TRUMBULL PUBLIC SCHOOLS

Trumbull, Connecticut

ADVANCED PLACEMENT PHYSICS 1

Grade 12

Science Department

2020

Curriculum Writing Team

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Advanced Placement Physics 1
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CORE VALUES AND BELIEFS

The Trumbull School Community engages in an environment conducive to learning which believes that all students will **read** and **write effectively**, therefore communicating in an articulate and coherent manner. All students will participate in activities **that present problem-solving through critical thinking**. Students will use technology as a tool applying it to decision making. We believe that by fostering self-confidence, self-directed and student-centered activities, we will promote **independent thinkers and learners**. We believe **ethical conduct** to be paramount in sustaining the welcoming school climate that we presently enjoy.

Approved 8/26/2011

INTRODUCTION & PHILOSOPHY

Advanced Placement Physics 1 is the equivalent of an introductory college physics course, without calculus, spread across a full academic year. A depth of understanding in introductory algebra-based college physics is promoted through rigorous exercise of seven science practices. Topics covered include kinematics, dynamics (Newton's Laws), circular motion, universal gravitation law, simple harmonic motion, impulse and momentum, work and energy, rotational motion and dynamics, electrostatics and charges, DC circuits, and mechanical waves. A significant physics application team project is part of the course. Superior mathematical and problem-solving skills are required. Students taking this course will be prepared to take the College Board's Advanced Placement Physics 1 Examination.

COURSE GOALS

The following course goals derive from the 2019 College Board Science Practices for AP Physics 1.

Science Practice 1: Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

Science Practice 2: Mathematical Routines: The student can use mathematics appropriately.

Science Practice 3: Scientific Questioning: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

Science Practice 4: Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.

Science Practice 5: Data Analysis: The student can perform data analysis and evaluation of evidence.

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

Science Practice 7: Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

COURSE ENDURING UNDERSTANDINGS

Students will understand that . . .

- the internal structure of a system determines many properties of the system.
- electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.
- objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- materials have many macroscopic properties that result from the arrangement and interactions of atoms and molecules that make up the material.
- a field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces), as well as a variety of other physical phenomena.
- a gravitational field is caused by an object with mass.
- all forces share certain common characteristics when considered by observers in inertial reference frames.
- classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \Sigma\vec{F}/m$.
- at the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
- a force exerted on an object can change the momentum of the object.
- a force exerted on an object can change the kinetic energy of the object.
- a force exerted on an object can cause a torque on that object.
- certain types of forces are considered fundamental.
- the acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \Sigma\vec{F}/m$.
- interactions with other objects or systems can change the total linear momentum of a system.
- interactions with other objects or systems can change the total energy of a system.
- a net torque exerted on a system by other objects or systems will change the angular momentum of the system.

- 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.
- the energy of a system is conserved.
- the electric charge of a system is conserved.
- the linear momentum of a system is conserved.
- the angular momentum of a system is conserved.
- a wave is a traveling disturbance that transfers energy and momentum.
- 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.
- interference and superposition lead to standing waves and beats.

COURSE ESSENTIAL QUESTIONS

- What are the properties of objects and systems?
- How do fields (existing in space) explain interactions?
- How do forces describe interactions of an object with other objects?
- How do interactions between systems result in changes in those systems?
- How are changes that occur as a result of interactions constrained by conservation laws?
- How do waves transfer energy and momentum from one location to another without the permanent transfer of mass?

COURSE KNOWLEDGE & SKILLS

Students will know . . .

- 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.
- Systems have properties that are determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an object.

- 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. Relevant Equation: $I = \frac{\Delta q}{\Delta t}$.
- 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.
  a. Like-charged objects and systems repel, and unlike-charged objects and systems attract. Relevant Equation: $F_E = \frac{kq_1 q_2}{r^2}$.
- 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 1.6×10^{-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.
- 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. $\vec{a} = \Sigma\vec{F}/m$
- Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.
  a. The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field.
  b. Near Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.
- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.
- 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. Relevant Equation: $R = \rho \frac{L}{A}$.
- A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.
  a. Vector fields are represented by field vectors indicating direction and magnitude.
  b. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition.
  c. Conversely, a known vector field can be used to make inferences about the number, relative size, and locations of sources.

- A gravitational field $\vec{g}$ at the location of an object with mass *m* causes a gravitational force of magnitude *mg* to be exerted on the object in the direction of the field.
  a. On Earth, this gravitational force is called weight.
  b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
  c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location. Relevant Equation: $\vec{F}_g = m\vec{g}$.
- The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.
  a. The gravitational field caused by a spherically symmetric object is a vector whose magnitude outside the object is equal to $G\frac{m}{r^2}$.
  b. Only spherically symmetric objects will be considered as sources of the gravitational field. Relevant Equation: $\vec{a} = \Sigma\vec{F}/m$.
- 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.
  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. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are:

$$v_x = v_{x0} + a_x t \qquad x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2 \qquad v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$$

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:

$$\omega = \omega_0 + \alpha t \qquad \theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2 \qquad \omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$$

- Forces are described by vectors.
  a. Forces are detected by their influence on the motion of an object.
  b. Forces have magnitude and direction.
- 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.
- 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.
- If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. Relevant Equation: $\vec{a} = \Sigma\vec{F}/m$.
- Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.
  a. An object can be drawn as if it were extracted from its environment and the interactions with the environment were identified.
  b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.
  c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.
  d. Free-body or force diagrams may be depicted in one of two ways – one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.
- Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples include gravitational force exerted by Earth on a simple pendulum and mass-spring oscillator.
  a. For a spring that exerts a linear restoring force, the period of a mass-spring oscillator increases with mass and decreases with spring stiffness.
  b. For a simple pendulum, the period increases with the length of the pendulum and decreases with the magnitude of the gravitational field.

c. Minima, maxima, and zeros of position, velocity, 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: $T_P = 2\pi\sqrt{\frac{l}{g}}$, $T_S = 2\pi\sqrt{\frac{m}{k}}$.

- Gravitational force describes the interaction of one object with mass with another object with mass.
  a. The gravitational force is always attractive.
  b. The magnitude of force between two spherically symmetric objects of mass m_1 and m_2 is $G\frac{m_1 m_2}{r^2}$, where r is the center-to-center distance between the objects.
  c. In a narrow range of heights above Earth's surface, the local gravitational field, g, is approximately constant. Relevant Equations: $F_G = G\frac{m_1 m_2}{r^2}$.
- 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 non-fundamental forces called contact forces, such as normal force, friction, and tension.
  b. Electric forces may be attractive or repulsive, depending on the charges on the objects involved. Relevant Equations: $F_E = k\frac{q_1 q_2}{r^2}$, $F_G = G\frac{m_1 m_2}{r^2}$.
- 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: $|\vec{F_f}| \leq \mu|\vec{F_N}|$, $|\vec{F_s}| = k|\vec{x}|$.
- The change in momentum of an object is a vector in the direction of the net force exerted on the object. Relevant Equation: $\vec{p} = m\vec{v}$.
- 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. Relevant Equation: $\vec{p} = m\vec{v}$.
- 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. Relevant Equation: $\Delta E = W = F_{\|} d = Fd \cos \theta$.

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: $K = \frac{1}{2}mv^2$, $\Delta E = W = F_{\|} d = Fd \cos \theta$.

- 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 Equations: $\tau = r_{\perp} F = rF \sin \theta$.
- The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.
  a. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.
  b. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.
  c. The angular acceleration of an object or a rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system. Relevant Equations: $\tau = r_{\perp} F = rF \sin \theta$, $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$, $\omega = \omega_0 + \alpha t$, $\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$.
- 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.
  d. The change in angular momentum of an object is given by the product of the average torque and the time for which the torque is exerted. Relevant Equations: $L = I\omega$, $\Delta L = \tau \Delta t$, $L = mvr$.

- Gravitational forces are exerted at all scales and dominate at the largest distances and mass scales.
- The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities. Relevant Equations:
  $v_x = v_{x0} + a_x t$, $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$, $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$.
- The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.
  a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.
  b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.
  c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.
  d. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities. Relevant Equations:
  $\vec{a} = \frac{\Sigma\vec{F}}{m}$, $\vec{v}_{avg} = \frac{\Delta\vec{x}}{\Delta t}$, $\vec{a}_{avg} = \frac{\Delta\vec{v}}{\Delta t}$.
- The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. Relevant Equation: $\vec{p} = m\vec{v}$.
- 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. Relevant Equations: $\vec{p} = m\vec{v}$, $\vec{p} = \vec{F}\Delta t$.
- The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples include gravitational potential energy, elastic potential energy, and kinetic energy.
  a. A rotating, rigid body may be considered to be a system and may have both translational and rotational kinetic energy.
  b. Although thermodynamics is not part of Physics 1, included is the idea that, during an inelastic collision, some of the mechanical energy dissipates as (converts to) thermal energy. Relevant Equations: $K = \frac{1}{2}mv^2$, $K = \frac{1}{2}I\omega^2$, $\Delta U_g = mg\Delta y$, $U_G = -\frac{Gm_1 m_2}{r}$, $U_s = \frac{1}{2}kx^2$.
- Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the forces

is parallel to its displacement. The process through which the energy is transferred is called work.

a. If the force is constant during a given displacement, then the work done is the product of the displacement and the component of the force parallel or antiparallel to the displacement. Relevant Equation: $W = F_{\|} d$.

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. Relevant Equation: $\Delta E = W = F_{\|} d = Fd \cos\theta$.

- 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: $\tau = r_{\perp} F = rF \sin\theta$, $\alpha = \frac{\Sigma\tau}{I}$, $L = I\omega$, $\Delta L = \tau\Delta t$, $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$, $\omega = \omega_0 + \alpha t$, $\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$.
- 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 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. Relevant Equations: $L = I\omega$, $\Delta L = \tau\Delta t$, $\tau = r_{\perp} F = rF \sin\theta$.

- 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: $L = I\omega$, $\Delta L = \tau\Delta t$, $\tau = r_{\perp} F = rF \sin\theta$.
- A system is an object or a collection of objects. The objects are treated as having no internal structure.
- 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.
- An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.
- 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.

- Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects. Relevant Equation: $K = \frac{1}{2}mv^2$.
- A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy.
- 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 per unit charge. Relevant Equations: $T_P = 2\pi\sqrt{\frac{l}{g}}$, $T_S = 2\pi\sqrt{\frac{m}{k}}$, $U_s = \frac{1}{2}kx^2$, $\Delta U_g = mg\Delta y$.
- 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.
- 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. Relevant Equations: $\Delta E = W = F_{\parallel}d = Fd\cos\theta$, $P = \frac{\Delta E}{\Delta t}$.
- Kirchhoff's loop rule describes conservation of energy in electrical circuits. The potential difference across an ideal battery is also referred to as the emf of the battery, represented as ε.
  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 potential difference across the resistor and the current through the resistor. Relevant Equations: $I = \frac{\Delta V}{R}$, $P = I\Delta V$.

- 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. Relevant Equations: $I = \frac{\Delta q}{\Delta t}$, $I = \frac{\Delta V}{R}$, $P = I\Delta V$, $R_s = \Sigma R_i$, $\frac{1}{R_p} = \Sigma \frac{1}{R_i}$.
- 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. Relevant Equations: $\vec{p} = m\vec{v}$, $K = \frac{1}{2}mv^2$.

- 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. Relevant Equations: $\vec{p} = m\vec{v}$, $K = \frac{1}{2}mv^2$.
- The velocity of the center of mass of the system cannot be changed by an interaction within the system.
  a. The center of mass of a system depends on the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.
  b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system.
  c. Where there is both a heavier and lighter mass, the center of mass is closer to the heavier mass.
- If the net external torque exerted on the system is zero, the angular momentum of the system does not change. Relevant Equations: $L = I\omega$, $\Delta L = \tau\Delta t$, $\tau = r_{\perp}F = rF\sin\theta$.
- 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: $I = mr^2$.
- 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 traveling disturbance consists of pressure variations coupled to displacement variations.
d. This applies to both periodic waves and to wave pulses.

- 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.
- 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.
- Classically, the energy carried by a wave depends on and 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.
- 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. Relevant Equation: $T = \frac{1}{f}$.
- For a periodic wave, the wavelength is the repeat distance of the wave.
- For a periodic wave, wavelength is the ratio of speed over frequency. Relevant Equation: $\lambda = vf$.
- The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only.
- 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.
- Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave.
- 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.

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.

- 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 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. Relevant Equations: $\lambda = vf$, $T = \frac{1}{f}$.
- 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 changes are called beats. Examples include the tuning of an instrument.
  b. The beat frequency is the difference in frequency between the two waves.

Students will be able to . . .

- create representations and models of natural or man-made phenomena and systems in the domain. (S.P. 1.1)
- describe representations and models of natural or man-made phenomena and systems in the domain. (S.P. 1.2)
- refine representations and models of natural or man-made phenomena and systems in the domain. (S.P. 1.3)
- use representations and models to analyze situations or solve problems qualitatively and quantitatively. (S.P. 1.4)
- re-express key elements of natural phenomena across multiple representations in the domain. (S.P. 1.5)
- justify the selection of a mathematical routine to solve problems. (S.P. 2.1)
- apply mathematical routines to quantities that describe natural phenomena. (S.P. 2.2)
- estimate numerically quantities that describe natural phenomena. (S.P. 2.3)
- pose scientific questions. (S.P. 3.1)
- refine scientific questions. (S.P. 3.2)

- evaluate scientific questions. (S.P. 3.3)
- justify the selection of the kind of data needed to answer a particular scientific question. (S.P. 4.1)
- design a plan for collecting data to answer a particular scientific question. (S.P. 4.2)
- collect data to answer a particular scientific question. (S.P. 4.3)
- evaluate sources of data to answer a particular scientific question. (S.P. 4.4)
- analyze data to identify patterns or relationships. (S.P. 5.1)
- refine observations and measurements based on data analysis. (S.P. 5.2)
- evaluate the evidence provided by data sets in relation to a particular scientific question. (S.P. 5.3)
- justify claims with evidence. (S.P. 6.1)
- construct explanations of phenomena based on evidence produced through scientific practices. (S.P. 6.2)
- articulate the reasons that scientific explanations and theories are refined or replaced. (S.P. 6.3)
- make claims and predictions about natural phenomena based on scientific theories and models. (S.P. 6.4)
- evaluate alternative scientific explanations. (S.P. 6.5)
- connect phenomena and models across spatial and temporal scales. (S.P. 7.1)
- connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. (S.P. 7.2)

COURSE SYLLABUS

Course Name

Advanced Placement Physics 1

Level

Advanced Placement

Prerequisites

Grade of B or higher in Honors Chemistry, along with concurrent or prior enrollment in PreCalculus or higher mathematics, or Grade of A- or higher in Advanced College-Preparatory Chemistry with teacher recommendation, along with concurrent or prior enrollment in PreCalculus or higher mathematics

Materials Required

None

General Description of the Course

Advanced Placement Physics 1 is the equivalent of an introductory college physics course, without calculus, spread across a full academic year. A depth of understanding in introductory algebra-based college physics is promoted through rigorous exercise of seven science practices. Topics covered include kinematics, dynamics (Newton's Laws), circular motion, universal gravitation law, simple harmonic motion, impulse and momentum, work and energy, rotational motion and dynamics, electrostatics and charges, DC circuits, and mechanical waves. A significant physics application team project is part of the course. Superior mathematical and problem-solving skills are required. Students taking this course will be prepared to take the College Board's Advanced Placement Physics 1 Examination.

Assured Assessments

Formative Assessments:

- Labs (Units 0, 5)
- Teacher-designed assessments based on released Advanced Placement questions (Units 1, 2, 3, 4, 5, 6, 7, 9, 10)
- *TIPERs* activities (Units 1, 2, 3, 4, 5, 6, 7, 9, 10)
- Individual and group worksheets (Unit 8)

Summative Assessments:

- Labs (Units 1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination (Units 1, 2, 3, 4, 5, 6, 7, 9, 10)
- Individual written exam (Unit 8)
- Final project and presentation (Unit 11)

Core Text

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.

UNIT 0
Conceptual Overview

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

S.P. 2.2	Apply mathematical routines to quantities that describe natural phenomena.
S.P. 3.1	Pose scientific questions.
S.P. 3.2	Refine scientific questions.
S.P. 3.3	Evaluate scientific questions.
S.P. 4.1	Justify the selection of the kind of data needed to answer a particular scientific question.
S.P. 4.2	Design a plan for collecting data to answer a particular scientific question.
S.P. 4.3	Collect data to answer a particular scientific question.
S.P. 5.1	Analyze data to identify patterns or relationships.
S.P. 6.1	Justify claims with evidence.

Unit Essential Questions

- What are the aspects of a complete scientific argument?
- What information can be inferred from a graph or diagram of data?
- What constraints exist that can be used to predict the behavior of objects?

Scope and Sequence

- Physics is the study of matter and interactions.
- Physics uses the SI system of units for measured and calculated quantities.
- Relationships between quantities are often interpreted using graphs. Features of a graph (such as slope, intercepts, and bound area) often correlate to other interesting quantities.
- A clear, coherent scientific argument includes three aspects: a claim (precise answer to the prompt), evidence (specific to the scenario at hand), and reasoning (connection to overarching scientific principles).

- Objects/systems in our universe possess certain properties that allow them to interact with other objects/systems. These interactions are called forces, and can result in the interacting systems changing their behavior.
- There are three quantities in the universe that have a fixed total value: linear momentum, angular momentum, and energy. Any increase in one of these quantities in one system must be accompanied by a decrease in another system. These constraints can be used to explain or predict the motion of objects.

Assured Assessments

Formative Assessment:

- Measuring & Graphing Lab
  Students will learn proper techniques for measuring quantities, making calculations, graphing data, and analyzing graphs.

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Laboratory equipment including, but not limited to:
  - Motion detectors
  - Ticker timers
  - Constant velocity carts
  - Low-friction tracks and carts
  - Photogate trigger apparatus
  - Metersticks

Supplemental

- Online resources
  - *Flipping Physics*. https://www.flippingphysics.com/. Web.
  - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
  - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
  - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 6 class sessions (1 week)

UNIT 1
Kinematics

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 3.A.1.1 Express the motion of an object using narrative, mathematical, and graphical representations.

LO 3.A.1.2 Design an experimental investigation of the motion of an object

LO 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.

LO 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.

LO 4.A.2.1 Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time.

LO 4.A.2.3 Create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system.

Unit Essential Questions

- How can the motion of objects (or systems) be predicted and/or explained?
- Can equations be used to answer questions regardless of the questions' specificity?
- How can the idea of frames of reference allow two people to tell the truth yet have conflicting reports?
- How can we use models to help us understand motion?
- Why is the general rule for stopping your car "when you double your speed, you must give yourself four times as much distance to stop"?

Scope and Sequence

- Constant velocity model
  - Position is determined on a selected coordinate system.

- Velocity is defined as change in position divided by time interval and includes both magnitude (speed) and direction.
    - Velocity depends upon reference frame.
    - Constant velocity is not detectable without reference to another object.
    - System velocity is determined by the motion of the system mass center.
- Constant acceleration
    - Acceleration is defined as velocity change divided by time interval
    - Acceleration can occur as velocity change in magnitude (speed), direction, or both.
    - Constant acceleration scenarios are quantified through kinematic equations.
- Position, velocity and acceleration can be represented by:
    - Graphs as functions of time
    - Numerical values determined using the graphs or the kinematic equations
    - Particle models representing system mass center motion

Assured Assessments

Formative Assessment:

- <u>Activity 1</u>
  Using a plastic ruler, stopwatch, and kinematic relationships, students will determine their own reaction time. One student will hold the ruler vertically (zero end down) from the top end, the other student will hold his/her thumb and finger about 2cm apart at the zero end. The student will release the ruler unannounced and the catching student will react. By noting the catching position on the ruler, the reaction time can be calculated using free-fall kinematics.
- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- <u>Lab 0</u>
  Students will be introduced to Pasco and Vernier probes which will be available to them throughout the year for their lab investigations. Probes include, but are not limited to: Photogate, Smart Pulley, Sonic Ranger, Force Sensor, Accelerometer, and Force Sensor Platform for measuring weight. The students will then be familiarized with functionality of the dynamics cart and track set-up for kinematics experiments. Students will then be presented with instructions on how to use the Probe interface for connecting probes and taking measurements. The students will then be given time within their lab groups to use the sensors and take some anecdotal measurements for the purposes of being acquainted with the data acquiring equipment.
- <u>Lab 1: "Walk a Graph"</u>
  Students, within their lab groups, will be presented with various constant velocity graphs on paper and will be challenged to individually replicate the graphs by walking appropriately in front of the sonic ranging detector. The output graphs of the sonic ranging detector will be projected on the classroom SMARTBoard.

- Lab 2: “Where and When I”
  Students will be presented with two constant velocity carts which move at different fixed velocities. They will be challenged with accurately predicting where (place) and when (time) the cars will collide after being placed facing each other on a line approximately 3m apart. The students will be expected to take relevant measurements of each car independently and will be expected to make their claim of collision location and time based on position-time and velocity-time graphs they will construct for their dynamics cart data.
- Lab 3: “Experimentally Determining ‘g’”
  Students will be instructed to gather position time and velocity time data for a freely falling object and then will be expected to construct position time and velocity time graphs. The students will then be charged with determining “g” from the velocity time graph.
- Lab 4: “Speeder and the Policeman”
  Students will simulate the following scenario using a variable angle ramp, a marble, a constant velocity cart, and appropriate measuring devices: A speeder passes a stationary police car; at that moment the police car begins pursuit of the speeder with constant acceleration and eventually catches up to the speeder. The ramp and marble will simulate the police officer and the constant velocity car will simulate the speeder. The students will determine the velocity of the car by taking appropriate measurements. The students will then construct superimposed displacement-time and velocity-time graphs and determine how the graphs for each vehicle are different, where they intersect, and what is the final velocity of the police car.
- Lab 5: “Linearizing Data”
  Students will acquire velocity as a function of position data for a cart accelerating down an inclined track. The students will then linearize their non-linear data and determine the acceleration from the slope of the linearized graph.
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O’Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
  - Motion detectors
  - Ticker timers
  - Constant velocity carts
  - Low-friction tracks and carts
  - Photogate trigger apparatus
  - Metersticks

Supplemental

- Online resources

- *Flipping Physics*. https://www.flippingphysics.com/. Web.
- *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
- *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
- University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 16 class sessions (3 weeks)

UNIT 2
Dynamics

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 1.A.5.1	Model verbally or visually the properties of a system based on its substructure and relate this to changes in the system properties over time as external variables are changed.
LO 2.B.1.1	Apply $\vec{F}_g = m\vec{g}$ 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.
LO 3.C.4.1	Make claims about various contact forces between objects based on the microscopic cause of these forces.
LO 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.
LO 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.
LO 1.C.3.1	Design a plan for collecting data to measure gravitational mass and inertial mass and to distinguish between the two experiments.
LO 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.
LO 3.A.3.1	Analyze a scenario and make claims (supported by evidence and reasoning) about the forces exerted on an object by other objects for different types of forces or components of forces.
LO 3.A.3.2	Challenge a claim that an object can exert a force on itself.
LO 3.A.3.3	Describe a force as an interaction between two objects, and identify both objects for any force.
LO 3.A.4.1	Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action reaction pairs of forces.

LO 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.
LO 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.
LO 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.
LO 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.
LO 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.
LO 3.B.2.1	Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
LO 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.
LO 4.A.2.2	Evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified.
LO 4.A.3.1	Apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system.
LO 4.A.3.2	Use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system.

Unit Essential Questions

- How can the properties of internal and gravitational mass be experimentally verified to be the same?
- How do you decide what to believe about scientific claims?
- How does something we cannot see determine how an object behaves?
- How do objects with mass respond when placed in a gravitational field?
- Why is the acceleration due to gravity constant on Earth's surface?
- Are different kinds of forces *really* different?
- How can Newton's laws of motion be used to predict the behavior of objects?

- Why does the same push change the motion of a shopping cart more than the motion of a car?

Scope and Sequence

- Forces are interactions between objects or systems and within systems. Gravitational forces result from the interaction of objects with mass. Electromagnetic forces result from the interaction of objects with charge. On the macroscopic scale, electromagnetic forces result in "contact forces" including normal forces, friction forces, tension forces, and spring/elastic forces.
- Forces are vector quantities that have magnitude (measured in Newtons) and direction. The vector sum of all forces acting on a system is called the "net force."
- Newton's 1st Law states that if the net force acting on a system is zero, the system will maintain a constant velocity; if the net force acting on a system is non-zero, the system's velocity will change.
- Newton's 2nd Law states that the acceleration of a system is directly proportional to the net force acting on the system and inversely proportional to the system's mass (inertia). The direction of the acceleration will always be the same as the direction of the net force.
- Newton's 3rd Law states that any interaction between objects/systems results in two forces: the force exerted on the first object by the second, and the force exerted on the second object by the first. These two forces always have the same magnitude, but act in opposite directions. This results in conservation of momentum.
- Gravitational forces result from the interaction of objects with mass. This force is generally weak unless at least one of the objects has a substantial amount of mass (such as planets and stars). Near Earth's surface, the only non-negligible gravitational force is the force exerted by Earth on a system. This force is proportional to the mass of the system and the Earth's gravitational field strength, g, where g = 9.8 N/kg. [This interaction will be further explored in Unit 3.] Relevant equation: $\vec{F}_g = m\vec{g}$.
- Normal forces result from the surfaces of the interacting objects squishing each other (compressing the chemical bonds holding the objects together). The strength of this interaction is situational and depends on the other forces acting on the objects.
- Friction forces result from the surfaces of the interacting objects shearing each other; this could be the result of relative motion between the two objects or not. If there is relative motion between the two sheared surfaces, this force is described as a kinetic friction force, the strength of which depends only on the normal force between the surfaces and the "grabbiness" of the surfaces (quantified as the coefficient of kinetic friction, μ_k). If the two surfaces are stationary relative to each other, there could still be a frictional interaction described as a static friction force. The strength of the static friction force is situational (dependent on other forces acting on the objects), but does have an upper limit which is proportional to the normal force between the surfaces and the "grabbiness" of the surfaces (quantified as the coefficient of static friction, μ_s). As a general rule, the

coefficient of static friction between two surfaces is a greater value than the coefficient of kinetic friction between the same two surfaces.

- Tension forces result from the interacting objects stretching each other, and are most commonly used to describe the behavior of a rope, string, or wire. The strength of this interaction is situational and depends on the other forces acting on the objects.
- Spring/elastic forces are similar to both normal and tension forces, as they are the result of the interacting objects squishing or stretching each other. The force exerted by an ideal spring can be modeled using Hooke's Law, where the strength of the spring force is directly proportional to the spring's change in length (from its rest position) and the rigidness of the spring, quantified as the spring constant, *k*, measured in units of newtons per meter (N/m).
- Mass plays two distinct roles in our universe: mass is a measurement of an object's inertia, its resistance to acceleration; mass also determines the strength of the gravitational force between two objects. There is no known quantitative difference between these two aspects of mass.

Assured Assessments

Formative Assessment:

- <u>Activity 1: Dueling Forces</u>
  Students will explore a series of situations involving two interacting blocks, make predictions on the magnitude and direction of forces acting on each block, and predict the relative strength of the forces the blocks exert on each other. Predictions will be tested against reality using Pasco force sensors and software.
- <u>Activity 2: Broom Ball</u>
  Students will participate in a relay race obstacle course to deepen their understanding of the relationship between mass, force, and acceleration. A follow-up handout will have the students think deeply about their experiences at different points in the course and articulate the motion of the bowling ball and its interaction with the broom at those snapshots.
- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- <u>Lab 1: Empirical Force Investigation – Gravitation</u>
  Students will design an experiment to find a quantitative relationship between the mass of a system and the gravitational force exerted on that system by the Earth.
- <u>Lab 2: Empirical Force Investigation – Spring</u>
  Students will design an experiment to find a quantitative relationship between the distance a spring is stretched and the force exerted by that stretched spring.
- <u>Lab 3: Empirical Force Investigation – Friction</u>

Students will design experiments to investigate the factors that affect the strength of the frictional force between two surfaces.
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core
- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
    - Motion detectors
    - Ticker timers
    - Constant velocity carts
    - Low-friction tracks and carts
    - Photogate trigger apparatus
    - Metersticks

Supplemental
- Online resources
    - *Flipping Physics*. https://www.flippingphysics.com/. Web.
    - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
    - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
    - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 19 class sessions (4 weeks)

UNIT 3
Circular Motion and Gravitation

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

	Describe vector fields as areas in space where field values are represented by vectors indicating both direction and magnitude.
LO 3.G.1.1	Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored
LO 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.
LO 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.
LO 3.C.2.2	Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.
LO 2.B.1.1	Apply $\vec{F}_g = m\vec{g}$ 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.
LO 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 *m*.
LO 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.
LO 1.C.3.1	Design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments.
LO 4.A.2.2	Evaluate, using given data, whether all the forces on a system or whether all the parts of a system have been identified.

LO 3.B.1.2 Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements, and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.

LO 3.B.1.3 Re-express a free-body diagram representation into a mathematical representation, and solve the mathematical representation for the acceleration of the object.

LO 3.B.2.1 Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.

LO 3.A.1.1 Express the motion of an object using narrative, mathematical, and graphical representations.

LO 3.A.1.2 Design an experimental investigation of the motion of an object.

LO 3.A.1.3 Analyze experimental data describing the motion of an object and express the results of the analysis using narrative, mathematical, and graphical representations.

LO 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.

LO 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.

LO 3.A.3.3 Describe a force as an interaction between two objects and identify both objects for any force.

LO 3.A.4.1 Construct explanations of physical situations involving the interaction of bodies using Newton’s third law and the representation of action-reaction pairs of forces.

LO 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.

LO 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.

Unit Essential Questions

- How does changing the mass of an object affect the gravitational force?
- Why is a refrigerator hard to push in space?
- Why do we feel pulled toward Earth but not toward a pencil?
- How can the acceleration due to gravity be modified?

- How can Newton's laws of motion be used to predict the behavior of objects?
- How can we use forces to predict the behavior of objects and keep us safe?
- How is the acceleration of the center of mass of a system related to the net force exerted on the system?
- Why is it more difficult to stop a fully loaded dump truck than a small passenger car?

Scope and Sequence

- A net force exerted on a system causes the system to accelerate. This could result in the system speeding up (if the net force is directed parallel to the system's direction of motion), slowing down (if the net force is directed antiparallel to the system's direction of motion), and/or changing direction (if the net force has a component perpendicular to the system's direction of motion).
- The motion of an object along a circular path at constant speed is called uniform circular motion, and is the result of a net force directed towards the center (centripetal) of the motion. This net force causes a centripetal acceleration that is related to the speed (*v*) and radius of the path (*r*) by: $a_c = v^2/r$.
- The gravitational force is a fundamental attractive interaction between any objects with mass. The strength of this force is directly proportional to the mass of both interacting objects and inversely proportional to the square of the distance between them. (For objects of non-negligible volume, this distance is measured from center-of-mass to center-of-mass.)
- The gravitational field strength at a point in three-dimensional space represents the force per unit of mass (newtons per kilogram) a system would experience at that location. If this location is near the surface of a massive object (such as a moon, planet, or star), this strength is directly proportional to the mass of the massive object, and inversely proportional to the square of the distance measured from the object's center-of-mass to the location.

Assured Assessments

Formative Assessment:

- <u>Activity 1: Driving in Circles</u>
  Students will be presented with a constant velocity cart tethered to a ring stand with a rope. When switched on, the cart drives in a circle around the ring stand. Students will use this apparatus to answer a series of questions, including determining the speed of the cart and deciding whether the cart is accelerating. This activity is designed as a bridge between Units 2 and 3.
- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- Lab Practicum
  Students will use their understanding of the physics of circular motion to determine the mass of a rubber stopper.
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
  - Motion detectors
  - Ticker timers
  - Constant velocity carts
  - Low-friction tracks and carts
  - Photogate trigger apparatus
  - Metersticks

Supplemental

- Online resources
  - *Flipping Physics*. https://www.flippingphysics.com/. Web.
  - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
  - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
  - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 9 class sessions (2 weeks)

UNIT 4
Energy

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 4.C.2.1 Make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass.

LO 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.

LO 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.

LO 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.

LO 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, 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.

LO 5.B.3.1 Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.

LO 5.B.3.2 Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.

LO 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.

LO 5.B.4.1 Describe and make predictions about the internal energy of systems.

LO 5.B.4.2 Calculate changes in kinetic energy and potential energy of a system using information from representations of that system.

LO 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.

LO 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.

LO 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.

LO 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).

LO 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 Essential Questions

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

Scope and Sequence

- Energy is a fundamental quantity of nature that exists in a variety of types, including (but not limited to) kinetic energy, gravitational potential energy, spring potential energy, electrical potential energy, and thermal energy. The SI unit for all energy types is the joule (J).
- Energy can be transferred between objects/systems or transformed between types or both. Any of these events are mitigated by forces exerted through a displacement of the object/system.
- Energy is a conserved quantity. Any event that causes one system to gain energy must also result in another system losing an equal amount of energy. Similarly, any event that causes one type of energy to increase must cause an equivalent decrease in other energy types.
- Kinetic energy is energy associated with an object's motion and is quantified as $K = \frac{1}{2}mv^2$, where *m* is the object's mass and *v* is the object's speed.
- Gravitational potential energy is energy associated with an object's location in another's gravitational field. In a uniform field of strength *g*, gravitational potential energy is quantified as $U_g = mgh$, where *m* is the mass of the object in the field and *h* is its vertical position measured from an arbitrary reference height. In a non-uniform gravitational field, gravitational potential energy is quantified as $U_G = -G\frac{m_1 m_2}{r}$, where m_1 is the mass of the object in the field, m_2 is the mass of the object creating the field, *r* is the distance between the two objects, and *G* is the universal gravitational constant.
- Spring potential energy is energy associated with a stretched or compressed spring and is quantified as $U_s = \frac{1}{2}kx^2$, where *k* is the spring constant of the spring and *x* is the distance it has been stretched or compressed from its rest length.
- The transfer/transformation of energy is known as work. Work is done by a force exerted through space, contributing to the displacement of an object. The work done by a force

(and therefore the amount of energy that has been transferred/transformed) can be quantified as $W = Fdcos\theta$, where *F* is the magnitude of the force exerted on the object, *d* is the magnitude of the displacement of the object, and θ is the angle between the force vector and displacement vector. Work can also be quantified as the area under a Force vs. Position graph. Like energy, work is measured in joules.

- The rate at which work is done is known as power. The SI unit for power is the watt (W) which is equivalent to a joule per second (J/s).

Assured Assessments

Formative Assessment:

- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- Lab: Human Power Activity
  Students will calculate the power their legs can develop as they walk up a flight of stairs.
- Lab: Collide & Slide Practicum
  A track is set up with a long horizontal section and a short incline at one end. A cart will start from rest at the top of the incline, travel down to the horizontal section, and then collide and stick to another cart that is placed upside-down on the track. Friction between the track and the upside-down cart cause the system to slide to a stop. Students will need to determine where the upside-down cart should be initially placed such that the system stops as close as possible to a predetermined point.
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
  - Motion detectors
  - Ticker timers
  - Constant velocity carts
  - Low-friction tracks and carts
  - Photogate trigger apparatus
  - Metersticks

Supplemental

- Online resources

- *Flipping Physics*. https://www.flippingphysics.com/. Web.
- *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
- *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
- University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 19 class sessions (4 weeks)

UNIT 5
Momentum

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 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.
LO 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.
LO 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.
LO 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.
LO 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.
LO 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.).
LO 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.
LO 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.
LO 4.B.2.2	Perform an analysis on data presented as a force-time graph and predict the change in momentum of a system.
LO 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.
LO 5.D.1.1	Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 5.D.2.4 Analyze data that verify conservation of momentum in collisions with and without an external frictional force.

LO 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.

LO 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.

Unit Essential Questions

- How does pushing an object change its momentum?

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

Scope and Sequence

- Linear momentum is defined as the product of a system's mass and its velocity. Linear momentum is a vector quantity, having the same direction as the velocity vector.
- Momentum is transferred to or from an object/system via forces (interactions with other objects/systems).
- Momentum is a conserved quantity, meaning the total amount of momentum in the universe is fixed.
- A system is defined as "closed" if the total momentum is constant (no momentum is exchanged with the environment). A system is defined as "open" if it gains momentum from or loses momentum to the environment.
- The area under a force vs. time graph is called an impulse. The impulse caused by a net force acting on an object/system is equal to change in momentum of the object/system.

Assured Assessments

Formative Assessment:

- <u>Lab Investigation 1: Sticky Collisions</u>
  A low-friction cart is pushed along a track such that it collides and sticks to another low-friction cart (initially at rest). Students will find a relationship between pre- and post-collision speeds and relate that to the masses of the carts.
- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- <u>Collision Lab Practicum</u>
  A low-friction cart sits at rest on a track, an object of unknown mass resting on top. A second low-friction cart is given a push such that it collides and sticks to the first. Students will use their understanding of conservation of momentum to determine the mass of the unknown.
- <u>Explosion Lab Practicum</u>
  Two low-friction carts sit together at rest on a horizontal track. An object of unknown mass rests on top of one of them. The plunger mechanism of one of the carts is activated, causing the carts to push off each other traveling in opposite directions along the track.

With a limited equipment list, students will use their understanding of conservation of momentum to determine the mass of the unknown.

- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

<u>Core</u>

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
    - Motion detectors
    - Ticker timers
    - Constant velocity carts
    - Low-friction tracks and carts
    - Photogate trigger apparatus
    - Metersticks

<u>Supplemental</u>

- Online resources
    - *Flipping Physics*. https://www.flippingphysics.com/. Web.
    - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
    - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
    - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 13 class sessions (3 weeks)

UNIT 6
Simple Harmonic Motion

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 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.
LO 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.
LO 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.
LO 3.B.3.4	Construct a qualitative and/ or quantitative explanation of oscillatory behavior given evidence of a restoring force.
LO 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, 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.
LO 5.B.3.1	Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.
LO 5.B.3.2	Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.
LO 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.
LO 5.B.4.1	Describe and make predictions about the internal energy of systems.
LO 5.B.4.2	Calculate changes in kinetic energy and potential energy of a system using information from representations of that system.

Unit Essential Questions

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

Scope and Sequence

- A pendulum consists of a mass suspended from a rope that swings back and forth about an equilibrium position. The period of this cyclical motion is related to the length of the pendulum and the local gravitational field strength by the equation: $T_P = 2\pi\sqrt{\frac{l}{g}}$. The behavior of the pendulum is due to a net restoring force directed towards the equilibrium position.
- A mass attached to a vertical or horizontal spring can also undergo cyclical motion about an equilibrium position. The period of this cyclical motion is related to the inertia of the mass and the spring constant of the spring by the equation: $T_S = 2\pi\sqrt{\frac{m}{k}}$. The behavior of the mass is due to a net restoring force directed towards the equilibrium position.
- From an energy perspective, the motions of both the pendulum and mass on a spring are predicated on the transformation of kinetic energy to potential energy and back again.

Assured Assessments

Formative Assessment:

- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- <u>Lab 1: Pendulum</u>
  Students will investigate multiple variables that may affect the period of a pendulum. Students will attempt to form a mathematical model between the most significant variable and its effect on the period, and then use that model to predict the period of a pendulum designed by the teacher.
- <u>Lab 2: Mass on a Spring</u>
  Students will find a relationship between the amount of mass and the period of oscillation. Students will find a relationship between the spring constant and the period of oscillation.

- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
  - Motion detectors
  - Ticker timers
  - Constant velocity carts
  - Low-friction tracks and carts
  - Photogate trigger apparatus
  - Metersticks
  - Springs
  - Mass sets

Supplemental

- Online resources
  - *Flipping Physics*. Web.
  - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
  - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
  - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 9 class sessions (2 weeks)

UNIT 7
Torque and Rotational Motion

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 3.A.1.1	Express the motion of an object using narrative, mathematical, and graphical representations.
LO 3.F.1.1	Use representations of the relationship between force and torque.
LO 3.F.1.3	Estimate the torque on an object caused by various forces in comparison with other situations.
LO 3.F.1.4	Design an experiment and analyze data testing a question about torques in a balanced rigid system.
LO 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).
LO 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.
LO 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.
LO 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.
LO 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.
LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

Unit Essential Questions

- How does a system in rotational equilibrium compare to a system in translational equilibrium?
- How does the choice of system and rotation point affect the forces that can cause a torque on an object or a system?
- How can balanced forces cause rotation?

- Why does it matter where the door handle is placed?
- Why are long wrenches more effective?
- How can an external net torque change the angular momentum of a system?
- Why is a rotating bicycle wheel more stable than a stationary one?
- How does the conservation of angular momentum govern interactions between objects and systems?
- Why do planets move faster when they travel closer to the sun?

Scope and Sequence

- A system's rotational motion can be described using similar terms to those that describe linear motion such as angular position (θ), angular displacement ($\Delta\theta$), angular velocity (ω), and angular acceleration (α). These quantities relate to each other mathematically through angular versions of the equations of motion.
- The linear and angular motions of a point on a rotating system are related by the following relationships: $s = \theta r$, $v = \omega r$, and $a = \alpha r$, where r is the distance between the point on the rotating system and the system's axis of rotation.
- Changes in the angular velocity of a system are caused by torques. A torque is caused by a force that is exerted at a point and in a direction that results in a twist. Torque is a vector quantity, the direction of which is described as "clockwise" or "counterclockwise" based on the way the system would rotate about its axis of rotation.
- Newton's 2nd Law can be written in terms of torque and angular acceleration as: $\vec{\alpha} = \frac{\Sigma\vec{\tau}}{I}$, where I is the rotational inertia of the system.
- Rotational inertia refers to the tendency of a system to resist changes in angular motion. The rotational inertia of a single particle is equal to mr^2, where m is the particle's mass and r is the distance between the particle and the axis of rotation. The rotational inertia of systems consisting of many particles can be determined by summing the rotational inertia of each particle (Σmr^2).
- A rotating system has angular momentum, equal to the product of its rotational inertia and angular velocity. A change in a system's angular momentum is caused by a net torque exerted through a time interval. In a closed system, angular momentum is conserved.
- A rotating system has rotational kinetic energy, equal to $\frac{1}{2}I\omega^2$. As with other forms of mechanical energy, it can be transformed into other forms of energy within the system or transferred to/from the system through the process of work.

Assured Assessments

Formative Assessment:

- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- Lab 1: Balancing Metersticks
  A meterstick will be suspended from its midpoint so that it is free to rotate. Students will attach different amounts of mass to either side of the meterstick, and will discover a pattern for how to keep the meterstick level.
- Lab 2: Newton's 2nd Law for Rotation
  Students will use a spring scale and string to exert a constant torque on a disk mounted to a low-friction axle. Students will find a relationship between the torque exerted on the disk and the disk's angular acceleration.
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
  - Motion detectors
  - Ticker timers
  - Constant velocity carts
  - Low-friction tracks and carts
  - Photogate trigger apparatus
  - Metersticks

Supplemental

- Online resources
  - *Flipping Physics*. Web.
  - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
  - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
  - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 15 class sessions (3 weeks)

UNIT 8
Electric Charge and Electric Force

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 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.
LO 1.B.1.1	Make claims about natural phenomena based on conservation of electric charge.
LO 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.
LO 1.B.2.1	Construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices.
LO 1.B.3.1	Challenge the claim that an electric charge smaller than the elementary charge has been isolated.
LO 3.C.2.1	Use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges.
LO 3.C.2.2	Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.

Unit Essential Questions

- How does electric charge change the way that something interacts with its surroundings?
- How do you decide what to believe about scientific claims?
- How does something we cannot see determine how an object behaves?
- How do charges exert forces on each other?
- How does the conservation of charge help us understand how charged objects behave?
- Why can you stick a balloon on the ceiling, if rubber is an insulator?

Scope and Sequence

- Charges can be positive or negative.
- An object or system's net charge depends upon the relative number of protons and electrons.

- The electron's negative charge, equal in magnitude to a proton's positive charge, is the smallest quantity of charge that is transferable.
- Objects are charged by the transfer of electrons by rubbing, conduction and induction.
- Charged objects exerts forces upon other charged objects. Oppositely charged objects are attracted while like charged objects are repelled. The magnitude of this electrostatic force is proportional to each charge and inversely proportional to the square of the separation distance.
- Forces of multiple charges on a charged object are added as vector quantities.

Assured Assessments

Formative Assessment:

- <u>Activity 1: Van de Graaff Generator Whole-Class Demonstration and Activity</u>
  Students, with the teacher's guidance, will explore electrostatics on a larger scale with the Van de Graaff generator.
- Individual and group worksheets, with student self-assessment using posted answer keys; students will demonstrate understanding of charge quantization and interactions by obtaining the correct narrative, numerical, and graphical responses

Summative Assessment:

- <u>Lab 1: Millikan Oil-Drop Simulation</u>
  Students will be given 24 boxes containing various amount of ¼ 20 nuts. Each box has a different number of nuts and there are no boxes with just one nut. Students will be provided balances to determine the mass of each box and then will be charged with determining the mass of one nut.
- <u>Lab 2: What's the Charge?</u>
  Students will use lengths of Scotch tape changed by friction to discover there are two "types" of charge. Two pieces charged the same way by being rubbed with a finger will repel each other. Two pieces will then be placed on top of one another, then rubbed with a finger, and finally, the topmost piece slid across a faucet to provide a path to ground. When the pieces are separated, the two pieces will repel. Students will then be introduced to the electroscope and how it is used to detect the presence and type of charge. Following this, students will be presented with various materials that can be rubbed together in order to be charged electrostatically; students will be encouraged to use the electroscope to determine the type of charge acquired on the material after rubbing. Variations of this lab using balloons or other easily charged insulators may be used.
- <u>Lab 3: How Do You Get So Charged?</u>
  Students will construct an electroscope with a Styrofoam cup, flexible straw, string and a small segment of foil-coated straw. They will then attach this cup-electroscope to the center of an aluminum pie plate with the foil-coated straw segment hanging to the side of the pie plate. The students will then be provided with a piece of Styrofoam and some wool, as well as acetate and paper to serve as a standard for positive charge. These items will provide the basis for exploring: ground, charge by friction, charge by contact, polarization, induction, net charge, and state of neutral charge. Variations of this lab may include different insulators to be charged and a standard lab electroscope.

- In an individual written exam, students will demonstrate understanding of charge quantization and interactions by obtaining the correct narrative, numerical, and graphical responses

Resources

Core

- Set of various samples that can be rubbed together to separate charge
- Van de Graaff generator
- Millikan oil-drop simulation set (boxes filled with various nut counts)

Supplemental

- Online resources
    - *Flipping Physics*. Web.
    - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
    - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
    - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 6 class sessions (1 week)

UNIT 9
DC Circuits

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 1.B.1.1 Make claims about natural phenomena based on conservation of electric charge.

LO 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.

LO 1.E.2.1 Choose and justify the selection of data needed to determine resistivity for a given material.

LO 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).

LO 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.

LO 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.

LO 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.

LO 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.

Unit Essential Questions

- How do you decide what to believe about scientific claims?
- How does something we cannot see determine how an object behaves?
- How do the laws of conservation of charge and energy allow us to light our homes and businesses?

- How does the conservation of charge govern interactions between objects and systems?
- How does the law of conservation of energy govern the interactions between objects and systems?

Scope and Sequence

- An electric circuit consists of a source of electric potential difference and a continuous conductive pathway from the high potential (positive) to low potential (negative) points.
- An electric potential difference (ΔV) is due to separate of electric charge. This separation can be created chemically by a battery or mechanically by a generator (either is considered the source of the potential difference). Electric potential difference is measured in volts (V), which are equivalent to joules per coulomb (energy per charge).
- The flow of charge in a circuit is quantified as current and measured in amperes (A), which are equivalent to coulombs per second.
- Resistance is a quantification of the opposition to the flow of charge through a particular conductive path. Resistance is measured in ohms (Ω). The amount of resistance a particular conductor has depends on the type of material the conductor is made of (quantified as resistivity, ρ, measured in ohm-meters), the length of the conductor, and its cross-sectional area: $R = \rho \frac{L}{A}$.
- Ohm's Law predicts the relationship between the current flowing through a circuit, the electric potential difference causing the current, and the resistance of the circuit: $I = \Delta V / R$.
- A series circuit consists of a single pathway from high potential to low potential that includes multiple resistive elements. The current is the same at all points through the circuit, and the potential drops across the resistive elements sum to the potential rise created by the source.
- A parallel circuit consists of multiple pathways from high potential to low potential that each include a resistive element. The potential drop is the same in each branch (and each equal to the potential rise created by the source), and the currents in the branches sum to the current through the source.
- More complicated circuits can be constructed with aspects of both series and parallel circuits. The rules governing series and parallel circuits can be used to analyze applicable portions of these types of circuits.

Assured Assessments

Formative Assessment:

- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- Labs: Ohm Ohm on the Range 1, 2, and 3
  Students will learn now to use ammeters and voltmeters to make measurements of an electric circuit and will find patterns in those measurements.
- Lab: Ohm's Law Lab
  Students will find a relationship between the potential difference across a lightbulb and the current flow through the lightbulb. They will repeat the investigation with a resistor and compare the results of the two trends.
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
  - Ammeters
  - Voltmeters
  - D cell batteries
  - Light

Supplemental

- Online resources
  - *Flipping Physics*. Web.
  - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
  - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
  - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 15 class sessions (3 weeks)

UNIT 10
Mechanical Waves and Sound

Unit Goals

Learning Objectives (LOs) derive from the 2019 College Board *AP Physics 1 Course and Exam Description*.

At the completion of this unit, students will:

LO 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.
LO 6.A.1.2	Describe representations of transverse and longitudinal waves.
LO 6.A.2.1	Describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples.
LO 6.A.3.1	Use graphical representation of a periodic mechanical wave to determine the amplitude of the wave.
LO 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.
LO 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.
LO 6.B.2.1	Use a visual representation of a periodic mechanical wave to determine the wavelength of the wave.
LO 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.
LO 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.
LO 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.
LO 6.D.1.2	Design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves).

LO 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.

LO 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.

LO 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.

LO 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.

LO 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.

LO 6.D.3.4 Describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region.

LO 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.

LO 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.

LO 6.D.5.1 Use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats.

Unit Essential Questions

- How can data be used to help us create models of phenomena we see around us?
- Why does a police siren sound different when it is moving toward you than when it is moving away from you?
- What happens when two waves meet?
- How is resonance responsible for the Tacoma Narrows Bridge collapse?
- How is sound produced?

Scope and Sequence

- Waves are a set of phenomena that transmit energy (and momentum) without the net movement of matter. Wave phenomena include sound and light.
- Most wave phenomena (with the exception of light) require matter to transmit the energy and momentum. The matter a wave travels through is called the medium. The properties of the medium determine how fast the waves travel (wave speed). For example, the speed at which sound waves travel through air is primarily dependent on the temperature of the air.
- A single traveling disturbance is called a wave pulse. A series of consistent wave pulses is called a period wave. Period waves can be described with quantities such as wavelength, period, and frequency.
- The wavelength, wave speed, and frequency of any period wave can be related mathematically by the wave equation: $\lambda = \frac{v}{f}$.
- Waves in which the medium particles oscillate perpendicularly to the direction of the wave motion are called transverse waves. Examples of transverse waves are seismic s-waves and "the wave" at a sporting event. Waves in which the medium particles oscillate parallel/antiparallel to the direction of the wave motion are called longitudinal waves. Examples of longitudinal waves are seismic p-waves and sound waves.
- The amplitude of a wave is a measurement of the maximum displacement from equilibrium for a particle in the medium. The amplitude is related to the amount of energy "carried" by the wave. When multiple wave pulses reach the same point in a medium, their amplitudes add together through a phenomenon called interference. This can result in larger amplitudes (constructive interference) or smaller amplitudes (destructive interference), depending on the orientation of the overlapping waves.
- In a medium of finite length, interference can result in standing waves where the medium appears to oscillate in place as waves travel back and forth. Examples explored include standing waves on strings, standing sound waves in closed pipes, and standing sound waves in open pipes.

Assured Assessments

Formative Assessment:

- Teacher-designed assessments based on released Advanced Placement questions (both multiple-choice and free-response)
- *TIPERs* activities (rankings, graph analysis, evaluating student responses, etc.)

Summative Assessment:

- Lab 1: Super Slinky Investigation
  Students will be provided with a set of questions regarding wave phenomena that they are to answer. Students will come up with their own procedure for each question, collect

qualitative/quantitative data using their procedure, and then interpret the results to come up with an answer for each question. Student groups will debate their results with each other, resulting in a consensus or the need for further investigation.

- Lab 2: Standing Waves on a String Investigation
  Students will make use of standing waves to find a relationship between the wave speed and the tension force.
- Lab Practicum: Measuring the Speed of Sound
  Students will use their understanding of standing waves in a closed pipe to calculate the speed of sound.
- Assessment consisting of multiple-choice and free-response questions similar to the format of the College Board Advanced Placement Physics 1 Examination

Resources

Core

- Cutnell, John D., and Kenneth W. Johnson. Goldsby. *Physics*. 7th ed. Hoboken, NJ: Wiley, 2006. Print.
- Hieggelke, C.J., Steve Kanim, D.P. Maloney, and T.L. O'Kuma. *TIPERs: Sensemaking Tasks for Introductory Physics*. New York: Pearson, 2013. Print.
- Laboratory equipment including, but not limited to:
  - Motion detectors
  - Ticker timers
  - Constant velocity carts
  - Low-friction tracks and carts
  - Photogate trigger apparatus
  - Metersticks
  - Super Slinkys

Supplemental

- Online resources
  - *Flipping Physics*. Web.
  - *Khan Academy*. https://www.youtube.com/user/khanacademy. Web.
  - *The Physics Classroom*. https://www.physicsclassroom.com/. Web.
  - University of Colorado Boulder. *PhET Interactive Simulations*. https://phet.colorado.edu/en/simulations/category/new. Web.

Time Allotment

- Approximately 15 class sessions (3 weeks)

UNIT 11
Independent Learning (Post-AP Exam)

After students take the AP Physics 1 Examination, the remainder of the year is focused on the completion of a project to demonstrate a deeper understanding of selected topics from the course. Projects may include, but are not limited to: (1) creation of a mural presenting an important idea in physics; (2) evaluation of the physics of the special effects in a film; (3) creation of a new lab to demonstrate a physics principle. Projects will include presentation to the rest of the class.

Time Allotment

- Approximately 10 class sessions (2 weeks)

COURSE CREDIT

1.25 credits in science
One class period daily, plus laboratory, for a full year

PREREQUISITES

Grade of B or higher in Honors Biology with teacher recommendation, along with concurrent or prior enrollment in Honors PreCalculus or higher mathematics, or Completion of Advanced College-Preparatory Chemistry or Honors Chemistry with teacher recommendation and Department Chair permission, along with concurrent or prior enrollment in Honors PreCalculus or higher mathematics.

CURRENT REFERENCE

AP Central. "AP Physics 1." https://apcentral.collegeboard.org/courses/ap-physics-1. Web.

ASSURED STUDENT PERFORMANCE RUBRICS

- Trumbull High School School-Wide Writing Rubric (attached)
- Trumbull High School School-Wide Problem-Solving Rubric (attached)
- Trumbull High School School-Wide Independent Learning and Thinking Rubric (attached)

Trumbull High School School-Wide Writing Rubric

Category/ Weight	Exemplary 4 Student work:	Goal 3 Student work:	Working Toward Goal 2 Student work:	Needs Support 1-0 Student work:
Purpose X_______	• Establishes and maintains a clear purpose • Demonstrates an insightful understanding of audience and task	• Establishes and maintains a purpose • Demonstrates an accurate awareness of audience and task	• Establishes a purpose • Demonstrates an awareness of audience and task	• Does not establish a clear purpose • Demonstrates limited/no awareness of audience and task
Organization X_______	• Reflects sophisticated organization throughout • Demonstrates logical progression of ideas • Maintains a clear focus • Utilizes effective transitions	• Reflects organization throughout • Demonstrates logical progression of ideas • Maintains a focus • Utilizes transitions	• Reflects some organization throughout • Demonstrates logical progression of ideas at times • Maintains a vague focus • May utilize some ineffective transitions	• Reflects little/no organization • Lacks logical progression of ideas • Maintains little/no focus • Utilizes ineffective or no transitions
Content X_______	• Is accurate, explicit, and vivid • Exhibits ideas that are highly developed and enhanced by specific details and examples	• Is accurate and relevant • Exhibits ideas that are developed and supported by details and examples	• May contain some inaccuracies • Exhibits ideas that are partially supported by details and examples	• Is inaccurate and unclear • Exhibits limited/no ideas supported by specific details and examples
Use of Language X_______	• Demonstrates excellent use of language • Demonstrates a highly effective use of standard writing that enhances communication • Contains few or no errors. Errors do not detract from meaning	• Demonstrates competent use of language • Demonstrates effective use of standard writing conventions • Contains few errors Most errors do not detract from meaning	• Demonstrates use of language • Demonstrates use of standard writing conventions • Contains errors that detract from meaning	• Demonstrates limited competency in use of language • Demonstrates limited use of standard writing conventions • Contains errors that make it difficult to determine meaning

Trumbull High School School-Wide Problem-Solving Rubric

Category/ Weight	Exemplary 4	Goal 3	Working Toward Goal 2	Needs Support 1-0
Understanding X_______	• Student demonstrates clear understanding of the problem and the complexities of the task	• Student demonstrates sufficient understanding of the problem and most of the complexities of the task	• Student demonstrates some understanding of the problem but requires assistance to complete the task	• Student demonstrates limited or no understanding of the fundamental problem after assistance with the task
Research X_______	• Student gathers compelling information from multiple sources including digital, print, and interpersonal	• Student gathers sufficient information from multiple sources including digital, print, and interpersonal	• Student gathers some information from few sources including digital, print, and interpersonal	• Student gathers limited or no information
Reasoning and Strategies X_______	• Student demonstrates strong critical thinking skills to develop a comprehensive plan integrating multiple strategies	• Student demonstrates sufficient critical thinking skills to develop a cohesive plan integrating strategies	• Student demonstrates some critical thinking skills to develop a plan integrating some strategies	• Student demonstrates limited or no critical thinking skills and no plan
Final Product and/or Presentation X_______	• Solution shows deep understanding of the problem and its components • Solution shows extensive use of 21st-century technology skills	• Solution shows sufficient understanding of the problem and its components • Solution shows sufficient use of 21st-century technology skills	• Solution shows some understanding of the problem and its components • Solution shows some use of 21st-century technology skills	• Solution shows limited or no understanding of the problem and its components • Solution shows limited or no use of 21st-century technology skills

Trumbull High School School-Wide
Independent Learning and Thinking Rubric

Category/ Weight	Exemplary 4	Goal 3	Working Toward Goal 2	Needs Support 1-0
Proposal X_______	• Student demonstrates a strong sense of initiative by generating compelling questions, creating uniquely original projects/work	• Student demonstrates initiative by generating appropriate questions, creating original projects/work	• Student demonstrates some initiative by generating questions, creating appropriate projects/work	• Student demonstrates limited or no initiative by generating few questions and creating projects/work
Independent Research & Development X_______	• Student is analytical, insightful, and works independently to reach a solution	• Student is analytical, and works productively to reach a solution	• Student reaches a solution with direction	• Student is unable to reach a solution without consistent assistance
Presentation of Final Product X_______	• Presentation shows compelling evidence of an independent learner and thinker • Solution shows deep understanding of the problem and its components • Solution shows extensive and appropriate application of 21st-century skills	• Presentation shows clear evidence of an independent learner and thinker • Solution shows adequate understanding of the problem and its components • Solution shows adequate application of 21st-century skills	• Presentation shows some evidence of an independent learner and thinker • Solution shows some understanding of the problem and its components • Solution shows some application of 21st-century skills	• Presentation shows limited or no evidence of an independent learner and thinker • Solution shows limited or no understanding of the problem and its components • Solution shows limited or no application of 21st-century skills