AP Physics I

UNIT 1: Kinematics

ESSENTIAL QUESTIONS	BIG IDEAS
How can the motion of objects be predicted and/or explained? **How can we use models to help us understand motion?**	• **Big Idea 3:** The interactions of an object with other objects can be described by forces.

GUIDING QUESTIONS

Content
- With what values can the motion of objects be described?
- What are vectors?
- What effects can an acceleration have on an object's velocity?
- What happens to the velocity of an object as it falls?
- How does the direction of an acceleration relate to the change in an object's speed?
- What path does an object take when it is in projectile motion?

Process
- How can the velocity of an object be determined from a position time graph?
- How can the acceleration of an object and the displacement of an object be determined from a velocity time graph?
- How can the quantities of displacement, initial and final velocity, acceleration, and time be related mathematically?
- How can vectors be combined?

Reflective
- How can the motion of objects be predicted and/or explained?
- Can equations be used to answer questions regardless of the questions specificity?
- How can the idea of frames of reference allow two people to tell the truth yet have conflicting reports?
- How can we use models to help us understand motion

- Why is the general rule for stopping your car, “when you double your speed you must give yourself four times as much distance to stop?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 3

- *Learning Objective 3.A.1.1:* express the motion of an object using narrative, mathematical, and graphical representations
- *Learning Objective 3.A.1.2:*The student is able to design an experimental investigation of the motion of an object.
- *Learning Objective 3.A.1.3:* The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations.

NGSS:

- 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. HS-PS2-1

UNIT 2: Dynamics

ESSENTIAL QUESTIONS	BIG IDEAS
How do forces affect our surroundings?	• **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 in those systems.

GUIDING QUESTIONS

Content

- What are Newton's Three Laws of Motion?
- What is inertia, and what quantity do we use to represent it?
- What is the relationship between an object's mass, the force acting on it, and its acceleration?
- How can the motion of an object that is not experiencing a net force be described?
- What factors affect the coefficient of friction between two surfaces?
- How are the mass and the weight of an object different?
- What force causes objects to slide down an inclined plane?
- What is the difference between static and kinetic friction?

Process

- How can the forces acting on an object be represented graphically?
- How can the acceleration of an object with multiple forces acting on them be calculated?
- How can the acceleration of systems of multiple masses, such as Atwood Machines, be calculated?
- How can the coefficient of friction between two surfaces be calculated?
- What effect does the mass of an object have on the force of friction acting on the object?
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Reflective

- How can the properties of internal and gravitational mass be experimentally verified to be the same?
- How do you decide what to believe about scientific claims?
- How does something we cannot see determine how an object behaves
- How do objects with mass respond when placed in a gravitational field

- Why is the acceleration due to gravity constant at Earth's surface?
- Are different kinds of forces really different?
- How can Newton's laws of motion be used to predict the behavior of objects?
- Why does the same push change the motion of a shopping cart more than the motion of the car?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 1

- *Learning Objective 1.C.1.1*-The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass and its acceleration. [**SP 4.2**]
- *Learning Objective 1.C.1.3:* The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments. [**SP 4.2**]

BIG IDEA 2

- *Learning Objective 2.B.1.1:* The student is able to apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass *m* in a gravitational field of strength *g* in the context of the effects of a net force on objects and systems. [**SP 2.2, 7.2**]

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.3.1:* The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [**SP 6.4, 7.2**]
- *Learning Objective 3.A.3.2:* The student is able to challenge a claim that an object can 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.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 use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [**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.1.1:*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 with acceleration in one dimension. [**SP 6.4, 7.2**]
- *Learning Objective 3.B.1.2:* The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. [**SP 4.2, 5.1**]
- *Learning Objective 3.B.1.3:* The student is able to reexpress 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.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 4

- *Learning Objective 4.A.1.1:* The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively. [**SP 1.2, 1.4, 2.3, 6.4**]
- *Learning Objective 4.A.2.1:* The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [**SP 6.4**]
- *Learning Objective 4.A.2.2:* The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified. [**SP 5.3**]
- *Learning Objective 4.A.2.3:* The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. [**SP 1.4, 2.2**]
- *Learning Objective 4.A.3.1:* The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. [**SP 2.2**]
- *Learning Objective 4.A.3.2:* The student is able to use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [**SP 1.4**]

NGSS

- 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. HS-PS2-1

UNIT 3: Circular Motion and Gravitation

ESSENTIAL QUESTIONS	BIG IDEAS
How does society make use of uniform circular motion?	• **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 in those systems.

GUIDING QUESTIONS

Content

- What keeps an object moving in a circle?
- What is centripetal force, and how does it affect an object's motion?
- What factors affect the force of gravity between two objects?
- What is Newton's Law of Universal Gravitation?

Process

- How are the force of gravity between two objects, the mass of the objects, and the distance between the objects mathematically related?
- How can the velocity of an object moving in uniform circular motion be calculated?
- How does changing the velocity of an object in uniform circular motion affect its radius of motion?

Reflective

- How does changing the mass of an object affect the gravitational force?
- Why is a refrigerator hard to push in space?
- Why do we feel pulled toward Earth but not toward a pencil?
- How can the acceleration due to gravity be modified?
- How can Newton's laws of motion be used to predict the behavior of objects?
- How can we use forces to predict the behavior of objects and keep us safe?
- How is the acceleration of the center of a system related to the net force exerted on the system?
- Why is it more difficult to stop a fully loaded dump truck than a small passenger car?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 1

- *Learning Objective* **1.C.3.1:** The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments. [**SP 4.2**]

BIG IDEA 2

- *Learning Objective:* **2.B.1.1:** The student is able to apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass *m* in a gravitational field of strength *g* in the context of the effects of a net force on objects and systems. [**SP 2.2, 7.2**]
- *Learning Objective* **2.B.2.1:** The student is able to apply $g = G\frac{M}{r^2}$ to calculate the gravitational field due to an object with mass *M*, where the field is a vector directed toward the center of the object of mass *M*. [**SP 2.2**]
- *Learning Objective* **2.B.2.2:** The student is able to approximate a numerical value of the gravitational field (*g*) near the surface of an object from its radius and mass relative to those of the Earth or other reference objects. [**SP 2.2**]

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.3.1:** The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [**SP 6.4, 7.2**]
- *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.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 use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [**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.1.2:** The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. [**SP 4.2, 5.1**]
- *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.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.1.1:** The student is able to use Newton's law of gravitation to calculate the gravitational force the two objects exert on each other and use that force in contexts other than orbital motion. [**SP 2.2**]
- *Learning Objective* **3.C.1.2:** The student is able to use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion [**SP 2.2**]
- *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.G.1.1:** The student is able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. [**SP 7.1**]

BIG IDEA 4

- *Learning Objective* **4.A.2.2:** The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified. [**SP 5.3**]

NGSS

- 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. HS-PS2-1
- Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects. HS-PS2-4

UNIT 4: Energy

ESSENTIAL QUESTIONS	BIG IDEAS
If energy is always conserved, where does the energy go when my phone dies?	• **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 in those systems. • **Big Idea 5:** Changes that occur as a result of interactions are constrained by conservation laws

GUIDING QUESTIONS

Content

- What is energy, and what is it's SI units?
- What does it mean for energy to be conserved?
- When is mechanical energy not conserved?
- How is work related to energy?
- What is mechanical advantage?

Process

- How can the kinetic and potential energy of an object be calculated?
- How can energy transfers be diagrammed for the motion of an object?
- How can the conservation of energy be modeled mathematically?
- How can the energy lost from of system be calculated?

Reflective

- How does pushing something give it energy?
- How is energy exchanged and transformed within or between systems?
- How does the choice of system influence how energy is stored or how work is done?
- How does energy conservation allow the riders in the back car of a rollercoaster have a thrilling ride
- How can the idea of potential energy be used to describe the work done to move celestial bodies?
- How is energy transferred between objects or systems?
- How does the law of conservation of energy govern the interactions between objects and systems?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 3

- *Learning Objective* **3.E.1.1:** The student is able to make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves. [**SP 6.4, 7.2**]
- *Learning Objective* **3.E.1.2:** The student is able to use net force and velocity vectors to determine qualitatively whether kinetic energy of an object would increase, decrease, or remain unchanged. [**SP 1.4**]
- *Learning Objective* **3.E.1.3:** The student is able to use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether kinetic energy of that object would increase, decrease, or remain unchanged. [**SP 1.4, 2.2**]
- *Learning Objective* **3.E.1.4:** The student is able to apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. [**SP 2.2**]

BIG IDEA 4

- *Learning Objective* **4.C.1.1:** The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. [**SP 1.4, 2.1, 2.2**]
- *Learning Objective* **4.C.1.2:** The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. [**SP 6.4**]
- *Learning Objective* **4.C.2.1:** The student is able to make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass. [**SP 6.4**]
- *Learning Objective* **4.C.2.2:** The student is able to apply the concepts of Conservation of Energy and the Work-Energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system. [**SP 1.4, 2.2, 7.2**]

BIG IDEA 5

- *Learning Objective* **5.A.2.1:** The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [**SP 6.4, 7.2**]
- *Learning Objective* **5.B.1.1:** The student is able to set up a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy. [**SP 1.4, 2.2**]
- *Learning Objective* **5.B.1.2:** The student is able to translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies**.** [**SP 1.5**]
- *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, the student can 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.3.1:** The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [**SP 2.2, 6.4, 7.2**]
- *Learning Objective* **5.B.3.2:** The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [**SP 1.4, 2.2**]
- *Learning Objective* **5.B.3.3:** The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [**SP 1.4, 2.2**]
- *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.5.1:** The student is able to design an experiment and analyze data to examine how a force exerted on an object or system does work on the object or system as it moves through a distance. [**SP 4.2, 5.1**]
- *Learning Objective* **5.B.5.2:** The student is able to design an experiment and analyze graphical data in which interpretations of the area under a force-distance curve are needed to determine the work done on or by the object or system. [**SP 4.2, 5.1**]

- *Learning Objective* **5.B.5.3:** The student is able to predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance. [**SP 1.4, 2.2, 6.4**]
- *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.D.1.1:** The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [**SP 6.4, 7.2**]
- *Learning Objective* **5.D.1.2:** The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations. [**SP 2.2, 3.2, 5.1, 5.3**]
- *Learning Objective* **5.D.1.3:** The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [**SP 2.1, 2.2**]
- *Learning Objective* **5.D.1.4:** The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [**SP 4.2, 5.1, 5.3, 6.4**]
- *Learning Objective* **5.D.1.5:** 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.2.1:** The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [**SP 6.4, 7.2**]
- *Learning Objective* **5.D.2.3:** 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**]

NGSS:

- Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. HS-PS3-1
- Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects). HS-PS3-2
- Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. HS-PS3-3

UNIT 5: Linear Momentum

ESSENTIAL QUESTIONS	BIG IDEAS
How do we stay safe during collisions?	• **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 in those systems. • **Big Idea 5:** Changes that occur as a result of interactions are constrained by conservation laws

GUIDING QUESTIONS

Content

- What is momentum, and what are its SI units?
- What differentiates elastic, inelastic, and perfectly inelastic collisions?
- How can forces change the momentum of a system?

Process

- How can the conservation of momentum be modeled mathematically?
- How can the direction of objects' motion after a collision be predicted?
- How can the average force acting on an object during a collision be calculated?

Reflective

- How does pushing an object change its momentum?
- How do interactions with other objects or systems change the linear momentum of a system?
- How is the physics definition of momentum different from how momentum is used to describe things in everyday life?
- How does the law of the conservation of momentum govern interactions between objects or systems?
- How can momentum be used to determine fault in car crashes?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 3

- *Learning Objective* **3.D.1.1:** The student is able to justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force. [**SP 4.1**]
- *Learning Objective* **3.D.2.1:** The student is able to justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. [**SP 2.1**]
- *Learning Objective* **3.D.2.2:** The student is able to predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [**SP 6.4**]
- *Learning Objective* **3.D.2.3:** The student is able to analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [**SP 5.1**]
- *Learning Objective* **3.D.2.4:** The student is able to design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. [**SP 4.2**]

BIG IDEA 4

- *Learning Objective* **4.B.1.1:** The student is able to calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). [**SP 1.4, 2.2**]
- *Learning Objective* **4.B.1.2:** The student is able to analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass. [**SP 5.1**]
- *Learning Objective* **4.B.2.1:** The student is able to apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. [**SP 2.2**]
- *Learning Objective* **4.B.2.2:** The student is able to perform analysis on data presented as a force-time graph and predict the change in momentum of a system. [**SP 5.1**]

BIG IDEA 5

- *Learning Objective* **5.A.2.1:** The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [**SP 6.4, 7.2**]
- *Learning Objective* **5.D.1.1**: The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [**SP 6.4, 7.2**]
- *Learning Objective* **5.D.1.2:** The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations. [**SP 2.2, 3.2, 5.1, 5.3**]
- *Learning Objective* **5.D.1.3:** The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [**SP 2.1, 2.2**]
- *Learning Objective* **5.D.1.4:** The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [**SP 4.2, 5.1, 5.3, 6.4**]
- *Learning Objective* **5.D.1.5:** 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.2.1:** The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [**SP 6.4, 7.2**]
- *Learning Objective* **5.D.2.2:** The student is able to plan data collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. [**SP 4.1, 4.2, 5.1**]
- *Learning Objective* **5.D.2.3:** 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.2.4:** The student is able to analyze data that verify conservation of momentum in collisions with and without an external friction force. [**SP 4.1, 4.2, 4.4, 5.1, 5.3**]

- *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.3.1:** The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force). **[SP 6.4]**

NGSS

- Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. HS-PS2-2
- Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during collision. HS-PS2-3

UNIT 6: Simple Harmonic Motion

ESSENTIAL QUESTIONS	BIG IDEAS
How does information travel across large distances to your devices?	• **Big Idea 3:** The interactions of an object with other objects can be described by forces • **Big Idea 5:** Changes that occur as a result of interactions are constrained by conservation laws

GUIDING QUESTIONS

Content

- What is simple harmonic motion?
- What factors affect the period of a pendulum and the period of a mass-spring system?
- What is frequency, wavelength, and wave speed?
- What differentiates a mechanical wave from an electromagnetic wave?
- How do waves interact with their surroundings and other waves?
- What is resonance?
- What is the Doppler Effect?
- How does the electromagnetic spectrum ordering relate to the energy of the waves?
- How did the single and double slit experiments provide evidence that light acts as a wave?

Process

- How are frequency and wavelength related?
- How can the motion of pendulums and mass-spring systems be described mathematically?

Reflective

- How does a restoring force differ from a “regular” force?
- How does the presence of restoring forces predict and lead to harmonic motion?
- How does a spring cause an object to oscillate?
- How can oscillations be used to make our lives easier?
- How does the law of conservation of energy govern the interactions between objects and systems?
- How can energy stored in a spring be used to create motion?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 3

- *Learning Objective* **3.B.3.1:** The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [**SP 6.4, 7.2**]
- *Learning Objective* **3.B.3.2:** The student is able to design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force. [**SP 4.2**]
- *Learning Objective* **3.B.3.3:** The student can analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown. [**SP 2.2, 5.1**]
- *Learning Objective* **3.B.3.4:** The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [**SP 2.2, 6.2**]

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, the student can 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.3.1:** The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. **[SP 2.2, 6.4, 7.2]**
- *Learning Objective* **5.B.3.2:** The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [**SP 1.4, 2.2**]
- *Learning Objective* **5.B.3.3:** The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [**SP 1.4, 2.2**]
- *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**]

NGSS

- Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. HS-PS4-1
- Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. HS-PS4-3
- Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. HS-PS4-4

UNIT 7: Torque and Rotational Motion

ESSENTIAL QUESTIONS	BIG IDEAS
Why would a tight-rope walker use a long pole?	• **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 in those systems. • **Big Idea 5:** Changes that occur as a result of interactions are constrained by conservation laws

GUIDING QUESTIONS

Content

- What causes rotational motion?
- What is a radian?
- What is the moment of inertia?
- What is the difference between linear and rotational motion?
- When an object rolls without slipping down an incline, is it experiencing static or kinetic friction?
- What is torque?

Process

- How is rotational motion described mathematically
- How would you mathematically find angular velocity?
- How would you mathematically find angular acceleration?
- How would you mathematically find torque?

Reflective

- How does a system at rotational equilibrium compare to a system in translational equilibrium?
- How does the choice of system and rotation point affect the forces that can cause a torque on an object or a system?
- How can balanced forces cause rotation?
- Why does it matter where the door handle is placed?
- Why are long wrenches more effective?
- How can an external net torque change the angular momentum of a system
- Why is a rotating bicycle wheel more stable than a stationary one?
- How does the conservation of angular momentum govern interactions between objects and systems?
- Why do planets move faster when they travel closer to the sun?

FOCUS STANDARDS

Mastered and Assessed in this Unit:

College Board:

BIG IDEA 3

- *Learning Objective* **3.F.1.1:** The student is able to use representations of the relationship between force and torque. [**SP 1.4**]
- *Learning Objective* **3.F.1.2:** The student is able to compare the torques on an object caused by various forces. [**SP 1.4**]
- *Learning Objective* **3.F.1.3:** The student is able to estimate the torque on an object caused by various forces in comparison to other situations. [**SP 2.3**]
- *Learning Objective* **3.F.1.4:** The student is able to design an experiment and analyze data testing a question about torques in a balanced rigid system. [**SP 4.1, 4.2, 5.1**]
- *Learning Objective* **3.F.1.5:** The student is able to calculate torques on a two-dimensional system in static equilibrium, by examining a representation or model (such as a diagram or physical construction). [**SP 1.4, 2.2**]
- *Learning Objective* **3.F.2.1:** The student is able to make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. [**SP 6.4**]:
- *Learning Objective* **3.F.2.2:** The student is able to plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. [**SP 4.1, 4.2, 5.1**]
- *Learning Objective* **3.F.3.1:** The student is able to predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum. [**SP 6.4, 7.2**]
- *Learning Objective* **3.F.3.2:** In an unfamiliar context or using representations beyond equations, the student is able to justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. [**SP 2.1**]
- *Learning Objective* **3.F.3.3:** The student is able to plan data collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object. [**SP 4.1, 4.2, 5.1, 5.3**]

BIG IDEA 4

- *Learning Objective* **4.A.1.1** The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively. [**SP 1.2, 1.4, 2.3, 6.4**]
- *Learning Objective* **4.D.1.1:** The student is able to describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. [**SP 1.2, 1.4**]
- *Learning Objective* **4.D.1.2:** The student is able to plan data collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data. [**SP 3.2, 4.1, 4.2, 5.1, 5.3**]
- *Learning Objective* **4.D.2.1:** The student is able to describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. [**SP 1.2, 1.4**]
- *Learning Objective* **4.D.2.2:** The student is able to plan a data collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems. [**SP 4.2**]
- *Learning Objective* **4.D.3.1:** The student is able to use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. [**SP 2.2**]
- *Learning Objective* **4.D.3.2:** The student is able to plan a data collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. [**SP 4.1, 4.2**]

BIG IDEA 5

- *Learning Objective* **5.E.1.1:** The student is able to make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. [**SP 6.4, 7.2**]
- *Learning Objective* **5.E.1.2:** The student is able to make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. [**SP 2.1, 2.2**]
- *Learning Objective* **5.E.2.1:** The student is able to describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Students are expected to do qualitative reasoning with compound objects. Students are expected to do calculations with a fixed set of extended objects and point masses. [**SP 2.2**]

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. [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.]
- **HS-PS2-2.** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.]
- **HS-PS2-3.** Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.* [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.]