Fairfield Public Schools
Science Curriculum

Draft Units

AP Physics 2

DRAFT August 2016

Course: Description

The AP Physics 2 course focuses on the big ideas typically included in the second semesters 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:

- **Thermodynamics: laws of thermodynamics, ideal gases, and kinetic theory**
- **Fluid statics and dynamics**
- **Electrostatics: electric force, electric field and electric potential**
- **DC circuits and RC circuits (steady-state only)**
- **Magnetism and electromagnetic induction**
- **Geometric and physical optics**
- **Quantum physics, atomic, and nuclear physics**

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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 2: Overview

Enduring Understandings

The AP Physics 2: 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.

The foundational physics principles support the development of the following 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.
Big idea 7: The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

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 2 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.

Taken from the AP Physics Course and Exam Description, Revised September 2014

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? 7. How can probabilities be used to describe the behavior of complex systems and interpret the behavior of quantum mechanical systems?

Course: Year-at-a Glance

Unit	Title	Unit Essential Questions
1	Fluid Mechanics	● What is density? ● What is the buoyancy force and how does it act on objects in various liquids? ● How does Bernoulli's equation describe the conservation of energy in fluid flow? ● How does the continuity equation describe conservation of mass in fluid flow? ● What classical laws and principles define the behavior of fluids?
2	Thermodynamics	● How does the internal structure of atoms affect their properties? ● What is thermal conductivity and how does it relate to energy transfer? ● How is energy transferred from one temperature to another? What is this called? ● How does the internal energy of the system relate to the kinetic energy of the individual components? ● How is energy transferred by thermal processes? ● How does the first law of thermodynamics relate to conservation of energy, and how can it be used to interpret PV diagrams? ● How does the pressure of a system relate to the force that system exerts on the walls of its container? How does it relate to changes in momentum of the particles contained in that system? ● How does the temperature relate to the kinetic energy of the particles in a system? ● How does probability describe the thermal equilibrium process? How does it describe the second law of thermodynamics?
3	Electricity	● How is electric charge conserved? ● What is the charge distribution on a neutral object? ● What is the elementary charge? ● What is electric permittivity? ● How can we represent an electric field as a vector field? ● What causes an electric field and how does it affect the electric force exerted on an object at various points in space? ● How can we visually represent an electric field? ● How does the electric field change between charged objects and charged plates?

		● What are isolines and what are they used to represent? ● How do Kirchhoff's Laws represent conservation of energy and charge in a circuit? ● How do capacitors affect a circuit?
4	Magnetism	● What causes a magnetic field? ● What objects are affected by a magnetic field? ● What is a magnetic dipole? ● What is a ferromagnetic material? ● What is magnetic flux? ● How does changing magnetic flux create an electric field?
5	Waves, Electromagnetic Radiation and Optics	● What is electromagnetic radiation? How can it be modeled as a wave? ● How does electromagnetic radiation transfer energy? ● How can waves be modeled mathematically? ● How do waves interact with each other? ● How do waves behave when passing through openings whose spacing is comparable to the wavelength of the wave? ● What happens when light waves encounter interfaces between media? ● How is electromagnetic radiation related to photons? ● How do scientists determine whether to model light as a particle or as a wave? ● How do scientists determine whether to model matter as a particle or as a wave? ● How can matter be modeled by a wave function? How does that function describe its motion and interactions?
6	Modern & Nuclear Physics	● What is the internal structure of an atom? How does that determine its properties? ● What forces exist inside an atom? ● What is Einstein's Theory of Special Relativity? Theory of General Relativity? ● How can mass be converted to energy? Energy to mass? ● Under what circumstances do space and time become unabsolute? ● What is nuclear radiation? What different forms exist? ● How does nuclear radiation follow the Law of Conservation of Charge? Law of Conservation of Energy? Law of Conservation of Nucleon Number?

UNIT 1 - Fluid Mechanics

Overview

The unit provides a basic algebraic overview of the behavior of non-compressible Newtonian fluids. The unit covers static fluid behavior including buoyancy force calculations as well as hydraulics. It then moves on to dynamic fluid flow centered around the use of Bernoulli's equation as a representation of the conservation of energy of the fluid system.

Unit Content Objectives

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

- define and calculate density.
- calculate the buoyancy force on various objects and use it to predict object behavior.
- use Bernoulli's equation to describe the conservation of energy in fluid flow and calculate unknowns.
- use the continuity equation describe conservation of mass in fluid flow and calculate unknowns.
- use classical laws and principles define the behavior of fluids and calculate unknowns.

Unit Essential Questions

- What is density?
- What is the buoyancy force and how does it act on objects in various liquids?
- How does Bernoulli's equation describe the conservation of energy in fluid flow?
- How does the continuity equation describe conservation of mass in fluid flow?
- What classical laws and principles define the behavior of fluids?

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)

PS2.B: Types of Interactions

- Newton's law of universal gravitation provides the mathematical model to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)

AP ESSENTIAL KNOWLEDGE:
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.1: Matter has a property called density.

Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using a=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 5.B: The energy of a system is conserved.

- Essential Knowledge 5.B.10**:** Bernoulli's equation describes the conservation of energy in fluid flow.

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

- 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.]

Enduring Understanding 5.F: Classically, the mass of a system is conserved.

- Essential Knowledge 5.F.1: The continuity equation describes conservation of mass flow rate in fluids. Examples should include volume rate of flow and mass flow rate.

Enduring Understanding 6.C: Only waves exhibit interference and diffraction.

- Essential Knowledge 6.C.4: When waves pass by an edge, they can diffract into the “shadow region” behind the edge. Examples should include hearing around corners, but not seeing around them, and water waves bending around obstacles

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 - Thermodynamics

Overview

This unit covers the Laws of Thermodynamics and Kinetic Theory of Gases. Instruction is centered around the Conservation of Energy (1st Law of Thermodynamics). Covered topics include PV Diagrams, heat flow/energy transfer and work done on and by systems.

Unit Content Objectives

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

- describe how internal structures of systems affect their properties.
- describe thermal conductivity in the context of energy transfer.
- describe how energy is transferred between two objects with differing temperatures.
- relate the internal energy of a system to the kinetic energy of its individual components.
- describe how energy is transferred through thermal processes.
- describe the Laws of Thermodynamics and how they relate to conservation of energy.
- describe how pressure is related the force exerted on the container by the internal particles, and relate this to the momentum of the internal particles.
- describe how probability relates to the thermal equilibrium process and the second law of thermodynamics.

Unit Essential Questions

- How does the internal structure of systems affect their properties?
- What is thermal conductivity and how does it relate to energy transfer?
- How is energy transferred from one temperature to another? What is this called?
- How does the internal energy of the system relate to the kinetic energy of the individual components?
- How is energy transferred by thermal processes?
- How does the first law of thermodynamics relate to conservation of energy, and how can it be used to interpret PV diagrams?
- How does the pressure of a system relate to the force that system exerts on the walls of its container? How does it relate to changes in momentum of the particles contained in that system?
- How does the temperature relate to the kinetic energy of the particles in a system?
- How does probability describe the thermal equilibrium process? How does it describe the second law of thermodynamics?

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.

AP ESSENTIAL KNOWLEDGE:

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

- Essential Knowledge 1.A.2: Fundamental particles have no internal structure.
- Essential Knowledge 1.A.4: Atoms have internal structures that determine their properties.

- Essential Knowledge 1.A.5: Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an *object*.

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.3**:** Matter has a property called thermal conductivity.

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

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

- Essential Knowledge 4.C.3: Energy is transferred spontaneously from a higher temperature system to a lower temperature system. This process of transferring energy is called heating. The amount of energy transferred is called heat.

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

- 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.6: Energy can be transferred by thermal processes involving differences in temperature; the amount of energy transferred in this process of transfer is called heat.
- Essential Knowledge 5.B.7: The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams — isovolumetric processes, isothermal processes, isobaric processes, and adiabatic processes. No calculations of internal energy change from temperature change are required; in this course, examples of these relationships are qualitative and/or semiquantitative.

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.

Enduring Understanding 7.A: The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure.

- Essential Knowledge 7.A.1: The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum, the impulse, of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.
- Essential Knowledge 7.A.2: The temperature of a system characterizes the average kinetic energy of its molecules.
- Essential Knowledge 7.A.3: In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV = nRT$.

Enduring Understanding 7.B: The tendency of isolated systems to move toward states with higher disorder is described by probability.

- Essential Knowledge 7.B.1: The approach to thermal equilibrium is a probability process.
- Essential Knowledge 7.B.2: The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a qualitative treatment is considered in this course.

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 - Electricity

Overview

Electric charge is the fundamental property of an object that determines how the object interacts with other electrically charged objects. The interaction of a charged object with a distribution of other charged objects is simplified by the field model, where a distribution of charged objects creates a field at every point and the charged object interacts with the field. There are two types of electric charge, positive and negative. The course covers static charges, charged plates, and DC and RC circuits. Where capacitors are involved, the course considers the initial and final steady states of the capacitors.

Unit Content Objectives

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

- describe the transfer and conservation of charge.
- explain charge distributions on differently charged objects.
- describe electric permittivity and how it affects conductors and insulators.
- use vector fields to represent electric fields.
- describe the electric field and how it relates to the electric force on an object at various points in space.
- describe quantitatively and visually the electric field between charged objects and charged plates.
- use isolines as equipotential lines.
- use Kirchhoff's Laws to evaluate circuit elements.
- evaluate and describe simple circuits with capacitors.

Unit Essential Questions

- How is electric charge conserved?
- What is the charge distribution on a neutral object?
- What is the elementary charge?
- What is electric permittivity?
- How can we represent an electric field as a vector field?
- What causes an electric field and how does it affect the electric force exerted on an object at various points in space?
- How can we visually represent an electric field?
- How does the electric field change between charged objects and charged plates?
- What are isolines and what are they used to represent?

- How do Kirchhoff's Laws represent conservation of energy and charge in a circuit?
- How do capacitors affect a circuit?

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.A:** The internal structure of a system determines many properties of the system. ● Essential Knowledge 1.A.4**:** Atoms have internal structures that determine their properties. **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.4: Matter has a property called electric permittivity. **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.

- Essential Knowledge 2.A.2: A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. In Physics 2, this should include electric potential.

Enduring Understanding 2.C: An electric field is caused by an object with electric charge.

- Essential Knowledge 2.C.1: The magnitude of the electric force F exerted on an object with electric charge q by an electric field . The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.
- Essential Knowledge 2.C.2: The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.
- Essential Knowledge 2.C.3: The electric field outside a spherically symmetric charged object is radial, and its magnitude varies as the inverse square of the radial distance from the center of that object. Electric field lines are not in the curriculum. Students will be expected to rely only on the rough intuitive sense underlying field lines, wherein the field is viewed as analogous to something emanating uniformly from a source.
- Essential Knowledge 2.C.4: The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object. Electric dipoles are treated qualitatively in this course as a teaching analogy to facilitate student understanding of magnetic dipoles.
- Essential Knowledge 2.C.5: Between two oppositely charged parallel plates with uniformly distributed electric charge, at points far from the edges of the plates, the electric field is perpendicular to the plates and is constant in both magnitude and direction.

Enduring Understanding 2.E: Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.

- Essential Knowledge 2.E.1: Isolines on a topographic (elevation) map describe lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential). As the distance between two different isolines decreases, the steepness of the surface increases. [Contour lines on topographic maps are useful teaching tools for introducing the concept of equipotential lines. Students are encouraged to use the analogy in their answers when explaining gravitational and electrical potential and potential differences.]
- Essential Knowledge 2.E.2: Isolines in a region where an electric field exists represent lines of equal electric potential, referred to as equipotential lines.
- Essential Knowledge 2.E.3: The average value of the electric field in a region equals the change in electric potential across that region divided by the change in position (displacement) in the relevant direction

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

- 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=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.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 3.G: Certain types of forces are considered fundamental.

- Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale.

Enduring Understanding 4.E: The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

- Essential Knowledge 4.E.3: The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.
- Essential Knowledge 4.E.4: The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces as well as the properties of materials and their geometry.
- Essential Knowledge 4.E.5: The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.

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

- 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.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.C: The electric charge of a system is conserved.

- Essential Knowledge 5.C.2: The exchange of electric charges among a set of objects in a system conserves electric charge.

- 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.]

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 - Magnetism

Overview

Knowledge of the properties and sources of magnetic forces and magnetic fields is necessary to student understanding of areas such as geophysical processes and medical applications. A magnetic dipole can be modeled as a current in a loop. A single magnetic pole (a magnetic monopole like an isolated north pole of a magnet) has never been observed in nature. The pattern of magnetic field vectors tangent to concentric circles around a current-carrying wire and the dipole pattern of field vectors around a bar magnet are needed representations. Magnetic materials contain magnetic domains that are themselves little magnets. Representations can be drawn of the atomic-scale structure of ferromagnetic materials, such as arrows or smaller bar magnets, which indicate the directional nature of magnets even at these small scales. These magnetic moments lead to discussions of important modern applications such as magnetic storage media.

Unit Content Objectives

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

- explain different originations of a magnetic field.
- describe a magnetic dipole and how it is observed in nature.
- explain a ferromagnetic material and how the properties of the internal components can affect/be affected by a magnetic field.
- explain the concept of magnetic flux.
- explain how a changing magnetic flux can create an electric field.

Unit Essential Questions

- What causes a magnetic field?
- What objects are affected by a magnetic field?
- What is a magnetic dipole?
- What is a ferromagnetic material?
- What is magnetic flux?
- How does changing magnetic flux create an electric field?

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

NGSS Unit Standards

DISCIPLINARY CORE IDEAS (DCI):

PS2.B: Types of Interactions

- 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)

AP ESSENTIAL KNOWLEDGE:

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.5: Matter has a property called magnetic permeability.
- Essential Knowledge 1.E.6: Matter has a property called magnetic dipole moment.

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.
- Essential Knowledge 2.A.2: A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. In Physics 2, this should include electric potential.

Enduring Understanding 2.D: A magnetic field is caused by a magnet or a moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles and never by single poles.

- Essential Knowledge 2.D.1: The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity, and the magnitude of the magnetic field. It also depends on the angle between the velocity and the magnetic field vectors. Treatment is quantitative for angles of 0°, 90°, or 180° and qualitative for other angles.
- Essential Knowledge 2.D.2: The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire.
- Essential Knowledge 2.D.3: A magnetic dipole placed in a magnetic field, such as the ones created by a magnet or the Earth, will tend to align with the magnetic field vector.
- Essential Knowledge 2.D.4: Ferromagnetic materials contain magnetic domains that are themselves magnets.

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

- 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=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.3: A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or another magnet.

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

- Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale.

Enduring Understanding 4.E: The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

- Essential Knowledge 4.E.1: The magnetic properties of some materials can be affected by magnetic fields at the system. Students should focus on the underlying concepts and not the use of the vocabulary.
- Essential Knowledge 4.E.2: Changing magnetic flux induces an electric field that can establish an induced emf in a system.

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 - Waves, Electromagnetic Radiation & Optics

Overview

This unit covers wave properties but focuses on electromagnetic (EM) radiation. Properties of different wavelengths are discussed as well as how different media affect the EM wave. Geometric optics are covered, including ray diagrams, for transparent media interfaces as well as traditional mirrors. The unit concludes with the discussion of EM waves as photon particles and of traditional matter as waves.

Unit Content Objectives

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

- identify electromagnetic radiation and model it as a wave and as a particle in appropriate contexts.
- explain the relationship between EM waves and photons.
- explain and calculate how EM radiation transfers energy.
- model waves mathematically using trigonometric functions.
- identify and describe wave interference and diffraction patterns.
- model reflection and refraction as an EM wave travels through an interface between two media.
- use a wave function to model the interaction and motion of matter.

Unit Essential Questions

- What is electromagnetic radiation? How can it be modeled as a wave?
- How does electromagnetic radiation transfer energy?
- How can waves be modeled mathematically?
- How do waves interact with each other?
- How do waves behave when passing through openings whose spacing is comparable to the wavelength of the wave?
- What happens when light waves encounter interfaces between media?
- How is electromagnetic radiation related to photons?
- How do scientists determine whether to model light as a particle or as a wave?
- How do scientists determine whether to model matter as a particle or as a wave?
- How can matter be modeled by a wave function? How does that function describe its motion and interactions?

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

NGSS Unit Standards

DISCIPLINARY CORE IDEAS (DCI):
PS3.D: Energy in Chemical Processes

- Solar cells are human-made devices that likewise capture the sun's energy and produce electrical energy. *(secondary to HS-PS4-5)*

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)
- Photoelectric materials emit electrons when they absorb light of a high-enough frequency. (HS-PS4-5)

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 1.D: Classical mechanics cannot describe all properties of objects.

- Essential Knowledge 1.D.1: Objects classically thought of as particles can exhibit properties of waves.
- Essential Knowledge 1.D.2: Certain phenomena classically thought of as waves can exhibit properties of particles.

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

- Essential Knowledge 5.B.8: Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.

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.

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.3: A simple wave can be described by an equation involving one sine or cosine function involving the wavelength, amplitude, and frequency of the wave.

Enduring Understanding 6.C: Only waves exhibit interference and diffraction.

- Essential Knowledge 6.C.1: When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition.
- Essential Knowledge 6.C.2: When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed.
- Essential Knowledge 6.C.3: When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference.
- Essential Knowledge 6.C.4: When waves pass by an edge, they can diffract into the "shadow region" behind the edge. Examples should include hearing around corners, but not seeing around them, and water waves bending around obstacles

Enduring Understanding 6.E: The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.

- Essential Knowledge 6.E.1: When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. (Qualitative understanding only.)
- Essential Knowledge 6.E.2: When light hits a smooth reflecting surface at an angle, it reflects at the same angle on the other side of the line perpendicular to the surface (specular reflection); this law of reflection accounts for the size and location of images seen in mirrors.
- Essential Knowledge 6.E.3: When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.
- Essential Knowledge 6.E.4: The reflection of light from surfaces can be used to form images.
- Essential Knowledge 6.E.5: The refraction of light as it travels from one transparent medium to another can be used to form images.

Enduring Understanding 6.F: Electromagnetic radiation can be modeled as waves or as fundamental particles.

- Essential Knowledge 6.F.1: Types of electromagnetic radiation are characterized by their wavelengths, and certain ranges of wavelength have been given specific names. These include (in order of increasing wavelength spanning a range from picometers to kilometers) gamma rays, x–rays, ultraviolet, visible light, infrared, microwaves, and radio waves.
- Essential Knowledge 6.F.2: Electromagnetic waves can transmit energy through a medium and through a vacuum.
- Essential Knowledge 6.F.3: Photons are individual energy packets of electromagnetic waves, with Ephoton = hf, where h is Planck's constant and f is the frequency of the associated light wave.
- Essential Knowledge 6.F.4: The nature of light requires that different models of light are most appropriate at different scales.

Enduring Understanding 6.G: All matter can be modeled as waves or as particles.

- Essential Knowledge 6.G.1: Under certain regimes of energy or distance, matter can be modeled as a classical particle.
- Essential Knowledge 6.G.2: Under certain regimes of energy or distance, matter can be modeled as a wave. The behavior in these regimes is described by quantum mechanics.

Enduring Understanding 7.C: At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.

- Essential Knowledge 7.C.1: The probabilistic description of matter is modeled by a wave function, which can be assigned to an object and used to describe its motion and interactions. The absolute value of the wave function is related to the probability of finding a particle in some spatial region. (Qualitative treatment only, using graphical analysis.)
- Essential Knowledge 7.C.4: Photon emission and absorption processes are described by probability

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 6 - Modern & Nuclear Physics

Overview

The final unit covers nuclear physics involving fission, fusion and radiation. The unit uses the conservation laws previously mentioned in prior units and adds the final conservation law, the Law of Nucleon Number. The unit concludes with a qualitative discussion of Einstein's Special and General Relativity. Students do not need to quantitatively calculate time dilation and length contraction but should be able to qualitatively explain these phenomena and identify scenarios that prove the existence of special relativity.

Unit Content Objectives

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

- describe the internal structures of an atom and the properties based on this.
- identify the forces at work inside an atom.
- describe nuclear radiation and the different forms.
- predict the end result of various nuclear radiation scenarios using the Law of conservation of Charge, Law of Conservation of Energy, and Law of Conservation of Nucleon Number.
- identify and calculate the allowed states of an electron.
- describe Einstein's Theories of Special and General Relativity.
- explain how energy and mass are related, and how one can be converted to the other.
- describe scenarios where time and space are not absolute and why this occurs.

Unit Essential Questions

- What is the internal structure of an atom? How does that determine its properties?
- What forces exist inside an atom?
- What are the allowed states inside an atom? How can they be calculated?
- What is Einstein's Theory of Special Relativity? Theory of General Relativity?
- How can mass be converted to energy? Energy to mass?
- Under what circumstances do space and time become not absolute?
- What is nuclear radiation? What different forms exist?
- How does nuclear radiation follow the Law of Conservation of Charge? Law of Conservation of Energy? Law of Conservation of Nucleon Number?

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

NGSS Unit Standards
AP ESSENTIAL KNOWLEDGE: **Enduring Understanding 1.A:** The internal structure of a system determines many properties of the system ● Essential Knowledge 1.A.2: Fundamental particles have no internal structure. ● Essential Knowledge 1.A.3: Nuclei have internal structures that determine their properties. ● Essential Knowledge 1.A.4: Atoms have internal structures that determine their properties. ● Essential Knowledge 1.A.5: Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an *object*. **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.4: In certain processes, mass can be converted to energy and energy can be converted to mass according to E = mc 2, the equation derived from the theory of special relativity. **Enduring Understanding 1.D:** Classical mechanics cannot describe all properties of objects. ● Essential Knowledge 1.D.3: Properties of space and time cannot always be treated as absolute. **Enduring Understanding 3.G:** Certain types of forces are considered fundamental. ● Essential Knowledge 3.G.3: The strong force is exerted at nuclear scales and dominates the interactions of nucleons. **Enduring Understanding 4.C:** Interactions with other objects or systems can change the total energy of a system. ● Essential Knowledge 4.C.4: Mass can be converted into energy, and energy can be converted into mass. **Enduring Understanding 5.B:** The energy of a system is conserved. ● Essential Knowledge 5.B.11: Beyond the classical approximation, mass is actually part of the internal energy of an object or system with E=mc2. **Enduring Understanding 5.C:** The electric charge of a system is conserved. ● Essential Knowledge 5.C.1: Electric charge is conserved in nuclear and elementary particle reactions, even when elementary particles are produced or destroyed. Examples should include equations representing nuclear decay. **Enduring Understanding 5.G:** Nucleon number is conserved. ● Essential Knowledge 5.G.1: The possible nuclear reactions are constrained by the law of conservation of nucleon number. **Enduring Understanding 7.C:** At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world. ● Essential Knowledge 7.C.2: The allowed states for an electron in an atom can be calculated from the wave model of an electron. ● Essential Knowledge 7.C.3: The spontaneous radioactive decay of an individual nucleus is described by probability. ● Essential Knowledge 7.C.4: Photon emission and absorption processes are described by probability.

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)

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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