Fairfield Public Schools
Science Curriculum

AP Physics 1

AP Physics 1: Description

Physics is the study of natural phenomena and interactions between matter and energy using mathematical models and laws to explain and understand them and how they impact our everyday lives. The AP Physics 1 course focuses on the big ideas typically included in the first semester (and parts of a second semester) of an algebra-based, introductory college-level physics sequence and provides students with enduring understandings to support future advanced course work in the sciences. Through inquiry-based learning, students will develop critical thinking and reasoning skills, as defined by the AP Science Practices.

Standards for this course are taken from the _College Board Advanced Placement Physics 1course description_ and are of three types:
Science Practices: The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena.

Big Ideas: The key concepts and related content that define the revised AP Biology course and exam are organized around a few underlying principles called the big ideas, which encompass the core scientific principles, theories and processes governing living organisms and biological systems.

Learning Objectives: Learning objectives provide clear and detailed articulation of what students should know and be able to do. Each learning objective is designed to help teachers integrate science practices with specific content, and to provide them with clear information about how students will be expected to demonstrate their knowledge and abilities.

AP Physics 1: Overview

Enduring Understandings

- 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.
- Materials have many microscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
- Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles
- 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 $a = \Sigma F /m$
- 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 cause a torque on that object.
- A force exerted on an object can change the kinetic energy of the object.
- A force exerted on an object can change the momentum of an object.
- Certain types of forces are considered fundamental.
- Enduring Understanding 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where $a = \Sigma F /m$.
- Interactions with other objects can change the total linear momentum of the system.
- Interactions with other objects or systems can change the total energy of the system.
- A net torque exerted on a system by other objects or systems will change the angular momentum of the system.
- Enduring Understanding 5.A: Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
- The energy of a system is conserved.
- The linear momentum of a system is conserved.
- The angular momentum of a system is conserved.
- The electric charge 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 mass and charge? What internal structures do systems have?   - How can fields existing in space be used to explain interactions?   - What are forces? How can they describe the interactions between or among objects?   - How do interactions between systems change those systems?   - How are changes that occur as a result of interactions explained by conservation laws? What are the constraints of those changes?   - What are waves? How do they transfer energy and momentum from one location to another without the permanent transfer of mass? How can waves serve as a mathematical model for the description of other phenomena?

AP Physics 1: Year-at-a Glance

Unit	Title	Unit Essential Questions
1	Forces & Interactions	- What is the nature of vectors and how do they differ from scalar quantities? - How can we use mathematical representation of forces to describe and predict interactions between objects? - How are displacement, velocity and acceleration related? - How does the Law of Universal Gravitation govern the interaction of objects in the universe?
2	Momentum & Energy	- How can we use models to illustrate that energy can be accounted for as a combination of energy associated with the motion of particles and the energy associated with the relative position of particles? - How can we model the change in energy of one component of the system when the change in energy of the other component(s) and of the system are known? - How can we use energy to predict the motion or displacement of objects? - How are impulse and momentum related?
3	Circular Motion & Rotation	- How does circular motion differ from linear motion? - How can we use rotational dynamics to predict rotational motion? - How does exerting a torque affect an object's motion? - How are angular acceleration, angular momentum and torque related?
4	Harmonic Motion & Waves	What properties affect the motion of an object in SHM?

			● How can SHM be modeled as a wave? ● How do waves interact with each other? ● How are the principles of wave behavior and interactions with matter used to transmit and capture information and energy?
5		Electricity	● What are the elementary particles and how do they get their charge? ● How is electric charge transferred and conserved? ● How does electric charge form a current, and what affects that current? ● What is a potential difference, and what effect does it have on charged particles?

AP Science Practices

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
1.1 The student can create representations and models of natural or manmade phenomena and systems in the domain.
1.2 The student can describe representations and models of natural or manmade phenomena and systems in the domain.
1.3 The student can refine representations and models of natural or manmade phenomena and systems in the domain.
1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.
Science Practice 2: The student can use mathematics appropriately
2.1 The student can justify the selection of a mathematical routine to solve problems.
2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
2.3 The student can estimate numerically quantities that describe natural phenomena.
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
3.1 The student can pose scientific questions.
3.2 The student can refine scientific questions.
3.3 The student can evaluate scientific questions.
Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question.
4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.
4.2 The student can design a plan for collecting data to answer a particular scientific question.
4.3 The student can collect data to answer a particular scientific question.
4.4 The student can evaluate sources of data to answer a particular scientific question
Science Practice 5: The student can perform data analysis and evaluation of evidence.
5.1 The student can analyze data to identify patterns or relationships.
5.2 The student can refine observations and measurements based on data analysis.
5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question.
Science Practice 6: The student can work with scientific explanations and theories.
6.1 The student can justify claims with evidence.
6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
6.3 The student can articulate the reasons that scientific explanations and theories are refined or replaced.
6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
6.5 The student can evaluate alternative scientific explanations.
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.
7.1 The student can connect phenomena and models across spatial and temporal scales.
7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Big Idea 2: Fields existing in space can be used to explain interactions.

Big Idea 3: The interactions of an object with other objects can be described by forces.

Big Idea 4: Interactions between systems can result in changes in those systems.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Big Idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

UNIT 1: Forces and Interactions

Overview

Classical mechanics describes the relationship between the motion of objects found in our world and the forces acting upon them. This unit involves Newton's three laws of motion and his law of gravity. Newton's three laws opened avenues of inquiry and discovery that are used routinely today in virtually all areas of mathematics, science, engineering, and technology. Newton's theory of universal gravitation had a similar impact, starting a revolution in celestial mechanics and astronomy that continues to this day. Newton's three laws of motion, together with his law of gravitation, are considered among the greatest achievements of the human mind.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:
- Vector and scalar quantities are different.
- Balanced forces are in static equilibrium.
- Newton's Laws of Motion are supported by data.
- There is a mathematical relationship between the force on a macroscopic object and its mass and acceleration.
- Mathematical representations of forces describe and predict interactions between objects.
- There is a relationship between displacement, velocity and acceleration.
- The Law of Universal Gravitation governs the interactions of objects in the universe.
- Gravitational fields can be illustrated and described.

Unit Essential Question

- What is the nature of vectors and how do they differ from scalar quantities?
- How can we use mathematical representation of forces to describe and predict interactions between objects?
- How are displacement, velocity and acceleration related?
- How does the Law of Universal Gravitation govern the interaction of objects in the universe?

College Board Unit Standards (Learning Objectives)

LO 3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations. [SP 1.5, 2.1, 2.2]

LO 3.A.1.2: The student is able to design an experimental investigation of the motion of an object. [SP 4.2]

LO 3.A.1.3: The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis

using narrative, mathematical, and graphical representations. [SP 5.1]

LO 1.C.1.1: The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. [SP 4.2]

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

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

LO 3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]

LO 3.A.3.1: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. [SP 6.4, 7.2]

LO 3.A.3.2: The student is able to challenge a claim that an object can exert a force on itself. [SP 6.1]

LO 3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]

LO 3.A.4.1: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]

LO 3.A.4.2: The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [SP 6.4, 7.2]

LO 4.A.2.1: The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. [SP 6.4]

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

LO 4.A.2.3: The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. [SP 1.4, 2.2]

LO 4.A.3.1: The student is able to apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. [SP 2.2]

LO 4.A.3.2: The student is able to use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. [SP 1.4]

UNIT 2: Momentum & Energy

Overview

Energy is present in the universe in a variety of forms, including mechanical, chemical, electromagnetic, and nuclear energy. Even the inert mass of everyday matter contains a very large amount of energy. Although energy can be transformed from one kind to another, all observations and experiments suggest that the total amount of energy in an isolated system remains the same. The focus of this unit is mainly on mechanical energy, which is the sum of kinetic energy (energy of motion) and potential energy (energy of position). This unit is linked to Newtonian Mechanics through the concept of work.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:
- A computational model can calculate the change in the energy of one component in a system when the change in energy of the other component(s) (energy flowing in and out of the system) is known
- Models illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
- Devices work within given constraints to convert one form of energy into another form of energy.
- The Law of Conservation of Energy predicts the motion and displacement of objects.
- There is a relationship between Impulse and Momentum.
- The Law of Conservation of Momentum models the motion of objects undergoing collisions and explosions
- Computational models describe the motion of objects in both an open (outside forces present) and closed (no outside forces present) system.

Unit Essential Questions

- How can we use models to illustrate that energy can be accounted for as a combination of energy associated with the motion of particles and the energy associated with the relative position of particles?
- How can we model the change in energy of one component of the system when the change in energy of the other component(s) and of the system are known?
- How can we use energy to predict the motion or displacement of objects?
- How are impulse and momentum related?

College Board Unit Standards

LO 3.E.1.1: The student is able to make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves. [SP 6.4, 7.2]

LO 3.E.1.2: The student is able to use net force and velocity vectors to determine qualitatively whether kinetic energy of an object would increase, decrease, or remain unchanged. [SP 1.4]

LO 3.E.1.3: The student is able to use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether kinetic energy of that object would increase, decrease, or remain unchanged. [SP 1.4, 2.2]

LO 3.E.1.4: The student is able to apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. [SP 2.2]

LO 4.C.1.1: The student is able to calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. [SP 1.4, 2.1, 2.2]

LO 4.C.1.2: The student is able to predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. [SP 6.4]

LO 4.C.2.2: The student is able to apply the concepts of Conservation of Energy and the Work---Energy theorem to determine qualitatively and/or quantitatively that work done on a two---object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system. [SP 1.4, 2.2, 7.2]

LO 5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2]

LO 5.B.1.1: The student is able to set up a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy. [SP 1.4, 2.2]

LO 5.B.1.2: The student is able to translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies**. [SP 1.5]

LO 5.B.2.1: The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [SP 1.4, 2.1]

LO 5.B.3.1: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2]

LO 5.B.3.2: The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2]

LO 5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [SP 1.4, 2.2]

LO 5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]

LO 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1.4, 2.1, 2.2]

LO 5.B.5.1: The student is able to design an experiment and analyze data to examine how a force exerted on an object or system does work on the object or system as it moves through a distance. [SP 4.2, 5.1]

LO 5.B.5.2: The student is able to design an experiment and analyze graphical data in which interpretations of the area under a force---distance curve are needed to determine the work done on or by the object or system. [SP 4.2, 5.1]

LO 5.B.5.3: The student is able to predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance. [SP 1.4, 2.2, 6.4]

LO 5.B.5.4: The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [SP 6.4, 7.2]

LO 5.B.5.5: The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [SP 2.2, 6.4]

LO 5.D.1.1: The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. [SP 6.4, 7.2]

LO 5.D.1.2: The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one---dimensional situations and only qualitatively in two---dimensional situations. [SP 2.2, 3.2, 5.1, 5.3]

LO 5.D.1.3: The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. [SP 2.1, 2.2]

LO 5.D.1.4: The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. [SP 4.2, 5.1, 5.3, 6.4]

LO 5.D.1.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [SP 2.1, 2.2]

LO 5.D.2.1: The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. [SP 6.4, 7.2**]**

LO 5.D.2.3: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2]

LO 3.D.1.1: The student is able to justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force. [SP 4.1]

LO 3.D.2.1: The student is able to justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. [SP 2.1]

LO 3.D.2.2: The student is able to predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [SP 6.4]

LO 3.D.2.3: The student is able to analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. [SP 5.1]

LO 3.D.2.4: The student is able to design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. [SP 4.2]

LO 4.B.1.1: The student is able to calculate the change in linear momentum of a two---object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). [SP 1.4, 2.2]

LO 4.B.1.2: The student is able to analyze data to find the change in linear momentum for a constant---mass system using the product of the mass and the change in velocity of the center of mass. [SP 5.1]

LO 4.B.2.1: The student is able to apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. [SP 2.2]

LO 4.B.2.2: The student is able to perform analysis on data presented as a force---time graph and predict the change in momentum of a system. [SP 5.1]

LO 5.D.2.2: The student is able to plan data collection strategies to test the law of conservation of momentum in a two---object collision that is elastic or inelastic and analyze the resulting data graphically. [SP 4.1, 4.2, 5.1]

LO 5.D.2.4: The student is able to analyze data that verify conservation of momentum in collisions with and without an external friction force. [SP 4.1, 4.2, 4.4, 5.1, 5.3]

LO 5.D.2.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values**. [SP 2.1, 2.2]

LO 5.D.3.1: The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force). [SP 6.4]

UNIT 3: Circular & Rotational Motion

Overview

Objects undergo rotational, circular, and rolling motion in addition to traditional linear motion. The Rotational Dynamics used to model rotational motion mimic those used for linear motion, as does angular momentum and rotational energy. Students will learn the constraints necessary for a torque to occur and the effects of that torque on the object's motion.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:
- There are differences between circular motion and linear motion.
- Models can be used to describe the rotational motion of an object.
- A force can exert a torque on an object, and the effects of a torque on an object.
- There is a relationship between angular acceleration, angular momentum, and torque.

Unit Essential Questions

- How does circular motion differ from linear motion?
- How can we use rotational dynamics to predict rotational motion?
- How does exerting a torque affect an object's motion?
- How are angular acceleration, angular momentum and torque related?

College Board Unit Standards

LO 3.F.1.1: The student is able to use representations of the relationship between force and torque. **[SP 1.4]**
LO 3.F.1.2: The student is able to compare the torques on an object caused by various forces. **[SP 1.4]**
LO 3.F.1.3: The student is able to estimate the torque on an object caused by various forces in comparison to other situations. **[SP 2.3]**
LO 3.F.1.4: The student is able to design an experiment and analyze data testing a question about torques in a balanced rigid system. **[SP 4.1, 4.2, 5.1]**
LO 3.F.1.5: The student is able to calculate torques on a two---dimensional system in static equilibrium, by examining a representation or model (such as a diagram or physical construction). **[SP 1.4, 2.2]**
LO 3.F.2.1: The student is able to make predictions about the change in the angular velocity about an axis for an object when forces exerted on the

object cause a torque about that axis. [SP 6.4]

LO 3.F.2.2: The student is able to plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. [SP 4.1, 4.2, 5.1**]**

LO 3.F.3.1: The student is able to predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum. [SP 6.4, 7.2]

LO 3.F.3.2: In an unfamiliar context or using representations beyond equations, the student is able to justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. [SP 2.1]

LO 3.F.3.3: The student is able to plan data collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object. [SP 4.1, 4.2, 5.1, 5.3]

LO 4.A.1.1 The student is able to use representations of the center of mass of an isolated two---object system to analyze the motion of the system qualitatively and semi-quantitatively. [SP 1.2, 1.4, 2.3, 6.4]

LO 4.D.1.1: The student is able to describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system. [SP 1.2, 1.4]

LO 4.D.1.2: The student is able to plan data collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data. [SP 3.2, 4.1, 4.2, 5.1, 5.3]

LO 4.D.2.1: The student is able to describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. [SP 1.2, 1.4]

LO 4.D.2.2: The student is able to plan a data collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems. [SP 4.2]

LO 4.D.3.1: The student is able to use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. [SP 2.2]

LO 4.D.3.2: The student is able to plan a data collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. [SP 4.1, 4.2]

LO 5.E.1.1: The student is able to make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. [SP 6.4, 7.2]

LO 5.E.1.2: The student is able to make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. [SP 2.1, 2.2]

LO 5.E.2.1: The student is able to describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Students are expected to do qualitative reasoning with compound objects. Students are expected to do calculations with a fixed set of extended objects and point masses.

UNIT 4: Harmonic Motion & Waves

Overview

Periodic vibrations can cause disturbances that move through a medium in the form of waves. Many kinds of waves occur in nature, such as sound waves, water waves, and electromagnetic waves. These waves are often caused by an object undergoing simple harmonic motion (SHM), caused by a restoring force. These very different physics phenomena are described by common terms and concepts introduced here.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:
- A restoring force affects an object's motion at each point during SHM.
- Certain properties affect the motion of an object for pendulums and mass-spring systems undergoing SHM.
- An experiment to collect data to determine the characteristics of an object in SHM is valid or not.
- There are relationships among the frequency, wavelength, and speed of waves traveling in various media.
- Some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
- There are interaction between different waves.
- Modern society depends on major technological systems, and use those systems to solve original problems.

Unit Essential Questions

- What properties affect the motion of an object in SHM?
- How can SHM be modeled as a wave?
- How do waves interact with each other?
- How are the principles of wave behavior and interactions with matter used to transmit and capture information and energy?

College Board Unit Standards

LO 3.B.3.1: The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. [SP 6.4, 7.2]

LO 3.B.3.2: The student is able to design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force. [SP 4.2]

LO 3.B.3.3: The student can analyze data to identify qualitative or quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion to use that data to determine the value of an unknown. [SP 2.2, 5.1]

LO 3.B.3.4: The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force. [SP 2.2, 6.2]

LO 5.B.2.1: The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [SP 1.4, 2.1]

LO 5.B.3.1: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. [SP 2.2, 6.4, 7.2]

LO 5.B.3.2: The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. [SP 1.4, 2.2]

LO 5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. [SP 1.4, 2.2]

LO 5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]

LO 5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1.4, 2.1, 2.2]

LO 6.A.1.1: The student is able to use a visual representation to construct an explanation of the distinction between transverse and longitudinal waves by focusing on the vibration that generates the wave. [SP 6.2]

LO 6.A.1.2: The student is able to describe representations of transverse and longitudinal waves. [SP 1.2]

LO 6.A.2.1: The student is able to describe sound in terms of transfer of energy and momentum in a medium and relate the concepts to everyday examples. [SP 6.4, 7.2]

LO 6.A.3.1: The student is able to use graphical representation of a periodic mechanical wave to determine the amplitude of the wave. [SP 1.4]

LO 6.A.4.1: The student is able to explain and/or predict qualitatively how the energy carried by a sound wave relates to the amplitude of the wave, and/or apply this concept to a real---world example. [SP 6.4]

LO 6.B.1.1: The student is able to use a graphical representation of a periodic mechanical wave (position versus time) to determine the period and frequency of the wave and describe how a change in the frequency would modify features of the representation. [SP 1.4, 2.2]

LO 6.B.2.1: The student is able to use a visual representation of a periodic mechanical wave to determine wavelength of the wave. [SP 1.4]

LO 6.B.4.1: The student is able to design an experiment to determine the relationship between periodic wave speed, wavelength, and frequency and relate these concepts to everyday examples. [SP 4.2, 5.1, 7.2]

LO 6.B.5.1: The student is able to create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent upon relative motions of source and observer. [SP 1.4]

LO 6.D.1.1: The student is able to use representations of individual pulses and construct representations to model the interaction of two wave pulses to analyze the superposition of two pulses. [SP 1.1, 1.4]

LO 6.D.1.2: The student is able to design a suitable experiment and analyze data illustrating the superposition of mechanical waves (only for wave pulses or standing waves). [SP 4.2, 5.1]

LO 6.D.1.3: The student is able to design a plan for collecting data to quantify the amplitude variations when two or more traveling waves or wave pulses interact in a given medium. [SP 4.2]

LO 6.D.2.1: The student is able to analyze data or observations or evaluate evidence of the interaction of two or more traveling waves in one or two dimensions (i.e., circular wave fronts) to evaluate the variations in resultant amplitudes. [SP 5.1]

LO 6.D.3.1: The student is able to refine a scientific question related to standing waves and design a detailed plan for the experiment that can be

conducted to examine the phenomenon qualitatively or quantitatively. [SP 2.1, 3.2, 4.2]

LO 6.D.3.2: The student is able to predict properties of standing waves that result from the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. [SP 6.4]

LO 6.D.3.3: The student is able to plan data collection strategies, predict the outcome based on the relationship under test, perform data analysis, evaluate evidence compared to the prediction, explain any discrepancy and, if necessary, revise the relationship among variables responsible for establishing standing waves on a string or in a column of air. [SP 3.2, 4.1, 5.1, 5.2, 5.3]

LO 6.D.3.4: The student is able to describe representations and models of situations in which standing waves result from the addition of incident and reflected waves confined to a region. [SP 1.2]

LO 6.D.4.1: The student is able to challenge with evidence the claim that the wavelengths of standing waves are determined by the frequency of the source regardless of the size of the region. [SP 1.5, 6.1]

LO 6.D.4.2: The student is able to calculate wavelengths and frequencies (if given wave speed) of standing waves based on boundary conditions and length of region within which the wave is confined, and calculate numerical values of wavelengths and frequencies. Examples should include musical instruments. [SP 2.2]

LO 6.D.5.1: The student is able to use a visual representation to explain how waves of slightly different frequency give rise to the phenomenon of beats. [SP 1.2]

UNIT 5: Electricity

Overview

Electricity is the lifeblood of technological civilization and modern society. With the discovery and harnessing of electric forces and fields,we can view arrangements of atoms, probe the inner workings of the cell, and send spacecraft beyond the limits of the solar system. In this unit, we use the effect of charging by friction to begin an investigation of electric forces. We then discuss Coulomb's law, which is the fundamental law of force between charged particles.

Performance Expectations

At the conclusion of this unit, students will be able to evaluate why:
- Elementary particles have a role in the Law of Conservation of Charge.
- Coulomb's Law describes and predicts the electrostatic forces between objects.
- An electric current has both macroscopic and microscopic charge interactions.
- Resistors have a role in circuits and they have an effect on other circuit elements.
- A potential difference has effects on other charged particles.

Unit Essential Questions

- What are the elementary particles and how do they get their charge?
- How is electric charge transferred and conserved?
- How does electric charge form a current, and what affects that current?
- What is a potential difference, and what effect does it have on charged particles?

College Board Unit Standards

LO 1.B.1.1: The student is able to make claims about natural phenomena based on conservation of electric charge. [SP 6.4]

LO 1.B.1.2: The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [SP 6.4, 7.2]

LO 1.B.2.1 The student is able to construct an explanation of the two---charge model of electric charge based on evidence produced through scientific practices. [SP 6.2]:

LO 1.B.3.1: The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. [SP 1.5, 6.1, 7.2]

LO 3.C.2.1: The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. [SP 2.2, 6.4]

LO 3.C.2.2: The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [See SP 7.2]

LO 5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6.4, 7.2]

LO 5.B.9.1: The student is able to construct or interpret a graph of the energy changes within an electrical circuit with only a single battery and resistors in series and/or in, at most, one parallel branch as an application of the conservation of energy (Kirchhoff's loop rule). [SP 1.1, 1.4]

LO 5.B.9.2: The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\sum \Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches. [SP 4.2, 6.4, 7.2]

LO 5.B.9.3: The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch. [SP 2.2, 6.4, 7.2]

LO 5.C.3.1: The student is able to apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed. [SP 6.4, 7.2]

LO 5.C.3.2: The student is able to design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed. [SP 4.1, 4.2, 5.1]

LO 5.C.3.3: The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit. [SP 1.4, 2.2]