CHS Physics

Diocese of Greensburg Curriculum

Unit	Standards	Content	Skills
Special Topic - The Math You Need to Know		• Solving algebraic equations for an unknown value • Graphing data, finding slope, area under a non-curved line • Metric system prefixes • Conversions between units • Basic trigonometric functions & Pythagorean Theorem • Significant values, measuring, precision & accuracy	The students will be able to: • Distinguish how mathematically concepts are applied within a physics context. • Correctly develop, analyze and interpret graphical data. • Demonstrate proficiency in algebraic calculations
Unit 1 - Kinematics	AP: Physics 1 (2019) AP: AP UNIT 1 Kinematics TOPIC 1.1 Position, Velocity, and Acceleration 3.A All forces share certain common characteristics when considered by observers in inertial reference frames. 3.A.1.1 Express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] Show details 3.A.1.2 Design an experimental investigation of the motion of an object. [SP 4.2] Show details 3.A.1.3 Analyze experimental data describing the motion of an object and be able to express the results of the analysis using narrative, mathematical, and graphical representations. [SP 5.1] Show details 3.A.1 An observer in a reference frame can describe the motion of an object	• Motion Graphs • Motion Maps • Distance • Displacement • Speed • Velocity • Acceleration • Acceleration due to gravity • Vector • Scalar • Time • Projectile • Trajectory Objectives: **3.A.1.1** Express the motion of an object using narrative, mathematical, and graphical representations.	1.2 The student can describe representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.

	using such quantities as position, displacement, distance, velocity, speed, and acceleration. Show details a. Displacement, velocity, and acceleration are all vector quantities. Show details 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: $\vec{v}\,\text{avg} = \frac{\overrightarrow{\triangle x}}{\triangle t}$ $\vec{a}\,\text{avg} = \frac{\overrightarrow{\triangle v}}{\triangle t}$ Show details c. A choice of reference frame determines the direction and the magnitude of each of these quantities. Show details f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are $v_x = v_{xo} + a_x t$ $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$ $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$ Show details © 2013 The College Board, Advanced Placement AP Frameworks	**3.A.1.2** Design an experimental investigation of the motion of an object. **3.A.1.3** Analyze experimental data describing the motion of an object and be able to express the results of the analysis using narrative, mathematical, and graphical representations. **4.A.1.1** Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. **4.A.2.1** Make predictions about the motion of a system based on the fact that acceleration is equal tot he change in velocity per unit time, and velocity is equal to the change in position per unit time.	2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.3 The student can estimate quantities that describe natural phenomena. 4.2 The student can design a plan for collecting date to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. Students will be able to: • Predict the motion of an object based on its trajectory.

			• Create graphs/plots and motion diagrams from equations of motion. • Create equations of motion from graphs/plots and motion diagrams. • Analyze the affect of initial velocity and acceleration on displacement. • Distinguish between speed and velocity and distance and displacement. • Design experiments that allow the gravitational acceleration to be determined. • Recognize the mathematical independence of motion in different dimensions.
Unit 2 - Dynamics	AP: Physics 1 (2019) AP: AP UNIT 2 Dynamics TOPIC 2.1 Systems 1.A The internal structure of a system determines many properties of the system. 1.A.1 A system is an object or a collection of objects. Objects are treated as having no internal structure. Show details TOPIC 2.2 The Gravitational Field 2.B A gravitational field is caused by an object with mass. 2.B.1.1 Apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. [SP 2.2, 7.2]	• Force • Newton's Laws of Motion • Inertia • Free-body diagrams • Vectors Objectives: 2.B.1.1 Apply F=mg 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.	Students will be able to: • Recognize and state the definition of a force • Differentiate between contact and field forces. • Calculate the force on an object using Newton's Laws of motion. • Construct force models of real world situations. • Synthesis free-body diagrams and solve for forces. • Apply concepts of force and vector resolution to solve for object motion.

	Show details 2.B.1 A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field. Show details TOPIC 2.3 Contact Forces 3.C At the macroscopic level, forces can be categorized as either long-range (action-ata-distance) forces or contact forces. 3.C.4.2 Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [SP 6.2] Show details 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: $\lvert \vec{F_f} \rvert \leq \lvert \vec{F_n} \rvert$ $\lvert \vec{F_s} \rvert = k \lvert \vec{x} \rvert$ Show details TOPIC 2.4 Newton's First Law 1.C Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles. LEARNING OBJECTIVE ESSENTIAL KNOWLEDGE 1.C.1.1 Design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. [SP 4.2] Show details	3.C.4.1 Make claims about various contact forces between objects based on the microscopic cause of these forces. 3.C.4.2 Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. 1.C.1.1 Design an experiment for collection data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. 1.C.3.1 Design a plan for collecting data to measure gravitational mass and inertial mass and to distinguish between the two experiments. 3.A.2.1 Represent forces in diagrams of mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. 3.A.3.1 Analyze a scenario and make claims (develop arguments, justify	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.3 The student can estimate quantities that describe natural phenomena. 4.2 The student can design a plan for collection data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 5.3 The student can evaluate the evidence provided by date sets in relation to a particular scientific question. 6.1 The student can justify claims with evidence.

	1.C.3.1 Design a plan for collecting data to measure gravitational mass and inertial mass and to distinguish between the two experiments. [SP 4.2] Show details 1.C.1 Inertial mass is the property of an object or system that determines how its motion changes when it interacts with other objects or systems. a. $\vec{a} = \frac{\vec{F}}{m}$ Show details 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. Show details TOPIC 2.5 Newton's Third Law and Free-Body Diagrams 3.A All forces share certain common characteristics when considered by observers in inertial reference frames. 3.A.2.1 Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1] Show details 3.A.3.1 Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [SP 6.4, 7.2] Show details 3.A.3.3 Describe a force as an interaction between two objects, and identify both objects for any force. [SP 1.4] Show details 3.A.4.1 Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of	assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. 3.A.4.1 Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representations of action-reaction pairs of forces. 3.A.4.2 Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. 3.A.4.3 Analyze situations involving interaction among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. 3.B.1.1 Predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations, with acceleration in one dimension. 3.B.1.2 Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurement, and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.	6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understanding and/or big ideas.

	actionreaction pairs of forces. [SP 1.4, 6.2] Show details 3.A.4.2 Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2] Show details 3.A.4.3 Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4] Show details 3.A.2 Forces are described by vectors. Show details 3.A.3 A force exerted on an object is always due to the interaction of that object with another object. Show details 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. Show details TOPIC 2.6 Newton's Second Law 3.B Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$ 3.B.1.1 Predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations, with acceleration in one dimension. [SP 6.4, 7.2] Show details 3.B.1.2 Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurement, and carry out an analysis to determine the relationship between the net force and the vector	3.B.1.3 Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object. 3.B.2.1 Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. 3.C.1.1 Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and use that force in contexts other than orbital motion. 3.C.1.2 Use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion. 3.C.2.2 Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. 2.B.1.1 Apply F=mg 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.	

	sum of the individual forces. [SP 4.2, 5.1] Show details 3.B.1.3 Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2] Show details 3.B.2.1 Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2] Show details UNIT 3 Circular Motion and Gravitation BIG IDEA 1 Systems SYS How does changing the mass of an object affect the gravitational force? Why is a refrigerator hard to push in space? BIG IDEA 2 Fields FLD Why do we feel pulled toward Earth but not toward a pencil? How can the acceleration due to gravity be modified? BIG IDEA 3 Force Interactions INT How can Newton's laws of motion be used to predict the behavior of objects? How can we use forces to predict the behavior of objects and keep us safe? BIG IDEA 4 Change CHA Why is it more difficult to stop a fully loaded dump truck than a small passenger car? TOPIC 3.3 Gravitational and Electric Forces 3.C At the macroscopic level, forces can be categorized as either long-range (action-ata-distance) forces or contact forces. 3.C.1.1 Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and	2.B.2.1 Apply $g = G(m/r^2)$ to calculate the gravitational field due to an object with mass m, where the field is a vector directed toward the center of the object of mass m. 2.B.2.2 Approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of Earth or other reference objects.	

	use that force in contexts other than orbital motion. [SP 2.2] Show details 3.C.1.2 Use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). [SP 2.2] Show details 3.C.1 Gravitational force describes the interaction of one object with mass with another object with mass. Show details TOPIC 3.4 Gravitational Field/Acceleration Due to Gravity on Different Planets 2.B A gravitational field is caused by an object with mass. 2.B.1.1 Apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. [SP 2.2, 7.2] Show details 2.B.2.1 Apply $g = G\frac{m}{r^2}$ to calculate the gravitational field due to an object with mass m, where the field is a vector directed toward the center of the object of mass Show details 2.B.2.2 Approximate a numerical value of the gravitational field (g) near the surface of an object from its radius and mass relative to those of Earth or other reference objects. [SP 2.2] Show details 2.B.1 A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.		

	Show details TOPIC 3.8 Applications of Circular Motion and Gravitation 3.A All forces share certain common characteristics when considered by observers in inertial reference frames. 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 $\theta = \theta_0 + w_0 t + \frac{1}{2}\alpha t^2$ $w = w_0 + \alpha t$ $w^2 = w_0^2 + 2\alpha_x(\theta - \theta_0)$ Show details h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path. Relevant Equation: $a_c = \frac{v^2}{r}$ For uniform circular motion of radius r, v is proportional to omega, ω (for a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = \frac{2\pi r}{T}$. Show details © 2013 The College Board, Advanced Placement AP Frameworks		
Unit 3 - Work & Energy	AP: Physics 1 (2019) AP: AP UNIT 4 Energy TOPIC 4.1 Open and Closed Systems: Energy 5.A Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always	• Potential energy • Kinetic Energy • Work • Mechanical Energy • Power	Students will be able to: • Predict the kinetic energy of an object based on its mass and speed

	equal to the transfer of that quantity to or from the system by all possible interactions with other systems. 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. Show details 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. Show details 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. Show details TOPIC 4.2 Work and Mechanical Energy 3.E A force exerted on an object can change the kinetic energy of the object. 3.E.1 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. Show details TOPIC 4.2 Work and Mechanical Energy 4.C Interactions with other objects or systems can change the total energy of a system. 4.C.1 The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples include gravitational potential energy, elastic potential energy, and kinetic energy. Show details	Objectives: **5.A.2.1** Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. **3.E.1.1** Make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves. **3.E.1.2** Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged. **3.E.1.3** Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether the kinetic energy of that object would increase, decrease, or remain unchanged. **3.E.1.4** Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. **4.C.1.1** Calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. **4.C.1.2** Predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. **4.C.2.1** Make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of	• Determine the potential energy of an object based on its position • Relate the work done on an object to it's change in kinetic energy • Recognize that mechanical energy is not always conserved • Distinguish between work and various forms of mechanical energy • Design experiments that allow assessment of whether energy is conserved • Recognize the difference between work and power 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 2.1 The student can justify the selection of a mathematical routine to solve problems.

	TOPIC 4.3 Conservation of Energy, the Work-Energy Principle, and Power 5.B The energy of a system is conserved. 5.B.1 Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects. Relevant Equation: $K = \frac{1}{2}mv^2$ Show details 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 massspring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.] Show details 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. Show details 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. Show details 5.B.5 Energy can be transferred by an external force exerted on an object or a system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A	the center of mass. 4.C.2.2 Apply the concepts of conservation of energy and the work-energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system. 5.B.1.1 Create a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy. 5.B.1.2 Translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies. 5.B.2.1 Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. 5.B.3.1 Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. 5.B.3.2 Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. 5.B.3.3 Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system.	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

	piston filled with gas getting compressed or expanded is treated in Physics 2 as part of thermodynamics.] Relevant Equations: $\triangle E = W = F_{\parallel} d = Fd\cos\theta$ $P = \frac{\triangle E}{\triangle t}$ Show details © 2013 The College Board, Advanced Placement AP Frameworks	5.B.4.1 Describe and make predictions about the internal energy of systems. 5.B.4.2 Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. 5.B.5.1 Design an experiment and analyze data to determine how a force exerted on an object or system does work on the object or system as it moves through a distance. 5.B.5.2 Design an experiment and analyze graphical data in which interpretations of the area under a force-distance curve are needed to determine the work done on or by the object or system. 5.B.5.3 Predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance. 5.B.5.4 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). 5.B.5.5 Predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance.	
Unit 4 - Impulse and Momentum	AP: Physics 1 (2019) AP: AP UNIT 5 Momentum TOPIC 5.1 Momentum and Impulse 3.D A force exerted on an object can change the momentum of the object. 3.D.1.1 Justify the selection of data needed to determine the relationship between the direction of the force	• Momentum • Inertia • Impulse • Collision, types of • Conservation of Momentum	Students will be able to: • Recognize and state the definition of momentum in terms of the mass and velocity of the object in question • Differentiate between momentum and inertia

	acting on an object and the change in momentum caused by that force. [SP 4.1] Show details 3.D.2.1 Justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. [SP 2.1] Show details 3.D.2.2 Predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [SP 6.4] Show details 3.D.2.3 Analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [SP 5.1] Show details 3.D.2.4 Design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. [SP 4.2] Show details 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: $\vec{p} = m\vec{v}$ Show details 3.D.2 The change in momentum of an object occurs over a time interval. Show details TOPIC 5.2 Representations of Changes in Momentum 4.B Interactions with other objects or systems can change the total linear momentum of a system. 4.B.1.1 Calculate the change in linear momentum of a two-object system with constant mass in linear motion from a	Objectives: 3.D.1.1 Justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force. 3.D.2.1 Justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. 3.D.2.2 Predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. 3.D.2.3 Analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. 3.D.2.4 Design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. 4.B.1.1 Calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). 4.B.1.2 Analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass. 4.B.2.1 Apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. 4.B.2.2 Perform an analysis on data presented as a force-time graph and predict the change in momentum of a	• Identify that momentum is a vector whose direction is determined by the velocity of the object. • Calculate the momentum of an object based its velocity and mass • Calculate the change in momentum (impulse) of an object as a result of the application of an external force for a given period of time • Predict the change in kinetic energy associated with an impulse • Determine the change in momentum of an object involved in a collision with another object based on the initial, final, or combination of conditions • Analyze the differences between various forms of collisions - elastic, inelastic, totally inelastic • Synthesize that although a collision involves multiple objects, it can be treated as a system so that forces between objects comprising the system are internal to the system and so the momentum of the system is conserved • Resolve the conservation of momentum to its x, y and z component parts

	representation of the system (data, graphs, etc.). [SP 1.4, 2.2] Show details 4.B.1.2 Analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass. [SP 5.1] Show details 4.B.2.1 Apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. [SP 2.2] Show details 4.B.2.2 Perform an analysis on data presented as a force-time graph and predict the change in momentum of a system. [SP 5.1] Show details 4.B.1 The change in linear momentum for a constantmass system is the product of the mass of the system and the change in velocity of the center of mass. Relevant Equation: $\vec{p} = m\vec{v}$ Show details 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. Show details TOPIC 5.3 Open and Closed Systems: Momentum 5.A Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems. 5.A.2.1 Define open and closed systems for everyday situations and apply conservation concepts for	system. 5.A.2.1 Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. 5.D.1.1 Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. 5.D.1.2 Apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and qualitatively in two-dimensional situations. 5.D.1.3 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. 5.D.1.4 Design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. 5.D.1.5 Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 4.4 The student can evaluate sources of data to answer a particular scientific question.* 5.1 The student can analyze data to identify patterns or relationships. 5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.*

	energy, charge, and linear momentum to those situations. [SP 6.4, 7.2] Show details 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. Show details TOPIC 5.4 Conservation of Linear Momentum 5.D The linear momentum of a system is conserved. 5.D.1.1 Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [SP 6.4, 7.2] Show details 5.D.1.2 Apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and qualitatively in two-dimensional situations. [SP 2.2, 3.2, 5.1, 5.3] Show details 5.D.1.3 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	energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. 5.D.2.1 Qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. 5.D.2.2 Plan data-collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. 5.D.2.3 Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. 5.D.2.4 Analyze data that verify conservation of momentum in collisions with and without an external frictional force. 5.D.2.5 Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values.	

	restoration of kinetic energy. [SP 2.1, 2.2] Show details 5.D.1.4 Design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [SP 4.2, 5.1, 5.3, 6.4] Show details 5.D.1.5 Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [SP 2.1, 2.2] Show details 5.D.2.1 Qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [SP 6.4, 7.2] Show details 5.D.2.2 Plan data-collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. [SP 4.1, 4.2, 5.1] Show details 5.D.2.3 Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2] Show details 5.D.2.4 Analyze data that verify conservation of momentum in collisions		

	with and without an external frictional force. [SP 4.1, 4.2, 4.4, 5.1, 5.3] Show details 5.D.2.5 Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [SP 2.1, 2.2] Show details 5.D.3.1 Predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center-of-mass motion of the system and is able to determine that there is no external force). [SP 6.4] Show details 5.D.1 In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after. Show details 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. Show details 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.] Show details © 2013 The College Board, Advanced Placement AP Frameworks		
Unit 5 - Simple Harmonic Motion	AP: Physics 1 (2019) AP: AP UNIT 6 Simple Harmonic Motion TOPIC 6.1 Period of Simple Harmonic Oscillators 3.B Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$. 3.B.3.1 Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [SP 6.4, 7.2] Show details 3.B.3.2 Design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force. [SP 4.2] Show details 3.B.3.3 Analyze data to identify qualitative and quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion and use those data to determine the value of an unknown. [SP 2.2, 5.1] Show details 3.B.3.4 Construct a qualitative and/ or quantitative explanation of oscillatory behavior given evidence of a restoring force. [SP 2.2, 6.2]	• Simple harmonic motion • waves • oscillation • amplitude • frequency • wavelenth • speed • energy • interference • standing waves • beats 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 standing waves and beats. 3.B.3.1 Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. 3.B.3.2 Design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in

	Show details 3.B.3 Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples include gravitational force exerted by Earth on a simple pendulum and mass-spring oscillator. Show details 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. Show details b. For a simple pendulum, the period increases with the length of the pendulum and decreases with the magnitude of the gravitational field. Show details 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: $T_p = 2\pi\sqrt{\frac{l}{g}}$ $T_s = 2\pi\sqrt{\frac{m}{k}}$ Show details TOPIC 6.2 Energy of a Simple Harmonic Oscillator 5.B The energy of a system is conserved. 5.B.2.1 Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of	oscillatory motion caused by a restoring force. 3.B.3.3 Analyze data to identify qualitative and quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion and use those data to determine the value of an unknown. 3.B.3.4 Construct a qualitative and/or quantitative explanation of oscillatory behavior given evidence of a restoring force. 5.B.2.1 Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. 5.B.3.1 Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.	and/or across enduring understandings and/or big ideas.

	conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [SP 1.4, 2.1] Show details 5.B.3.1 Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2] Show details 5.B.3.2 Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2] Show details 5.B.3.3 Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [SP 1.4, 2.2] Show details 5.B.4.1 Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] Show details 5.B.4.2 Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [SP 1.4, 2.1, 2.2] Show details 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 massspring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.] Show details	5.B.3.2 Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. 5.B.3.3 Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. 5.B.4.1 Describe and make predictions about the internal energy of systems. 5.B.4.2 Calculate changes in kinetic energy and potential energy of a system using information from representations of that system.	

	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. Show details 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. Show details 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. Show details c. The change in electric potential in a circuit is the change in potential energy per unit charge. [In Physics 1, only in the context of circuits] Relevant Equations: $T_p = 2\pi\sqrt{\frac{l}{g}}$ $T_s = 2\pi\sqrt{\frac{m}{k}}$ $U_s = \frac{1}{2}kx^2$ $\triangle U_s = mg\triangle y$ Show details 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. Show details 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.		

	Show details b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system. Show details © 2013 The College Board, Advanced Placement AP Frameworks		
Unit 6 - Torque & Rotational Motion	AP: Physics 1 (2019) AP: AP UNIT 7 Torque and Rotational Motion TOPIC 7.1 Rotational Kinematics 3.A All forces share certain common characteristics when considered by observers in inertial reference frames. 3.A.1.1 Express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2] Show details 3.A.1 An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. Show details TOPIC 7.2 Torque and Angular Acceleration 3.F A force exerted on an object can cause a torque on that object. 3.F.1.1 Use representations of the relationship between force and torque. [SP 1.4] Show details 3.F.1.2 Compare the torques on an object caused by various forces. [SP 1.4] Show details 3.F.1.3 Estimate the torque on an object caused by various forces in	• torque • equilibrium • axis • angular velocity • angular momentum 3.A.1.1 Express the motion of an object using narrative, mathematical, and graphical representations. 3.F.1.1 Use representations of the relationship between force and torque. 3.F.1.2 Compare the torques on an object caused by various forces. 3.F.1.3 Estimate the torque on an object caused	1.2 The student can describe representations and models of natural or man-made phenomena and systems in the domain.* 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.* 2.3 The student can estimate quantities that describe natural phenomena.

	comparison with other situations. [SP 2.3] Show details 3.F.1.4 Design an experiment and analyze data testing a question about torques in a balanced rigid system. [SP 4.1, 4.2, 5.1] Show details 3.F.1.5 Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction). [SP 1.4, 2.2] Show details 3.F.2.1 Make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. [SP 6.4] Show details 3.F.2.2 Plan data-collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. [SP 4.1, 4.2, 5.1] Show details 3.F.3.1 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] Show details 3.F.3.2 In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. [SP 2.1] Show details	by various forces in comparison with other situations. 3.F.1.4 Design an experiment and analyze data testing a question about torques in a balanced rigid system. 3.F.1.5 Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction). 3.F.2.1 Make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. 3.F.2.2 Plan data-collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. 3.F.3.1 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.	3.2 The student can refine scientific questions.* 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

	3.F.3.3 Plan data-collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object. [SP 4.1, 4.2, 5.1, 5.3] Show details 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. Show details 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. Show details 3.F.3 A torque exerted on an object can change the angular momentum of an object. Show details TOPIC 7.3 Angular Momentum and Torque 4.D A net torque exerted on a system by other objects or systems will change the angular momentum of the system. 4.D.1.1 Describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. [SP 1.2, 1.4] Show details 4.D.1.2 Plan data-collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research	3.F.3.2 In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. 3.F.3.3 Plan data-collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object. 4.D.1.1 Describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. 4.D.1.2 Plan data-collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data. 4.D.2.1 Describe a model of a rotational system and use that model to analyze a situation in which angular momentum	

	question based on the examination of data. [SP 3.2, 4.1, 4.2, 5.1, 5.3] Show details 4.D.2.1 Describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. [SP 1.2, 1.4] Show details 4.D.2.2 Plan a data-collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems. [SP 4.2] Show details 4.D.3.1 Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. [SP 2.2] Show details 4.D.3.2 Plan a data-collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. [SP 4.1, 4.2] Show details 4.D.1 Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending on whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. Relevant Equations: $\tau = r_{\perp} F = rF \sin\theta$ $\alpha = \frac{\sum \tau}{I}$	changes due to interaction with other objects or systems. 4.D.2.2 Plan a data-collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems. 4.D.3.1 Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. 4.D.3.2 Plan a data-collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. 5.E.1.1 Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. 5.E.1.2 Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. 5.E.2.1 Describe or calculate the angular momentum and rotational inertia of a	

	$w^2 = w_0^2 + 2_x(\theta - \theta_0)$ $L = Iw$ $\triangle L = \iota \triangle t$ $\theta = \theta_0 + w_0 t + \frac{1}{2}\alpha t^2$ $w = w_0 + \alpha t$ $w^2 = w_0^2 + 2\alpha(\theta - \theta_0)$ Show details 4.D.2 The angular momentum of a system may change due to interactions with other objects or systems. Show details 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. Relevant Equations: L=Iw $\triangle L = \iota \triangle t$ $\iota = r_\perp F = rF \sin\theta$ Show details TOPIC 7.4 Conservation of Angular Momentum 5.E The angular momentum of a system is conserved. 5.E.1.1 Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. [SP 6.4, 7.2] Show details 5.E.1.2 Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. [SP 2.1, 2.2] Show details 5.E.2.1 Describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Use qualitative reasoning with compound objects and perform calculations with a fixed set of extended objects and point masses. [SP 2.2]	system in terms of the locations and velocities of objects that make up the system. Use qualitative reasoning with compound objects and perform calculations with a fixed set of extended objects and point masses.	

	Show details 5.E.1 If the net external torque exerted on the system is zero, the angular momentum of the system does not change. Relevant Equations: L=Iw $\triangle L = \iota \triangle t$ $\iota = r_{\perp} F = rF \sin\theta$ Show details 5.E.2 The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or a system depends on the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation. Relevant Equation: $I = mr^2$ Show details © 2013 The College Board, Advanced Placement AP Frameworks		
Unit 7 - Electric	AP: Physics 1 (2019) AP: AP	• electric charge • Coulomb's Law	1.5 The student can re-express key elements of natural phenomena

Charge & Electric Force	UNIT 8 Electric Charge and Electric Force TOPIC 8.1 Conservation of Charge 5.A Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems. 5.A.2.1 Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2] Show details 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. Show details TOPIC 8.2 Electric Charge 1.B Electric charge is a property of an object or a system that affects its interactions with other objects or systems containing charge. 1.B.1.1 Make claims about natural phenomena based on conservation of electric charge. [SP 6.4] Show details 1.B.1.2 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] Show details 1.B.2.1 Construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. [SP 6.2]	• Electric Force 5.A.2.1 Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. 1.B.1.1 Make claims about natural phenomena based on conservation of electric charge. 1.B.1.2 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. 1.B.2.1 Construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. 1.B.3.1 Challenge the claim that an electric charge smaller than the elementary charge has been isolated. 3.C.2.1 Use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. 3.C.2.2 Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.	across multiple representations in the domain. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.1 The student can justify claims with evidence. 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

	Show details 1.B.3.1 Challenge the claim that an electric charge smaller than the elementary charge has been isolated. [SP 1.5, 6.1, 7.2] Show details 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. Show details 1.B.2 There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge. Show details 1.B.3 The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge. Show details TOPIC 8.3 Electric Force 3.C At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. 3.C.2.1 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] Show details 3.C.2.2 Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [SP 7.2] Show details 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. Show details © 2013 The College Board, Advanced Placement AP Frameworks		
Unit 8 - DC Circuits	AP: Physics 1 (2019) AP: AP UNIT 9 DC Circuits TOPIC 9.1 Definition of a Circuit 1.B Electric charge is a property of an object or a system that affects its interactions with other objects or systems containing charge. 1.B.1.1 Make claims about natural phenomena based on conservation of electric charge. [SP 6.4] Show details 1.B.1.2 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] Show details 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. Show details TOPIC 9.2 Resistivity 1.E Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. 1.E.2.1 Choose and justify the selection of data needed to determine resistivity for a given material. [SP 4.1] Show details	• circuit • parallel circuit • series circuit • battery • resistor • Kirchhoff's Loop Rule • Kirchhoff's Junction Rule 1.B.1.1 Make claims about natural phenomena based on conservation of electric charge. 1.B.1.2 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. 1.E.2.1 Choose and justify the selection of data needed to determine resistivity for a given material. 5.B.9.1 Construct or interpret a graph of the energy changes within an electrical circuit with only a single battery and resistors in series and/or in, at most,	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

	1.E.2 Matter has a property called resistivity. Show details TOPIC 9.3 Ohm's Law, Kirchhoff's Loop Rule (Resistors in Series and Parallel) 5.B The energy of a system is conserved. 5.B.9.1 Construct or interpret a graph of the energy changes within 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] Show details 5.B.9.2 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] Show details 5.B.9.3 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] Show details 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 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-	one parallel branch as an application of the conservation of energy (Kirchhoff's loop rule). 5.B.9.2 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. 5.B.9.3 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. 5.C.3.1 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. 5.C.3.2 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. 5.C.3.3 Use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit.	

	ideal batteries are not covered in Physics 1.] Show details TOPIC 9.4 Kirchhoff's Junction Rule, Ohm's Law (Resistors in Series and Parallel) 5.C The electric charge of a system is conserved. 5.C.3.1 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] Show details 5.C.3.2 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] Show details 5.C.3.3 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] Show details 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.] Relevant Equations: $I \equiv \frac{\triangle q}{\triangle t}$ $I = \frac{\triangle V}{R}$ $P = I\triangle V$ $R_s = \sum_i R_i$ $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$ Show details © 2013 The College Board, Advanced Placement AP Frameworks		
Unit 9: Mechanical Waves & Sound	AP: Physics 1 (2019) AP: AP UNIT 10 Mechanical Waves and Sound TOPIC 10.1 Properties of Waves 6.A A wave is a traveling disturbance that transfers energy and momentum. 6.A.1.1 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] Show details 6.A.1.2 Describe representations of transverse and longitudinal waves. [SP 1.2] Show details 6.A.2.1 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] Show details 6.A.3.1 Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [SP 1.4] Show details	• transverse waves • longitudinal waves • sound • amplitude • frequency • decibels • period • wavelength • pulses • superposition • nodes • antinodes • Doppler Effect 6.A.1.1 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.	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.2 The student can describe representations and models of natural or man-made phenomena and systems in the domain.* 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.* 2.1 The student can justify the selection of a mathematical routine to solve problems.

	6.A.4.1 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] Show details 6.A.1 Waves can propagate via different oscillation modes such as transverse and longitudinal. Show details 6.A.2 For propagation, 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. Show details 6.A.3 The amplitude is the maximum displacement of a wave from its equilibrium value. Show details 6.A.4 Classically, the energy carried by a wave depends on and increases with amplitude. Examples include sound waves. Show details TOPIC 10.2 Periodic Waves 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.B.1.1 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] Show details 6.B.2.1 Use a visual representation of a periodic mechanical wave to determine the wavelength of the wave. [SP 1.4] Show details	6.A.1.2 Describe representations of transverse and longitudinal waves. 6.A.2.1 Describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples. 6.A.3.1 Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. 6.A.4.1 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. 6.B.1.1 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. 6.B.2.1 Use a visual representation of a periodic mechanical wave to determine the wavelength of the wave. 6.B.4.1 Design an experiment to determine the relationship between periodic wave speed, wavelength, and frequency and relate these concepts to everyday examples. 6.B.5.1 Create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent on relative motions of source and observer. 6.D.1.1 Use representations of individual pulses	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 3.2 The student can refine scientific questions.* 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.* 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 5.2 The student can refine observations and measurements based on data analysis. 5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question. 6.1 The student can justify claims with evidence. 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.* 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in

	6.B.4.1 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] Show details 6.B.5.1 Create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent on relative motions of source and observer. [SP 1.4] Show details 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. Show details 6.B.2 For a periodic wave, the wavelength is the repeat distance of the wave. Show details 6.B.4 For a periodic wave, wavelength is the ratio of speed over frequency. Relevant Equation: $\lambda = \frac{v}{f}$ Show details 6.B.5 The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only. Show details TOPIC 10.3 Interference and Superposition (Waves in Tubes and on Strings) 6.D Interference and superposition lead to standing waves and beats. 6.D.1.1 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] Show details	and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses. 6.D.1.2 Design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves). 6.D.1.3 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. 6.D.2.1 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. 6.D.3.1 Refine a scientific question related to standing waves and design a detailed plan for the experiment that can be conducted to examine the phenomenon qualitatively or quantitatively. 6.D.3.2 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. 6.D.3.3 Plan data-collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared with 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. 6.D.3.4 Describe representations and models of situations in which standing waves result from the addition of incident and	and/or across enduring understandings and/or big ideas.

	6.D.1.2 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] Show details 6.D.1.3 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] Show details 6.D.2.1 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] Show details 6.D.3.1 Refine a scientific question related to standing waves and design a detailed plan for the experiment that can be conducted to examine the phenomenon qualitatively or quantitatively. [SP 2.1, 3.2, 4.2] Show details 6.D.3.2 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] Show details 6.D.3.3 Plan data-collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared with 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] Show details 6.D.3.4 Describe representations and models of situations in which standing	reflected waves confined to a region. 6.D.4.1 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. 6.D.4.2 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. 6.D.5.1 Use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats.	

	waves result from the addition of incident and reflected waves confined to a region. [SP 1.2] Show details 6.D.4.1 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] Show details 6.D.4.2 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] Show details 6.D.5.1 Use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats. [SP 1.2] Show details 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. Show details 6.D.2 Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave. Show details 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 length of string and sound waves in both closed and open tubes. Show details 6.D.4 The possible wavelengths of a standing wave are determined by the size of the region to which it is confined. Show details 6.D.5 Beats arise from the addition of waves of slightly different frequency. Show details © 2013 The College Board, Advanced Placement AP Frameworks		
Special Topic - Heat & Internal Energy		• heat • temperature • thermal energy • First Law of Thermodynamics • adiabatic • isothermal • isochoric • isobaric • Second Law of Thermodynamics • efficiancy • entropy	Students will be able to: • Distinguish among the various ways to measure temperature • Correlate temperature as a statistical processes related to the average speed of molecules • Recognize that heat and temperature are different but related and that heat flows from regions of higher to lower temperature • Calculate the internal heat of an object using its specific heat, temperature and mass • Determine heat absorbed/released of various materials undergoing phase transitions from the latent heat values • Distinguish among convective, conductive and

			radiative forms of heat transfer • Apply concepts of heat and heat transfer to predict temperature differences
Special Topic - Fluids		• density • pressure • hydrostatic pressure • buoyancy • Archimedes' Principle • Fluid flow continuity • Bernoulli's Equation • Pascal's Principle	Students will be able to: • Predict whether an object sinks or floats based on density • Evaluate forces transmitted by fluids • Differentiate between static and dynamic conditions of fluids • Apply Pascal's Principle to problems involving hydraulics • Compute the buoyant force of objects in a fluid environment • Apply concepts of fluid dynamics (Bernoulli's Principle) to assess velocity and pressure in various media based on conservation laws
Special Topic - Optics		• Law of reflection • angle of incidence • angle of reflection • refraction • concave • convex • index of refraction • Snell's law • Electromagnetic Spectrum • real/virtual image	Students will be able to: Understand & explain the principle of diffraction. Understand & can analyze the refraction o waves, including the use of Snell's Law.

		• diffraction	Can apply the Law of Reflection to plane surfaces. Can explain the Electromagnetic spectrum and its applications.
Special Topic - Nuclear & Special Relativity		• Particle Nature of Waves • Photoelectric Effect • Compton Effect • photon • de Broglie • Heisenberg Uncertainty Principle • Radioactive Decay • fission • fusion • antimatter	•