Appendix B: AP Physics 2 Concepts at a Glance

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

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.	6.1
	Essential Knowledge 1.A.4: Atoms have internal structures that determine their properties.	6.1
	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*.	6.1
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.	**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.	2.3
	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.	2.3
	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.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.	3.3
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.	2.4, 5.3
	Essential Knowledge 1.D.2: Certain phenomena classically thought of as waves can exhibit properties of particles.	2.4, 5.3
	Essential Knowledge 1.D.3: Properties of space and time cannot always be treated as absolute.	3.4

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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.
	Essential Knowledge 1.E.2: Matter has a property called resistivity.
	Essential Knowledge 1.E.3: Matter has a property called thermal conductivity.
	Essential Knowledge 1.E.4: Matter has a property called electric permittivity.
	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.

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

2.2 2.3 7.2 –	**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.	
2.3 –	**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 $\vec{F} = q\vec{E}$. 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.	2.3
		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.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 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.

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

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.	2.1
	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.	2.1
Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\vec{F}}{m}$.	**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.	2.3
	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.	2.3
	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.	2.2
	Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale.	2.3
	Essential Knowledge 3.G.3: The strong force is exerted at nuclear scales and dominates the interactions of nucleons.	6.1–6.4

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

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.
	Essential Knowledge 4.C.4: Mass can be converted into energy, and energy can be converted into mass.
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.
	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.

3.3, 6.3, 7.1

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

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.]	2.2, 6.3
	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.	
	Essential Knowledge 5.B.8: Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.	6.1-6.3
	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.]	
	Essential Knowledge 5.B.10: Bernoulli's equation describes the conservation of energy in fluid flow.	
	Essential Knowledge 5.B.11: Beyond the classical approximation, mass is actually part of the internal energy of an object or system with $E = mc^2$.	3.3, 6.3 7.1

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.
	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.]
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.]
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 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.

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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.

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.	2.4
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.	5.1
	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.	5.1
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.)	5.1
	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.	

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.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.	2.4, 5.1
	Essential Knowledge 6.F.2: Electromagnetic waves can transmit energy through a medium and through a vacuum.	2.4
	Essential Knowledge 6.F.3: Photons are individual energy packets of electromagnetic waves, with $E_{photon} = hf$, where h is Planck's constant and f is the frequency of the associated light wave.	5.1
	Essential Knowledge 6.F.4: The nature of light requires that different models of light are most appropriate at different scales.	5.2
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.	~2.1
	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.	5.1, 5.3

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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.

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.	
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.)	5.2
	Essential Knowledge 7.C.2: The allowed states for an electron in an atom can be calculated from the wave model of an electron.	6.2
	Essential Knowledge 7.C.3: The spontaneous radioactive decay of an individual nucleus is described by probability.	6.3
	Essential Knowledge 7.C.4: Photon emission and absorption processes are described by probability.	6.2