Fairfield Public Schools
Science Curriculum

Draft Units

AP Physics 1

DRAFT August 2016

Course: Description

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.

Students will cultivate their understanding of physics and science practices as they explore the following topics:

- Vectors and trigonometry
- Forces and static equilibrium
- Kinematics, dynamics and Newton's laws
- Impulse, linear momentum, and conservation of linear momentum: collisions
- Work, energy, and conservation of energy
- Rotational & circular motion: torque, rotational kinematics and energy, rotational dynamics, and conservation of angular momentum
- Electrostatics: electric charge and electric force
- DC circuits: resistors only
- Simple harmonic motion: simple pendulum and mass-spring systems
- Mechanical waves and sound

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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.

Standards for this course are taken from the *Next Generation Science Standards* and are of three types:

Disciplinary Core Ideas: Shown as content objectives, these standards define what students should know about the most essential ideas in the major science disciplines. The focus is on a limited number of core ideas in science and engineering both within and across the disciplines to avoid the shallow coverage of a large number of topics and to allow more time for teachers and students to explore each idea in greater depth. Reduction of the sheer sum of details to be mastered is intended to give time for students to engage in scientific investigations and argumentation and to achieve depth of understanding of the core ideas presented.

Science and Engineering Practices: These standards enable students to apply the content in the DCI's and the skills of practicing scientists and engineers to explain phenomena and solve real world problems. Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science.

Cross-cutting Concepts: These standards provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas. These broad concepts tie together the influence of engineering, technology, and science on society and the natural world.

http://www.nextgenscience.org/next-generation-science-standards

CROSS CUTTING CONCEPTS

Patterns: Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

Systems and system models. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

Energy and matter: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

Structure and function. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

AP Physics 1: Overview

Enduring Understandings

The AP Physics 1: Algebra-Based Curriculum framework is structured around the "big ideas" of physics, which encompass core scientific principles, theories, and processes of the discipline. The framework encourages instruction that allows students to make connections across domains through a broader way of thinking about the physical world. Big ideas cut across the traditional physics principles and are supported with enduring understandings, which incorporate the core concepts that students should retain from their learning experiences.
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.

This course also provides students with opportunities to engage in the AP Science Practices, whereby they establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. Focusing on these reasoning skills enables teachers to use the principles of scientific inquiry to promote a more engaging and rigorous experience for AP Physics students.
Science practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
Science practice 2: The student can use mathematics appropriately.
Science practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
Science practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question.
Science practice 5: The student can perform data analysis and evaluation of evidence.
Science practice 6: The student can work with scientific explanations and theories.
Science practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
In the AP Physics 1 course, the content and reasoning skills (science practices) are equally important and are therefore described together in the concept outline to define what a student should *know* and *do* within the context of the course.

Course Essential Questions
1. What are the properties of mass and charge? What internal structures do systems have? 2. How can fields existing in space be used to explain interactions? 3. What are forces? How can they describe the interactions between or among objects? 4. How do interactions between systems change those systems? 5. How are changes that occur as a result of interactions explained by conservation laws? What are the constraints of those changes? 6. 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?

Course: 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 does data support Newton's second law of motion to describe the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration? • 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? • What is a gravitational field? • How can we quantify problem-solving requirements? • How can we break down problem-solving criteria into simpler ones, and make decisions about the priority of certain criteria?
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 energy be converted from one form to another according to the Law of Conservation of Energy? • How can we use energy to predict the motion or displacement of objects? • How are impulse and momentum related? • How does the Law of Conservation of Momentum apply to collisions and explosions? • How can we use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system? • How can we minimize the force on a macroscopic object during a collision? • How can we quantify problem-solving requirements?
3	Circular Motion & Rotation	• How does circular motion differ from linear motion? • How can we use rotational dynamics to predict rotational motion? • How does the moment of inertia of an object compare to its mass? • How can a force exert a torque on an object?

		• How does exerting a torque affect an object’s motion? • How does an object's linear momentum compare to its angular momentum? • How are angular acceleration, angular momentum and torque related?
4	Harmonic Motion & Waves	• How does a restoring force affect an object? • How can we describe the motion of an object undergoing simple harmonic motion (SHM)? • What properties affect the motion of an object in SHM? • How can we collect data to determine the characteristics of an object in SHM? • How can SHM be modeled as a wave? • How do waves interact with each other? • How can we tell waves are interacting? • How are the frequency, wavelength, and speed of a wave related mathematically? • 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? • How does Coulomb’s Law describe the mathematical relationship between charges? • How do resistors affect an electric circuit? • What is a potential difference, and what effect does it have on charged particles?

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.

Unit Content Objectives

At the conclusion of this unit, students will be able to:

- Define vector and scalar quantities and differentiate between the two.
- Determine balanced forces in static equilibrium.
- Use data to support Newton's Laws of Motion.
- Describe the mathematical relationship between the force on a macroscopic object and its mass and acceleration.
- Use mathematical representations of forces to describe and predict interactions between objects.
- Explain the relationship between displacement, velocity and acceleration.
- Describe how the Law of Universal Gravitation governs the interactions of objects in the universe.
- Describe and illustrate a gravitational field.

Unit Essential Questions

- What is the nature of vectors and how do they differ from scalar quantities?
- How does data support Newton's second law of motion to describe the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration?
- 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?
- What is a gravitational field?

- How can we quantify problem-solving requirements?
- How can we break down problem-solving criteria into simpler ones, and make decisions about the priority of certain criteria?

Crosscutting Concepts
Patterns Cause and Effect Systems and System Models

NGSS Unit Standards

DISCIPLINARY CORE IDEAS (DCI):

PS2.A: Forces and Motion

- Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)
- Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-2)
- If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system. (HS-PS2-2),(HS-PS2-3)

PS2.B: Types of Interactions

- Newton's law of universal gravitation ... provide(s) the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)
- Forces at a distance are explained by fields (gravitational...) permeating space that can transfer energy (HS-PS2-4)

AP ESSENTIAL KNOWLEDGE:

Enduring Understanding 1.A: The internal structure of a system determines many properties of the system.

- Essential Knowledge 1.A.1: A system is an object or a collection of objects. Objects are treated as having no internal structure.

Enduring Understanding 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles

- Essential Knowledge 1.C.1: Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems.
- Essential Knowledge 1.C.2: Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.
- Essential Knowledge 1.C.3: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

Enduring Understanding 2.A: A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.

- Essential Knowledge 2.A.1: A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.

Enduring Understanding 2.B: A gravitational field is caused by an object with mass.

- Essential Knowledge 2.B.1: A gravitational field g at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.
- Essential Knowledge 2.B.2: The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.

Enduring Understanding 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.

- Essential Knowledge 3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
- Essential Knowledge 3.A.2: Forces are described by vectors.
- Essential Knowledge 3.A.3: A force exerted on an object is always due to the interaction of that object with another object.
- Essential Knowledge 3.A.4: If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $a = \Sigma F / m$

- Essential Knowledge 3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- Essential Knowledge 3.B.2: Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.

Enduring Understanding 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

- Essential Knowledge 3.C.1: Gravitational force describes the interaction of one object that has mass with another object that has mass.
- Essential Knowledge 3.C.4: Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).

Enduring Understanding 3.G: Certain types of forces are considered fundamental.

- Essential Knowledge 3.G.1: Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.

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 $a = \Sigma F / m$

- Essential Knowledge 4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.
- Essential Knowledge 4.A.2: The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.
- Essential Knowledge 4.A.3: Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

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.

- Essential Knowledge 5.A.1: A system is an object or a collection of objects. The objects are treated as having no internal structure.
- Essential Knowledge 5.A.3: An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.
- Essential Knowledge 5.A.4: The 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.

SCIENCE AND ENGINEERING PRACTICES (SEP):

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS2-3)

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS2-3)

Corresponding CT Core Standards:

Common Core State Standards Connections:
ELA/Literacy - RST.11-12.1, RST.11-12.7, WHST.11-12.2, WHST.11-12.7, WHST.11-12.8, WHST.11-12.9
Mathematics - MP.2; MP.4; HSN.Q.A.1; HSN.Q.A.2; HSN.Q.A.3; HSA.SSE.A.1; HSA.SSE.B.3; HSA.CED.A.1; HSA.CED.A.2; HSA.CED.A.4; HSF-IF.C.7; HSS-IS.A.1

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*.

Unit Content Objectives

At the conclusion of this unit, students will be able to:

- Create a computational model to 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
- Develop and use models to 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).
- Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- Use the Law of Conservation of Energy to predict the motion and displacement of objects.
- Describe the relationship between Impulse and Momentum.
- Use the Law of Conservation of Momentum to model the motion of objects undergoing collisions and explosions
- Use computational models to model the motion of objects in both an open (outside forces present) and closed (no outside forces present) system.
- Students will be able to solve problems satisfying any requirements set by society, such as taking issues of risk mitigation into account, and quantifying them to the extent possible.

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 energy be converted from one form to another according to the Law of Conservation of Energy?
- How can we use energy to predict the motion or displacement of objects?
- How are impulse and momentum related?

- How does the Law of Conservation of Momentum apply to collisions and explosions?
- How can we use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system?
- How can we minimize the force on a macroscopic object during a collision?
- How can we quantify problem-solving requirements?

Crosscutting Concepts

Cause and Effect

Systems and System Models

Energy and Matter

Corresponding CT Core Standards:

ELA/Literacy - RST.11-12.1, WHST.9-12.7, WHST.11-12.8, WHST.9-12.9, SL.11-12.5,
Mathematics - MP.2, MP.4, HSN.Q.A.1, HSN.Q.A.2, HSN.Q.A.3

NGSS Unit Standards
DISCIPLINARY CORE IDEAS (DCI): PS3.A: Definitions of Energy ● Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. ● At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. ● These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. PS3.B: Conservation of Energy and Energy Transfer ● Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. ● Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. ● Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. ● The availability of energy limits what can occur in any system. ● Uncontrolled systems always evolve toward more stable states— that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) PS3.D: Energy in Chemical Processes ● Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. ETS1.A: Defining and Delimiting an Engineering Problem ● Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary)* PS3.C: Relationship Between Energy and Forces ● When two objects interacting through a field change relative position, the energy stored in the field is changed.

AP ESSENTIAL KNOWLEDGE:

Enduring Understanding 3.D: A force exerted on an object can change the momentum of the object.

- Essential Knowledge 3.D.1: The change in momentum of an object is a vector in the direction of the net force exerted on the object.
- Essential Knowledge 3.D.2: The change in momentum of an object occurs over a time interval.

Enduring Understanding 3.E: A force exerted on an object can change the kinetic energy of the object.

- Essential Knowledge 3.E.1: The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the time interval that the force is exerted.

Enduring Understanding 4.B: Interactions with other objects or systems can change the total linear momentum of a system.

- Essential Knowledge 4.B.1: The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.
- Essential Knowledge 4.B.2: The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.

Enduring Understanding 4.C: Interactions with other objects or systems can change the total energy of a system.

- Essential Knowledge 4.C.1: The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy.
- Essential Knowledge 4.C.2: Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work.

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.

- Essential Knowledge 5.A.2: For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.
- Essential Knowledge 5.A.3: An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.

Enduring Understanding 5.B: The energy of a system is conserved.

- Essential Knowledge 5.B.1: Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.
- Essential Knowledge 5.B.2: A system with internal structure can have internal energy, and changes in a system’s internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums. Physics 2: includes charged object in electric fields and examining changes in internal energy with changes in configuration.]
- Essential Knowledge 5.B.3: A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.

- Essential Knowledge 5.B.4: The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.
- Essential Knowledge 5.B.5: Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance. This process is called doing work on a system. The amount of energy transferred by this mechanical process is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.]
- Essential Knowledge 5.B.9: Kirchhoff's loop rule describes conservation of energy in electrical circuits. [The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors.]

Enduring Understanding 5.D: The linear momentum of a system is conserved.

- Essential Knowledge 5.D.1: In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.
- Essential Knowledge 5.D.2: In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.
- Essential Knowledge 5.D.3: The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]

SCIENCE AND ENGINEERING PRACTICES (SEP):

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS2-3)

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS2-3)

Corresponding CT Core Standards:

ELA/Literacy - RST.11-12.1, RST.11-12.7, WHST.11-12.2, WHST.11-12.7, WHST.11-12.8, WHST.11-12.9,
Mathematics - MP.2, MP.4, HSN.Q.A.1, HSN.Q.A.2, HSN.Q.A.3, HSA.SSE.A.1, HSA.SSE.B.3, HSA.CED.A.1, HSA.CED.A.2, HSA.CED.A.4, HSF-IF.C.7, HSS-IS.A.1

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.

Unit Content Objectives

At the conclusion of this unit, students will be able to:

- Describe the differences between circular motion and linear motion.
- Model the rotational motion of an object.
- Explain how a force can exert a torque on an object, and the effects of a torque on an object.
- Explain the 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 the moment of inertia of an object compare to its mass?
- How can a force exert a torque on an object?
- How does exerting a torque affect an object's motion?
- How does an object's linear momentum compare to its angular momentum?
- How are angular acceleration, angular momentum and torque related?

Crosscutting Concepts
Patterns   **Cause and Effect**   **Systems and System Models**

NGSS Unit Standards
AP ESSENTIAL KNOWLEDGE: **Enduring Understanding 3.F: A force exerted on an object can cause a torque on that object.** ● Essential Knowledge 3.F.1: Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis. ● Essential Knowledge 3.F.2: The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis. ● Essential Knowledge 3.F.3: A torque exerted on an object can change the angular momentum of an object. **Enduring Understanding 4.D: A net torque exerted on a system by other objects or systems will change the angular momentum of the system.** ● Essential Knowledge 4.D.1: Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. ● Essential Knowledge 4.D.2: The angular momentum of a system may change due to interactions with other objects or systems. ● Essential Knowledge 4.D.3: The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted. **Enduring Understanding 5.E: The angular momentum of a system is conserved.** ● Essential Knowledge 5.E.1: If the net external torque exerted on the system is zero, the angular momentum of the system does not change. ● Essential Knowledge 5.E.2: The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or system depends upon the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples should 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.

SCIENCE AND ENGINEERING PRACTICES (SEP):

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS2-3)

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS2-3)

Corresponding CT Core Standards:

ELA/Literacy - RST.11-12.1, RST.11-12.7, WHST.11-12.2, WHST.11-12.7, WHST.11-12.8, WHST.11-12.9,
Mathematics - MP.2, MP.4, HSN.Q.A.1, HSN.Q.A.2, HSN.Q.A.3, HSA.SSE.A.1, HSA.SSE.B.3, HSA.CED.A.1, HSA.CED.A.2, HSA.CED.A.4, HSF-IF.C.7, HSS-IS.A.1

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.

Unit Content Objectives

At the conclusion of this unit, students will be able to:

- Explain how a restoring force affects an object's motion at each point during SHM.
- Determine what properties affect the motion of an object for pendulums and mass-spring systems undergoing SHM.
- Create and conduct an experiment to collect data to determine the characteristics of an object in SHM.
- Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
- Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.
- Describe and evaluate the interaction between different waves.
- Describe how modern society depends on major technological systems, and use those systems to solve original problems.

Unit Essential Questions

- How does a restoring force affect an object?
- How can we describe the motion of an object undergoing SHM?
- What properties affect the motion of an object in SHM?
- How can we collect data to determine the characteristics of an object in SHM?
- How can SHM be modeled as a wave?
- How do waves interact with each other?
- How can we tell waves are interacting?
- How are the frequency, wavelength, and speed of a wave related mathematically?
- How are the principles of wave behavior and interactions with matter used to transmit and capture information and energy?

Crosscutting Concepts
Cause and Effect   **Systems and System Models**   **Stability and Change**

NGSS Unit Standards

DISCIPLINARY CORE IDEAS (DCI):

PS4.A: Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. (HS-PS4-1)
- Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. (HS-PS4-2),(HS-PS4-5)
- [From the 3–5 grade band endpoints] Waves can add or cancel one another as they cross, depending on their relative phase (i.e., relative position of peaks and troughs of the waves), but they emerge unaffected by each other. (Boundary: The discussion at this grade level is qualitative only; it can be based on the fact that two different sounds can pass a location in different directions without getting mixed up.) (HS-PS4-3)

PS4.B: Electromagnetic Radiation

- Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. (HS-PS4-3)
- When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. (HS-PS4-4)

PS4.C: Information Technologies and Instrumentation

- Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (HS-PS4-5)

AP ESSENTIAL KNOWLEDGE:

Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $a = \Sigma F / m$

- Essential Knowledge 3.B.3: Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum, mass-spring oscillator

Enduring Understanding 6.A: A wave is a traveling disturbance that transfers energy and momentum.

- Essential Knowledge 6.A.1: Waves can propagate via different oscillation modes such as transverse and longitudinal.
- Essential Knowledge 6.A.2: For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum.
- Essential Knowledge 6.A.3: The amplitude is the maximum displacement of a wave from its equilibrium value.
- Essential Knowledge 6.A.4: Classically, the energy carried by a wave depends upon and increases with amplitude.Examples should include sound waves.

Enduring Understanding 6.B: A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.

- Essential Knowledge 6.B.1: For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time.
- Essential Knowledge 6.B.2: For a periodic wave, the wavelength is the repeat distance of the wave.
- Essential Knowledge 6.B.4: For a periodic wave, wavelength is the ratio of speed over frequency.
- Essential Knowledge 6.B.5: The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only.

Enduring Understanding 6.D: Interference and superposition lead to standing waves and beats.

- Essential Knowledge 6.D.1: Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition.
- Essential Knowledge 6.D.2: Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave.
- Essential Knowledge 6.D.3: Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string and sound waves in both closed and open tubes.
- Essential Knowledge 6.D.4: The possible wavelengths of a standing wave are determined by the size of the region to which it is confined.
- Essential Knowledge 6.D.5: Beats arise from the addition of waves of slightly different frequency.

SCIENCE AND ENGINEERING PRACTICES (SEP):

Interdependence of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). (HS-PS4-5)

Influence of Engineering, Technology, and Science on Society and the Natural World

- Modern civilization depends on major technological systems. (HS-PS4-2),(HS-PS4-5)
- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to

increase benefits while decreasing costs and risks. (HS-PS4-2)
Corresponding CT Core Standards: ***ELA/Literacy - RST.9-10.8, RST.11-12.1, RST.11-12.7, RST.11-12.8, WHST.9-12.2, WHST.11-12.8,*** ***Mathematics - MP.2, MP.4, HSA-SSE.A.1, HSA-SSE.B.3, HSA.CED.A.4***

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.

Unit Content Objectives

At the conclusion of this unit, students will be able to:

- Describe the elementary particles and their role in the Law of Conservation of Charge.
- Use mathematical representations of Coulomb’s Law to describe and predict the electrostatic forces between objects.
- Describe an electric current in terms of both macroscopic and microscopic charge interactions.
- Describe the role of resistors in a circuit and their effects on other circuit elements.
- Describe a potential difference and its 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?
- How does Coulomb’s Law describe the mathematical relationship between charges?
- How do resistors affect an electric circuit?
- What is a potential difference, and what effect does it have on charged particles?

Crosscutting Concepts
Patterns **Cause and Effect**   **Systems and System Models**

NGSS Unit Standards

DISCIPLINARY CORE IDEAS (DCI):

PS2.B: Types of Interactions

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. (HS-PS2-4),(HS-PS2-5)

PS3.A: Definitions of Energy

- "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. (secondary to HS-PS2-5)

AP ESSENTIAL KNOWLEDGE:
Enduring Understanding 1.B: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.

- Essential Knowledge 1.B.1: Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.
- Essential Knowledge 1.B.2: There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.
- Essential Knowledge 1.B.3: The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.

Enduring Understanding 1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

- Essential Knowledge 1.E.2: Matter has a property called resistivity.

Enduring Understanding 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

- Essential Knowledge 3.C.2: Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.

Enduring Understanding 5.C: The electric charge of a system is conserved.

- Essential Knowledge 5.C.3: Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only. Physics 2: includes capacitors in steady-state situations. For circuits with capacitors, situations should be limited to open circuit, just after circuit is closed, and a long time after the circuit is closed.]

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SCIENCE AND ENGINEERING PRACTICES (SEP):

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS2-3)

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS2-3)

Corresponding CT Core Standards:

ELA/Literacy - RST.11-12.1, RST.11-12.7, WHST.11-12.2, WHST.11-12.7, WHST.11-12.8, WHST.11-12.9,
Mathematics - MP.2, MP.4, HSN.Q.A.1, HSN.Q.A.2, HSN.Q.A.3, HSA.SSE.A.1, HSA.SSE.B.3, HSA.CED.A.1, HSA.CED.A.2, HSA.CED.A.4, HSF-IF.C.7, HSS-IS.A.1