The Concept Outline

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

This big idea collects the properties of matter into one area so that they can be employed in other big ideas. The universe contains fundamental particles with no internal structure such as electrons, and systems built from fundamental particles, such as protons and neutrons. These further combine to form atoms, molecules, and macroscopic systems, all of which have internal structures. A system has various attributes or "properties" that determine how it behaves in different situations. When the properties of the system depend on the internal structure of the system, we must treat it as a system. In other cases, the properties of interest may not depend on the internal structure — in AP Physics we call these *objects*. For example, the free-fall motion of a ball can be understood without consideration of the internal structure of the ball, so in this case the ball can be treated as an object. Objects and systems have properties that determine their interactions with other objects and systems. The choice of modeling something as an object or a system is a fundamental step in determining how to describe and analyze a physical situation.

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

In a problem of interest, this enduring understanding distinguishes *systems,* where internal structure exists and may need to be taken into account, from *objects,* where internal structure is not present or can be ignored.

Matter builds from fundamental particles, which are objects that have no internal structure, up to systems such as nuclei, atoms, molecules, and macroscopic objects that do have internal structure. The number and arrangements of atomic constituents cause substances to have different properties. There is much contact with chemistry in this enduring understanding in terms of atomic structure, chemical properties of elements, and the incorporation of concepts leading to the quantum model of the atom: energy states, quantized parameters, and transitions.

PHYSICS 1

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

a. A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object.

b. Some elementary particles are fundamental particles (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed.

c. The electric charges on neutrons and protons result from their quark compositions.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.

PHYSICS 2

Essential Knowledge 1.A.2: Fundamental particles have no internal structure.

a. Electrons, neutrinos, photons, and quarks are examples of fundamental particles.

b. Neutrons and protons are composed of quarks.

c. All quarks have electric charges, which are fractions of the elementary charge of the electron. Students will not be expected to know specifics of quark charge or quark composition of nucleons.

Learning Objective 1.A.2.1:
The student is able to construct representations of the differences between a fundamental particle and a system composed of fundamental particles and to relate this to the properties and scales of the systems being investigated.
[See **Science Practices 1.1 and 7.1**]

PHYSICS 2

Essential Knowledge 1.A.3: Nuclei have internal structures that determine their properties.

a. The number of protons identifies the element.

b. The number of neutrons together with the number of protons identifies the isotope.

c. There are different types of radioactive emissions from the nucleus.

d. The rate of decay of any radioactive isotope is specified by its half-life.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.

PHYSICS 2

Essential Knowledge 1.A.4: Atoms have internal structures that determine their properties.

a. The number of protons in the nucleus determines the number of electrons in a neutral atom.

b. The number and arrangements of electrons cause elements to have different properties.

c. The Bohr model based on classical foundations was the historical representation of the atom that led to the description of the hydrogen atom in terms of discrete energy states (represented in energy diagrams by discrete energy levels).

d. Discrete energy state transitions lead to spectra.

Learning Objective 1.A.4.1:
The student is able to construct representations of the energy-level structure of an electron in an atom and to relate this to the properties and scales of the systems being investigated.
[See **Science Practices 1.1 and 7.1**]

PHYSICS 1 PHYSICS 2

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*.

Learning Objective 1.A.5.1:
The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed.
[See **Science Practices 1.1 and 7.1**]

PHYSICS 2

Learning Objective 1.A.5.2:
The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures.
[See **Science Practices 1.1**, **1.4**, **and 7.1**]

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.

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. Protons are examples of positively charged objects, and electrons are examples of negatively charged objects. Neutral objects and systems are ones whose net charge is zero. The magnitudes of the charge of a proton and of an electron are equal, and this is the smallest unit of charge that is found in an isolated object. Electric charge is conserved in all known processes and interactions.

Return to the Table of Contents

Boundary Statement: Full coverage of electrostatics occurs in Physics 2. A basic introduction to the concepts that there are positive and negative charges, and the electrostatic attraction and repulsion between these charges, is included in Physics 1 as well.

PHYSICS 1

PHYSICS 2

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.

a. An electrical current is a movement of charge through a conductor.

b. A circuit is a closed loop of electrical current.

Learning Objective: 1.B.1.1:
The student is able to make claims about natural phenomena based on conservation of electric charge.
[See **Science Practice 6.4**]

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

PHYSICS 1 | PHYSICS 2

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.

a. Like-charged objects and systems repel, and unlike-charged objects and systems attract.

b. Charged objects or systems may attract neutral systems by changing the distribution of charge in the neutral system.

PHYSICS 1

Learning Objective 1.B.2.1:
The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices.
[See **Science Practice 6.2**]

Learning Objective 1.B.2.2:
The student is able to make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes.
[See **Science Practices 6.4 and 7.2**]

Learning Objective 1.B.2.3:
The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object.
[See **Science Practice 6.1**]

PHYSICS 1 | PHYSICS 2

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.

a. The magnitude of the elementary charge is equal to 1.6×10^{-19} coulombs.

b. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron.

Learning Objective 1.B.3.1:
The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated.
[See **Science Practices 1.5, 6.1, and 7.2**]

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.

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. Gravitational mass is the property of an object or a system that determines the magnitude of its gravitational interaction with other objects, systems, or gravitational fields. From these definitions, classically, there is no expectation that these quantities would be identical. Einstein's assumption that these two quantities, experimentally verified to be equivalent, are in fact the same, is fundamental to the general theory of relativity (which is not part of this course).

Mass is conserved in any process, such as change of shape, change of state, or dissolution, when it is not converted to energy or when energy is not converted to mass. Mass is a central concept in this course; further discussions of mass are found throughout.

PHYSICS 1

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.

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

PHYSICS 1

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.

a. The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field.

b. Near the Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.

PHYSICS 1

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.

Learning Objective 1.C.3.1:
The student is able to design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments.
[See **Science Practice 4.2**]

PHYSICS 2

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.

Learning Objective 1.C.4.1:
The student is able to articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass–energy.
[See **Science Practice 6.3**]

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

Physicists developed classical mechanics from the intuitive partition of behavior of nature at the human scale into objects that behaved like particles (e.g., rocks) and systems that behaved like waves (e.g., sound waves). Similarly, in classical mechanics they recognized from experience that the motion of objects would appear differently to observers moving relative to each other but assumed that measurements of elapsed time would not be affected by motion. As physicists in the late 19th and early 20th centuries probed the structure of matter at smaller and smaller scales, they discovered that models of atomic and subatomic behavior based on classical intuitions could not explain the experimental results. Ultimately, new mathematical theories were developed that could predict the outcome of experiments but lacked the intuitive underpinning of the classical view. The mathematics gives unambiguous results, but has no single intuitive reference or analogy that can be described in ordinary language. As a result, the best we can do is to describe certain results of experiments as analogous to classical particle behavior and others as analogous to classical wavelike behavior while recognizing that the underlying nature of the object has no precise analogy in human-scale experience.

Return to the Table of Contents

During the same period, experimental results and theoretical predictions of results in the study of electromagnetic radiation came into conflict with the classical assumption of a common time for all observers. At relative velocities that are large compared with common experience, the special theory of relativity correctly predicts changes in the observed momentum, length, and elapsed time for objects in relative motion. Because humans have no experience of relative motion at such velocities, we have no intuitive underpinnings to explain this behavior. The physics of large relative velocities will only be treated qualitatively in this course.

PHYSICS 2

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

a. This wavelike behavior of particles has been observed, e.g., in a double-slit experiment using elementary particles.

b. The classical models of objects do not describe their wave nature. These models break down when observing objects in small dimensions.

Learning Objective 1.D.1.1:
The student is able to explain why classical mechanics cannot describe all properties of objects by articulating the reasons that classical mechanics must be refined and an alternative explanation developed when classical particles display wave properties.
[See **Science Practice 6.3**]

PHYSICS 2

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

a. The classical models of waves do not describe the nature of a photon.

b. Momentum and energy of a photon can be related to its frequency and wavelength.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.

PHYSICS 2

Essential Knowledge 1.D.3: Properties of space and time cannot always be treated as absolute.

a. Relativistic mass–energy equivalence is a reconceptualization of matter and energy as two manifestations of the same underlying entity, fully interconvertible, thereby rendering invalid the classically separate laws of conservation of mass and conservation of energy. Students will not be expected to know apparent mass or rest mass.

b. Measurements of length and time depend on speed. (Qualitative treatment only.)

Learning Objective 1.D.3.1:
The student is able to articulate the reasons that classical mechanics must be replaced by special relativity to describe the experimental results and theoretical predictions that show that the properties of space and time are not absolute. [Students will be expected to recognize situations in which nonrelativistic classical physics breaks down and to explain how relativity addresses that breakdown, but students will not be expected to know in which of two reference frames a given series of events corresponds to a greater or lesser time interval, or a greater or lesser spatial distance; they will just need to know that observers in the two reference frames can "disagree" about some time and distance intervals.] [See **Science Practices 6.3 and 7.1**]

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.

Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. Some of the most important fundamental characteristics of matter and space are identified here and employed in other big ideas.

Matter has properties called density, resistivity, and thermal conductivity that are used when discussing thermodynamics, fluids, electric current, and transfer of thermal energy. The values of these quantities depend upon the molecular and atomic structure of the material. Matter and space also have properties called electric permittivity and magnetic permeability. The permittivity and the permeability of free space are constants that appear in physical relationships and in the relationship for the speed of electromagnetic radiation in a vacuum.

The electric permittivity and the magnetic permeability of a material both depend upon the material's structure at the atomic level.

Electric dipole moments (as treated in Enduring Understanding 2.C) and magnetic dipole moments are other properties of matter. A separated pair of positively and negatively charged objects is an example of an electric dipole. A current loop is an example of a magnetic dipole.

PHYSICS 2

Essential Knowledge 1.E.1: Matter has a property called density.

Learning Objective 1.E.1.1:
The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction.
[See **Science Practices 4.2 and 6.4**]

Learning Objective 1.E.1.2:
The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects.
[See **Science Practices 4.1 and 6.4**]

PHYSICS 1 PHYSICS 2

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

a. The resistivity of a material depends on its molecular and atomic structure.
b. The resistivity depends on the temperature of the material.

Learning Objective 1.E.2.1:
The student is able to choose and justify the selection of data needed to determine resistivity for a given material.
[See **Science Practice 4.1**]

PHYSICS 2

Essential Knowledge 1.E.3: Matter has a property called thermal conductivity.

a. The thermal conductivity is the measure of a material's ability to transfer thermal energy.

Learning Objective 1.E.3.1:
The student is able to design an experiment and analyze data from it to examine thermal conductivity.
[See **Science Practices 4.1**, **4.2**, **and 5.1**]

PHYSICS 2

Essential Knowledge 1.E.4: Matter has a property called electric permittivity.

a. Free space has a constant value of the permittivity that appears in physical relationships.

b. The permittivity of matter has a value different from that of free space.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.

PHYSICS 2

Essential Knowledge 1.E.5: Matter has a property called magnetic permeability.

a. Free space has a constant value of the permeability that appears in physical relationships.

b. The permeability of matter has a value different from that of free space.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.

PHYSICS 2

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

a. Magnetic dipole moment is a fundamental source of magnetic behavior of matter and an intrinsic property of some fundamental particles such as the electron.

b. Permanent magnetism or induced magnetism of matter is a system property resulting from the alignment of magnetic dipole moments within the system.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.