Advanced Placement (AP) Physics I Curricular Document

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COURSE INFORMATION

Advanced Placement (AP) Physics I	
CURRICULUM/CONTENT AREA	**COURSE LENGTH**
SCIENCE	2 Terms
GRADE LEVEL	**DATE LAST REVIEWED**
10-12	2018, Program Eval 2023
PREREQUISITE(s) ***if applicable***	**BOARD APPROVAL DATE**
Algebra II or concurrent enrollment	04/2024
PRIMARY RESOURCE: (if applicable): AP Classroom, Physics: by Douglas Giancoli 5ed	

DESIRED RESULTS

What students will know and be able to do

COURSE DESCRIPTION AND PURPOSE

AP Physics 1 is an algebra-based, introductory college-level physics course. Students cultivate their understanding of physics through inquiry-based investigations as they explore these topics: kinematics, dynamics, circular motion and gravitation, energy, momentum, simple harmonic motion, torque and rotational motion, electric charge and electric force, DC circuits, and mechanical waves and sound.

BIG IDEAS: *Crosscutting concepts that build conceptual understanding and spiral throughout the course. These serve as the foundation to create meaningful connections among concepts.*	**SCIENCE PRACTICES:** *The science practices are central to the study and practice of biology. Students should develop and apply develop and apply the described practices on a regular basis over the span of the course.*
BIG IDEA 1: SYSTEMS (SYS) Objects and systems have properties such as mass and charge. Systems may have internal structure.	1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

BIG IDEA 2: FIELDS (FLD) Fields existing in space can be used to explain interactions. **BIG IDEA 3: FORCE INTERACTIONS (INT)** The interactions of an object with other objects can be described by forces. **BIG IDEA 4: CHANGE (CHA)** Interactions between systems can result in changes in those systems. **BIG IDEA 5: CONSERVATION (CON)** Changes that occur as a result of interactions are constrained by conservation laws.	2 Mathematical Routines: The student can use mathematics appropriately. 3 Scientific Questioning: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course (not assessed on the AP Exam). 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question. 5 Data Analysis: The student can perform data analysis and evaluation of evidence. 6 Argumentation: The student can work with scientific explanations and theories. 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

Unit 1: KINEMATICS

The world is in a constant state of motion. To understand the world, students must first understand movement. Unit 1 introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by beginning to explore the complex idea of acceleration and showing them how representations can be used to model and analyze scientific information as it relates to the motion of objects. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units.

ENDURING UNDERSTANDING The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year.	**LEARNING OBJECTIVE** Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.	**ESSENTIAL KNOWLEDGE** Statements that describe the knowledge required to perform the learning objective.
TOPIC 1.1: Position, Velocity, and Acceleration 3.A. All forces share certain common characteristics when considered by observers in inertial reference frames.	3.A.1.1 Express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] 3.A.1.2 Design an experimental investigation of the motion of an object. [SP 4.2] 3.A.1.3 Analyze experimental data describing the motion of an object and be able to express the results of the analysis using narrative,	3.A.1 An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. A. Displacement, velocity, and acceleration are all vector quantities. B. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values. C. A choice of reference frame determines the direction and the magnitude of each of these

	mathematical, and graphical representations. [SP 5.1]	quantities. D. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects. E. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force. F. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3. G. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. H. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path. For uniform circular motion of radius r, v is proportional to omega, ω (for a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = (2\pi r)/T$.
TOPIC 1.2: Representations of Motion 4.A. The acceleration of the center of mass of a system is related to the net force exerted on the system where	4.A.1.1 Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. [SP 1.2, 1.4, 2.3, 6.4]	4.A.1 The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. A. The variables x, v, and a all refer to the center-of-mass quantities.

$\vec{a} = \frac{\Sigma \vec{F}}{m}$.		
	4.A.2.1 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] 4.A.2.3 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]	4.A.2 The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. A. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system. B. Force and acceleration are both vectors, with acceleration in the same direction as the net force. C. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time. D. The variables x, v, and a all refer to the center-of-mass quantities.

Assessment Evidence
Performance is evaluated in terms of…
Students will show their learning by…

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 3: 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?
  - BIG IDEA 4: 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?"
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
  - 5 Data Analysis: The student can perform data analysis and evaluation of evidence.

- 6 Argumentation: The student can work with scientific explanations and theories.

➢ **Rubric based on AP Physics Scoring Guidelines**
➢ **AP Classroom: Progress Checks, Assessment Resource, Reassessment Opportunities**
➢ **Laboratory work:**
- **Constant Motion**
- **Free Fall**
- **Constant Acceleration**

Unit 2 : DYNAMICS

In Unit 2, students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit 1, specifically the introduction to the free-body diagram. Translation, however, is key in this unit: Students must be able to portray the same object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change.

Alongside mastering the use of specific force equations, Unit 2 also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments.

ENDURING UNDERSTANDING The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year.	**LEARNING OBJECTIVE** Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.	**ESSENTIAL KNOWLEDGE** Statements that describe the knowledge required to perform the learning objective.
TOPIC 2.1: Systems 1.A. The internal structure of a system determines many properties of the system.	[While there is no specific learning objective for it, EK 1.A.1 serves as a foundation for other learning objectives in the course.]	1.A.1 A system is an object or a collection of objects. Objects are treated as having no internal structure. A. A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object. B. Some elementary particles are fundamental particles, (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed. C. The electric charges on neutrons and protons

		result from their quark compositions.
	1.A.5.1 Model verbally or visually the properties of a system based on its substructure and relate this to changes in the system properties over time as external variables are changed. [SP 1.1, 7.1]	1.A.5 Systems have properties that are determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an object.
TOPIC 2.2: The Gravitational Field 2.B. A gravitational field is caused by an object with mass.	2.B.1.1 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]	2.B.1 A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field. A. On Earth, this gravitational force is called weight. B. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force. C. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location.
TOPIC 2.3: Contact Forces 3.C. At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.	3.C.4.1 Make claims about various contact forces between objects based on the microscopic cause of these 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]	3.C.4 Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).

TOPIC 2.4: Newton's First Law 1.C. Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.	1.C.1.1 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]	1.C.1 Inertial mass is the property of an object or system that determines how its motion changes when it interacts with other objects or systems.
	1.C.3.1 Design a plan for collecting data to measure gravitational mass and inertial mass and to distinguish between the two experiments. [SP 4.2]	1.C.3 Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
TOPIC 2.5: Newton's Third Law and Free-Body Diagrams 3.A. All forces share certain common characteristics when considered by observers in inertial reference frames.	3.A.2.1 Represent forces in diagrams or thematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]	3.A.2 Forces are described by vectors. A. Forces are detected by their influence on the motion of an object. B. Forces have magnitude and direction.
	3.A.3.1 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] 3.A.3.2 Challenge a claim that an object can exert a force on itself. [SP 6.1] 3.A.3.3 Describe a force as an interaction between two objects, and identify both objects for any force. [SP 1.4] 3.A.4.1 Construct explanations of physical situations	3.A.3 A force exerted on an object is always due to the interaction of that object with another object. A. An object cannot exert a force on itself. B. Even though an object is at rest, there may be forces exerted on that object by other objects. C. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects. 3.A.4 If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

	involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2] 3.A.4.2 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] 3.A.4.3 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]	
TOPIC 2.6: Newton's Second Law 3.B. Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma\vec{F}}{m}$.	3.B.1.1 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] 3.B.1.2 Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurement, 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] 3.B.1.3 Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2]	3.B.1 If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. Projectile motion and circular motion are both included in AP Physics 1. 3.B.2 Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation. A. a. An object can be drawn as if it were extracted from its environment and the interactions with the environment were identified. B. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force. C. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.

	3.B.2.1 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]	D. Free-body or force diagrams may be depicted in one of two ways—one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.
TOPIC 2.7: Applications of Newton's Second Law 4.A. The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\Sigma \vec{F}}{m}$.	4.A.1.1 Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. [SP 1.2, 1.4, 2.3, 6.4]	4.A.1 The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. The variables x, v, and a all refer to the center-of-mass quantities.
	4.A.2.2 Evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified. [SP 5.3]	4.A.2 The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. A. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system. B. Force and acceleration are both vectors, with acceleration in the same direction as the net force. C. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time. D. The variables x, v, and a all refer to the center-of-mass quantities.
	4.A.3.1 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]	4.A.3 Forces that the systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

	4.A.3.2 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]	

Assessment Evidence
Performance is evaluated in terms of…
Students will show their learning by…

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 1: 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?
  - BIG IDEA 2: How do objects with mass respond when placed in a gravitational field?
    Why is the acceleration due to gravity constant on Earth's surface?
  - BIG IDEA 3: Are different kinds of forces really different?
    How can Newton's laws of motion be used to predict the behavior of objects?
  - BIG IDEA 4: Why does the same push change the motion of a shopping cart more than the motion of a car?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
  - 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
  - 6 Argumentation: The student can work with scientific explanations and theories.
  - 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
- **Rubric based on AP Physics Scoring Guidelines**
- **AP Classroom: Progress Checks, Assessment Resource, Reassessment Opportunities**
- **Laboratory work**
  - **Mass vs Weight**
  - **Friction**
  - **Acceleration - Newton's 2nd Law**
  - **Newton's 3rd Law**

- **2D Projectile**

Unit 3 : CIRCULAR MOTION AND GRAVITATION

In Unit 3, students will continue to enhance their understanding of the physical world using models and representations to create a more complete and complex model of motion, particularly as ti relates to gravitational mass and inertial mass. Again, translation and connections are essential–students must be able to use content and science practices from the previous two units and pally them in different ways.

While it's essential that students are able to calculate numerical answers to questions, it is more important that they can combine mathematical representations to make new representations that more accurately describe natural phenomena. For example, students should be comfortable combining equations for uniform circular motion with gravitational equations to describe the circular path of a satellite circling the planet.

It is also vital that students are given opportunities to think about and discuss the impact that changes or modifications have on physical scenarios. For example, students should be able to use mathematical and graphical representation to determine how doubling the distance of a satellite from a planet with change the period of orbit and then justify their answer with evidence and reasoning. Specific preconceptions will be addressed in this unit, such as the idea of a centrifugal force. Students will also have opportunities to wrestle with the idea of field models, which will be expanded upon in Unit 8.

ENDURING UNDERSTANDING The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year.	**LEARNING OBJECTIVE** Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.	**ESSENTIAL KNOWLEDGE** Statements that describe the knowledge required to perform the learning objective.
TOPIC 3.1: Vector Fields 2.A. A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces), as well as a variety of other physical phenomena.	[While there is no specific learning objective for it, EK 2.A.1 serves as a foundation for other learning objectives in the course.]	2.A.1 A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector. A. Vector fields are represented by field vectors indicating direction and magnitude. B. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition. C. Conversely, a known vector field can be used to make inferences about the number, relative size, and locations of sources.

TOPIC 3.2: Fundamental Forces 3.G. Certain types of forces are considered fundamental.	3.G.1.1 Articulate situations when the gravitational force is the dominant force. [SP 7.1]	3.G.1 Gravitational forces are exerted at all scales and dominate at the largest distances and mass scales.
TOPIC 3.3: Gravitational and Electric Forces 3.C. At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.	3.C.1.1 Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and use that force in contexts other than orbital motion. [SP 2.2] 3.C.1.2 Use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [SP 2.2]	3.C.1 Gravitational force describes the interaction of one object with mass with another object with mass. A. The gravitational force is always attractive. B. The magnitude of force between two spherically symmetric objects of mass m_1 and m_2 is $G\frac{m_1 m_1}{r^2}$, where r is the center-to-center distance between the objects. C. In a narrow range of heights above Earth's surface, the local gravitational field, g, is approximately constant.
TOPIC 3.4: Gravitational Field/Acceleration Due to Gravity on Different Planets 2.B. A gravitational field is caused by an object with mass.	2.B.1.1 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]	2.B.1 A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field. A. On Earth, this gravitational force is called weight. B. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force. C. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location.
	2.B.2.1	2.B.2

	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] 2.B.2.2 Approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of Earth or other reference objects. [SP 2.2]	The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object. A. The gravitational field caused by a spherically symmetric object is a vector whose magnitude outside the object is equal to $G\frac{m}{r^2}$ B. Only spherically symmetric objects will be considered as sources of the gravitational field.
TOPIC 3.5: Inertial vs. Gravitational Mass 1.C. Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.	[While there is no specific learning objective for it, EK 1.C.2 serves as a foundation for other learning objectives in the course.]	1.C.2 Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields. A. The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field. B. Near Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.
	1.C.3.1 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]	1.C.3 Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
TOPIC 3.6: Centripetal Acceleration and Centripetal Force 4.A. The acceleration of the center of mass of a system is related to the net force exerted on the system, where	4.A.2.2 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]	4.A.2 The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. A. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it

$\vec{a} = \frac{\Sigma \vec{F}}{m}$.		by all objects interacting with the system and inversely proportional to the mass of the system. B. Force and acceleration are both vectors, with acceleration in the same direction as the net force. C. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time. D. The variables x, v, and a all refer to the center-of-mass quantities.
TOPIC 3.7: Free-Body Diagrams for Objects in Uniform Circular Motion 3.B. Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$.	3.B.1.2 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] 3.B.1.3 Re-express a free-body diagram representation into a mathematical representation, and solve the mathematical representation for the acceleration of the object. [SP1.5, 2.2]	3.B.1 If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. Projectile motion and circular motion are both included in AP Physics 1.
	3.B.2.1 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]	3.B.2 Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation. A. An object can be drawn as if it were extracted from its environment and the interactions with the environment were identified. B. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the

		direction of the force. C. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation. D. Free-body or force diagrams may be depicted in one of two ways—one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.
TOPIC 3.8: Applications of Circular Motion and Gravitation 3.A. All forces share certain common characteristics when considered by observers in inertial reference frames.	3.A.1.1 Express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] 3.A.1.2 Design an experimental investigation of the motion of an object. [SP 4.2] 3.A.1.3 Analyze experimental data describing the motion of an object and express the results of the analysis using narrative, mathematical, and graphical representations. [SP 5.1]	3.A.1 An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. A. Displacement, velocity, and acceleration are all vector quantities. B. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values. C. A choice of reference frame determines the direction and the magnitude of each of these quantities. D. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects. E. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an

		object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force. F. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3. G. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. H. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path. For uniform circular motion of radius r, v is proportional to omega, ω (for a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = (2\pi r)/T$.
	3.A.2.1 Represent forces in diagrams or mathematically, using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]	3.A.2 Forces are described by vectors. A. Forces are detected by their influence on the motion of an object. B. Forces have magnitude and direction.
	3.A.3.1 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] 3.A.3.3 Describe a force as an interaction between	3.A.3 A force exerted on an object is always due to the interaction of that object with another object. A. An object cannot exert a force on itself. B. Even though an object is at rest, there may be forces exerted on that object by other objects. C. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

	two objects and identify both objects for any force. [SP 1.4]	
	3.A.4.1 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] 3.A.4.2 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] 3.A.4.3 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]	3.A.4 If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

Assessment Evidence
Performance is evaluated in terms of…
Students will show their learning by…

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 1: How does changing the mass of an object affect the gravitational force?
    Why is a refrigerator hard to push in space?
  - BIG IDEA 2: Why do we feel pulled toward Earth but not toward a pencil?
    How can the acceleration due to gravity be modified?
  - BIG IDEA 3: 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?
  - BIG IDEA 4: How is the acceleration of the center of mass 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?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

- 2 Mathematical Routines: The student can use mathematics appropriately.
- 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
- 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
- 6 Argumentation: The student can work with scientific explanations and theories.
- 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

➢ **Rubric based on AP Physics Scoring Guidelines**
➢ **AP Classroom: Progress Checks, Assessment Resource, Reassessment Opportunities**
➢ **Laboratory work**
- **Circular motion**
- **Conical Pendulum**

Unit 4 : ENERGY

In Unit 4, students will be introduced to the idea of conservation as a foundational model of physics, along with the concept of work as the agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of Units 1–4 to determine the most appropriate technique and will be challenged to understand the limiting factors of each. Describing, creating, and using these representations will also help students grapple with common misconceptions that they may have about energy, such as whether or not a single object can "have" potential energy. A thorough understanding of these energy models will support students' ability to make predications—and ultimately justify claims with evidence—about physical situations. This is crucial, as the mathematical models and representations used in Unit 4 will mature throughout the course and appear in subsequent units.

As students' comprehension of energy (particularly kinetic, potential, and microscopic internal energy) evolves, they will begin to connect and relate knowledge across scales, concepts, and representations, as well as across disciplines, particularly physics, chemistry, and biology.

ENDURING UNDERSTANDING The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year.	**LEARNING OBJECTIVE** Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.	**ESSENTIAL KNOWLEDGE** Statements that describe the knowledge required to perform the learning objective.
TOPIC 4.1: Open and Closed Systems: Energy 5.A. Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.	[While there is no specific learning objective for it, EK 5.A.1 serves as a foundation for other learning objectives in the course.]	5.A.1 A system is an object or a collection of objects. The objects are treated as having no internal structure.
	5.A.2.1 Define open and closed systems for everyday	5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are

	situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2]	conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.
	[While there is no specific learning objective for it, EK 5.A.3 serves as a foundation for other learning objectives in the course.]	5.A.3 An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.
	[While there is no specific learning objective for it, EK 5.A.4 serves as a foundation for other learning objectives in the course.]	5.A.4 The placement of a boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.
TOPIC 4.2: Work and Mechanical Energy 3.E. A force exerted on an object can change the kinetic energy of the object.	3.E.1.1 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] 3.E.1.2 Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged. [SP 1.4] 3.E.1.3 Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether the kinetic energy of that object would increase, decrease, or remain unchanged. [SP 1.4, 2.2] 3.E.1.4 Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of	3.E.1 The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted. A. Only the component of the net force exerted on an object parallel or antiparallel to the displacement of the object will increase (parallel) or decrease (antiparallel) the kinetic energy of the object. B. The magnitude of the change in the kinetic energy is the product of the magnitude of the displacement and of the magnitude of the component of force parallel or antiparallel to the displacement. C. The component of the net force exerted on an object perpendicular to the direction of the displacement of the object can change the direction of the motion of the object without changing the kinetic energy of the object. This should include uniform circular motion and projectile motion. D. The kinetic energy of a rigid system may be translational, rotational, or a combination of both. The change in the rotational kinetic energy of a

	the object. [SP 2.2]	rigid system is the product of the angular displacement and the net torque.
TOPIC 4.2: Work and Mechanical Energy 4.C. Interactions with other objects or systems can change the total energy of a system.	4.C.1.1 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] 4.C.1.2 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] 4.C.2.1 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] 4.C.2.2 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]	4.C.1 The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples include gravitational potential energy, elastic potential energy, and kinetic energy. A. A rotating, rigid body may be considered to be a system and may have both translational and rotational kinetic energy. B. Although thermodynamics is not part of Physics 1, included is the idea that, during an inelastic collision, some of the mechanical energy dissipates as (converts to) thermal energy. 4.C.2 Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the forces is parallel to its displacement. The process through which the energy is transferred is called work. A. If the force is constant during a given displacement, then the work done is the product of the displacement and the component of the force parallel or antiparallel to the displacement. B. Work (change in energy) can be found from the area under a graph of the magnitude of the force component parallel to the displacement versus displacement.
TOPIC 4.3: Conservation of Energy, the Work-Energy Principle, and Power	5.B.1.1 Create a representation or model showing that a single object can only have kinetic energy and use information about that object to	5.B.1 Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.

5.B. The energy of a system is conserved.	calculate its kinetic energy. [SP 1.4, 2.2] 5.B.1.2 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]	
	5.B.2.1 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]	5.B.2 A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1 includes mass-spring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.]
	5.B.3.1 Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2] 5.B.3.2 Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2] 5.B.3.3 Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the	5.B.3 A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. A. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system. B. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators and objects falling in a gravitational field. C. The change in electric potential in a circuit is the

	objects and interactions in that system. [SP 1.4, 2.2]	change in potential energy per unit charge. [In Physics 1, only in the context of circuits]
	5.B.4.1 Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] 5.B.4.2 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]	5.B.4 The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. A. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy. B. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.
	5.B.5.1 Design an experiment and analyze data to determine 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] 5.B.5.2 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] 5.B.5.3 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] 5.B.5.4	5.B.5 Energy can be transferred by an external force exerted on an object or a system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as part of thermodynamics.]

	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] 5.B.5.5 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]	

Assessment Evidence
Performance is evaluated in terms of…
Students will show their learning by…

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 3: How does pushing something give it energy?
  - BIG IDEA 4: 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 to have a thrilling ride?
  - BIG IDEA 5: 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?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
  - 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
  - 6 Argumentation: The student can work with scientific explanations and theories.
  - 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
- **Rubric based on AP Physics Scoring Guidelines**
- **AP Classroom: Progress Checks, Assessment Resource, Reassessment Opportunities**

- Laboratory work
  - Popper Lab
  - Spring Lab with Hooke's Law
  - Ramp & Cart at an Angle
  - Work to Climb Stairs

Unit 5 : MOMENTUM

Unit 5 introduces students to the relationship between force, time, and momentum via calculations, data analysis, designing experiments, and making predictions. Students will learn how to use new models and representations to illustrate the law of the conservation of momentum of objects and systems while simultaneously building on their knowledge of previously studied representations. Using the law of the conservation of momentum to analyze physical situations gives students a more complete picture of forces and leads them to revisit their misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between the conserved quantities of momentum and energy to determine under what conditions each quantity is conserved. It's essential that students are not only comfortable solving numerical equations (such as the speed of a system after an inelastic collision) but also confident in their ability to discuss when momentum is conserved and how the type of collision affects the outcome. Threading such connections between physical quantities is fundamental to understanding the broader relationship between this unit and the rest of the course.
Students will have more opportunities to apply conservation laws to make predictions and justify claims in Unit 7 when they are introduced to rotational quantities.

ENDURING UNDERSTANDING The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year.	**LEARNING OBJECTIVE** Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.	**ESSENTIAL KNOWLEDGE** Statements that describe the knowledge required to perform the learning objective.
TOPIC 5.1: Momentum and Impulse 3.D. A force exerted on an object can change the momentum of the object.	3.D.1.1 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]	3.D.1 The change in momentum of an object is a vector in the direction of the net force exerted on the object.
	3.D.2.1 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]	3.D.2 The change in momentum of an object occurs over a time interval. A. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on the second object).

	3.D.2.2 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] 3.D.2.3 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] 3.D.2.4 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]	B. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred.
TOPIC 5.2: Representations of Changes in Momentum 4.B. Interactions with other objects or systems can change the total linear momentum of a system.	4.B.1.1 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] 4.B.1.2 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]	4.B.1 The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.
	4.B.2.1 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]	4.B.2 The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted. A. The units for momentum are the same as the units

	4.B.2.2 Perform an analysis on data presented as a force-time graph and predict the change in momentum of a system. [SP 5.1]	of the area under the curve of a force versus time graph. B. The change in linear momentum and force are both vectors in the same direction.
TOPIC 5.3: Open and Closed Systems: Momentum 5.A Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.	5.A.2.1 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]	5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.
TOPIC 5.4: Conservation of Linear Momentum 5.D The linear momentum of a system is conserved.	5.D.1.1 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] 5.D.1.2 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 qualitatively in two-dimensional situations. [SP 2.2, 3.2, 5.1, 5.3] 5.D.1.3 Apply mathematical routines	5.D.1 In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after. A. In a closed system, the linear momentum is constant throughout the collision. B. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision.

	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] 5.D.1.4 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] 5.D.1.5 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]	
	5.D.2.1 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] 5.D.2.2 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]	5.D.2 In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision. A. In a closed system, the linear momentum is constant throughout the collision. B. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.

	5.D.2.3 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] 5.D.2.4 Analyze data that verify conservation of momentum in collisions with and without an external frictional force. [SP 4.1, 4.2, 4.4, 5.1, 5.3] 5.D.2.5 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]	
	5.D.3.1 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]	5.D.3 The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1 includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.] A. The center of mass of a system depends on the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.

		B. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system. C. Included in Physics 1 is the idea that, where there is both a heavier and lighter mass, the center of mass is closer to the heavier mass. Only a qualitative understanding of this concept is required.

Assessment Evidence
Performance is evaluated in terms of...
Students will show their learning by...

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 3: How does pushing an object change its momentum?
  - BIG IDEA 4: 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?
  - BIG IDEA 5: 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?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 3 Scientific Questioning: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course (not assessed on the AP Exam).
  - 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
  - 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
  - 6 Argumentation: The student can work with scientific explanations and theories.
  - 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
- **Rubric based on AP Physics Scoring Guidelines**
- **AP Classroom: Progress Checks, Assessment Resource, Reassessment Opportunities**
- **Laboratory work**
  - **Collisions - Conservation of Momentum**
  - **Impulse momentum Theorem**

Unit 6 : SIMPLE HARMONIC MOTION

In Unit 6, students will continue to use the same tools, techniques, and models that they have been using throughout this course. However, they will now use them to analyze a new type of motion: simple harmonic motion. Although simple harmonic motion is unique, students will learn that even in new situations, the fundamental laws of physics remain the same. Energy bar charts, as well as free-body diagrams, become increasingly important as students work toward determining which model is most appropriate for a given physical situation. Preconceptions—such as the relationship between the amplitude and period of oscillation—will also be addressed to provide students with a more nuanced awareness of simple harmonic motion.
Students are expected to use the content knowledge they gained in the first five units to make and defend claims while also making connections in and across the content topics and big ideas. Because Unit 6 is the first unit in which students possess all the tools of force, energy, and momentum conservation, it's important that teachers scaffold lessons to help them develop a better understanding of each fundamental physics principles as well as its limitations. Throughout this unit, students will be asked to create force, energy, momentum, and position versus time graphs for a single scenario and to make predictions based on their representations. Students will enhance their study of motion when they learn about oscillatory motion in Unit 10.

ENDURING UNDERSTANDING The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year.	**LEARNING OBJECTIVE** Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.	**ESSENTIAL KNOWLEDGE** Statements that describe the knowledge required to perform the learning objective.
TOPIC 6.1: Period of Simple Harmonic Oscillators 3.B. Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$.	3.B.3.1 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] 3.B.3.2 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] 3.B.3.3 Analyze data to identify qualitative and	3.B.3 Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples include gravitational force exerted by Earth on a simple pendulum and mass-spring oscillator. A. For a spring that exerts a linear restoring force, the period of a mass-spring oscillator increases with mass and decreases with spring stiffness. B. For a simple pendulum, the period increases with the length of the pendulum and decreases with the magnitude of the gravitational field. C. Minima, maxima, and zeros of position, velocity,

	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 and use those data to determine the value of an unknown. [SP 2.2, 5.1] 3.B.3.4 Construct a qualitative and/or quantitative explanation of oscillatory behavior given evidence of a restoring force. [SP 2.2, 6.2]	and acceleration are features of harmonic motion. Students should be able to calculate force and acceleration for any given displacement for an object oscillating on a spring.
TOPIC 6.2: Energy of a Simple Harmonic Oscillator 5.B. The energy of a system is conserved.	5.B.2.1 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] 5.B.3.1 Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2] 5.B.3.2 Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2]	5.B.2 A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1 includes mass-spring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.] 5.B.3 A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. A. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system. B. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators and objects falling in a gravitational field.

	5.B.3.3 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]	C. The change in electric potential in a circuit is the change in potential energy per unit charge. [In Physics 1, only in the context of circuits]
	5.B.4.1 Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] 5.B.4.2 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]	5.B.4 The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. A. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy. B. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.

Assessment Evidence
Performance is evaluated in terms of…
Students will show their learning by…

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 3: 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?
  - BIG IDEA 5: 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?
  -
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.

- 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
- 6 Argumentation: The student can work with scientific explanations and theories.
- 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

➢ **Rubric based on AP Physics Scoring Guidelines**
➢ **AP Classroom: Progress Checks, Assessment Resource, Reassessment Opportunities**
➢ **Laboratory work**
- **Pendulum**
- **Spring Oscillations**
- **Turning Forks**

Unit 7: TORQUE AND ROTATIONAL MOTION

Unit 7 completes the study of mechanical physics by introducing students to torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same: The content and models explored in the first six units of AP Physics 1 set the foundation for Unit 7. During their study of torque and rotational motion, students will be confronted with different ways of thinking about and modeling forces. As in previous units, it's critical that students are given opportunities to create and use representations and models to make predictions and justify claims. It's equally important that students are comfortable deriving new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts.

Unit 7 also focuses on the mathematical practice of estimating quantities that can describe natural phenomena. For example, students need to be able to estimate the torque on an object caused by various forces in comparison to other situations. Although this particular science practice doesn't appear often in AP Physics 1, it nonetheless is an important conceptual skill for students to be able to compare estimated values of physical quantities.

Throughout this unit, students will have opportunities to compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to make meaning of these concepts as a whole, rather than as distinct and separate units.

ENDURING UNDERSTANDING The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year.	**LEARNING OBJECTIVE** Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings.	**ESSENTIAL KNOWLEDGE** Statements that describe the knowledge required to perform the learning objective.
TOPIC 7.1: Rotational Kinematics 3.A. All forces share certain common characteristics when considered by observers in inertial reference frames.	3.A.1.1 Express the motion of an object using arrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2]	3.A.1 An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. A. Displacement, velocity, and acceleration are all vector quantities. B. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values. C. A choice of reference frame determines the

		direction and the magnitude of each of these quantities. D. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects. E. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force. F. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3. G. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. H. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path. For uniform circular motion of radius r, v is proportional to omega, ω (for a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = (2\pi r)/T$.
TOPIC 7.2: Torque and Angular Acceleration 3.F. A force exerted on an object can cause a torque on that object.	3.F.1.1 Use representations of the relationship between force and torque. [SP 1.4] 3.F.1.2	3.F.1 Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis. A. The lever arm is the perpendicular distance from

	Compare the torques on an object caused by various forces. [SP 1.4] 3.F.1.3 Estimate the torque on an object caused by various forces in comparison with other situations. [SP 2.3] 3.F.1.4 Design an experiment and analyze data testing a question about torques in a balanced rigid system. [SP 4.1, 4.2, 5.1] 3.F.1.5 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]	the axis of rotation or revolution to the line of application of the force. B. The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force. The net torque on a balanced system is zero.
	3.F.2.1 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] 3.F.2.2 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]	3.F.2 The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis. A. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis. B. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation. C. The angular acceleration of an object or a rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.
	3.F.3.1 Predict the behavior of rotational collision situations by the same processes that are	3.F.3 A torque exerted on an object can change the angular momentum of an object.

	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] 3.F.3.2 In an unfamiliar context or using representations beyond equations, 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] 3.F.3.3 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]	A. Angular momentum is a vector quantity, with its direction determined by a right-hand rule. B. The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum. C. The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense of what factors affect rotational inertia—for example, why a hoop has more rotational inertia than a puck of the same mass and radius. D. The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted.
TOPIC 7.3: Angular Momentum and Torque 4.D. A net torque exerted on a system by other objects or systems will change the angular momentum of the system.	4.D.1.1 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] 4.D.1.2 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	4.D.1 Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending on whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. 4.D.2 The angular momentum of a system may change due to interactions with other objects or systems. A. The angular momentum of a system with respect to an axis of rotation is the sum of the angular momenta, with respect to that axis, of the objects that make up the system. B. The angular momentum of an object about a fixed axis can be found by multiplying the momentum of

	research question based on the examination of data. [SP 3.2, 4.1, 4.2, 5.1, 5.3] 4.D.2.1 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] 4.D.2.2 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] 4.D.3.1 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] 4.D.3.2 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]	the particle by the perpendicular distance from the axis to the line of motion of the object. C. Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation. 4.D.3 The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.
TOPIC 7.4: Conservation of Angular Momentum 5.E. The angular momentum of a system	5.E.1.1 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]	5.E.1 If the net external torque exerted on the system is zero, the angular momentum of the system does not change.

is conserved.	5.E.1.2 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] 5.E.2.1 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. Use qualitative reasoning with compound objects and perform calculations with a fixed set of extended objects and point masses. [SP 2.2]	5.E.2 The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or a system depends on the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

Assessment Evidence
Performance is evaluated in terms of…
Students will show their learning by…

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 3: 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?
  - BIG IDEA 4: 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?
  - BIG IDEA 5: 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?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

- 2 Mathematical Routines: The student can use mathematics appropriately.
- 3 Scientific Questioning: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course (not assessed on the AP Exam).
- 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
- 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
- 6 Argumentation: The student can work with scientific explanations and theories.
- 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

➢ **Rubric based on AP Physics Scoring Guidelines**
➢ **AP Classroom: Progress Checks, Assessment Resource, Reassessment Opportunities**
➢ **Laboratory work**
- **Torque Lab**
- **Rotational vs. Linear Velocity**
- **Rotational Inertia**