unchanged.
- The current in a series circuit is equal to the potential difference divided by the equivalent resistance. The sum of the voltage drops across resistors that are in series is equal to the potential difference applied across the combination. The equivalent resistance of a series circuit is the sum of the resistances of its parts.
- In a parallel circuit, the total current is equal to the sum of the currents in the branches. The voltage drops across all branches of a parallel circuit are the same. The reciprocal of the equivalent resistance of parallel resistors is equal to the sum of the reciprocals of the individual resistances.

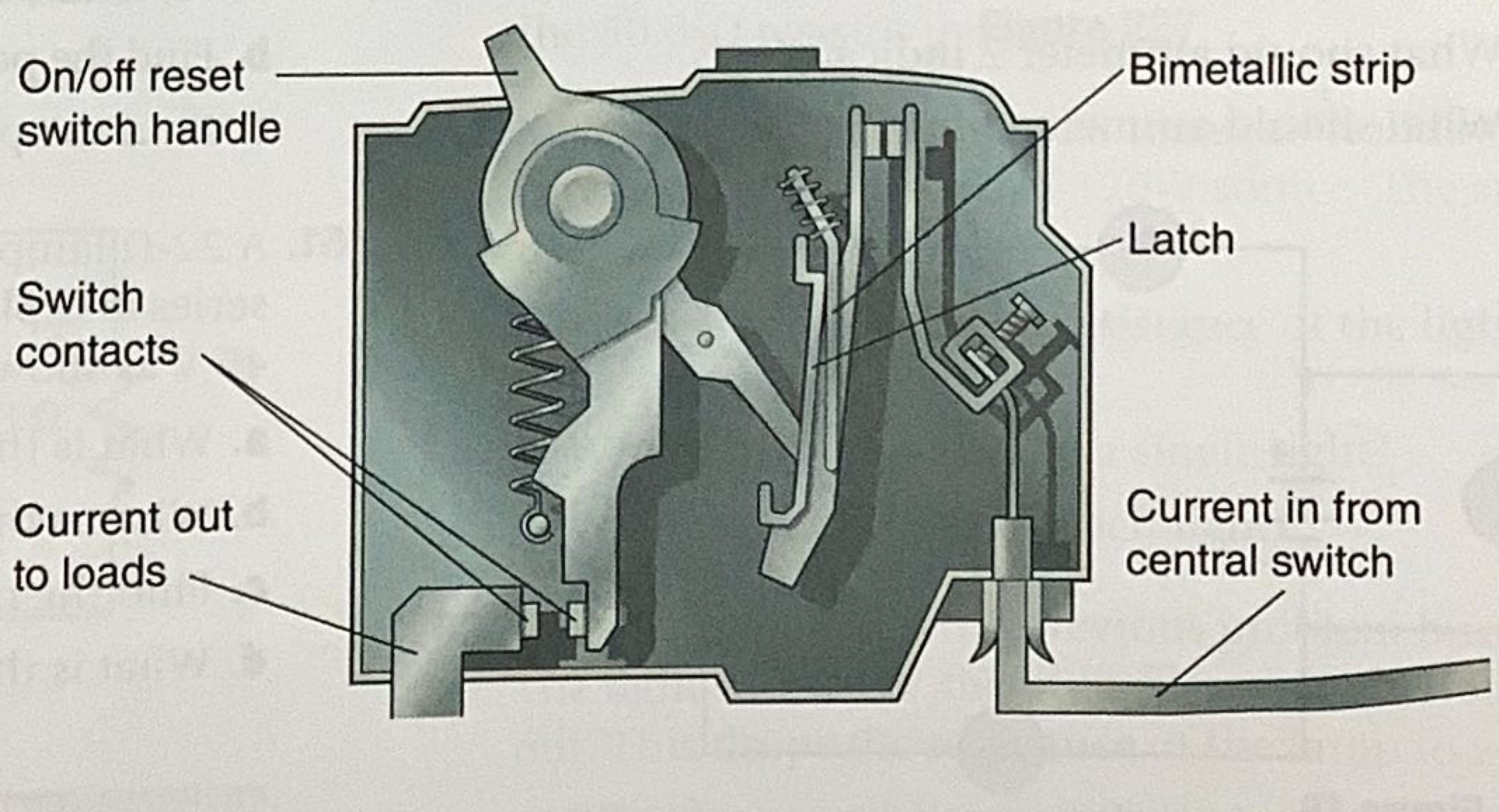
SECTION 2 Applications of Circuits

VOCABULARY
- **short circuit** *(p. 635)*
- **fuse** *(p. 635)*
- **circuit breaker** *(p. 635)*
- **ground-fault interrupter** *(p. 635)*
- **combination series-parallel circuit** *(p. 637)*

MAINIDEA Most circuits are combination series-parallel circuits.

- A fuse, a circuit breaker, and a ground-fault interrupter create an open circuit and stop current when currents are dangerously high.

Circuit Breaker



- To find currents and potential differences in complex circuits, a combination of series and parallel branches, any parallel branch first is reduced to a single equivalent resistance. Then, any resistors in series are replaced by a single resistance.
- A voltmeter measures the potential difference (voltage) across any part or combination of parts of a circuit. A voltmeter always has a high resistance and is connected in parallel with the part of the circuit being measured. An ammeter is used to measure the current in a branch or part of a circuit. An ammeter always has a low resistance and is connected in series.

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Vocabulary Practice

CHAPTER 24

STUDY GUIDE

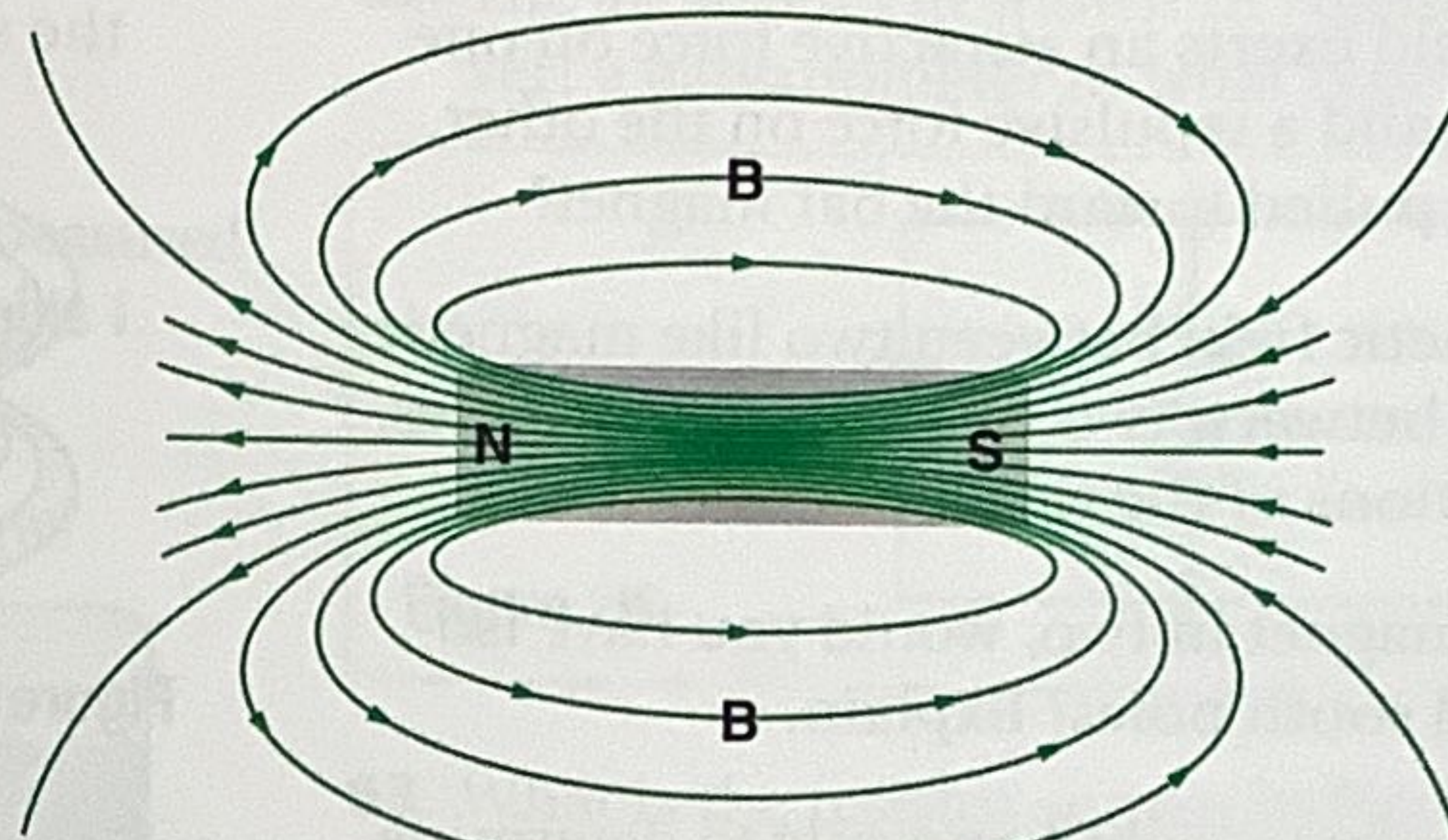
BIGIDEA Magnets and moving electric charges are surrounded by magnetic fields that exert forces on magnetic materials and on moving charges.

VOCABULARY
- polarized *(p. 650)*
- domain *(p. 652)*
- magnetic field *(p. 653)*
- magnetic flux *(p. 654)*
- solenoid *(p. 656)*
- electromagnet *(p. 656)*

SECTION 1 Understanding Magnetism

MAINIDEA Magnets and electric currents produce magnetic fields.

- All magnets have north poles and south poles and are surrounded by magnetic fields.
- Ferromagnetic materials become magnetic when their domains are in alignment with each other.
- Magnetic fields are vector quantities because they have direction and magnitude. They exist in any region in space where a magnet would experience a force. Magnetic fields can be represented by field lines, which exit from a north pole and enter at a south pole, forming closed loops.



- A magnetic field exists around any current-carrying wire. The magnetic field around a coil of wire is proportional to the number of loops in the coil because the individual fields of the loops are in the same direction.

VOCABULARY
- galvanometer *(p. 661)*
- electric motor *(p. 662)*
- armature *(p. 662)*

SECTION 2 Applying Magnetic Forces

MAINIDEA Many devices, including earbuds and electric motors, rely on forces from magnetic fields in order to work.

- When a current-carrying wire is placed in a magnetic field, a force is exerted on the wire that is perpendicular to both the field and the wire.
- The force on a current-carrying wire in a magnetic field is proportional to the current times the length of the wire times the field strength times the sine of the angle between the current and the magnetic field.

$$F = ILB(\sin \theta)$$

- An electric motor consists of a coil of wire in a magnetic field. When there is current in the coil, the coil rotates as a result of the force on the wire in the magnetic field. Complete 360° rotation is achieved by using a split-ring commutator to switch the direction of the current in the coil as the coil rotates.
- The force that a magnetic field exerts on a moving charged particle depends on the charge of the particle, the velocity of the particle, the strength of the magnetic field, and the angle between the directions of the velocity and the field. The direction of the force is perpendicular to both the field and the particle's velocity.

$$F = qvB(\sin \theta)$$

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Vocabulary Practice

CHAPTER 25 STUDY GUIDE

BIGIDEA A changing magnetic field can induce current in a conductor.

SECTION 1 Inducing Currents

VOCABULARY
- **electromagnetic induction** *(p. 676)*
- **induced electromotive force** *(p. 677)*
- **electric generator** *(p. 680)*

MAINIDEA A changing magnetic field induces an *EMF* in a wire, and the *EMF*, in turn, generates current when the wire is in a circuit.

- An *EMF* is induced in a wire when the magnetic field at the location of the wire changes, as when the wire moves through the magnetic field.
- The *EMF* induced in a length of wire moving through a uniform magnetic field is the product of the magnetic field (B), the length of the wire (L), and the component of the wire's velocity that is perpendicular to the field ($v(\sin\theta)$).

$$EMF = BLv(\sin\theta)$$

- As the armature in a generator is turned by mechanical force, the induced *EMF* creates a current that changes direction each time the armature turns 180°.
- In an AC circuit, the effective current and potential difference are related to their maximum values in the following way:

$$I_{\text{eff}} = 0.707\, I_{\text{max}}$$
$$V_{\text{eff}} = 0.707\, V_{\text{max}}$$

SECTION 2 Applications of Induced Currents

VOCABULARY
- **Lenz's law** *(p. 684)*
- **eddy current** *(p. 686)*
- **self-inductance** *(p. 687)*
- **transformer** *(p. 688)*
- **mutual inductance** *(p. 688)*
- **step-up transformer** *(p. 688)*
- **step-down transformer** *(p. 688)*

MAINIDEA The magnetic fields produced by induced currents are crucial to the operation of generators, motors, and transformers.

- Lenz's law states that a current created by an induced *EMF* is in a direction that produces a magnetic field that opposes the change in the magnetic field that generated the current.
- In a generator, an induced *EMF* makes the armature harder to turn when the generator supplies more current. In a motor, induced *EMF* reduces the current through the motor when the motor runs at high speed.
- Self-inductance is a property of a wire or coil that carries a changing current. The faster the current is changing, the greater is the change in the resulting magnetic field and the greater is the induced *EMF* that opposes that change.
- Transformers have two coils close together. An AC current in the primary coil induces an alternating *EMF* in the secondary coil. The turns ratio—the number of turns on the secondary coil divided by the number of turns on the primary coil—is equal to the ratio of the potential difference in the secondary coil to the potential difference in the primary coil. It is also equal to the ratio of the current in the primary coil to the current in the secondary coil.

$$\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}$$

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Vocabulary Practice

CHAPTER 26 STUDY GUIDE

BIG IDEA Electromagnetic waves are coupled, oscillating electric and magnetic fields generated by accelerating electrons.

SECTION 1 Electric and Magnetic Forces on Particles

VOCABULARY
- isotope *(p. 706)*
- mass spectrometer *(p. 706)*

MAIN IDEA Deflection of moving particles in electric and magnetic fields can be used to find properties of those particles.

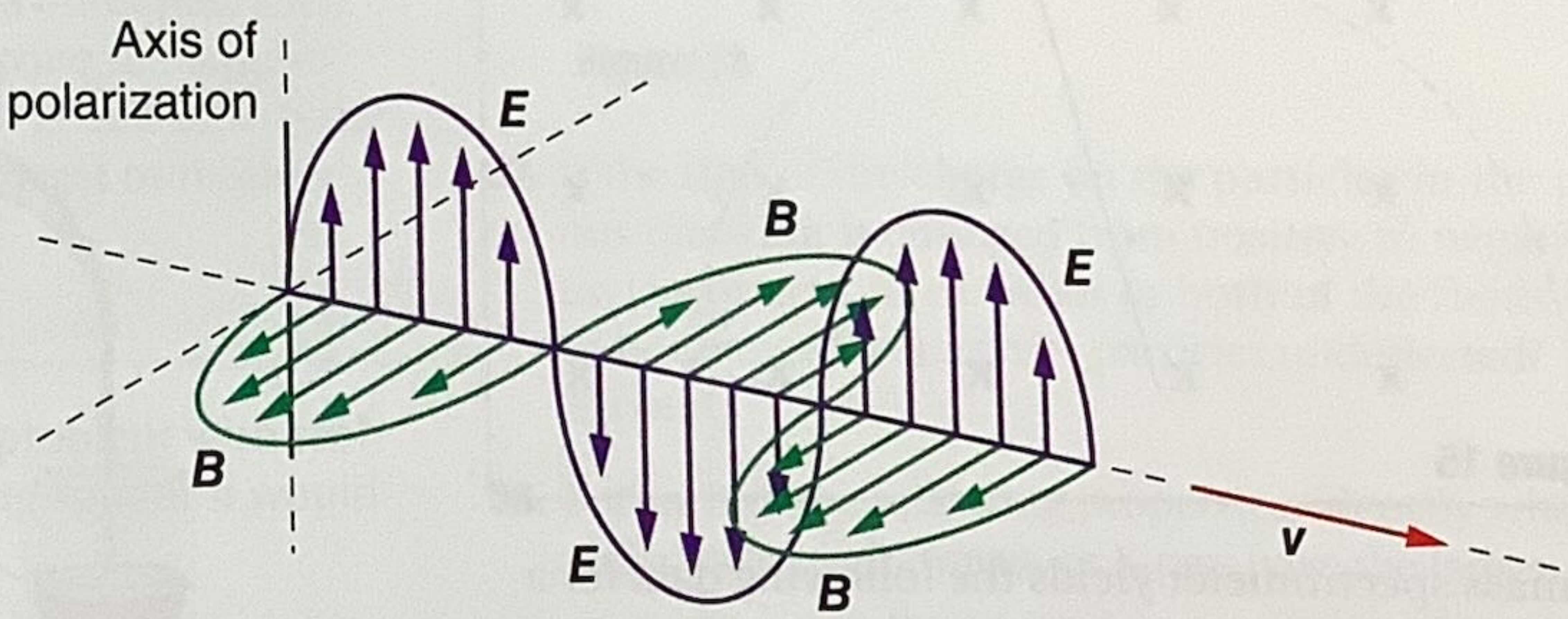
- By using electric and magnetic fields to deflect a beam of electrons in a tube nearly evacuated of air—the cathode-ray tube—J.J. Thomson measured the electron's charge-to-mass ratio. R.A. Millikan later measured the charge, allowing the electron's mass to be calculated.
- The charge-to-mass ratio of an electron or positive ion is found by first using crossed electric and magnetic fields to determine the particle's velocity and then using a magnetic field to deflect the particle.
- A mass spectrometer uses both electric and magnetic fields to separate and measure the masses of ionized atoms and molecules. The electric field gives the ion a specific kinetic energy. In the magnetic field, the ion follows a circular path that depends on the ion's mass and charge.

SECTION 2 Electric and Magnetic Fields in Space

VOCABULARY
- electromagnetic wave *(p. 710)*
- electromagnetic spectrum *(p. 712)*
- electromagnetic radiation *(p. 712)*
- transmitter *(p. 714)*
- antenna *(p. 714)*
- dielectric *(p. 714)*
- carrier wave *(p. 715)*
- piezoelectricity *(p. 717)*
- receiver *(p. 719)*

MAIN IDEA Electromagnetic waves are coupled, oscillating electric and magnetic fields that move through space and interact with matter.

- The electric and magnetic fields that make up an electromagnetic wave oscillate at right angles to each other and to the direction of the wave's velocity (***v***).



- Wavelength is equal to wave speed divided by wave frequency. For an electromagnetic wave traveling in a vacuum, *v* is equal to the speed of light (c). For an electromagnetic wave traveling through a dielectric, *v* is equal to c divided by the square root of the relative dielectric constant (*k*).
- Electromagnetic waves can carry information if their amplitude or frequency is varied by the data, voice, or video information that is to be transmitted. Waves also can be encoded with digitized information.
- An antenna is most sensitive and most efficient when its length is one-half or one-quarter as long as the wavelength of the electromagnetic wave it is designed to detect.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA Waves can behave like particles, and particles can behave like waves.

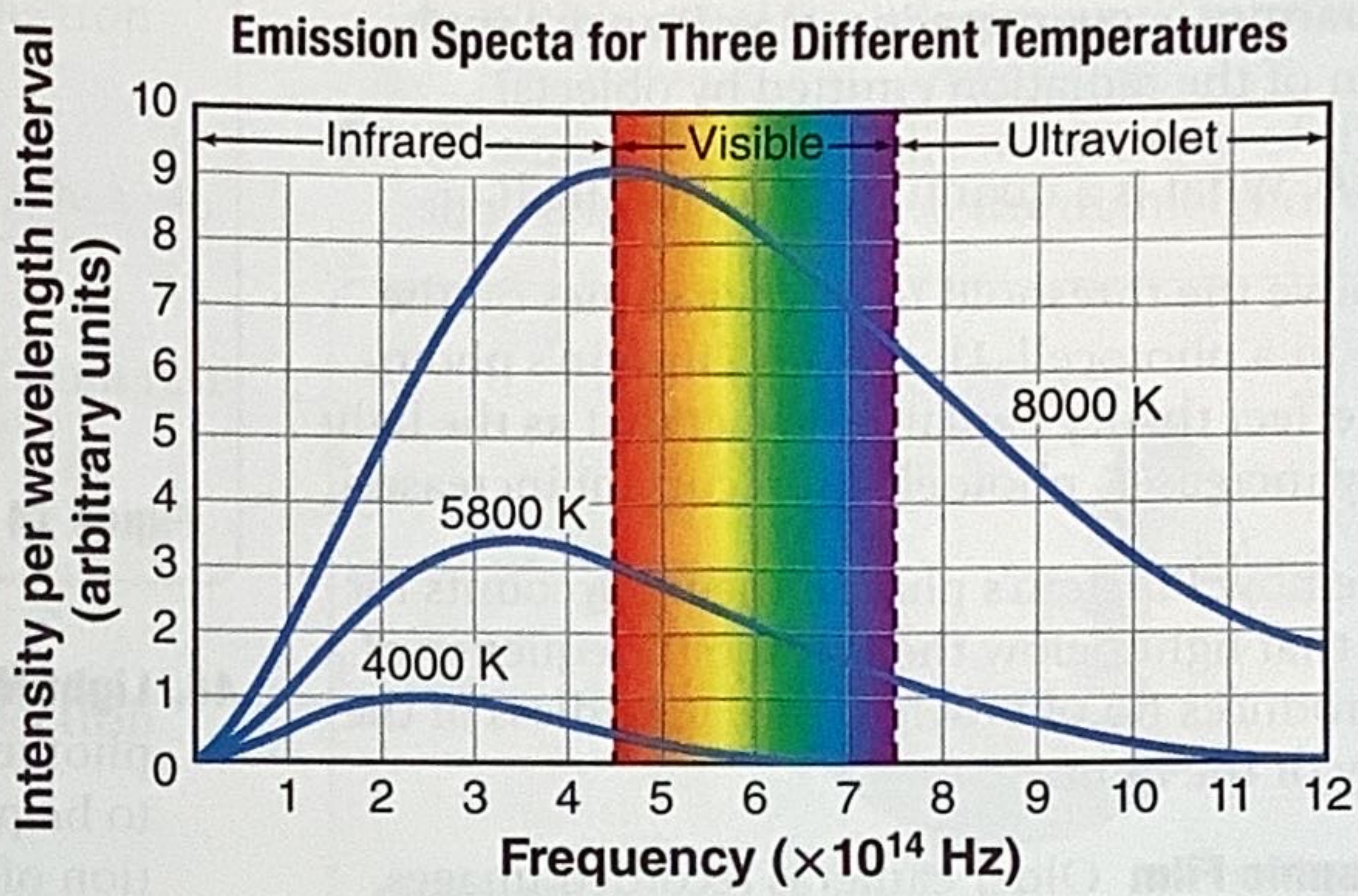
VOCABULARY

- **emission spectrum** *(p. 729)*
- **quantized** *(p. 730)*
- **photoelectric effect** *(p. 731)*
- **threshold frequency** *(p. 732)*
- **photon** *(p. 732)*
- **work function** *(p. 737)*
- **Compton effect** *(p. 739)*

SECTION 1 A Particle Model of Waves

MAINIDEA Light can behave as massless particles called photons.

- The spectrum emitted by an object covers a broad range of wavelengths. The spectrum depends on the object's temperature. Planck explained an object's spectrum by supposing that a particle can absorb or emit only certain energies that are integer multiples of a constant, now called Planck's constant.



- The photoelectric effect is the emission of electrons by certain metals when they are exposed to electromagnetic radiation. Einstein explained the photoelectric effect by postulating that light exists in bundles of energy called photons. The relationship between a photon's energy, frequency, and wavelength is given below.

$$E = hf = \frac{hc}{\lambda} = \frac{1240\ \text{eV}\cdot\text{nm}}{\lambda}$$

- The Compton effect demonstrates that photons have momentum, as predicted by Einstein. Even though photons, which travel at the speed of light, have zero mass, they do have energy and momentum. A photon's momentum, frequency, and wavelength are related by the following equation:

$$p = \frac{hf}{c} = \frac{h}{\lambda}$$

VOCABULARY

- **de Broglie wavelength** *(p. 741)*
- **Heisenberg uncertainty principle** *(p. 743)*

SECTION 2 Matter Waves

MAINIDEA Moving particles have wavelike properties.

- The wave nature of material particles was suggested by de Broglie and verified experimentally by the diffraction of electrons through crystals. All moving particles have a wavelength, known as the de Broglie wavelength. The following equation is used to calculate a particle's de Broglie wavelength.

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

- The particle and the wave aspects are complementary parts of the complete nature of both matter and light. The Heisenberg uncertainty principle states that it is not possible to simultaneously measure the precise position and momentum of any particle of light or matter.

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Vocabulary Practice

CHAPTER 28 STUDY GUIDE

BIGIDEA An atom consists of a nucleus of protons and neutrons surrounded by one or more electrons.

VOCABULARY
- **alpha particles** *(p. 753)*
- **nucleus** *(p. 753)*
- **absorption spectrum** *(p. 755)*
- **energy level** *(p. 757)*
- **ground state** *(p. 757)*
- **excited state** *(p. 757)*
- **principal quantum number** *(p. 760)*

SECTION 1 Bohr's Model of the Atom

MAINIDEA The Bohr model of the atom represents the atom as a massive, central nucleus with orbiting electrons that have quantized energies.

- Ernest Rutherford directed positively charged, high-speed alpha particles at thin metal foils. By studying the paths of the reflected particles, he showed that an atom is mostly empty space with a tiny, massive, positively charged nucleus at its center. Electrons move in a large volume around the nucleus but contribute less than 0.1 percent of an atom's mass.
- Atoms make transitions between allowable energy levels, absorbing or emitting energy in the form of photons (electromagnetic waves). Emitted photons form the atom's emission spectrum, and absorbed photons form the absorption spectrum. The photon's energy is equal to the decrease from the initial to the final state of the atom.

$$E_{\text{photon}} = -\Delta E$$

- According to the Bohr model, the radius of an electron's orbit can have only certain (quantized) values. The radius of the electron orbit in energy level *n* of a hydrogen atom is given by the following equation.

$$r_n = \frac{h^2n^2}{4\pi^2Km_ee^2}$$

Niels Bohr's model of the atom correctly showed that the energy of an atom can have only certain values; thus, it is quantized. He showed that the energy of a hydrogen atom in energy level *n* is equal to the product of −13.6 eV and the inverse of n^2.

$$E_n = -13.6\text{ eV} \times \frac{1}{n^2}$$

VOCABULARY
- **quantum model** *(p. 766)*
- **electron cloud** *(p. 766)*
- **quantum mechanics** *(p. 766)*
- **stimulated emission** *(p. 767)*
- **laser** *(p. 767)*

SECTION 2 The Quantum Model of the Atom

MAINIDEA The quantum model of the atom predicts the probability of finding an electron within a specific region.

- In the quantum model of the atom, the atom's energy has only specific, quantized values. Only the probability of finding the electron in a specific region can be determined. In the hydrogen atom, the most probable distance of the electron from the nucleus is the same as the electron's orbital radius predicted by the Bohr model.
- Lasers produce coherent light by creating a chain reaction of stimulated emissions. Stimulated emission occurs when an incident photon causes an atom's electron in an excited state to emit a coherent photon as it falls into a lower energy state. The incident photon and the emitted photon can then cause other atoms to emit more coherent photons. The laser cavity is constructed to reflect these coherent photons back and forth through the lasing material, producing even more photons.
- Lasers produce light that is directional, powerful, monochromatic, and coherent. Each of these properties has useful applications.

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Vocabulary Practice

STUDY GUIDE

BIGIDEA We can make a variety of electronic devices by controlling the conductivity of materials.

VOCABULARY
- **semiconductor** *(p. 778)*
- **band theory** *(p. 779)*
- **intrinsic semiconductor** *(p. 782)*
- **dopant** *(p. 783)*
- **extrinsic semiconductor** *(p. 783)*

SECTION 1 Conduction in Solids

MAINIDEA A material's conductivity depends on the energy difference between the valence and conducting bands.

- The band theory of solids states that, in solids, the electric fields of neighboring atoms spread the allowed energy levels for an atom's outer electrons into broad bands. The valence and conduction bands are separated by forbidden energy gaps. The smaller the forbidden gap, the better the material's conduction.
- In conductors, electrons can move through the solid because the conduction band is partially filled. In insulators, more energy is needed to move electrons into the conduction band than is generally available. In semiconductors, the energy gap is small enough that some electrons can reach the conduction band.
- Conductivity of semiconductors increases with increasing temperature or illumination. Conduction in semiconductors is also enhanced by doping pure crystals with small amounts of other kinds of atoms, called dopants.
- The *n*-type semiconductors are doped with electron donor atoms. They conduct by the response of these donor electrons to applied potential differences. The *p*-type semiconductors are doped with electron acceptor atoms. They conduct by making holes available to electrons in the conduction band.

VOCABULARY
- **diode** *(p. 788)*
- **depletion layer** *(p. 788)*
- **transistor** *(p. 791)*
- **microchip** *(p. 792)*

SECTION 2 Electronic Components

MAINIDEA Diodes and transistors are the fundamental components in today's electronic circuits.

- A *pn*-junction diode consists of a layer of a *p*-type semiconductor joined with a layer of an *n*-type semiconductor. Diodes conduct charges in one direction only. If a potential difference is applied across the diode in the direction of polarity, the diode is forward-biased and conducts charge. If a potential difference is applied opposite its polarity, the diode is reverse-biased and does not conduct charge.
- Diodes can be used to convert AC to DC. Some diodes emit light when a potential difference is applied; these diodes can also detect light.
- A transistor is a sandwich of three layers of semiconductor material, configured as either *npn* or *pnp* layers. The center base layer is very thin compared to the other layers, which are called the emitter and the collector.
- A transistor can amplify a weak signal into a much stronger one. The ratio of the collector-emitter current to the base current is known as the current gain and is a useful measure of transistor amplification.

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Vocabulary Practice

CHAPTER 30

STUDY GUIDE

BIG IDEA Splitting and fusing atomic nuclei release energy.

SECTION 1 The Nucleus

VOCABULARY
- nucleon (p. 802)
- atomic number (p. 802)
- mass number (p. 802)
- atomic mass unit (p. 802)
- strong nuclear force (p. 804)
- mass defect (p. 805)
- binding energy (p. 805)

MAIN IDEA The binding energy of the nucleus is equivalent to the mass defect of that nucleus.

- The number of protons in a nucleus is given by the atomic number (Z). The sum of the numbers of protons and neutrons in a nucleus is equal to the mass number (A).
- Atoms with the same number of protons but different numbers of neutrons are called isotopes.
- The strong nuclear force binds the nucleus together.
- The mass defect of a nucleus is the difference between the sum of the masses of its parts and the mass of the assembled nucleus. The energy difference between separated nucleons and the assembled nucleus is the binding energy.
- The mass defect is the energy equivalent of the binding energy of the nucleus.

$$E = mc^2$$

SECTION 2 Nuclear Decay and Reactions

VOCABULARY
- radioactive (p. 808)
- alpha decay (p. 809)
- beta decay (p. 809)
- gamma decay (p. 809)
- nuclear reaction (p. 810)
- half-life (p. 812)
- activity (p. 813)
- fission (p. 814)
- chain reaction (p. 815)
- fusion (p. 817)

MAIN IDEA Radioactive decay releases particles and energy and can change an atom into another element.

- An unstable nucleus decays and can transmute into another element. Radioactive decay produces three kinds of particles. Alpha (α) particles are helium nuclei, beta (β) particles are high-speed electrons, and gamma (γ) rays are high-energy photons. In nuclear reactions, the sums of the mass numbers (A) and the nuclear charges (Z) are not changed.
- The half-life of a radioactive isotope is the time required for half of the nuclei to decay. After t half-lives:

$$\text{remaining} = \text{original}\left(\frac{1}{2}\right)^t$$

The number of decays of a radioactive sample per second is the activity.

- In nuclear fission, a nucleus is split into two smaller nuclei with a release of neutrons and energy. Nuclear reactors use the energy released in fission to generate electrical energy.
- In nuclear fusion, nuclei with small masses combine to form a nucleus with a larger mass. The loss of mass that occurs in this process corresponds to a release of energy.

SECTION 3 The Building Blocks of Matter

VOCABULARY
- Standard Model (p. 822)
- quark (p. 822)
- lepton (p. 822)
- force carrier (p. 823)
- pair production (p. 824)
- weak nuclear force (p. 825)

MAIN IDEA All matter is made of quarks and leptons and interacts with other matter through force carriers.

- Particles are produced by radioactive decay, during high-energy collisions in accelerators, and in stars. They can detected if they expose film, ionize matter, or cause matter to emit photons.
- The Standard Model includes quarks, leptons, and force carriers. Ordinary matter is made of quarks and leptons. Matter interacts with other matter through particles called force carriers.
- When corresponding antimatter and matter particles combine, their mass is converted into gamma rays or lighter matter-antimatter particle pairs. Energy can be transformed into a matter-antimatter pair through pair production.
- The weak nuclear force is a short-range force that allows quarks and leptons to change flavor. It is responsible for beta decay in which a neutron is transformed into a proton or a proton is transformed into a neutron.

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Vocabulary Practice