AP Physics 1

Curriculum Guide

Dunmore School District

Dunmore, PA

<u>AP Physics 1</u>

Prerequisite:

From The College Board® AP® Physics 1: Algebra-Based Course and Exam Description,

"Students should have completed geometry and be concurrently taking Algebra II or an equivalent course. Although the Physics 1 course includes basic use of trigonometric functions, this understanding can be gained either in the concurrent math course or in the AP Physics 1 course itself."

Note: Materials that are "Teacher Prepared" are reflected in The College Board® approved AP® Course Audit.

AP Physics 1 is an algebra-based college level course designed to either prepare students to succeed in their introductory college physics courses or to possibly test out of their introductory college physics courses based on performance on the AP® Physics 1 exam by The College Board®. Course content is aligned to course framework described in *AP® Physics 1: Algebra-Based Course and Exam Description*.

Dunmore School District
Curriculum Guide

Year-at-a-glance

Subject: AP Physics 1	Grade Level: 12	Date Completed: 1/23/2018

1st Quarter

Topic	Resources	Standards
Content Area 1: Kinematics	Teacher Prepared	3.A, 4.A
Content Area 2: Dynamics	Teacher Prepared	1.A, 1.C, 2.B, 3.A, 3.B, 4.A
Content Area 3: Circular Motion and Gravitation	Teacher Prepared	1.C, 2.A, 2.B, 3.A,

2nd Quarter

Topic	Resources	Standards
Content Area 4: Energy	Teacher Prepared	3.E, 4.C, 5.A, 5.B, 5.D
Content Area 5: Momentum	Teacher Prepared	3.D, 4.B, 5.A, 5.D
Content Area 6: Simple Harmonic Motion	Teacher Prepared	3.B, 5.B

3rd Quarter

Topic	Resources	Standards
Content Area 7: Torque and Rotational Motion	Teacher Prepared	3.A, 3.F, 4.D, 5.E
Content Area 8: Electric Charge and Electric Force	Teacher Prepared	1.B, 3.C, 5.A

4th Quarter

Topic	Resources	Standards
Content Area 9: DC Circuits	Teacher Prepared	1.B, 1.E, 5.B, 5.C
Content Area 10: Mechanical Waves and Sound	Teacher Prepared	6.A, 6.B, 6.D
Review and Final Exam		

General Topic Content Area 1: Kinematics	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames. **4.A:** The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.	**Essential Knowledge:** **3.A.1:** An observer in a particular 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. *Relevant Equations:* $\overrightarrow{v_{avg}} = \frac{\overrightarrow{\Delta x}}{\Delta t}$ $\overrightarrow{a_{avg}} = \frac{\overrightarrow{\Delta v}}{\Delta t}$	**Learning Objective:** **3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]** **3.A.1.2:** The student is able to design an experimental investigation of the motion of an object. **[SP 4.2]** **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. **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 semi-	**Approved textbook** **Lab Investigation 1: 1D and 2D Kinematics** **Projectile Motion Activity (Optional)**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

	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	quantitatively. **[SP 1.2, 1.4, 2.3, 6.4]** **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 is equal to the change in position per unit time. **[SP 6.4]** **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]** **Vocabulary:** position displacement velocity acceleration angular position angular displacement angular velocity angular acceleration			

	projectile motion are both included. Circular motion is further covered in Content Area 3. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are: $v = v_0 + at$ $x = x_0 = v_0 t + \frac{1}{2}at^2$ $v^2 = {v_0}^2 + 2a\Delta x$ g. For rotational motion there are analogous quantities such as angular position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are: $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$ $\omega = \omega_0 + \alpha t$ $\omega^2 = {\omega_0}^2 + 2\alpha\Delta\theta$ Circular motion and projectile motion are both included. Circular motion will be discussed later in this document. **4.A.1:** The linear motion of a system can be described by the	uniform motion			

	displacement, velocity, and acceleration of its center of mass. a. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities. *Relevant Equations:* $v = v_0 + at$ $x = x_0 = v_0 t + \frac{1}{2}at^2$ $v^2 = {v_0}^2 + 2a\Delta x$ **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 the position of the center of mass with time. d. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities. *Relevant Equations:* $\vec{a} = \frac{\sum \vec{F}}{m_{system}}$ $\overrightarrow{v_{avg}} = \frac{\overrightarrow{\Delta x}}{\Delta t}$ $\overrightarrow{a_{avg}} = \frac{\overrightarrow{\Delta v}}{\Delta t}$				

General Topic Content Area 2: Dynamics	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **1.A:** The internal structure of a system determines many properties of the system. **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. **2.B:** A gravitational field is caused by an object with mass. **3.A:** All forces	**Essential Knowledge:** **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.	**Learning Objective:** **1.A.5.1:** The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed. **[SP 1.1, 7.1]** **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]** **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]**	**Approved textbook** **Lab Investigation 2: Newton's Second Law**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

share certain common characteristics when considered by observers in inertial reference frames. **3.B:** Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m_{system}}$. **3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **4.A:** The acceleration of the center of mass of a system is related to the net force exerted on the system, where	**1.A.5:** Systems have properties 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. **1.C.1:** Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems. a. $$\vec{a} = \frac{\sum \vec{F}}{m_{system}}$$ **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. **2.B.1:** A gravitational field $\vec{g}$ at the location of an object with mass *m* causes a gravitational force *mg* to be exerted on the	**2.B.1.1:** The student is able to apply 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]** **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]** **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]** **3.A.3.2:** The student is able to challenge a claim that an object can exert a			

$\vec{a} = \frac{\sum \vec{F}}{m_{system}}$.	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 per second) is numerically equal to the magnitude of the gravitational field (in Newtons per kilogram) at that location *Relevant Equation:* $\vec{F} = m\vec{g}$ **3.A.2:** Forces are described by vectors. a. Forces are detected by their influence on the motion of an object.	force on itself. **[SP 6.1]** **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]** **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]** **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]** **3.A.4.3:** The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the			

	b. Forces have magnitude and direction. **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. **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.	application of Newton's third law to identify forces. **[SP 1.4]** **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]** **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]** **3.B.1.3:** The student is able to re-express a free-body diagram representation into a mathematical representation and			

	Relevant Equation: $$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\overrightarrow{F_{net}}}{m}$$ **Boundary Statement:** *AP Physics 2 contains learning objectives for Enduring Understanding **3.B** that focus on electric and magnetic forces and other forces arising in context of interactions introduced in Physics 2, rather than the mechanical systems introduced in 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. An object can be drawn as if it was extracted from its environment and the interactions with the environment 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.	solve the mathematical representation for the acceleration of the object. **[SP 1.5, 2.2]** **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]** **3.C.4.1:** The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. **[SP 6.1]** **3.C.4.2: T**he 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]** **4.A.1.1** The student is able to use representations of the center of mass of an			

	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 diagrams are depicted where the forces exerted on an object are represented as arrows pointing outward from a dot, and also diagrams that show at what point on the object each force is exerted. **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). *Relevant Equations:* $\left\|\overrightarrow{F_f}\right\| = \mu\left\|\vec{F}_N\right\|$ $\left\|\overrightarrow{F_{sp}}\right\| = k\left\|\vec{x}\right\|$ **4.A.1:** The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of	isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively. **[SP 1.2, 1.4, 2.3, 6.4]** **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]** **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]** **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]**			

	mass. The variables x, v, and a; all refer to the center-of-mass quantities. *Relevant Equations:* $v = v_0 + at$ $x = x_0 = v_0 t + \frac{1}{2}at^2$ $v^2 = {v_0}^2 + 2a\Delta x$ **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. *Relevant Equation:* $\vec{a} = \frac{\sum \vec{F}}{m_{system}}$ b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.	**Vocabulary:** Force Newton's Laws of Motion Object System Particle Center of mass Weight Gravitational field Electrostatic Force Normal Force Tension Force Friction Force Static coefficient of friction Kinetic coefficient of friction Spring Force Spring constant Equilibrium Free Body Diagram Force Equation			

	Relevant Equations: $$\overrightarrow{v_{avg}} = \frac{\overrightarrow{\Delta x}}{\Delta t}$$ $$\overrightarrow{a_{avg}} = \frac{\overrightarrow{\Delta v}}{\Delta t}$$ 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 the position of the center of mass with time. d. The variables x, v, and a all refer to the center-of-mass quantities. *Relevant Equation:* $$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\overrightarrow{F_{net}}}{m}$$ 4.A.3: Forces that 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.				

	Relevant Equation: $$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\overrightarrow{F_{net}}}{m}$$				

General Topic Content Area 3: Circular Motion and Gravitation	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **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. **2.A:** A field associates a value of some physical quantity with every point in space. Field models are useful for describing	**Essential Knowledge:** **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 the Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass. **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	**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]** **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]** **2.B.2.1:** The student is able to apply $\vec{g} = \frac{GM}{r^2}$ to calculate the gravitational	**Approved textbook** **Lab Investigation 3: Circular Motion**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena. **2.B:** A gravitational field is caused by an object with mass. **3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.B:** Classically, the acceleration of an object interacting with other objects can be	principles. **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 location of sources. **Boundary Statement:** Physics 1 treats gravitational fields; Physics 2 treats electric and magnetic fields. **2.B.1:** A gravitational field *g* at the location of an object with mass *m* causes a gravitational force of magnitude *mg* to be	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:** 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]** **3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]** **3.A.1.2:** The student is able to design an experimental investigation of the motion of an object. **[SP 4.2]** **3.A.1.3:** The student is able to analyze experimental data describing the motion of			

predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$. **3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **3.G:** Certain types of forces are considered fundamental. **4.A:** The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m_{system}}$.	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. *Relevant Equation:* $\vec{g} = \frac{\vec{F_g}}{m}$ **2.B.2:** The gravitational field caused by a	an object and is able to express the results of the analysis using narrative, mathematical and graphical representatives. **[SP 5.1]** **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]** **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]** **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]**			

	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. **3.A.1:** An observer in a particular 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	**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]** **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]** **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]** **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			

	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. We know of 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,	net force and the vector sum of the individual forces. **[SP 4.2, 5.1]** **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]** **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]** **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]** **3.C.1.2:** The student is			

	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 three kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Content Area 3. g. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion will be discussed later in this document. h. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. i. This also includes situations where there is both a radial and tangential acceleration for	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 (for circular orbital motion only in Physics 1). **[SP 2.2]** **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]** **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]** **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]**			

	an object moving in a circular path. *Relevant Equation:* $a_c = \frac{v^2}{r}$ **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:** 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.	**Vocabulary:** Gravitational Field Gravitational Mass Gravitational Force Coulomb's Law Weight Centripetal Force Centripetal Acceleration Angular Velocity Angular Acceleration Uniform Circular Motion			

	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. **3.B.1:** If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. **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 was extracted from its environment and the interactions with the environment 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.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 $\frac{Gm_1m_2}{r^2}$where r is the center-to-center distance between the objects. c. In a narrow range of heights above the Earth's surface, the local gravitational field, g, is approximately constant. **3.C.2:** Electric force results from the interaction of one object that has an electric				

	charge with another object that has an electric charge. a. Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension. b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved. *Relevant Equations:* $F_g = \frac{Gm_1m_2}{r^2}$ $F_e = \frac{kq_1q_2}{r^2}$ **3.G.1:** Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.				

	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.				

General Topic Content Area 4: Energy	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **3.E:** A force exerted on an object can change the kinetic energy of the object. **4.C:** Interactions with other objects or systems can change the total energy of a system. **5.A:** Certain quantities are conserved, in the sense that the changes of those quantities in a given system are	**Essential Knowledge:** **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.	**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]** **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]** **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,	**Approved textbook** **Lab Investigation 4: Conservation of Energy**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

always equal to the transfer of that quantity to or from the system by all possible interactions with other systems. **5.B:** The energy of a system is conserved. **5.D:** The linear momentum of a system is conserved.	*Relevant Equation:* $\Delta E = W = F_{\parallel} d$ 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 rigid system is the product of the angular displacement and the net torque. *Relevant Equations:* $\Delta E = W = F_{\parallel} d \cos\theta$ $K = \frac{1}{2} m v^2$ **4.C.1:** The energy of a system includes	decrease, or remain unchanged. **[SP 1.4, 2.2]** **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]** **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]** **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]** **4.C.2.1:** The student is able to make predictions			

	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. *Relevant Equations:* $K = \frac{1}{2}mv^2$ $K = \frac{1}{2}I\omega^2$ $\Delta U_g = mg\Delta y$ $U_g = -\frac{Gm_1m_2}{r}$ $U_s = \frac{1}{2}kx^2$ **4.C.2:** Mechanical energy (the sum of kinetic	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:** 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]** **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			

	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 force 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. **5.A.1:** A system is an object or a collection of objects. The objects are treated as having no internal structure.	situations. **[SP 6.4, 7.2]** **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]** **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]** **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			

	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. **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. **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. **5.B.1:** Classically, an object can only have kinetic energy since potential	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:** 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]** **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]** **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]**			

	energy requires an interaction between two or more objects. **Boundary Statement:** Conservation principles apply in the context of the appropriate Physics 1 and Physics 2 courses. Work, potential energy, and kinetic energy concepts are related to mechanical systems in Physics 1 and electric, magnetic, thermal, and atomic and elementary particle systems in Physics 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	**5.B.4.1:** The student is able to describe and make predictions about the internal energy of systems. **[SP 6.4, 7.2]** **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]** **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]** **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]**			

	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, objects falling in a gravitational field. c. The change in electric potential in a circuit is the change in potential energy per unit charge. [Physics 1: only in the	**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]** **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]** **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]**			

	context of circuits.] **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:** Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work.	**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]** **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]**			

	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.] *Relevant Equation:* $$P = \frac{\Delta E}{t}$$ **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.	**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]** **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]** **5.D.1.5:** The student is able to classify a given			

	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.	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:** 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]** **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]** **Vocabulary:**			

		Mechanical Energy Work Translational Kinetic Energy Rotational Kinetic Energy Gravitational Potential Energy Elastic Potential Energy Power Elastic Collision Conservation of Energy			

General Topic Content Area 5: Momentum	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **3.D:** A force exerted on an object can change the momentum of the object. **4.B:** Interactions with other objects or systems can change the total linear momentum of a system. **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	**Essential Knowledge:** **3.D.1:** The change in momentum of an object is a vector in the direction of the net force exerted on the object. *Relevant Equation:* $\overrightarrow{\Delta p} = \vec{F}\Delta t$ **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). 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. **4.B.1:** The change in linear momentum for	**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]** **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]** **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]** **3.D.2.3:** The student is able to analyze data to	**Approved textbook** **Lab Investigation 5: Impulse and Momentum**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

that quantity to or from the system by all possible interactions with other systems. **5.D:** The linear momentum of a system is conserved.	a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. *Relevant Equation:* $\vec{p} = m\vec{v}$ **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 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. **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	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:** 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]** **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]** **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]**			

	are constant. An open system is one that exchanges any conserved quantity with its surroundings. **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. **Boundary Statement:** Physics 1 includes a quantitative and qualitative treatment of conservation of momentum in one dimension and a semiquantitative treatment of conservation of momentum in two dimensions. Test items	**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]** **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]** **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]** **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]**			

	involving solution of simultaneous equations are not included in Physics 1, but items testing whether students can set up the equations properly and can reason about how changing a given mass, speed, or angle would affect other quantities are included. Physics 1 includes only conceptual understanding of center of mass motion of a system without the need for calculation of center of mass. The Physics 1 course includes topics from Enduring Understanding 5.D in the context of mechanical systems. 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	**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]** **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]**			

	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.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 upon the masses and positions of the objects	**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]** **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]** **5.D.2.1:** The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how			

	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.	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: T**he 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]** **5.D.2.3: T**he 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]** **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]** **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]** **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]** **Vocabulary:** Impulse Momentum			

		Impulse-Momentum Theorem Conservation of Momentum Elastic Collision Perfectly Inelastic Collision			

General Topic Content Area 6: Simple Harmonic Motion	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **3.B:** Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m_{system}}$. **5.B:** The energy of a system is conserved.	**Essential Knowledge:** **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 the 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	**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]** **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]** **3.B.3.3: T**he student can analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity,	**Approved textbook** **Lab Investigation 6: Harmonic Motion**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

	and decreases with the magnitude of the gravitational field. c. Minima, maxima, and zeros of position, velocity, 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. *Relevant Equations:* $T_s = 2\pi\sqrt{\frac{m}{k}}$ $T_p = 2\pi\sqrt{\frac{l}{g}}$ **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 object in electric fields and	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]** **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]** **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			

	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. c. The change in electric potential in a circuit is the change in potential energy	system. **[SP 1.4, 2.1]** **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]** **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]** **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]** **5.B.4.1:** The student is able to describe and make predictions about			

	per unit charge. [Physics 1: only in the context of circuits.] **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.	the internal energy of systems. **[SP 6.4, 7.2]** **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]** **Vocabulary:** Period Frequency Restoring Force Equilibrium Simple Harmonic Motion			

General Topic Content Area 7: Torque and Rotational Motion	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.F:** A force exerted on an object can cause a torque on that object. **4.D:** A net torque exerted on a system by other objects or systems will change the angular	**Essential Knowledge:** **3.A.1:** An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. a. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. *Relevant Equations:* $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$ $\omega = \omega_0 + \alpha t$ $\omega^2 = {\omega_0}^2 + 2\alpha\Delta\theta$ b. For uniform circular motion of radius r, v is proportional to omega (for a given r), and proportional to r (for a given omega). Given a radius r and a period of rotation	**Learning Objective:** **3.A.1.1:** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]** **3.F.1.1:** The student is able to use representations of the relationship between force and torque. **[SP 1.4]** **3.F.1.2:** The student is able to compare the torques on an object caused by various forces. **[SP 1.4]** **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]**	**Approved textbook** **Lab Investigation 7: Rotational Motion**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

momentum of the system. **5.E:** The angular momentum of a system is conserved.	T, students derive and apply v = (2πr)/T. **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 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. c. The net torque on a balanced system is zero. *Relevant Equation:* $\tau = r_{\perp}F = rF\ sin\theta$ **Boundary Statement:** Quantities such as angular acceleration, velocity, and momentum are defined as vector quantities, but in Physics 1 the determination of "direction" is limited to	**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]** **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]** **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]** **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			

	clockwise and counterclockwise with respect to a given axis of rotation. **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 rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system. *Relevant Equation:* $\alpha = \frac{\Sigma\tau}{I}$	object and the change in angular velocity of that object about an axis. **[SP 4.1, 4.2, 5.1]** **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]** **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]** **3.F.3.3:** The student is able to plan data collection and analysis			

	3.F.3: A torque exerted on an object can change the angular momentum of an object. 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	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]** **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]** **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			

	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. *Relevant Equations:* $L = I\omega$ $\Delta L = \tau \Delta t$ $L = mvr$ **4.D.1:** Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. **Boundary Statement:** Students do not need to know the right hand rule. A full dynamic treatment of	based on the examination of data. **[SP 3.2, 4.1, 4.2, 5.1, 5.3]** **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]** **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]** **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			

	rolling without slipping—for instance, using forces and torques to find the linear and angular acceleration of a cylinder rolling down a ramp—is not included in Physics 1. **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 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	situation involving torque and angular momentum. **[SP 2.2]** **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]** **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]** **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]**			

	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. **5.E.1:** If the net external torque exerted on the system is zero, the angular momentum of the system does not change. **5.E.2:** The angular momentum of a system is determined by the locations and velocities of the objects that make up the	**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]** **Vocabulary:** Torque Rotational Inertia (Moment of Inertia) Angular Acceleration Angular Velocity Angular Momentum Conservation of Angular Momentum Unstable Equilibrium Stable Equilibrium			

	system. The rotational inertia of an object or system depends upon 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.				

General Topic Content Area 8: Electric Charge and Electric Force	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **1.B:** Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge. **3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **5.A:** Certain quantities are conserved, in	**Essential Knowledge:** **1.B.3:** The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge. a. The magnitude of the elementary charge is equal to 1.6 x 10^{-19} coulombs. b. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron. **3.C.2:** Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge. a. Electric forces dominate the properties	**Learning Objective:** **1.B.1.1:** The student is able to make claims about natural phenomena based on conservation of electric charge. **[SP 6.4]** **1.B.1.2:** The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. **[SP 6.4, 7.2]** **1.B.2.1:** The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. **[SP 6.2]** **1.B.3.1:** The student is	**Approved textbook** **Coulomb's Law Lab Activity** **Circuit Measuring Activity**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

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.	of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension. b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved. *Relevant Equations:* $F_e = \frac{kq_1q_2}{r^2}$ $I = \frac{\Delta q}{\Delta t}$ **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.	able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. **[SP 1.5, 6.1, 7.2]** **3.C.2.1:** The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). **[SP 2.2, 6.4]** **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. **[See SP 7.2]** **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]** **Vocabulary:** Electrostatic Force Coulomb's Law Charge Current			

General Topic Content Area 9: DC Circuits	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **1.B**: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge. **1.E**: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. **5.B**: The energy of a system is	**Essential Knowledge:** **1.B.1**: Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system. a. An electrical current is a movement of charge through a conductor. b. A circuit is a closed loop of electrical current. **1.E.2**: Matter has a property called resistivity. a. The resistivity of a material depends on its molecular and atomic structure. b. The resistivity depends on the temperature of the material. Resistivity changes with temperature. **5.B.9**: Kirchhoff's loop rule describes conservation of energy in electrical circuits. [The application of Kirchhoff's laws to circuits is introduced in Physics 1	**Learning Objective:** **1.B.1.1:** The student is able to make claims about natural phenomena based on conservation of electric charge. **[SP 6.4]** **1.B.1.2:** The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. **[SP 6.4, 7.2]** **1.E.2.1:** The student is able to choose and justify the selection of data needed to determine resistivity for a given material. **[SP 4.1]** **5.B.9.1:** The student is able to construct or interpret a graph of the energy changes within	**Approved textbook** **Lab Investigation 9: Resistor Circuits**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

conserved. **5.C**: The electric charge of a system is conserved.	and further developed in Physics 2 in the context of more complex circuits, including those with capacitors.] The potential difference across an ideal battery is also referred to as the emf of the battery, represented as ε. [Non-ideal batteries are not covered in Physics 1.] a. Energy changes in simple electrical circuits are conveniently represented in terms of energy change per charge moving through a battery and a resistor. b. Since electric potential difference times charge is energy, and energy is conserved, the sum of the potential differences about any closed loop must add to zero. c. The electric potential difference across a resistor is given by the product of the current and the resistance. d. The rate at which energy is transferred from a resistor is equal to the product of the electric	an electrical circuit with only a single battery and resistors in series and/or in, at most, one parallel branch as an application of the conservation of energy (Kirchhoff's loop rule). **[SP 1.1, 1.4]** **5.B.9.2:** The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\sum\Delta V=0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. **[SP 4.2, 6.4, 7.2]** **5.B.9.3:** The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. **[SP 2.2, 6.4, 7.2]**			

	potential difference across the resistor and the current through the resistor. **5.C.3**: Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only. Physics 2: includes capacitors in steady-state situations. For circuits with capacitors, situations should be limited to open circuit, just after circuit is closed, and a long time after the circuit is closed.]	**5.C.3.1:** The student is able to apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed. **[SP 6.4, 7.2]** **5.C.3.2:** The student is able to design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. **[SP 4.1, 4.2, 5.1]** **5.C.3.3:** The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various			

		segments or branches of the circuit. **[SP 1.4, 2.2]** **Vocabulary:** Charge Electromotive force Resistance Resistivity Kirchoff's Node Rule Kirchoff's Loop Rule Capacitance			

General Topic Content Area 10: Mechanical Waves and Sound	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Enduring Understanding: **6.A**: A wave is a traveling disturbance that transfers energy and momentum. **6.B**: A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy. **6.D:** Interference and superposition lead to	**Essential Knowledge:** **6.A.1**: Waves can propagate via different oscillation modes such as transverse and longitudinal. a. Mechanical waves can be either transverse or longitudinal. Examples include waves on a stretched string and sound waves. b. This includes, as part of the mechanism of "propagation," the idea that the speed of a wave depends only on properties of the medium. c. The propagation of sound waves included in this EK includes the idea that the traveling disturbance consists of pressure variations coupled to displacement variations. d. This applies to both periodic waves and to wave pulses. **6.A.2**: For propagation,	**Learning Objective:** **6.A.1.1:** The student is able to use a visual representation to construct an explanation of the distinction between transverse and longitudinal waves by focusing on the vibration that generates the wave. **[SP 6.2]** **6.A.1.2:** The student is able to describe representations of transverse and longitudinal waves. **[SP 1.2]** **6.A.2.1:** The student is able to describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples. **[SP 6.4, 7.2].** **6.A.3.1:** The student is able to use graphical	**Approved textbook** **Lab Investigation 8: Mechanical Waves**	**Teacher prepared tests, quizzes, etc.** **Series available assessments online. (Optional)**	**17**

standing waves and beats.	mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples include light traveling through a vacuum and sound not traveling through a vacuum. **6.A.3**: The amplitude is the maximum displacement of a wave from its equilibrium value. a. The amplitude is the maximum displacement from equilibrium of the wave. A sound wave may be represented by either the pressure or the displacement of atoms or molecules. This covers both periodic waves and wave pulses. b. The pressure amplitude of a sound wave is the maximum difference between local pressure and atmospheric pressure. **6.A.4**: Classically, the energy carried by a wave depends upon and	representation of a periodic mechanical wave to determine the amplitude of the wave. **[SP 1.4]** **6.A.4.1:** The student is able to explain and/or predict qualitatively how the energy carried by a sound wave relates to the amplitude of the wave, and/or apply this concept to a real-world example. **[SP 6.4]** **6.B.1.1:** The student is able to use a graphical representation of a periodic mechanical wave (position versus time) to determine the period and frequency of the wave and describe how a change in the frequency would modify features of the representation. **[SP 1.4, 2.2]** **6.B.2.1:** The student is able to use a visual representation of a periodic mechanical wave to determine wavelength of the wave. **[SP 1.4]**			

	increases with amplitude. Examples include sound waves. a. Higher amplitude refers to both greater pressure variations and greater displacement variations. b. Examples include both periodic waves and wave pulses. **6.B.1**: For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time. a. In a periodic sound wave, pressure variations and displacement variations are both present and with the same frequency. **6.B.2**: For a periodic wave, the wavelength is the repeat distance of the wave. **6.B.4**: For a periodic wave, wavelength is the ratio of speed over frequency. **6.B.5**: The observed frequency of a wave	**6.B.4.1:** The student is able to design an experiment to determine the relationship between periodic wave speed, wavelength, and frequency and relate these concepts to everyday examples. **[SP 4.2, 5.1, 7.2]** **6.B.5.1:** The student is able to create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent upon relative motions of source and observer. **[SP 1.4]** **6.D.1.1:** The student is able to use representations of individual pulses and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses. **[SP 1.1, 1.4]** **6.D.1.2:** The student			

	depends on the relative motion of source and observer. This is a qualitative treatment only. **6.D.1**: Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition. **6.D.2**: Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave. **6.D.3**: Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples include waves on a fixed	is able to design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves). **[SP 4.2, 5.1]** **6.D.1.3:** The student is able to design a plan for collecting data to quantify the amplitude variations when two or more traveling waves or wave pulses interact in a given medium. **[SP 4.2]** **6.D.2.1:** The student is able to analyze data or observations or evaluate evidence of the interaction of two or more traveling waves in one or two dimensions (i.e., circular wave fronts) to evaluate the variations in resultant amplitudes. **[SP 5.1]** **6.D.3.1:** The student is able to refine a scientific question related to standing waves and design a detailed plan for			

	length of string and sound waves in both closed and open tubes. a. Reflection of waves and wave pulses, even if a standing wave is not created, is covered in Physics 1. b. For standing sound waves, pressure nodes correspond to displacement antinodes, and vice versa. For example, the open end of a tube is a pressure node because the pressure equalizes with the surrounding air pressure and therefore does not oscillate. The closed end of a tube is a displacement node because the air adjacent to the closed end is blocked from oscillating. **6.D.4:** The possible wavelengths of a standing wave are determined by the size of the region to which it is confined. a. A standing wave with zero amplitude at both ends can only have certain wavelengths. Examples include fundamental	the experiment that can be conducted to examine the phenomenon qualitatively or quantitatively. **[SP 2.1, 3.2, 4.2]** **6.D.3.2:** The student is able to predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. **[SP 6.4]** **6.D.3.3:** The student is able to plan data collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared to the prediction, explain any discrepancy and, if necessary, revise the relationship among variables responsible for establishing standing waves on a string or in a column of air. **[SP 3.2, 4.1, 5.1, 5.2, 5.3]** **6.D.3.4:** The student is able to describe representations			

	frequencies and harmonics. b. Other boundary conditions or other region sizes will result in different sets of possible wavelengths. c. The term first harmonic refers to the standing waves corresponding to the fundamental frequency, i.e., the lowest frequency corresponding to a standing wave. The second harmonic is the standing wave corresponding to the second lowest frequency that generates a standing wave in the given scenario. d. Resonance is another term for standing sound wave. **6.D.5**: Beats arise from the addition of waves of slightly different frequency. a. Because of the different frequencies, the two waves are sometimes in phase and sometimes out of phase. The resulting regularly spaced amplitude	and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. **[SP 1.2]** **6.D.4.1:** The student is able to challenge with evidence the claim that the wavelengths of standing waves are determined by the frequency of the source regardless of the size of the region. **[SP 1.5, 6.1]** **6.D.4.2:** The student is able to calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples include musical instruments. **[SP 2.2]** **6.D.5.1:** The student is able to use a visual			

	changes are called beats. Examples include the tuning of an instrument. b. The beat frequency is the difference in frequency between the two waves. c. In Physics 1, only qualitative understanding of EK 6.D.5 is necessary.	representation to explain how waves of slightly different frequency give rise to the phenomenon of beats. **[SP 1.2]** **Vocabulary:** Frequency Wavelength Amplitude Pitch Wave Speed Superposition Interference Constructive Interference Destructie Interference Standing Wave			

General Topic	**AP Standards**	**Learning Objective, Skills & Vocabulary**	**Resources & Activities**	**Assessments**	**Suggested Time (In Days)**
Review For Final Exam					**10**