AP Physics 2

UNIT 1: FLUIDS

ESSENTIAL QUESTIONS	BIG IDEAS
Why do some objects sink while others float? Why does water spray farther when you put your thumb over the hose opening? Why can a strong wind cause the roof to blow off of a house?	• **Big Idea 1:** Objects and systems have properties such as mass and charge. Systems may have internal structure. • **Big Idea 3:** The interactions of an object with other objects can be described by forces. • **Big Idea 4:** Interactions between systems can result in changes to those systems.

GUIDING QUESTIONS

Content HS-PS2-1

- What is density?
- How does the specific gravity of an object or material relate to its density?
- What effect does velocity of a fluid have on its pressure?
- What causes a buoyant force to act on an object, and in what direction does it act?
- What is viscosity, and how does it affect the flow of a fluid?

Process

- How can the buoyant force on an object be calculated?
- How can the percent of an object's volume that is submerged when floating be calculated?
- How can we predict whether an object will float or sink?

Reflective

- How can a flammable substance such as oil burn when it is spilled in water?
- How does the properties of a fluid affect the design of hydraulic brakes?
- How can a boat that is made of a very dense material, such as steel, still float?
- What shape of container will be the most effective at floating with an added weight load?
- Why do cars passing at high speeds feel as if they are being pulled together?
- What causes "the bends" for divers?
- How do airplanes generate lift?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 1

- *Learning Objective 1.A.5.2* The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures. **[SP 1.1, 1.4, 7.1]**
- *Learning Objective 1.E.1.1:* The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction. [SP 4.2, 6.4]
- *Learning Objective 1.E.1.2:* The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. **[SP 4.1, 6.4]**

BIG IDEA 3

- *Learning Objective 3.A.2.1:* The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1]**
- *Learning Objective 3.A.3.2*: The student is able to construct an explanation for why an object cannot exert a force on itself. **[SP 6.1]**
- Learning Objective 3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. **[SP 1.4]**
- *Learning Objective 3.A.3.4*: The student is able to make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. **[SP 6.1, 6.4]**
- *Learning Objective 3.A.4.1*: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs
- *Learning Objective 3.A.4.2*: The student is able to make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. **[SP 6.4, 7.2]**
- *Learning Objective 3.A.4.3*: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. **[SP 1.4]**

- *Learning Objective 3.B.1.3*: The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. **[SP 1.5, 2.2]**
- *Learning Objective 3.B.1.4:* The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. **[SP 6.4, 7.2]**
- *Learning Objective 3.B.2.1*: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. **[SP 1.1, 1.4, 2.2]**
- *Learning Objective 3.C.4.1*: The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. **[SP 6.1]**
- *Learning Objective 3.C.4.2*: The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. **[SP 6.2]**

BIG IDEA 5

- *Learning Objective 5.B.10.1*: The student is able to make calculations related to a moving fluid using Bernoulli's equation. **[SP 2.2]**
- *Learning Objective 5.B.10.2*: The student is able to make calculations related to a moving fluid using Bernoulli's equation and/or the relationship between force and pressure. **[SP 2.2]**
- *Learning Objective 5.B.10.3*: The student is able to make calculations related to a moving fluid using Bernoulli's equation and the continuity equation. **[SP 2.2]**
- *Learning Objective 5.B.10.4*: The student is able to construct an explanation of Bernoulli's equation in terms of the conservation of energy. **[SP 6.2]**
- *Learning Objective 5.F.1.1*: The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). **[SP 2.1, 2.2, 7.2]**

NGSS:

- *HS-PS2-1:* Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

UNIT 2: Thermodynamics

ESSENTIAL QUESTIONS

How does sweating protect our bodies from overheating?
How does your car engine work?
How does the inside of a refrigerator stay cold?

BIG IDEAS

- **Big Idea 1:** Objects and systems have properties such as mass and charge. Systems may have internal structure.
- **Big Idea 3:** The interactions of an object with other objects can be described by forces.
- **Big Idea 4:** Interactions between systems can result in changes to those systems.
- **Big Idea 5:** Changes that occur as a result of interactions are constrained by conservation laws.
- **Big Idea 7:** The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems

GUIDING QUESTIONS

Content
- How are temperature, pressure, and volume related?
- What causes pressure in a closed container?
- How do we know thermal energy is transferred or exchanged?

Process
- How do you calculate the work done by a piston as the volume expands?
- How can you determine the direction of energy transfer due to temperature difference?
- How can a plot of pressure versus volume for a thermodynamic process be used to determine internal energy changes?

Reflective
- What is the significance of absolute zero temperature?
- What is it impossible to create 100% efficient automobile engine?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 1
- *Learning Objective 1.A.5.2:* The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures. **[SP 1.1, 1.4, 7.1]**

- *Learning Objective 1.E.3.1*: The student is able to design an experiment, and analyze data from it to examine thermal conductivity. [**SP 4.1, 4.2, 5.1**]

BIG IDEA 3

- *Learning Objective 3.A.2.1:* The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [**SP 1.1**]
- *Learning Objective 3.A.3.2:* The student is able to construct an explanation for why an object cannot exert a force on itself. [**SP 6.1**]
- Learning Objective 3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. [**SP 1.4**]
- *Learning Objective 3.A.3.4:* The student is able to make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [**SP 6.1, 6.4**]
- *Learning Objective 3.A.4.1:* The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [**SP 1.4, 6.2**]
- *Learning Objective 3.A.4.2:* The student is able to make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law**.** [**SP 6.4, 7.2**]
- *Learning Objective 3.A.4.3*: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [**SP 1.4**]
- *Learning Objective 3.B.2.1* : The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [**SP 1.1, 1.4, 2.2**]
- *Learning Objective 3.C.4.1:* The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. [SP 6.1] 3.C.4.2 Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [**SP 6.2**]

BIG IDEA 4

- *Learning Objective 4.C.3.1:* The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [**SP 6.4**]

BIG IDEA 5

- *Learning Objective 5.B.2.1:* The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [**SP 1.4, 2.1**]
- *Learning Objective 5.B.4.1:* The student is able to describe and make predictions about the internal energy of systems. [**SP 6.4, 7.2**]
- Learning Objective 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [**SP 1.4, 2.1, 2.2**]
- *Learning Objective 5.B.5.4:* The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [**SP 6.4, 7.2**] *Learning Objective 5.B.5.5:* The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [**SP 2.2, 6.4**]
- Learning Objective 5.B.5.6: The student is able to design an experiment and analyze graphical data in which interpretations of the area under a pressure-volume curve are needed to determine the work done on or by the object or system. [**SP 4.2, 5.1**]
- *Learning Objective 5.B.6.1:* The student is able to describe the models that represent processes by which energy can be transferred between a system and its environment because of differences in temperature: conduction, convection, and radiation. [**SP 1.2**]
- *Learning Objective 5.B.7.1:* The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving

transfer of energy due to heat or work done, and justify those predictions in terms of conservation of energy principles. [**SP 6.4, 7.2**]

- *Learning Objective 5.B.7.2:* The student is able to create a plot of pressure versus volume for a thermodynamic process from given data. [**SP 1.1**]
- *Learning Objective 5.B.7.3:* The student is able to make calculations of internal energy changes, heat, or work, based on conservation of energy principles (i.e., the first law of thermodynamics), using a plot of pressure versus volume for a thermodynamic process.: The student is able to
- *Learning Objective 5.D.1.6*: The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. [SP 6.4]
- *Learning Objective 5.D.1.7:* The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values **(SP 2.1, 2.2]**
- *Learning Objective 5.D.2.5:* The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [**SP 2.1, 2.2**]
- *Learning Objective 5.D.2.6*: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [**SP 6.4, 7.2**]

BIG IDEA 7

- *Learning Objective 7.A.1.1:* The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container and how changes in pressure affect the thermal equilibrium of the system. [**SP 6.4, 7.2**]
- *Learning Objective 7.A.1.2:* The student is able to, treating a gas molecule as an object (i.e., ignoring its internal structure), analyze qualitatively the collisions with a container wall and determine the cause of pressure, and at thermal equilibrium, quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables. [**SP 1.4, 2.2**]
- *Learning Objective 7.A.2.1:* The student is able to qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. [**SP 7.1**]
- *Learning Objective 7.A.2.2:* The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and relate this to thermodynamic processes. [**SP 7.1**]
- *Learning Objective 7.A.3.1:* The student is able to extrapolate from pressure and temperature or volume and temperature data to make the prediction that there is a temperature at which the pressure or volume extrapolates to zero. [**SP 6.4, 7.2**]
- *Learning Objective 7.A.3.2:* The student is able to design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and/or the amount of an ideal gas; and to refine a scientific question proposing an incorrect relationship between the variables. [**SP 3.2, 4.2**]
- *Learning Objective 7.A.3.3:* The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law PV = nRT. [**SP 5.1**]
- *Learning Objective 7.B.1.1:* The student is able to construct an explanation, based on atomic-scale interactions and probability, of how a system approaches thermal equilibrium when energy is transferred to it or from it in a thermal process. [**SP 6.2**]
- *Learning Objective 7.B.2.1*: The student is able to connect qualitatively the second law of thermodynamics in terms of the state function called entropy and how it (entropy) behaves in reversible and irreversible processes. [**SP 7.1**]

UNIT 3: Electric Field, Force, and Potential

ESSENTIAL QUESTIONS	BIG IDEAS
Why does your hair stand on end when you rub it with a balloon? What keeps electrons in orbit around the nucleus of an atom? How does a photocopier work?	• **Big Idea 1:** Objects and systems have properties such as mass and charge. Systems may have internal structure. • **Big Idea 2:** Fields existing in space can be used to explain interactions. • **Big Idea 3:** The interactions of an object with other objects can be described by forces. • **Big Idea 4:** Interactions between systems can result in changes to those systems. • **Big Idea 5:** Changes that occur as a result of interactions are constrained by conservation laws.

GUIDING QUESTIONS

Content HS-PS2-4; HS-PS3-5

- What is the atom made of, what is the charge of each component, and which component can carry charge from place to place?
- What does it mean for something to be quantized, and how does that relate to electric charge?
- What is the conservation of charge?
- What occurs when an object is grounded?
- What is the difference between a conductor and an insulator?
- What are electric fields, and how do they influence charged particles?
- How can charged particles be described in terms of energy?

Process

- How can an electroscope be used to describe the charge on an object?
- What different ways can objects gain an electric charge?
- How can the attractive or repulsive force between two charged objects be calculated?
- How are the electrostatic force and the gravitational force similar and different?
- How can electric fields be represented graphically?

Reflective

- Why do you get shocked more during the winter instead of during the summer?
- How is lightning formed?
- Why does your hair stand up when touching a Van de Graaff generator?
- Why is touching a 120-Volt outlet more dangerous than touching a 100,000-Volt Van de Graaff generator?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 1

- *Learning Objective 1.A.5.2:* The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [**SP 1.1, 1.4, 7.1**]
- *Learning Objective 1.B.1.1:* The student is able to make claims about natural phenomena based on conservation of electric charge. [**SP 6.4**]
- *Learning Objective 1.B.1.2:* The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [**SP 6.4, 7.2**]
- *Learning Objective 1.B.2.1:* The student is able to construct an explanation of the two charge model of electric charge based on evidence produced through scientific practices. [**SP 6.2**]
- *Learning Objective 1.B.2.2:* The student is able to make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. [**SP 6.4, 7.2**]
- *Learning Objective 1.B.2.3:* The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [**SP 6.1**]
- *Learning Objective 1.B.3.1:* The student is able to construct an explanation that challenges the claim that an electric charge smaller than the elementary charge has been isolated. [**SP 1.5, 6.1, 7.2**]

BIG IDEA 2

- *Learning Objective 2.C.1.1:* The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: F qE = a vector relation. [**SP 6.4, 7.2**]
- *Learning Objective 2.C.1.2:* The student is able to calculate any one of the variables—electric force, electric charge, and electric field—at a point given the values and sign or direction of the other two quantities. [**SP 2.2**]
- *Learning Objective 2.C.2.1:* The student is able to qualitatively and semi quantitatively apply the vector relationship between the electric field and the net electric charge creating that field. [**SP 2.2, 6.4**]

- *Learning Objective 2.C.3.1:* The student is able to explain the inverse square dependence of the electric field surrounding a spherically symmetric, electrically charged object. **[SP 6.2]**
- *Learning Objective 2.C.4.1:* The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single-point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field. **[SP 2.2, 6.4, 7.2]**
- *Learning Objective 2.C.4.2:* The student is able to apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (two to four) of point charges and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points. **[SP 1.4, 2.2]**
- *Learning Objective 2.C.5.1:* The student is able to create representations of the magnitude and direction of the electric field at various distances (small compared with plate size) from two electrically charged plates of equal magnitude and opposite signs, and be able to recognize that the assumption of uniform field is not appropriate near edges of plates. **[SP 1.1, 2.2]**
- *Learning Objective 2.C.5.2:* The student is able to calculate the magnitude and determine the direction of the electric field between two electrically charged parallel plates, given the charge of each plate, or the electric potential difference and plate separation. **[SP 2.2]**
- *Learning Objective 2.C.5.3:* The student is able to represent the motion of an electrically charged particle in the uniform field between two oppositely charged plates, and express the connection of this motion to projectile motion of an object with mass in Earth's gravitational field. **[SP 1.1, 2.2, 7.1]**
- *Learning Objective 2.E.1.1:* The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential. **[SP 1.4, 6.4, 7.2]**
- *Learning Objective 2.E.2.1:* The student is able to cetermine the structure of isolines of electric potential by constructing them in a given electric field. **[SP 6.4, 7.2]**
- *Learning Objective 2.E.2.2:* The student is able to predict the structure of isolines of electric potential by constructing them in a given electric field, and make connections between these isolines and those found in a gravitational field. **[SP 6.4, 7.2]**
- *Learning Objective 2.E.2.3:* The student is able to construct isolines of electric potential in an electric field, and determine the effect of that field on electrically charged objects, qualitatively using the concept of isolines. **[SP 1.4]**
- *Learning Objective 2.E.3.1:* The student is able to apply mathematical routines to calculate the average value of the magnitude of the electric field in a region from a description of the electric potential in that region using the displacement along the line on which the difference in potential is evaluated. **[SP 2.2]**
- *Learning Objective 2.E.3.2:* The student is able to apply the concept of the isoline representation of electric potential for a given electric charge distribution to predict the average value of the electric field in the region. **[SP 1.4, 6.4]**

BIG IDEA 3

- *Learning Objective 3.A.2.1:* The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1]**
- *Learning Objective 3.A.3.2:* The student is able to construct an explanation for why an object cannot exert a force on itself. **[SP 6.1]**
- *Learning Objective 3.A.3.3:* The student is able to describe a force as an interaction between two objects and identify both objects for any force. **[SP 1.4]**

- *Learning Objective 3.A.3.4:* The student is able to make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [**SP 6.1, 6.4**]
- *Learning Objective 3.A.4.1:* The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [**SP 1.4, 6.2**]
- Learning Objective 3.A.4.2*:* The student is able to make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [**SP 6.4, 7.2**]
- *Learning Objective 3.A.4.3:* The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [**SP 1.4**]
- *Learning Objective 3.B.1.3:* The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [**SP 1.5, 2.2**]
- *Learning Objective 3.B.1.4:* The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [**SP 6.4, 7.2**]
- *Learning Objective 3.B.2.1:* The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [**SP 1.1, 1.4, 2.2**]
- *Learning Objective 3.C.2.1:* The student is able to make predictions about the interaction between two electric point charges, using Coulomb's law qualitatively and quantitatively. [**SP 2.2, 6.4**]
- *Learning Objective 3.C.2.2:* The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [**SP 7.2**]
- *Learning Objective 3.C.2.3:* The student is able to describe the electric force that results from the interaction of several separated point charges (generally two to four point charges, though more are permitted in situations of high symmetry) using appropriate mathematics. [**SP 2.2**]
- *Learning Objective 3.G.1.2:* The student is able to connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength with other types of forces. [**SP 7.1**]
- *Learning Objective 3.G.2.1:* The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [**SP 7.1**]

BIG IDEA 4

- *Learning Objective 4.E.3.1:* The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction. [**SP 6.4**]
- *Learning Objective 4.E.3.2:* The student is able to make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. [**SP 6.4, 7.2**]
- *Learning Objective 4.E.3.3:* The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [**SP 1.1, 1.4, 6.4**]
- *Learning Objective 4.E.3.4:* The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors that predicts charge distribution in processes involving induction or conduction. [**SP 1.1, 1.4, 6.4**]
- *Learning Objective 4.E.3.5:* The student is able to plan and/or analyze the results of experiments in which electric-charge rearrangement occurs by electrostatic induction, or be able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure. [**SP 3.2, 4.1, 4.2, 5.1, 5.3**]

BIG IDEA 5

- *Learning Objective 5.B.2.1:* The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [**SP 1.4, 2.1**]
- *Learning Objective 5.B.4.1:* The student is able to describe and make predictions about the internal energy of systems. [**SP 6.4, 7.2**]
- *Learning Objective 5.B.4.2:* The student is able to calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [**SP 1.4, 2.1, 2.2**]
- *Learning Objective 5.B.5.4:* The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [**SP 6.4, 7.2**]
- *Learning Objective 5.B.5.5:* The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [**SP 2.2, 6.4**]
- *Learning Objective 5.C.2.1:* The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system. [**SP 6.4**]
- *Learning Objective 5.C.2.2:* The student is able to design a plan to collect data on the electrical charging of objects and electric charge induction on neutral objects and qualitatively analyze that data. [**SP 4.2, 5.1**]
- *Learning Objective 5.C.2.3:* The student is able to justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects. [**SP 4.1**]

UNIT 4: Electric Circuits

ESSENTIAL QUESTIONS	BIG IDEAS
Why is it dangerous to use a hair dryer while taking a bath?	• **Big idea 1:** Objects and systems have properties such as mass and charge. Systems may have internal structure. • **Big Idea 4:** Interactions between systems can result in changes to those systems. • **Big Idea 5:** Changes that occur as a result of interactions are constrained by conservation laws.

GUIDING QUESTIONS

Content HS-PS3-1; HS-PS2-5; HS-PS2-6

- What is an electric current, and what is its SI unit?
- What are the defining characteristics of a series circuit?
- What are the defining characteristics of a parallel circuit?
- What are Kirchhoff's Rules?
- What is meant by conventional current? Which way does charge actually flow in a circuit?
- What is a magnetic field?
- How can a magnet be used to create an electric current?

Process

- How can electrical circuits be represented schematically?
- How can the potential difference, current, and resistance be calculated for circuit elements connected in series, parallel, or a combination of both?
- What happens to the overall resistance in a series circuit when resistors are added? In a parallel circuit? What happens to the total current in each circuit?
- How can the rate of energy usage for a circuit be calculated?

Reflective

- Why is your house wired in parallel instead of series?
- What is the function of a circuit breaker in a home?
- Why is copper typically used to wire a house instead of aluminum? Instead of silver/gold?
- Is the north pole of the earth also magnetically north?
- As current flows from high potential to low potential, where does the energy go?
- Why do power lines transmit current at high voltages?
-

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 1

- *Learning Objective 1.B.1.1:* The student is able to make claims about natural phenomena based on conservation of electric charge. [**SP 6.4**]
- *Learning Objective 1.B.1.2:* The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [**SP 6.4, 7.2**]
- *Learning Objective 1.B.2.1:* The student is able to construct an explanation of the two charge model of electric charge based on evidence produced through scientific practices. [**SP 6.2**]
- *Learning Objective 1.B.2.2:* The student is able to make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. [**SP 6.4, 7.2**]
- *Learning Objective 1.B.2.3:* The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [**SP 6.1**]
- *Learning Objective 1.E.2.1:* The student is able to select and justify the data needed to determine resistivity for a given material. [**SP 4.1**]

BIG IDEA 4

- *Learning Objective 4.E.4.1:* The student is able to make predictions about the properties of resistors and/or capacitors when placed in a simple circuit based on the geometry of the circuit element and supported by scientific theories and mathematical relationships. [**SP 2.2, 6.4**]
- *Learning Objective 4.E.4.2:* The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element, and relate results to the basic properties of resistors and capacitors. [**SP 4.1, 4.2**]
- *Learning Objective 4.E.4.3:* The student is able to analyze data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element, and relate results to the basic properties of resistors and capacitors. [**SP 5.1**]

- *Learning Objective 4.E.5.1:* The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [**SP 2.2, 6.4**]
- *Learning Objective 4.E.5.2:* The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [**SP 6.1, 6.4**]
- *Learning Objective 4.E.5.3:* The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [**SP 2.2, 4.2, 5.1**]

BIG IDEA 5

- *Learning Objective 5.B.9.4:* The student is able to analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule: Δ = V 0. [**SP 5.1**]
- *Learning Objective 5.B.9.5:* The student is able to describe and make predictions regarding electrical potential difference, charge, and current in steadystate circuits composed of various combinations of resistors and capacitors using conservation of energy principles (Kirchhoff's loop rule). [**SP 6.4**]
- *Learning Objective 5.B.9.6:* The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit, and justify this expression using the principle of the conservation of energy. [**SP 2.1, 2.2**]
- *Learning Objective 5.B.9.7:* The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. [**SP 4.1, 4.2, 5.1, 5.3**]
- *Learning Objective 5.B.9.8:* The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [**SP 1.5**]
- *Learning Objective 5.C.3.4:* The student is able to predict or describe current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule, and explain the relationship of the rule to the law of charge conservation. [**SP 6.4, 7.2**]
- *Learning Objective 5.C.3.5:* The student is able to determine missing values and direction of electric current in branches of a circuit with resistors and NO capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [**SP 1.4, 2.2**]
- *Learning Objective 5.C.3.6:* The student is able to determine missing values and direction of electric current in branches of a circuit with both resistors and capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [**SP 1.4, 2.2**]
- *Learning Objective 5.C.3.7:* The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. [**SP 1.4, 2.2**]

UNIT 5: Magnetism and Electromagnetic Induction

ESSENTIAL QUESTIONS

What causes the Northern Lights?
How does the Earth protect us from the solar wind and cosmic rays?
How does a microphone work?
How does a vending machine sort coins?

BIG IDEAS

- **Big idea 1:** Objects and systems have properties such as mass and charge. Systems may have internal structure.
- **Big idea 2:** Fields existing in space can be used to explain interactions
- **Big Idea 3:** The interactions of an object with other objects can be described by forces.
- **Big Idea 4:** Interactions between systems can result in changes to those systems.

GUIDING QUESTIONS

Content

- How does a magnet influence the movement of charged particles?
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Process

- How does the presence of a magnetic field generate a current in a conductive material?
- 10 pt. Proxima Nova font

Reflective

- Can there be a magnetic monopole?
- How are magnetic and electric fields related to the speed of light?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

<u>**College Board:**</u>

BIG IDEA 1

- *Learning Objective 1.A.5.2:* The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures. **[SP 1.1, 1.4, 7.1]**

BIG IDEA 2

- *Learning Objective 2.C.4.1:* The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single-point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field. **[SP 2.2, 6.4, 7.2]**

- *Learning Objective 2.D.1.1:* The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [**SP 2.2**]
- *Learning Objective 2.D.2.1:* The student is able to create a verbal or visual representation of a magnetic field around a straight wire or a pair of parallel wires. [**SP 1.1**]
- *Learning Objective 2.D.3.1:* The student is able to describe the orientation of a magnetic dipole placed in a magnetic field in general and the particular cases of a compass in the magnetic field of Earth and iron filings surrounding a bar magnet. [**SP 1.2**]
- *Learning Objective 2.D.4.1:* The student is able to qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material. [**SP 1.4**]

BIG IDEA 3

- *Learning Objective 3.C.3.1:* The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [**SP 1.4**]
- *Learning Objective 3.C.3.2:* The student is able to plan a data collection strategy appropriate to an investigation of the direction of the force on a moving electrically charged object caused by a current in a wire in the context of a specific set of equipment and instruments, and analyze the resulting data to arrive at a conclusion. [**SP 4.2, 5.1**]
- *Learning Objective 3.A.2.1:* The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [**SP 1.1**]
- *Learning Objective 3.A.3.2:* The student is able to construct an explanation for why an object cannot exert a force on itself. [**SP 6.1**]
- *Learning Objective 3.A.3.3:* The student is able to describe a force as an interaction between two objects and identify both objects for any force. [**SP 1.4**]
- *Learning Objective 3.A.3.4:* The student is able to make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [**SP 6.1, 6.4**]
- *Learning Objective 3.A.4.1:* The student is able to construct explanations of physical situations involving the interaction of bodies using Newton’s third law and the representation of action-reaction pairs of forces. [**SP 1.4, 6.2**]
- *Learning Objective 3.A.4.2:* The student is able to make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton’s third law. [**SP 6.4, 7.2**]
- *Learning Objective 3.A.4.3:* The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton’s third law to identify forces. [**SP 1.4**]
- *Learning Objective 3.B.1.3:* The student is able to re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [**SP 1.5, 2.2**]
- *Learning Objective 3.B.1.4:* The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton’s second law in a variety of physical situations. [**SP 6.4, 7.2**]
- *Learning Objective 3.B.2.1:* The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [**SP 1.1, 1.4, 2.2**]
- *Learning Objective 3.G.2.1:* The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [**SP 7.1**]

BIG IDEA 4

- *Learning Objective 4.E.1.1:* The student is able to use representations and models to qualitatively describe the magnetic properties of some materials that can be affected by magnetic properties of other objects in the system. [**SP 1.1, 1.4, 2.2**]

- *Learning Objective 4.E.2.1:* The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [**SP 6.4**]

UNIT 6: Geometric and Physical Optics

ESSENTIAL QUESTIONS	BIG IDEAS
What is fiber optics? How do eyeglasses correct vision? When you look in a mirror, where is the face you see? Why do we see colors in soap bubbles?	• **Big idea 6:** Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena. •

GUIDING QUESTIONS

Content HS-PS4-2; HS-PS4-5

- What is the difference between reflection and refraction?
- What is focal length?
- What is Snell's Law?
- What is the difference between a real image and a virtual image?
- Under what conditions does total internal reflection occur?

Process

- How can a ray diagram be used to illustrate how images are created with flat, convex, and concave mirrors?
- How can a ray diagram be used to illustrate how images are created with converging and diverging lenses?
- How is magnification calculated?
- How is the index of refraction for a material calculated?

Reflective

- Why do different objects appear different colors?
- Why do parking garages and supermarkets use convex mirrors instead of concave mirrors?
- How do corrective lenses serve to fix vision problems?
- What is the smallest flat mirror that can be used to see your whole body?
- What are the benefits and disadvantages of refracting or reflecting telescopes?

- How is information transmitted through fiber optic cables?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 6

- *Learning Objective 6.A.1.2:* The student is able to describe representations of transverse and longitudinal waves. [**SP 1.2**]
- *Learning Objective 6.A.1.3:* The student is able to analyze data (or a visual representation) to identify patterns that indicate that a particular mechanical wave is polarized, and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation. [**SP 5.1, 6.2**]
- *Learning Objective 6.A.2.2:* The student is able to contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. [**SP 6.4, 7.2**]
- *Learning Objective 6.F.1.1:* The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [**SP 6.4, 7.2**]
- *Learning Objective 6.F.2.1:* The student is able to describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. [**SP 1.1**]
- *Learning Objective 6.B.3.1:* The student is able to construct an equation relating the wavelength and amplitude of a wave from a graphical representation of the electric or magnetic field value as a function of position at a given time instant and vice versa, or construct an equation relating the frequency or period and amplitude of a wave from a graphical representation of the electric or magnetic field value at a given position as a function of time and vice versa. [**SP 1.5**]
- *Learning Objective 6.E.1.1:* The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [**SP 6.4, 7.2**]
- *Learning Objective 6.E.2.1:* The student is able to make predictions about the locations of object and image relative to the location of a reflecting surface. The prediction should be based on the model of specular reflection with all angles measured relative to the normal to the surface. [**SP 6.4, 7.2**]
- *Learning Objective 6.E.3.1:* The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. [**SP 1.1, 1.4**]
- *Learning Objective 6.E.3.2:* The student is able to plan data collection strategies as well as perform data analysis and evaluation of the evidence for finding the relationship between the angle of incidence and the angle of refraction for light crossing boundaries from one transparent material to another (Snell's law). [**SP 4.1, 5.1, 5.2, 5.3**]
- *Learning Objective 6.E.3.3:* The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [**SP 6.4, 7.2**]
- *Learning Objective 6.E.4.1:* The student is able to plan data collection strategies and perform data analysis and evaluation of evidence about the formation of images due to reflection of light from curved spherical mirrors. [**SP 3.2, 4.1, 5.1, 5.2, 5.3**]

- *Learning Objective 6.E.4.2:* The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the reflection of light from surfaces. [**SP 1.4, 2.2**]
- *Learning Objective 6.E.5.1:* The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the refraction of light through thin lenses. [**SP 1.4, 2.2**]
- *Learning Objective 6.E.5.2:* The student is able to plan data collection strategies, perform data analysis and evaluation of evidence, and refine scientific questions about the formation of images due to refraction for thin lenses. [**SP 3.2, 4.1, 5.1, 5.2, 5.3**]
- *Learning Objective 6.C.1.1:* The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples include standing waves. [**SP 6.4, 7.2**]
- *Learning Objective 6.C.1.2:* The student is able to construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [**SP 1.4**]
- *Learning Objective 6.C.2.1:* The student is able to make claims about the diffraction pattern produced when a wave passes through a small opening, and qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. [**SP 1.4, 6.4, 7.2**]
- *Learning Objective 6.C.3.1:* The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared with the wavelength of the waves. [SP 1.4, 6.4]
- *Learning Objective 6.C.4.1:* The student is able to predict and explain, using representations and models, the ability or inability of waves to transfer energy around corners and behind obstacles in terms of the diffraction property of waves in situations involving various kinds of wave phenomena, including sound and light. [**SP 6.4, 7.2**]

UNIT 7: Quantum, Atomic, and Nuclear Physics

ESSENTIAL QUESTIONS	BIG IDEAS
How can atomic clocks on satellites help determine your location on Earth? Why do some stars look red and some look blue? How do scientists determine the chemical composition of stars? How are new elements created? How does carbon dating work?	• **Big idea 1:** Objects and systems have properties such as mass and charge. Systems may have internal structure. • **Big Idea 3:** The interactions of an object with other objects can be described by forces. • **Big Idea 4:** Interactions between systems can result in changes to those systems. • **Big idea 5:** Changes that occur as a result of interactions are constrained by conservation laws. • **Big Idea 6:** Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena. • **Big Idea 7:** The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems

GUIDING QUESTIONS

Content
- How do LEDs work?
- Why are only certain transitions between energy states allowed?
- What are the possible causes of nuclear radiation?

Process
- How can we determine the energy of an incident photon on an metallic surface?

Reflective
- What is meant by the search for a Unified Theory?
- Why did it take LIGO so long to record the existence of gravitational waves.

FOCUS STANDARDS

Mastered and Assessed in this Unit:

<u>**College Board:**</u>

BIG IDEA 1
- *Learning Objective 1.A.2.1:* The student is able to construct representations of the differences between a fundamental particle and a system composed of fundamental particles, and relate this to the properties and scales of the systems being investigated. **[SP 1.1, 7.1]**

- *Learning Objective 1.A.4.1:* The student is able to construct representations of the energy-level structure of an electron in an atom, and relate this to the properties and scales of the systems being investigated. [**SP 1.1, 7.1**]
- *Learning Objective 1.C.4.1:* The student is able to articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass–energy. [**SP 6.3**]
- *Learning Objective 1.D.1.1:* The student is able to explain why classical mechanics cannot describe all properties of objects by articulating the reasons that classical mechanics must be refined and an alternative explanation developed when classical particles display wave properties. [**SP 6.3**]
- *Learning Objective 1.D.3.1:* The student is able to articulate the reasons that classical mechanics must be replaced by special relativity to describe the experimental results and theoretical predictions that show that the properties of space and time are not absolute. [Students will be expected to recognize situations in which non-relativistic classical physics breaks down and to explain how relativity addresses that breakdown, but students will not be expected to know in which of two reference frames a given series of events corresponds to a greater or lesser time interval, or a greater or lesser spatial distance; they will just need to know that observers in the two reference frames can "disagree" about some time and distance intervals.] [**SP 6.3, 7.1**]

BIG IDEA 3

- *Learning Objective 3.G.3.1:* The student is able to identify the strong force as the force that is responsible for holding the nucleus together. [**SP 7.2**]

BIG IDEA 4

- *Learning Objective 4.C.4.1:* The student is able to apply mathematical routines to describe the relationship between mass and energy, and apply this concept across domains of scale. [**SP 2.2, 2.3, 7.2**]

BIG IDEA 5

- *Learning Objective 5.C.1.1:* The student is able to analyze electric charge conservation for nuclear and elementary particle reactions, and make predictions related to such reactions based on conservation of charge. [**SP 6.4, 7.2**]
- *Learning Objective 5.D.1.6:* The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. [**SP 6.4**]
- *Learning Objective 5.D.1.7:* The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [**SP 2.1, 2.2**]
- *Learning Objective 5.D.2.5:* The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [**SP 2.1, 2.2**]
- *Learning Objective 5.D.2.6:* The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [**SP 6.4, 7.2**]
- *Learning Objective 5.D.3.2:* The student is able to make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. [**SP 6.4**]
- *Learning Objective 5.D.3.3:* The student is able to make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. [**SP 6.4**]

- *Learning Objective 5.G.1.1:* The student is able to apply conservation of nucleon number and conservation of electric charge to make predictions about nuclear reactions and decays such as fission, fusion, alpha decay, beta decay, or gamma decay. [**SP 6.4**]
- *Learning Objective 5.B.2.1:* The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [**SP 1.4, 2.1**]
- *Learning Objective 5.B.4.1:* The student is able to describe and make predictions about the internal energy of systems. [**SP 6.4, 7.2**]
- *Learning Objective 5.B.4.2:* The student is able to calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [**SP 1.4, 2.1, 2.2**]
- *Learning Objective 5.B.5.4:* The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [**SP 6.4, 7.2**]
- *Learning Objective 5.B.8.1:* The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed. [**SP 1.2, 7.2**]
- *Learning Objective 5.B.11.1:* The student is able to apply conservation of mass and conservation of energy concepts to a natural phenomenon, and use the equation = 2 E mc to make a related calculation. [**SP 2.2, 7.2**]

BIG IDEA 6

- *Learning Objective 6.C.1.1:* The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples include standing waves. [**SP 6.4, 7.2**]
- *Learning Objective 6.C.1.2:* The student is able to construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [**SP 1.4**]
- *Learning Objective 6.C.2.1:* The student is able to make claims about the diffraction pattern produced when a wave passes through a small opening, and qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. [**SP 1.4, 6.4, 7.2**]
- *Learning Objective 6.C.3.1:* The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared with the wavelength of the waves. [**SP 1.4, 6.4**]
- *Learning Objective 6.C.4.1:* The student is able to predict and explain, using representations and models, the ability or inability of waves to transfer energy around corners and behind obstacles in terms of the diffraction property of waves in situations involving various kinds of wave phenomena, including sound and light. [**SP 6.4, 7.2**]
- *Learning Objective6.G.1.1:* The student is able to make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. [**SP 6.4, 7.1**]
- *Learning Objective 6.G.2.1:* The student is able to articulate the evidence supporting the claim that a wave model of matter is appropriate to explain the diffraction of matter interacting with a crystal, given conditions where a particle of matter has momentum corresponding to a de Broglie wavelength smaller than the separation between adjacent atoms in the crystal. [**SP 6.1**]
- *Learning Objective 6.G.2.2:* The student is able to predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima) based on the particle speed and de Broglie wavelength of electrons in an electron beam interacting with a crystal. (De Broglie wavelength need not be given, so students may need to obtain it.) [**SP 6.4**]

- *Learning Objective 6.F.3.1:* The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. [**SP 6.4**]
- *Learning Objective 6.F.4.1:* The student is able to select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. [**SP 6.4, 7.1**]
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BIG IDEA 7

- *Learning Objective 7.C.1.1:* The student is able to use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region. [**SP 1.4**]
- *Learning Objective 7.C.2.1:* The student is able to use a standing wave model in which an electron orbit circumference is an integer multiple of the de Broglie wavelength to give a qualitative explanation that accounts for the existence of specific allowed energy states of an electron in an atom. [**SP 1.4**]
- *Learning Objective 7.C.3.1:* The student is able to predict the number of radioactive nuclei remaining in a sample after a certain period of time, and also predict the missing species (alpha, beta, gamma) in a radioactive decay. [**SP 6.4**]
- *Learning Objective 7.C.4.1:* The student is able to construct or interpret representations of transitions between atomic energy states involving the emission and absorption of photons. [For questions addressing stimulated emission, students will not be expected to recall the details of the process, such as the fact that the emitted photons have the same frequency and phase as the incident photon; but given a representation of the process, students are expected to make inferences such as figuring out from energy conservation that, since the atom loses energy in the process, the emitted photons taken together must carry more energy than the incident photon.] [**SP 1.1, 1.2**]