knight | jones | field

college physics

a strategic approach 4e

AP® Edition

AP® is a trademark registered and/or owned by the College Board, which was not involved in the production of, and does not endorse, this product.

Correlation to the AP® Physics 1 and AP® Physics 2 Curriculum Framework

This chart correlates the College Board's Advanced Placement Physics Curriculum Framework (effective Fall 2017) to the corresponding chapters and sections in Knight/Jones/Field AP Edition of *College Physics: A Strategic Approach*, 4th Edition, AP Edition. For the most current correlation for this textbook, visit PearsonSchool.com/AdvancedCorrelations.

BIG IDEA 1 Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.A:		Chapter/Section
The internal structure of a system determines many properties of the system.		
1.A.1. A system is an object or a collection of objects. Objects are treated as having no internal structure.	Phys. 1	2.6, 7.2, 7.4, 9.4, 20.3, 30.7
1.A.2. Fundamental particles have no internal structure. SP 1.1, 7.2	Phys. 2	28.3, 30.7
1.A.3. Nuclei have internal structures that determine their properties.	Phys. 2	29.2, 30.1, 30.2, 30.4, 30.5
1.A.4. Atoms have internal structures that determine their properties. SP 1.1, 7.1	Phys. 2	29.2–29.7
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*. SP 1.1, 1.4, 7.1	Phys. 1, 2	11.3, 12.1, 12.2, 12.4, 12.5, 12.7, 12.8, 13.1

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.		
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. SP 6.4, 7.2	Phys. 1, 2	20.1, 20.2, 22.1, 22.2
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. SP 6.1, 6.2, 6.4, 7.2	Phys. 1, 2	20.1–20.3, 30.1, 30.7
1.B.3. The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge. SP 1.5, 6.1, 7.2	Phys. 1, 2	20.1, 20.2, 29.2, 30.7

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.		
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. SP 4.2	Phys. 1	4.5, 9.4–9.6
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.	Phys. 1	2.7, 6.5
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. SP 4.2	Phys. 1	6.5
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. SP 6.3	Phys. 2	27.10

Enduring Understanding 1.D:		
Classical mechanics cannot describe all properties of objects.		
1.D.1. Objects classically thought of as particles can exhibit properties of waves. SP 6.3	Phys. 2	28.4

1.D.2. Certain phenomena classically thought of as waves can exhibit properties of particles.	Phys. 2	28.2, 28.3, 28.6, 28.7
1.D.3. Properties of space and time cannot always be treated as absolute. SP 6.3, 7.1	Phys. 2	27.1, 27.5, 27.6, 27.10

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.

1.E.1. Matter has a property called density. SP 4.1, 4.2, 6.4	Phys. 2	13.1, 13.3
1.E.2. Matter has a property called resistivity. SP 4.1	Phys. 1, 2	22.4
1.E.3. Matter has a property called thermal conductivity. SP 4.1, 4.2, 5.1	Phys. 2	12.8
1.E.4. Matter has a property called electric permittivity.	Phys. 2	20.4, 21.7
1.E.5. Matter has a property called magnetic permeability.	Phys. 2	24.4
1.E.6. Matter has a property called magnetic dipole moment.	Phys. 2	24.8

BIG IDEA 2 Fields existing in space can be used to explain interactions.

Enduring Understanding 2.A: — Chapter/Section

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.

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.	Phys. 1, 2	20.4, 20.5
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.	Phys. 2	21.4, 21.5

Enduring Understanding 2.B:

A gravitational field is caused by an object with mass.

2.B.1. A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field. SP 2.2, 7.2	Phys. 1	5.3, 6.5
2.B.2. The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object. SP 2.2	Phys. 1	6.5

Enduring Understanding 2.C:

An electric field is caused by an object with electric charge.

2.C.1. The magnitude of the electric force F exerted on an object with electric charge q by an electric field $\vec{E}$ is $\vec{F} = q\vec{E}$. 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 distribution, and uniformly charged parallel plates. SP 2.2, 6.4, 7.2	Phys. 2	20.4, 20.5
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. SP 2.2, 6.4	Phys. 2	20.4, 20.5
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. SP 6.2	Phys. 2	20.4
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. SP 1.4, 2.2, 6.4, 7.2	Phys. 2	20.5

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. — 20.5

SP 1.1, 2.2, 7.1 — Phys. 2

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.

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. — 24.5

SP 2.2 — Phys. 2

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. — 24.3, 24.4

SP 1.1 — Phys. 2

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. — 24.7

SP 1.2 — Phys. 2

2.D.4. Ferromagnetic materials contain magnetic domains that are themselves magnets. — 24.8

SP 1.4 — Phys. 2

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.

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.] — 21.4

SP 1.4, 6.4, 7.2 — Phys. 2

2.E.2. Isolines in a region where an electric field exists represent lines of equal electric potential, referred to as equipotential lines. — 21.4

SP 1.4, 6.4, 7.2 — Phys. 2

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. — 21.5

Phys. 2

BIG IDEA 3 The interactions of an object with other objects can be described by forces.

Enduring Understanding 3.A:	Chapter/Section
All forces share certain common characteristics when considered by observers in inertial reference frames.	
3.A.1. An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. SP 1.5, 2.1, 2.2, 4.2, 5.1 — Phys. 1	1.3, 1.4, 1.6. 1.7, 2.1, 2.2, 2.4, 2.5, 3.2, 3.8, 27.2, 27.3
3.A.2. Forces are described by vectors. SP 1.1 — Phys. 1, 2	4.1, 4.4
3.A.3. A force exerted on an object is always due to the interaction of that object with another object. SP 1.4, 6.1, 6.4, 7.2 — Phys. 1, 2	4.1, 4.2, 4.5, 5.1, 5.7, 6.2, 6.5, 9.2
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. SP 1.4, 6.2, 6.4, 7.2 — Phys. 1, 2	4.7, 5.7, 6.5, 9.4

Enduring Understanding 3.B:

Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$.

3.B.1. If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. — 4.6, 5.1–5.3, 5.8, 5.9, 6.1, 20.3

SP 1.5, 2.2, 4.2, 5.1, 6.4, 7.2 — Phys. 1, 2

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. — 4.1–4.3, 4.6, 4.7, 5.1, 5.3, 5.8, 5.9, 6.1

SP 1.1, 1.4, 2.2 — Phys. 1, 2

3.B.3. Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum, mass-spring oscillator. — 14.2–14.5

SP 2.2, 4.2, 5.1, 6.2, 6.4, 7.2 — Phys. 1

Enduring Understanding 3.C:

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

3.C.1. Gravitational force describes the interaction of one object that has mass with another object that has mass. — 5.3, 6.5

SP 2.2 — Phys. 1

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. — 20.1, 20.2, 20.3

SP 2.2, 6.4, 7.2 — Phys. 1, 2

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. — 24.1, 24.5, 24.7

SP 1.4, 4.2, 5.1 — Phys. 2

3.C.4. Contact forces result from the interaction of one object touching another object and they arise from inter-atomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2). — 4.2, 4.7, 9.1, 9.2, 9.4, 14.2

SP 6.1, 6.2 — Phys. 1, 2

Enduring Understanding 3.D:

A force exerted on an object can change the momentum of the object.

3.D.1. The change in momentum of an object is a vector in the direction of the net force exerted on the object. — 9.2, 9.4

SP 4.1 — Phys. 1

3.D.2. The change in momentum of an object occurs over a time interval. — 9.2, 9.4

SP 2.1, 4.2, 5.1, 6.4 — Phys. 1

Enduring Understanding 3.E:

A force exerted on an object can change the kinetic energy of the object.

3.E.1. The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted. — 10.2, 10.3, 10.4

SP 1.4, 2.2, 6.4, 7.2 — Phys. 1

Enduring Understanding 3.F:

A force exerted on an object can cause a torque on that object.

3.F.1. Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis. — 7.3, 8.1

SP 1.4, 2.2, 2.3, 4.1, 4.2, 5.1 — Phys. 1

3.F.2. The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis. — 7.1–7.3, 7.5–7.7

SP 4.1, 4.2, 5.1, 6.4 — Phys. 1

3.F.3. A torque exerted on an object can change the angular momentum of an object. — 9.7

SP 2.1, 4.1, 4.2, 5.1, 5.3, 6.4, 7.2 — Phys. 1

Enduring Understanding 3.G:

Certain types of forces are considered fundamental.

3.G.1. Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales. — 6.6

SP 7.1 — Phys. 1, 2

3.G.2. Electromagnetic forces are exerted at all scales and can dominate at the human scale. — 20.1, 20.2

SP 7.1 — Phys. 2

3.G.3. The strong force is exerted at nuclear scales and dominates the interactions of nucleons. — 30.3

SP 7.2 — Phys. 2

BIG IDEA 4 Interactions between systems can result in changes in those systems.

Enduring Understanding 4.A: — Chapter/Section

The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.

4.A.1. The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. — 7.3

SP 1.2, 1.4, 2.3, 6.4 — Phys. 1

4.A.2. The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time. — 2.1–2.5, 4.1, 4.5, 9.4

SP 1.4, 2.2, 5.3, 6.4 — Phys. 1

4.A.3. Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system. SP 1.4, 2.2 — Phys. 1		9.4

Enduring Understanding 4.B:		
Interactions with other objects or systems can change the total linear momentum of a system.		
4.B.1. The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. SP 1.4, 2.2, 5.1	Phys. 1	9.2
4.B.2. The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted. SP 2.2, 5.1	Phys. 1	9.2–9.4

Enduring Understanding 4.C:		
Interactions with other objects or systems can change the total energy of a system.		
4.C.1. The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy. SP 1.4, 2.1, 2.2, 6.4	Phys. 1	10.1–10.9, 21.1–21.4
4.C.2. Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work. SP 1.4, 2.2, 6.4, 7.2	Phys. 1	10.1–10.3, 12.3
4.C.3. Energy is transferred spontaneously from a higher temperature system to a lower temperature system. The process through which energy is transferred between systems at different temperatures is called heat. SP 6.4	Phys. 2	12.5, 12.6, 12.8
4.C.4. Mass can be converted into energy and energy can be SP 2.2, 2.3, 7.2	Phys. 2	27.10, 30.2, 30.4

Enduring Understanding 4.D:		
A net torque exerted on a system by other objects or systems will change the angular momentum of the system.		
4.D.1. Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. SP 1.2, 1.4, 3.2, 4.1, 4.2, 5.1, 5.3	Phys. 1	7.2, 7.3, 8.1
4.D.2. The angular momentum of a system may change due to interactions with other objects or systems. SP 1.2, 1.4, 4.2	Phys. 1	9.7
4.D.3. The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted. SP 2.2, 4.1, 4.2	Phys. 1	9.7

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.		
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. SP 1.1, 1.4, 2.2	Phys. 2	24.8
4.E.2. Changing magnetic flux induces an electric field that can establish an induced emf in a system. SP 6.4	Phys. 2	25.1–25.4
4.E.3. The charge distribution in a system can be altered by the effects of electric forces produced by a charged object. SP 1.1, 1.4, 3.2, 4.1, 4.2, 5.1, 5.3, 6.4, 7.2	Phys. 2	20.1, 20.2, 22.1, 22.2
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. SP 2.2, 4.1, 4.2, 5.1, 6.4	Phys. 2	20.5, 21.7, 22.4, 22.5, 22.6
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. SP 2.2, 4.2, 5.1, 6.1, 6.4	Phys. 2	23.1–23.7

BIG IDEA 5 Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.A:		Chapter/Section
Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.		
5.A.1. A system is an object or a collection of objects. The objects are treated as having no internal structure.	Phys. 1	9.4

5.A.2. For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. — 9.4–9.7, 10.1, 20.1, 20.2, 22.1, 22.2

SP 6.4, 7.2 — Phys. 1

Enduring Understanding 5.A:

5.A.3. An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system. — 9.1–9.3, 9.7, 10.1–10.3, 10.5, 10.6, 11.2, 11.3, 11.4, 14.6, 14.7, 20.1

Phys. 1

5.A.4. The boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis. — 9.4

Phys. 1

Enduring Understanding 5.B:

The energy of a system is conserved.

5.B.1. Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects. — 10.1, 10.3

SP 1.4, 1.5, 2.2 — Phys. 1

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.]

SP 1.4, 2.1 — Phys. 1, 2

5.B.3. A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. — 10.1, 10.2, 10.4, 21.1–21.3, 22.4–22.6

SP 1.4, 2.2, 6.4, 7.2 — Phys. 1

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. — 10.1, 10.3, 10.4, 10.7, 14.4

SP 1.4, 2.1, 2.2, 6.4, 7.2 — Phys. 1, 2

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 energy transfer 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.] — 10.1–10.4, 10.10, 12.3, 22.6

SP 1.4, 2.2, 4.2, 5.1, 6.4, 7.2 — Phys. 1, 2

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. — 11.1, 11.3, 12.5–12.8

SP 1.2 — Phys. 2

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 process, isothermal process, isobaric process, adiabatic process. No calculations of heat or internal energy from temperature change; and in this course, examples of these relationships are qualitative and/or semi-quantitative. — 11.1, 11.3–11.6, 12.3

SP 1.1, 1.4, 2.2, 6.4, 7.2 — Phys. 2

5.B.8. Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei. — 28.5, 28.6

SP 1.2, 7.2 — Phys. 2

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. — 21.1, 21.2, 22.3, 22.4, 22.5, 22.6, 23.2–23.7

SP 1.1, 1.4, 1.5, 2.1, 2.2, 4.1, 4.2, 5.1, 5.3, 6.4, 7.2 — Phys. 1, 2

5.B.10. Bernoulli's equation describes the conservation of energy in fluid flow. — 13.5

SP 2.2, 6.2 — Phys. 2

5.B.11. Beyond the classical approximation, mass is actually part of the internal energy of an object or system with $E = mc^2$. — 27.10

SP 2.2, 7.2 — Phys. 2

Enduring Understanding 5.C:

The electric charge of a system is conserved.

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. — 30.4, 30.7

SP 6.4, 7.2 — Phys. 2

5.C.2. The exchange of electric charges among a set of objects in a system conserves electric charge. — 20.1, 20.2

SP 4.1, 4.2, 5.1, 6.4 — Phys. 2

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.] — 22.1, 22.2, 23.2, 23.6–23.8

SP 1.4, 2.2, 4.1, 4.2, 5.1, 6.4, 7.2 — Phys. 1, 2

Enduring Understanding 5.D:

The linear momentum of a system is conserved.

5.D.1. In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after. — 9.4, 10.9

SP 2.1, 2.2, 3.2, 4.2, 5.1, 5.3, 6.4, 7.2 — Phys. 1, 2

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. — 9.4–9.6, 10.9

SP 2.1, 2.2, 4.1, 4.2, 4.4, 5.1, 5.3, 6.4, 7.2 — Phys. 1, 2

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.] — 7.3

SP 6.4 — Phys. 1, 2

Enduring Understanding 5.E:

The angular momentum of a system is conserved.

5.E.1. If the net external torque exerted on the system is zero, the angular momentum of the system does not change. — 9.7

SP 2.1, 2.2, 6.4, 7.2 — Phys. 1

5.E.2. The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or system depends upon the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples should include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. — 9.7

SP 2.2 — Phys. 1

Enduring Understanding 5.F:

Classically, the mass of a system is conserved.

5.F.1. The continuity equation describes conservation of mass flow rate in fluids. Examples should include volume rate of flow, mass flow rate. — 13.4

SP 2.1, 2.2, 7.2 — Phys. 2

Enduring Understanding 5.G:

Nucleon number is conserved.

5.G.1. The possible nuclear reactions are constrained by the law of conservation of nucleon number. — 30.2, 30.4

SP 6.4 — Phys. 2

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: — Chapter/Section

A wave is a traveling disturbance that transfers energy and momentum.

6.A.1. Waves can propagate via different oscillation modes such as transverse and longitudinal. — 15.1, 25.5

SP 1.2, 5.1, 6.2 — Phys. 1, 2

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. — 15.1, 15.2, 15.4, 25.5

SP 6.4, 7.2 — Phys. 1, 2

6.A.3. The amplitude is the maximum displacement of a wave from its equilibrium value. — 15.3

SP 1.4 — Phys. 1

6.A.4. Classically, the energy carried by a wave depends upon and increases with amplitude. Examples should include sound waves. — 15.5, 15.6, 25.5

SP 6.4 — Phys. 1

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.

6.B.1. For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time. — 15.3, 25.5

SP 1.4, 2.2 — Phys. 1

6.B.2. For a periodic wave, the wavelength is the repeat distance of the wave. — 15.3, 25.5

SP 1.4 — Phys. 1

Enduring Understanding 6.B:

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. — 15.3, 25.5

SP 1.5 — Phys. 2

6.B.4. For a periodic wave, wavelength is the ratio of speed over frequency. — 15.3, 25.5

SP 4.2, 5.1, 7.2 — Phys. 1

6.B.5. The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only. — 15.7

SP 1.4 — Phys. 1

Enduring Understanding 6.C:

Only waves exhibit interference and diffraction.

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. — 16.1

SP 1.4, 6.4, 7.2 — Phys. 2

6.C.2. When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed. — 17.1, 17.5, 17.6, 28.1, 28.4

SP 1.4, 6.4, 7.2 — Phys. 2

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. — 17.2–17.4

SP 1.4, 6.4 — Phys. 2

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. — 17.1

SP 6.4, 7.2 — Phys. 2

Enduring Understanding 6.D:

Interference and superposition lead to standing waves and beats.

6.D.1. Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition. — 16.1

SP 1.1, 1.4, 4.2, 5.1 — Phys. 1

6.D.2. Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave. — 16.7

SP 5.1 — Phys. 1

6.D.3. Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string, and sound waves in both closed and open tubes. — 16.2–16.4

SP 1.2, 2.1, 3.2, 4.1, 4.2, 5.1, 5.2, 5.3, 6.4 — Phys. 1

6.D.4. The possible wavelengths of a standing wave are determined by the size of the region to which it is confined. — 16.2–16.4

SP 1.5, 2.2, 6.1 — Phys. 1

6.D.5. Beats arise from the addition of waves of slightly different frequency. — 16.7

SP 1.2 — Phys. 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.

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.) — 18.1

SP 6.4, 7.2 — Phys. 2

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); and this law of reflection accounts for the size and location of images seen in plane mirrors. — 18.2

SP 6.4, 7.2 — Phys. 2

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. — 18.3

SP 1.1, 1.4, 4.1, 5.1, 5.2, 5.3, 6.4, 7.2 — Phys. 2

6.E.4. The reflection of light from surfaces can be used to form images.		18.2
SP 1.4, 2.2, 3.2, 4.1, 5.1, 5.2, 5.3	Phys. 2	
6.E.5. The refraction of light as it travels from one transparent medium to another can be used to form images.		18.4, 18.5, 19.1–19.5
SP 1.4, 2.2, 3.2, 4.1, 5.1, 5.2, 5.3	Phys. 2	
Enduring Understanding 6.F:		
Electromagnetic radiation can be modeled as waves or as fundamental particles.		
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.		15.1, 15.4, 25.5
SP 6.4, 7.2	Phys. 2	
6.F.2. Electromagnetic waves can transmit energy through a medium and through a vacuum.		15.1, 15.4, 25.5
SP 1.1	Phys. 2	
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.		28.2, 28.3, 28.6
SP 6.4	Phys. 2	
6.F.4. The nature of light requires that different models of light are most appropriate at different scales.		28.3
SP 6.4, 7.1	Phys. 2	
Enduring Understanding 6.G:		
All matter can be modeled as waves or as particles.		
6.G.1. Under certain regimes of energy or distance, matter can be modeled as a classical particle.		28.4
SP 6.4, 7.1	Phys. 2	
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.		28.4
SP 6.1, 6.4	Phys. 2	

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:		Chapter/Section
The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure.		
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 or 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.		12.2
SP 1.4, 2.2, 6.4, 7.2	Phys. 2	
7.A.2. The temperature of a system characterizes the average kinetic energy of its molecules.		11.3, 12.2
SP 7.1	Phys. 2	
7.A.3. In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV = nkT$.		12.2, 12.3
SP 3.2, 4.2, 5.1, 6.4, 7.2	Phys. 2	
Enduring Understanding 7.B:		
The tendency of isolated systems to move toward states with higher disorder is described by probability.		
7.B.1. The approach to thermal equilibrium is a probability process.		11.3, 11.4, 12.5, 12.8
SP 6.2	Phys. 2	
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.		11.7
SP 7.1	Phys. 2	
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.		
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.)		28.4
SP 1.4	Phys. 2	
7.C.2. The allowed states for an electron in an atom can be calculated from the wave model of an electron.		28.4–28.6
SP 1.4	Phys. 2	
7.C.3. The spontaneous radioactive decay of an individual nucleus is described by probability.		30.1, 30.4, 30.5
SP 6.4	Phys. 2	
7.C.4. Photon emission and absorption processes are described by probability.		28.6, 29.3, 29.4, 29.7, 29.9
SP 1.1, 1.2	Phys. 2	