STRATFORD PUBLIC SCHOOLS
Stratford, Connecticut

"Tantum eruditi sunt liberi"
Only The Educated Are Free

AP Physics 2 / UConn PHYS 1202Q
Grades 11-12

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Advanced Placement Physics 2/UConn PHYS 1202Q

AP Physics 2 is the equivalent of the second semester of an introductory, non-calculus based college physics course, taught over one school year. This College Board course is co-aligned to UConn PHYS 1202Q through the UConn Early College Experience (ECE) program. The primary textbook for the course is College Physics, 7th edition 2006 by Serway/Faughn (ISBN 0-534-99723-6)

In *AP Physics 2/UConn PHYS 1202Q*, students will explore principles of fluid statics and dynamics; thermodynamics with kinetic theory; PV diagrams and probability; electrostatics; electrical circuits (DC and AC) with capacitors; magnetic fields; electromagnetism; physical and geometric optics; modern physics (quantum, atomic, and nuclear physics); and relativity. The course is based on seven Big Ideas (BI), which encompass core scientific principles, theories, and processes that cut across traditional boundaries and provide a broad way of thinking about the physical world. The following are Big Ideas:

- Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1)
- Fields existing in space can be used to explain interactions. (BI2)
- The interactions of an object with other objects can be described by forces. (BI3)
- Interactions between systems can result in changes in those systems. (BI4)
- Changes that occur as a result of interactions are constrained by conservation laws. (BI5)
- 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. (BI6)
- The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems. (BI7)

Throughout the units in this course, students will establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena, promoting an engaging and rigorous experience for AP/ECE physics students. Such Science Practices (SP) require that students:

SP1: Use representations and models to communicate scientific phenomena and solve scientific problems

1.1 The student can *create representations and models* of natural or man-made phenomena and systems in the domain.
1.2 The student can *describe representations and models* of natural or man- made phenomena and systems in the domain.
1.3 The student can *refine representations and models* of natural or man-made phenomena and systems in the domain.
1.4 The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively.
1.5 The student can *reexpress key elements of natural phenomena across multiple*

representations in the domain.

SP2: Use mathematics appropriately

2.1 The student can *justify the selection of a mathematical routine* to solve problems.

2.2 The student can *apply mathematical routines* to quantities that describe natural phenomena.

2.3 The student can *estimate numerically quantities* that describe natural phenomena.

SP3: Engage in scientific questioning to extend thinking or to guide investigations within the context of the course

3.1 The student can *pose scientific questions.*

3.2 The student can *refine scientific questions.*

3.3 The student can *evaluate scientific questions.*

SP4: Plan and implement data collection strategies in relation to a particular scientific question

4.1 The student can *justify the selection of the kind of data* needed to answer a particular scientific question.

4.2 The student can *design a plan* for collecting data to answer a particular scientific question.

4.3 The student can *collect data* to answer a particular scientific question.

4.4 The student can *evaluate sources of data* to answer a particular scientific question.

SP5: Perform data analysis and evaluation of evidence

5.1 The student can *analyze data* to identify patterns or relationships.

5.2 The student can *refine observations and measurements* based on data analysis.

5.3 The student can *evaluate the evidence provided by data sets* in relation to a particular scientific question.

SP6: Work with scientific explanations and theories

6.1 The student can *justify claims with evidence.*

6.2 The student can *construct explanations of phenomena based on evidence* produced through scientific practices.

6.3 The student can *articulate the reasons that scientific explanations and theories are refined or replaced.*

6.4 The student can *make claims and predictions about natural phenomena* based on scientific theories and models.

6.5 The student can *evaluate alternative scientific explanations*.

SP7: Connect and relate knowledge across various scales, concepts, and representations in and across domains

7.1 The student can *connect phenomena and models* across spatial and temporal scales.

7.2 The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

These Science Practices developed by the College Board parallel the eight practices of science and engineering found in the NRC's *A Science Framework for K-12 Science Education*, upon which the *Next Generation Science Standards* (NGSS) are based. The importance of combining science and engineering practices with disciplinary core ideas is stated in the Framework as follows:

> "…students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content." (NRC Framework, 2012, p. 218)

The eight practices of science and engineering that the Framework identifies as essential for all students to learn (and describes in detail in Chapter 3 of the Framework) are listed below:

- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

In this course, students will also become familiar with the three components of scientific argumentation:

1) The Claim - an explanation or prediction for what, why or how something happens
2) The Evidence – the data or reasoning that supports the claim
3) The Questioning – the process through which claims are examined and defended

Throughout the year, as a result of the scientific argumentation process, students will expected revise their claims and make revisions as appropriate to their scientific thinking. Opportunities to engage in scientific argumentation will occur during class discussions (including peer questioning), laboratory work and data analysis presentations (peer critique/questions), project write-ups and presentations (peer critique/questions), and also on in-class assessments (quizzes and tests). Students will regularly be expected to explain not only the "what's", but also the "why's" and "how's" of the content learning in this course through the sighting of both qualitative and quantitative evidence. During lab time in particular, students should expect to engage regularly in peer critique and questioning of experimental procedures, data collection and analysis, and experimental conclusions.

Students will be provided opportunities to apply the Science Practices and demonstrate growth in their scientific argumentation skills through laboratory work and projects. At least twenty-five percent of instructional time in this course is devoted to such work, with an emphasis on inquiry-based investigations that will require students to ask questions, make observations and predictions, design experiments, analyze data, and construct arguments in a collaborative setting. The objective of the course is to have students develop the skills and intuition to be able to understand physics problems and, along with mathematical reasoning, to be able to solve college-level physics problems. The lab experiments parallel and support the core concepts of the curriculum. Ultimately most of the lab experimental designs lead to the collection of data that is analyzed through graphical methods to draw conclusions about scientific phenomena, and all have written components to them. Students are expected to record their observations, data, and data analyses as part of their *Lab Portfolio*. Data analyses include identification of the sources and effects of experimental uncertainty, calculations, results and conclusions, and suggestions for further refinement of the experiment as appropriate.

The lab work in this course supports the following Common Core English Language Arts Standards in Science and Technical Subjects:

CCSS.ELA-LITERACY.RST.11-12.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

CCSS.ELA-LITERACY.RST.11-12.7
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

CCSS.ELA-LITERACY.RST.11-12.8
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

CCSS.ELA-LITERACY.RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

CCSS.ELA-LITERACY.WHST.11-12.1.B
Develop claim(s) and counterclaims fairly and thoroughly, supplying the most relevant data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form that anticipates the audience's knowledge level, concerns, values, and possible biases.

CCSS.ELA-LITERACY.WHST.11-12.1.D
Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.

CCSS.ELA-LITERACY.WHST.11-12.2
Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

CCSS.ELA-LITERACY.WHST.11-12.2.E
Provide a concluding statement or section that follows from and supports the information or explanation provided (e.g., articulating implications or the significance of the topic).

CCSS.ELA-LITERACY.WHST.11-12.4
Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

In *AP Physics 2/UConn PHYS 1202Q*, students will cultivate their understanding of Big Ideas and Science Practices as they explore the following topics:

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

* AP Physics 1 Topic #UConn PHYS 1201Q Topic

Topics that are UConn PHYS 1202Q specific will be taught as part of the course summer assignment and/or after the AP Physics 2 College Board examination. It is intended that the first semester of the course will cover thermodynamics, electrostatics, DC circuits with capacitors, magnetic fields, and induction. All students will take a common District Midterm Exam covering those units of study. The student's final grade for this course will be determined by the grading policy of the UConn Physics Department: *Course Work 75%, Final Exam 25%.* All students will take the final exam for the course provided by the UConn Physics Department. There are no final exam exemptions in this course.

References:

AP Physics 2 Course Overview; College Board; New York, NY; 2014
AP Physics 1 and AP Physics 2 Course and Exam Description Including the Curriculum Framework; College Board; New York, NY; 2014

AP Physics 2/UConn PHYS 1202Q Concepts At a Glance

(Adapted from Appendix A of The College Board's 2014 Curriculum Framework)

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.
	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.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.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.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.

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

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. This includes 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.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.
	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.
	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.
	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, and buoyant.
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.
	Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale.
	Essential Knowledge 3.G.3: The strong force is exerted at nuclear scales and dominates the interactions of nucleons.

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.

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. [This includes charged objects 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 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.
	Essential Knowledge 5.B.8: Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.
	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 $E = mc^2$.
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. [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 provided in Physics 2.
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.

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.
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.

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.
	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 $E_{photon} = hf$, 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.

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.)
	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.

Throughout the course, at least one assignment or activity outside the laboratory experience will be designed to apply learning objectives connecting across two or more enduring understandings.

Additional information about the Big Ideas, Enduring Understandings, Essential Knowledge and Learning Objectives found in the following unit plans can be found on pages 17 – 109 of the Fall 2014 edition of the College Board's *AP Physics 1 and AP Physics 2 Course and Exam Description Including the Curriculum Framework*.

Unit Name: Thermodynamics **Est. # of Weeks:** 4 weeks 1st semester

Synopsis: This is a continuation of the Thermodynamics unit taught in AP Physics 1/UConn 1201Q, designed to meet the Learning Objectives of the AP Physics 2 exam. The Learning Objectives previously taught in AP Physics 1/UConn 1201Q are reviewed as part of this unit before moving on to the concepts related to the work done in thermodynamic processes and the first and second laws of Thermodynamics, including the study of heat engines and the principles that limit their efficiency.

STUDENT LEARNING GOALS	
AP Physics Big Ideas (College Board Curriculum Framework) • Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1) • Interactions between systems can result in changes in those systems. (BI4) • Changes that occur as a result of interactions are constrained by conservation laws. (BI5) • 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. (BI6) • The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems. (BI7)	**AP Physics Enduring Understandings (College Board Curriculum Framework)** **1.A:** The internal structure of a system determines many properties of the system. **1.E:** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. **4.C:** Interactions with other objects or systems can change the total energy of a system. **5.B:** The energy of a system is conserved. **7.A:** The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure. **7.B:** The tendency of isolated systems to move toward states with higher disorder is described by probability. **Key Vocabulary** Textbook Ch 10 – 12 absolute temperature absolute zero adiabatic Avagadro's number boil Boltzmann's constant calorie Carnot cycle condense conduction convection entropy freeze fusion gas heat ideal gas internal energy irreversible isobaric

	isothermal isovolumetric kelvin kinetic energy kinetic theory of gases latent heat laws of thermodynamics (zeroth, 1st, and 2nd) liquid melt molar mass mole phase change plasma pressure radiation reversible root-mean-square speed solid specific heat thermal conductivity thermal contact thermal equilibrium universal gas constant vaporization work

AP Physics Essential Knowledge (College Board Curriculum Framework)	**Guiding Questions (College Board Course Planning Guides)**
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*. **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. **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. 1. Conduction, convection, and radiation are mechanisms for this energy transfer. 2. At a microscopic scale the mechanism of conduction is the transfer of kinetic energy between particles.	How do we know thermal energy is transferred or exchanged? How is the expansion of a gas related to mechanical work? How is the law of conservation of energy applied to the understanding of the laws of thermodynamics? What are the implications of the second law of thermodynamics?

3. During average collisions between molecules, kinetic energy is transferred from faster molecules to slower molecules. **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. **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. 1. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy. 2. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system. **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. **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. **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. **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. **7.A.2:** The temperature of a system characterizes the average kinetic energy of its molecules. 1. The average kinetic energy of the system is an average over the many different speeds of the molecules in the system that can be described by a distribution curve. 2. The root mean square speed corresponding to the average kinetic energy for a specific gas at a given temperature can be obtained from this distribution. **7.A.3:** In an ideal gas, the macroscopic (average)	

pressure *(P)*, temperature *(T)*, and volume *(V)* are related by the equation $PV = nRT$. **7.B.1:** The approach to thermal equilibrium is a probability process. 1. The amount of thermal energy needed to change the temperature of a system of particles depends both on the mass of the system and on the temperature change of the system. 2. The details of the energy transfer depend upon interactions at the molecular level. 3. Since higher momentum particles will be involved in more collisions, energy is most likely to be transferred from higher to lower energy particles. The most likely state after many collisions is that both systems of particles have the same temperature. **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. 1. Entropy, like temperature, pressure, and internal energy, is a state function whose value depends only on the configuration of the system at a particular instant and not on how the system arrived at that configuration. 2. Entropy can be described as a measure of the disorder of a system or of the unavailability of some system energy to do work. 3. The entropy of a closed system never decreases, i.e., it can stay the same or increase. 4. The total entropy of the universe is always increasing.	

AP Physics Learning Objectives (College Board Curriculum Framework)

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**]

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.

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**]

4.C.3.1:
The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level.[See **Science Practice 6.4**]

5.B.2.1:
The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system.

5.B.4.1:
The student is able to describe and make predictions about the internal energy of systems. [See **Science Practices 6.4 and 7.2**]

5.B.4.2:
The student is able to calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [See **Science Practices 1.4**, **2.1**, **and 2.2**]

5.B.5.1:
The student is able to design an experiment and analyze data to examine how a force exerted on an object or system does work on the object or system as it moves through a distance. [See **Science Practices 4.2 and 5.1**]
5.B.5.4:
The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). [See **Science Practices 6.4 and 7.2**]
5.B.5.5:
The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. [See **Science Practices 2.2 and 6.4**]
5.B.5.6:
The student is able to design an experiment and analyze graphical data in which interpretations of the area under a pressure-volume curve are needed to determine the work done on or by the object or system. [See **Science Practices 4.2 and 5.1**]
5.B.6.1:
The student is able to describe the models that represent processes by which energy can be transferred between a system and its environment because of differences in temperature: conduction, convection, and radiation. [See **Science Practice 1.2**]
5.B.7.1:
The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving transfer of energy due to heat or work done and justify those predictions in terms of conservation of energy principles.
5.B.7.2:
The student is able to create a plot of pressure versus volume for a thermodynamic process from given data. [See **Science Practice 1.1**]
5.B.7.3:
The student is able to use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics). [See **Science Practices 1.1**, **1.4**, **and 2.2**]
7.A.1.1:
The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system. [See **Science Practices 6.4 and 7.2**]
7.A.1.2:
Treating a gas molecule as an object (i.e., ignoring its internal structure), the student is able to analyze qualitatively the collisions with a container wall and determine the cause of pressure and at thermal equilibrium to quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables.
7.A.2.1:
The student is able to qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. [See **Science Practice 7.1**]
7.A.2.2:
The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes. [See **Science Practice 7.1**]
7.A.3.1:
The student is able to extrapolate from pressure and temperature or volume and temperature data to make the prediction that there is a temperature at which the pressure or volume extrapolates to zero. [See **Science Practices 6.4 and 7.2**]
7.A.3.2:
The student is able to design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and amount of an ideal gas, and to refine a scientific question concerning a proposed incorrect relationship between the variables. [See **Science Practices 3.2 and 4.2**]
7.A.3.3:
The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law $PV = nRT$. [See **Science Practice 5.1**]
7.B.1.1:
The student is able to construct an explanation, based on atomic-scale interactions and probability, of how a system approaches thermal equilibrium when energy is transferred to it or from it in a thermal process.
7.B.2.1:
The student is able to connect qualitatively the second law of thermodynamics in terms of the state function called entropy and how it (entropy) behaves in reversible and irreversible processes.

ASSESSMENT PLAN	
Summative Assessment(s) • Teacher designed quizzes and unit test aligned to Essential Knowledge • Midterm (Common District Exam) • UCONN PHYS 1201 Q Exit Exam (to be provided each year by UConn Physics Department)	**Formative and Diagnostic Assessment(s)** • AP Physics 2 practice exam • Teacher designed homework problem sets

Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment)

States of Matter PhET Simulation Lab (if not completed during AP Physics 1/UConn 1201Q)
Specific Heat Lab (if not completed during AP Physics 1/UConn 1201Q)
Heat of Fusion of Ice Lab (if not completed during AP Physics 1/UConn 1201Q)
Gas Laws PhET Simulation Lab (if not completed during AP Physics 1/UConn 1201Q)
Thermal Conductivity Lab

LEARNING PLAN COMPONENTS

➢ Identify those components that the district expects will provide the basis for major learning activities in the lesson designs that staff create:
- Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6
- Reference textbooks: College-level textbooks as selected by teacher
- AP Central – AP Physics 2 Course Homepage Resources
- Quest Learning and Assessment, Minds On Physics, and/or other similar online homework submission site
- PhET Interactive Simulations https://phet.colorado.edu

Unit Name: Electrostatics **Est. # of Weeks:** 4 weeks 1st semester

<table>
<tr><td colspan="2">Synopsis: Topics covered in AP Physics 1/UConn PHYS 1201Q are expanded upon in this unit. Methods of charging are introduced, as is the concept of an electric field. Because the Coulomb force is conservative, we can define electric potential energy corresponding to that force. The concept of electric potential – the potential energy per unit of charge – corresponds to the electric field.</td></tr>
<tr><td colspan="2">STUDENT LEARNING GOALS</td></tr>
<tr><td>AP Physics Big Ideas (College Board Curriculum Framework)
• Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1)

• Fields existing in space can be used to explain interactions. (BI2)

• The interactions of an object with other objects can be described by forces. (BI3)

• Interactions between systems can result in changes in those systems. (BI4)

• Changes that occur as a result of interactions are constrained by conservation laws. (BI5)</td>
<td>AP Physics Enduring Understandings (College Board Curriculum Framework)
1.A: The internal structure of a system determines many properties of the system.
1.B: Electric charge is
a property of an object or system that affects its interactions with other objects or systems containing charge.
1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
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.
2.C: An electric field is caused by an object with electric charge.
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.
3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $\mathbf{a} = \mathbf{F}/m$.
3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
3.G: Certain types of forces are considered fundamental.
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.
5.B: The energy of a system is conserved.
5.C: The electric charge of a system is conserved.

Key Vocabulary
➢
conduction
conductor
coulomb
Coulomb constant
Coulomb's law
electric charge
electric dipole
electric field
electric field lines
electric potential
electric potential difference
electric potential energy
electron
electron volt
electrostatic equilibrium
elementary charge</td></tr>
</table>

	equipotential line equipotential surface equivalent capacitance induction insulator isoline negative charge neutral neutron permittivity of free space polarization positive charge proton quantization superposition volt

AP Physics Essential Knowledge (College Board Curriculum Framework)	**Guiding Questions (College Board Course Planning Guides)**
1.A.2: Fundamental particles have no internal structure. 1. Electrons, neutrinos, photons, and quarks are examples of fundamental particles. 2. Neutrons and protons are composed of quarks. 3. 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. **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*. **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. **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. 4. Like-charged objects and systems repel, and unlike- charged objects and systems attract. 5. Charged objects or systems may attract neutral systems by changing the distribution of charge in the neutral system. **1.B.3:** The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.	How can the charge model be used to explain electric phenomena? How can electric charge interactions be explained with an electric field model? How can we visualize the electric field and electric potential produced by a charge configuration? How does the change of electric potential determine the movement of charges?

6. The magnitude of the elementary charge is equal to 1.6 x 10^{-19} coulombs. 7. 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. **1.E.4:** Matter has a property called electric permittivity. 8. Free space has a constant value of the permittivity that appears in physical relationships. 9. The permittivity of matter has a value different from that of free space. **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. 10. Vector fields are represented by field vectors indicating direction and magnitude. 11. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition. 12. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources. **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. 13. Scalar fields are represented by field values. 14. When more than one source object with mass or charge is present, the scalar field value can be determined by scalar addition. 15. Conversely, a known scalar field can be used to make inferences about the number, relative size, and location of sources. **2.C.1:** The magnitude of the electric force **F** exerted on an object with electric charge *q* by an electric field **E** is **F** = *q***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. **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.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.

a. The inverse square relation known as Coulomb's law gives the magnitude of the electric field at a distance *r* from the center of a source object of electric charge *Q* as $E = [1/(4 \bullet \bullet_o)][Q/r^2]$
b. This relation is based on a model of the space surrounding a charged source object by considering the radial dependence of the area of the surface of a sphere centered on the source object.

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.

a. When an object is small compared to the distances involved in the problem, or when a larger object is being modeled as a large number of very small constituent particles, these can be modeled as charged objects of negligible size, or "point charges."
b. The expression for the electric field due to a point charge can be used to determine the electric field, either qualitatively or quantitatively, around a simple, highly symmetric distribution of point charges.

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.

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.]

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

a. An isoline map of electric potential can be constructed from an electric field vector map, using the fact that the isolines are perpendicular to the electric field vectors.
b. Since the electric potential has the same

value along an isoline, there can be no component of the electric field along the isoline. **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. **3.A.2:** Forces are described by vectors. a. Forces are detected by their influence on the motion of an object. b. Forces have magnitude and direction. **3.A.3:** A force exerted on an object is always due to the interaction of that object with another object. a. An object cannot exert a force on itself. b. Even though an object is at rest, there may be forces exerted on that object by other objects. c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects. **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. **3.B.1:** If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. **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. a. An object can be drawn as if it was extracted from its environment and the interactions with the environment identified. b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force. c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free- body diagram to the algebraic representation. **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. a. Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension. b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved. **3.G.1:** Gravitational forces are exerted at all scales and	

dominate at the largest distance and mass scales. **3.G.2:** Electromagnetic forces are exerted at all scales and can dominate at the human scale. **4.E.3:** The charge distribution in a system can be altered by the effects of electric forces produced by a charged object. a. Charging can take place by friction or by contact. b. An induced charge separation can cause a neutral object to become polarized. c. Charging by induction can occur when a polarizing conducting object is touched by another. d. In solid conductors, some electrons are mobile. When no current flows, mobile charges are in static equilibrium, excess charge resides at the surface, and the interior field is zero. In solid insulators, excess (fixed) charge may reside in the interior as well as at the surface. **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. [Includes charged object in electric fields and examining changes in internal energy with changes in configuration.] **5.C.2:** The exchange of electric charges among a set of objects in a system conserves electric charge. a. Charging by conduction between objects in a system conserves the electric charge of the entire system. b. Charge separation in a neutral system can be induced by an external charged object placed close to the neutral system. c. Grounding involves the transfer of excess charge to another larger system (e.g., the Earth).	

AP Physics Learning Objectives (College Board Curriculum Framework)

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**]
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**]
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**]
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**]
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**]

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**]
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**]
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**]
2.C.1.1:
The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\mathbf{F} = q\mathbf{E}$; a vector relation. [See **Science Practices 6.4 and 7.2**]
2.C.1.2:
The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities. [See **Science Practice 2.2**]
2.C.2.1:
The student is able to qualitatively and semiquantitatively apply the vector relationship between the electric field and the net electric charge creating that field. [See **Science Practices 2.2 and 6.4**]
2.C.3.1:
The student is able to explain the inverse square dependence of the electric field surrounding a spherically symmetric electrically charged object. [See **Science Practice 6.2**]
2.C.4.1:
The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field. [See **Science Practices 2.2**, **6.4**, **and 7.2**]
2.C.4.2:
The student is able to apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (2–4) of point charges, and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points.
[See **Science Practices 1.4 and 2.2**]
2.C.5.1:
The student is able to create representations of the magnitude and direction of the electric field at various distances (small compared to plate size) from two electrically charged plates of equal magnitude and opposite signs and is able to recognize that the assumption of uniform field is not appropriate near edges of plates. [See **Science Practices 1.1 and 2.2**]
2.C.5.2:
The student is able to calculate the magnitude and determine the direction of the electric field between two electrically charged parallel plates, given the charge of each plate, or the electric potential difference and plate separation. [See **Science Practice 2.2**]
2.C.5.3:
The student is able to represent the motion of an electrically charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in the Earth's gravitational field.
[See **Science Practices 1.1**, **2.2**, **and 7.1**]
2.E.1.1:
The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential. [See **Science Practices 1.4**, **6.4**, **and 7.2**]
2.E.2.1:
The student is able to determine the structure of isolines of electric potential by constructing them in a given electric field.
[See **Science Practices 6.4 and 7.2**]
2.E.2.2:
The student is able to predict the structure of isolines of electric potential by constructing them in a given electric field and make connections between these isolines and those found in a gravitational field. [See **Science Practices 6.4 and 7.2**]
2.E.2.3:
The student is able to qualitatively use the concept of isolines to construct isolines of electric potential in an electric field and determine the effect of that field on electrically charged objects. [See **Science Practice 1.4**]

2.E.3.1:
The student is able to apply mathematical routines to calculate the average value of the magnitude of the electric field in a region from a description of the electric potential in that region using the displacement along the line on which the difference in potential is evaluated. [See **Science Practice 2.2**]
2.E.3.2:
The student is able to apply the concept of the isoline representation of electric potential for a given electric charge distribution to predict the average value of the electric field in the region. [See **Science Practices 1.4 and 6.4**]
3.A.2.1:
The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See **Science Practice 1.1**]
3.A.3.2:
The student is able to challenge a claim that an object can exert a force on itself. [See **Science Practice 6.1**]
3.A.3.3:
The student is able to describe a force as an interaction between two objects and identify both objects for any force. [See **Science Practice 1.4**]
3.A.3.4:
The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge. [See **Science Practices 6.1 and 6.4**]
3.A.4.1:
The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [See **Science Practices 1.4 and 6.2**]
3.A.4.2:
The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [See **Science Practices 6.4 and 7.2**]
3.A.4.3:
The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [See **Science Practice 1.4**]
3.B.1.3:
The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See **Science Practices 1.5 and 2.2**]
3.B.1.4:
The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See **Science Practices 6.4 and 7.2**]
3.B.2.1:
The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
3.C.2.1:
The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). [See **Science Practices 2.2 and 6.4**]
3.C.2.2:
The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [See **Science Practice 7.2**]
3.C.2.3:
The student is able to use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situations of high symmetry). [See **Science Practice 2.2**]
3.G.1.2 :
The student is able to connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength to other types of forces. [See **Science Practice 7.1**]
3.G.2.1:
The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [See **Science Practice 7.1**]
4.E.3.1:
The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction. [See **Science Practice 6.4**]
4.E.3.2:

The student is able to make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. [See **Science Practices 6.4 and 7.2**]
4.E.3.3:
The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [See **Science Practices 1.1**, **1.4**, **and 6.4**]
4.E.3.4:
The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors that predicts charge distribution in processes involving induction or conduction. [See **Science Practices 1.1**, **1.4**, **and 6.4**]
4.E.3.5:
The student is able to explain and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or is able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure. [See **Science Practices 3.2**, **4.1**, **4.2**, **5.1**, **and 5.3**]
5.B.2.1:
The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [See **Science Practices 1.4 and 2.1**]
5.C.2.1:
The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system. [See **Science Practice 6.4**]
5.C.2.2:
The student is able to design a plan to collect data on the electrical charging of objects and electric charge induction on neutral objects and qualitatively analyze that data. [See **Science Practices 4.2 and 5.1**]
5.C.2.3:
The student is able to justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects. [See **Science Practice 4.1**]

ASSESSMENT PLAN

Summative Assessment(s)	Formative and Diagnostic Assessment(s)
• Teacher designed quizzes and unit test aligned to Essential Knowledge • UConn PHYS 1202 Q Exit Exam (to be provided each year by UConn Physics Department)	• AP Physics 1 practice exam (previous course) • AP Physics 2 practice exam • Teacher designed homework problem sets

Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment)

Electroscope Lab (if not completed during AP Physics 1/UConn 1201Q)
Scotch Tape Lab (if not completed during AP Physics 1/UConn 1201Q)
Tin Can Race
E-Field PhET Simulation Lab
Equipotential Line Lab
Capacitor Lab

LEARNING PLAN COMPONENTS

➢ Identify those components that the district expects will provide the basis for major learning activities in the lesson designs that staff create:
- Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6
- Reference textbooks: College-level textbooks as selected by teacher
- AP Central – AP Physics 2 Course Homepage Resources
- Quest Learning and Assessment, Minds On Physics, and/or other similar online homework submission site
- PhET Interactive Simulations https://phet.colorado.edu

Unit Name: Electric Current and Circuits **Est. # of Weeks:** 4 weeks 1st semester

<table>
<tr><td colspan="2">Synopsis: Topics covered in AP Physics 1/UConn PHYS 1201Q are expanded upon in this unit. Energy and charge conservation are used to examine more complex circuits (both series and parallel), including those with capacitors (in series and parallel, limited to an open circuit, just after circuit is closed, and a long time after the circuit is closed). The direction of electric current in braches is explored.</td></tr>
<tr><th colspan="2">STUDENT LEARNING GOALS</th></tr>
<tr><td>AP Physics Big Ideas (College Board Curriculum Framework)
• Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1)

• Interactions between systems can result in changes in those systems. (BI4)

• Changes that occur as a result of interactions are constrained by conservation laws. (BI5)</td><td>AP Physics Enduring Understandings (College Board Curriculum Framework)

1.B: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.
1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
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.
5.B: The energy of a system is conserved.
5.C: The electric charge of a system is conserved.

Key Vocabulary

ammeter
ampere
battery
capacitance
capacitor
circuit
dielectric
dielectric constant
electric current
electric potential
electric potential difference
electric power
electromotive force
equivalent resistance
farad
Kirchoff's laws: junction rule and loop rule
nonohmic
ohm
ohmic
ohmmeter
parallel
parallel-plate capacitor
resistance
resistivity
resistor
series</td></tr>
</table>

	temperature coefficient of resistivity volt voltage voltmeter

AP Physics Essential Knowledge (College Board Curriculum Framework)	**Guiding Questions (College Board Course Planning Guides)**
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. **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. **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. a. The resistance of a resistor is proportional to its length and inversely proportional to its cross-sectional area. The constant of proportionality is the resistivity of the material. b. The capacitance of a parallel plate capacitor is proportional to the area of one of its plates and inversely proportional to the separation between its plates. The constant of proportionality is the product of the dielectric constant, •, of the material between the plates and the electric permittivity, $\bullet_o$ c. The current through a resistor is equal to the potential difference across the resistor divided by its resistance. d. The magnitude of charge of one of the plates of a parallel plate capacitor is directly proportional to the product of the potential difference across the capacitor and the capacitance. The plates have equal amounts of charge of opposite sign. **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. **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.] a. Energy changes in simple electrical circuits are conveniently represented in terms of	What produces resistance and why are there resistors and conductors? How do conservation laws apply to electric circuits? How is the behavior of an electric circuit determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors?

energy change per charge moving through a battery and a resistor. b. Since electric potential difference times charge is energy, and energy is conserved, the sum of the potential differences about any closed loop must add to zero. c. The electric potential difference across a resistor is given by the product of the current and the resistance. d. The rate at which energy is transferred from a resistor is equal to the product of the electric potential difference across the resistor and the current through the resistor. e. Energy conservation can be applied to combinations of resistors and capacitors in series and parallel circuits. [Physics 2 only] **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. [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.]	

AP Physics Learning Objectives (College Board Curriculum Framework)

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**]

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**]

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**]

4.E.4.1:
The student is able to make predictions about the properties of resistors and/or capacitors when placed in a simple circuit based on the geometry of the circuit element and supported by scientific theories and mathematical relationships.
[See **Science Practices 2.2 and 6.4**]

4.E.4.2:
The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors.
[See **Science Practices 4.1 and 4.2**]

4.E.4.3:
The student is able to analyze data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. [See **Science Practice 5.1**]

4.E.5.1:
The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See **Science Practices 2.2 and 6.4**]

4.E.5.2:
The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See **Science Practices 6.1 and 6.4**]

4.E.5.3:
The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential

differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [See **Science Practices 2.2**, **4.2**, **and 5.1**]

5.B.9.4:
The student is able to analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff 's loop rule. [See **Science Practice 5.1**]

5.B.9.5:
The student is able to use conservation of energy principles (Kirchhoff 's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [See **Science Practice 6.4**]

5.B.9.6:
The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See **Science Practices 2.1 and 2.2**]

5.B.9.7:
The student is able to refine and analyze a scientific question for an experiment using Kirchhoff 's loop rule for circuits that includes determination of internal resistance of the battery and analysis of a nonohmic resistor.
[See **Science Practices 4.1**, **4.2**, **5.1**, **and 5.3**]

5.B.9.8:
The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [See **Science Practice 1.5**]

5.C.3.4:
The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff 's junction rule and relate the rule to the law of charge conservation. [See **Science Practices 6.4 and 7.2**]

5.C.3.5:
The student is able to determine missing values and direction of electric current in branches of a circuit with resistors and NO capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [See **Science Practices 1.4 and 2.2**]

5.C.3.6:
The student is able to determine missing values and direction of electric current in branches of a circuit with both resistors and capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [See **Science Practices 1.4 and 2.2**]

5.C.3.7:
The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit.
[See **Science Practices 1.4 and 2.2**]

ASSESSMENT PLAN

Summative Assessment(s)

- Teacher designed quizzes and unit test aligned to Essential Knowledge
- UConn PHYS 1202 Q Exit Exam (to be provided each year by UConn Physics Department)

Formative and Diagnostic Assessment(s)

- AP Physics 1 practice exam (previous course)
- AP Physics 2 practice exam
- Teacher designed homework problem sets

Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment)
Quantitative Circuits Lab
Complex Circuits Lab

LEARNING PLAN COMPONENTS

➢ Identify those components that the district expects will provide the basis for major learning activities in the lesson designs that staff create:

- Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6
- Reference textbooks: College-level textbooks as selected by teacher
- AP Central – AP Physics 1 Course Homepage Resources
- Quest Learning and Assessment, Minds On Physics, and/or other similar online homework submission site
- PhET Interactive Simulations https://phet.colorado.edu

Unit Name: Magnetism/Electromagnetic Induction **Est. # of Weeks:** 5 weeks 1st semester

Synopsis: The unit explores concepts related to magnets and magnetic fields, including the underlying unity of electricity and magnetism and the symmetry of these two phenomena. Ampere's Law, Faraday's Law, and Lenz's Law are each explored.

STUDENT LEARNING GOALS

AP Physics Big Ideas (College Board Curriculum Framework)	**AP Physics Enduring Understandings (College Board Curriculum Framework)**
• Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1) • Fields existing in space can be used to explain interactions. (BI2) • The interactions of an object with other objects can be described by forces. (BI3) • Interactions between systems can result in changes in those systems. (BI4)	**1.E:** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. **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. **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. **3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.B:** Classically, the acceleration of an object interacting with other objects can be predicted by using $\mathbf{a} = \mathbf{F}/m$. **3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **3.G:** Certain types of forces are considered fundamental. **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. **Key Vocabulary** cyclotron equation diamagnetic Faraday's law of induction ferromagnetic generator induced current induced emf Lenz's law magnet magnetic dipole moment magnetic domain magnetic field magnetic field line magnetic flux magnetic induction magnetic pole motional emf motor north pole paramagnetic permeability of free space

	right-hand rule south pole tesla weber

AP Physics Essential Knowledge (College Board Curriculum Framework)	Guiding Questions (College Board Course Planning Guides)
1.E.5: Matter has a property called magnetic permeability. 1. Free space has a constant value of the permeability that appears in physical relationships. 2. The permeability of matter has a value different from that of free space. **1.E.6:** Matter has a property called magnetic dipole moment. 1. Magnetic dipole moment is a fundamental source of magnetic behavior of matter and an intrinsic property of some fundamental particles such as the electron. 2. Permanent magnetism or induced magnetism of matter is a system property resulting from the alignment of magnetic dipole moments within the system. **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. 1. Vector fields are represented by field vectors indicating direction and magnitude. 2. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition. 3. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources. **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. **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. 1. The magnitude of the magnetic field is proportional to the magnitude of the current in a long straight wire. 2. The magnitude of the field varies inversely with distance from the wire, and the direction of the field can be determined by a right-hand	How can we describe a magnetic field? How does a magnetic field influence the movement of charged particles? How can changing magnetic flux produce an electric potential?

rule. **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. 1. A simple magnetic dipole can be modeled by a current in a loop. The dipole is represented by a vector pointing through the loop in the direction of the field produced by the current as given by the right-hand rule. 2. A compass needle is a permanent magnetic dipole. Iron filings in a magnetic field become induced magnetic dipoles. 3. All magnets produce a magnetic field. Examples should include magnetic field pattern of a bar magnet as detected by iron filings or small compasses. 4. Earth has a magnetic field. **2.D.4:** Ferromagnetic materials contain magnetic domains that are themselves magnets. 1. Magnetic domains can be aligned by external magnetic fields or can spontaneously align. 2. Each magnetic domain has its own internal magnetic field, so there is no beginning or end to the magnetic field — it is a continuous loop. 3. If a bar magnet is broken in half, both halves are magnetic dipoles in themselves; there is no magnetic north pole found isolated from a south pole. **3.A.2:** Forces are described by vectors. 1. Forces are detected by their influence on the motion of an object. 2. Forces have magnitude and direction. **3.A.3:** A force exerted on an object is always due to the interaction of that object with another object. 1. An object cannot exert a force on itself. 2. Even though an object is at rest, there may be forces exerted on that object by other objects. 3. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects. **3.B.1:** If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. **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. 1. An object can be drawn as if it was extracted from its environment and the interactions with the environment identified. 2. A force exerted on an object can be represented as an arrow whose length	

represents the magnitude of the force and whose direction shows the direction of the force.

3. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free- body diagram to the algebraic representation.

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.

1. Magnetic dipoles have north and south polarity.
2. The magnetic dipole moment of an object has the tail of the magnetic dipole moment vector at the south end of the object and the head of the vector at the north end of the object.
3. In the presence of an external magnetic field, the magnetic dipole moment vector will align with the external magnetic field.
4. The force exerted on a moving charged object is perpendicular to both the magnetic field and the velocity of the charge and is described by a right-hand rule.

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

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.

1. Ferromagnetic materials can be permanently magnetized by an external field that causes the alignment of magnetic domains or atomic magnetic dipoles.
2. Paramagnetic materials interact weakly with an external magnetic field in that the magnetic dipole moments of the material do not remain aligned after the external field is removed.
3. All materials have the property of diamagnetism in that their electronic structure creates a (usually) weak alignment of the dipole moments of the material opposite to the external magnetic field.

4.E.2: Changing magnet flux induces an electric field that can establish an induced emf in a system.

1. Changing magnetic flux induces an emf in a system, with the magnitude of the induced emf equal to the rate of change in magnetic flux.
2. When the area of the surface being considered is constant, the induced emf is the area multiplied by the rate of change in the component of the magnetic field perpendicular to the surface.
3. When the magnetic field is constant, the induced emf is the magnetic field multiplied

by the rate of change in area perpendicular to the magnetic field. 4. The conservation of energy determines the direction of the induced emf relative to the change in the magnetic flux.	

AP Physics Learning Objectives (College Board Curriculum Framework)

2.D.1.1:
The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [See **Science Practice 2.2**]

2.D.2.1:
The student is able to create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires. [See **Science Practice 1.1**]

2.D.3.1:
The student is able to describe the orientation of a magnetic dipole placed in a magnetic field in general and the particular cases of a compass in the magnetic field of the Earth and iron filings surrounding a bar magnet. [See **Science Practice 1.2**]

2.D.4.1:
The student is able to use the representation of magnetic domains to qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material. [See **Science Practice 1.4**]

3.A.2.1:
The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.

3.A.3.2:
The student is able to challenge a claim that an object can exert a force on itself. [See **Science Practice 6.1**]

3.A.3.3:
The student is able to describe a force as an interaction between two objects and identify both objects for any force. [See **Science Practice 1.4**]

3.B.1.3:
The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See **Science Practices 1.5 and 2.2**]

3.B.1.4:
The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See **Science Practices 6.4 and 7.2**]

3.B.2.1:
The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See **Science Practices 1.1**, **1.4**, **and 2.2**]

3.C.3.1:
The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current- carrying conductor. [See **Science Practice 1.4**]

3.C.3.2:
The student is able to plan a data collection strategy appropriate to an investigation of the direction of the force on a moving electrically charged object caused by a current in a wire in the context of a specific set of equipment and instruments and analyze the resulting data to arrive at a conclusion. [See **Science Practices 4.2 and 5.1**]

3.G.2.1:
The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [See **Science Practice 7.1**]

4.E.1.1:
The student is able to use representations and models to qualitatively describe the magnetic properties of some materials that can be affected by magnetic properties of other objects in the system. [See **Science Practices 1.1**, **1.4**, **and 2.2**]

4.E.2.1:
The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [See **Science Practice 6.4**]

ASSESSMENT PLAN	
Summative Assessment(s) • Teacher designed quizzes and unit test aligned to Essential Knowledge • UConn PHYS 1202 Q Exit Exam (to be provided each year by UConn Physics Department)	**Formative and Diagnostic Assessment(s)** • AP Physics 2 practice exam • Teacher designed homework problem sets
Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment) Magnetic Field Mapping Lab Homo-polar Motor Lab AP Physics 2 Sample Lab #1	

LEARNING PLAN COMPONENTS
➢ Identify those components that the district expects will provide the basis for major learning activities in the lesson designs that staff create: • Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6 • Reference textbooks: College-level textbooks as selected by teacher • AP Central – AP Physics 2 Course Homepage Resources • Quest Learning and Assessment, Minds On Physics, and/or other similar online homework submission site • PhET Interactive Simulations https://phet.colorado.edu

Unit Name: Fluids **Est. # of Weeks:** 3 weeks 2nd semester

Synopsis: This unit covers topics related to density, pressure, Pascal's and Archimedes' principals, and fluids in motion. This unit is required content for UConn Physics 1201Q and AP Physics 2, thus is will be taught in both the first and second year AP Physics courses. In AP Physics 1/UConn 1201Q this unit was covered after the AP Physics 1 (since the content was specific to UConn 1201Q) to the level sufficient to meet the assessment criteria of the UConn 1201Q Final Exam provided that year by the UConn Physics Department. It is assumed that the content will be covered in more depth in this course to meet the AP Physics 2 exam requirements.

STUDENT LEARNING GOALS

AP Physics Big Ideas (College Board Curriculum Framework)

• Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1)

• The interactions of an object with other objects can be described by forces. (BI3)

• Changes that occur as a result of interactions are constrained by conservation laws. (BI5)

AP Physics Enduring Understandings (College Board Curriculum Framework)

1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using **a** = **F**/*m*.
3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
5.B: The energy of a system is conserved.
5.F: Classically, the mass of a system is conserved.

Key Vocabulary

apparent weight
Archimedes' principle
barometer
Bernoulli's equation
buoyancy
continuity equation
density
fluid
gas
liquid
pascal
Pascal's principle
pressure

AP Physics Essential Knowledge (College Board Curriculum Framework)

1.E.1: Matter has a property called density.
3.A.2: Forces are described by vectors.
1. Forces are detected by their influence on the motion of an object.
2. Forces have magnitude and direction.

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.
1. An object can be drawn as if it was extracted from its environment and the interactions with

Guiding Questions (College Board Course Planning Guides)

Why does liquid pressure vary with depth when gas pressure does not?

How does Archimedes' principle help us to understand why certain objects float in fluids?

How can conservation of mass and conservation of energy be used to predict the behavior of moving liquids?

the environment identified. 2. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force. 3. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free- body diagram to the algebraic representation. **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, and buoyant. **5.B.10:** Bernoulli's equation describes the conservation of energy in fluid flow. **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.	

AP Physics Learning Objectives (College Board Curriculum Framework)

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**]

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**]

3.A.2.1:
The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [See **Science Practice 4.2**]

3.B.2.1:
The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See **Science Practices 1.1**, **1.4**, **and 2.2**]

3.C.4.1:
The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. [See **Science Practice 6.1**]

3.C.4.2:
The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [See **Science Practice 6.2**]

5.B.10.1:
The student is able to use Bernoulli's equation to make calculations related to a moving fluid. [See **Science Practice 2.2**]

5.B.10.2:
The student is able to use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid. [See **Science Practice 2.2**]

5.B.10.3:
The student is able to use Bernoulli's equation and the continuity equation to make calculations related to a moving fluid. [See **Science Practice 2.2**]

5.B.10.4:
The student is able to construct an explanation of Bernoulli's equation in terms of the conservation of energy. [See **Science Practice 6.2**]

5.F.1.1:
The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [See **Science Practices 2.1**, **2.2**, **and 7.2**]

ASSESSMENT PLAN

Summative Assessment(s)	**Formative and Diagnostic Assessment(s)**
• Teacher designed quizzes and unit test aligned to Essential Knowledge	• AP Physics 2 practice exam • Teacher designed homework problem sets

	• UConn 1201Q Exit Exam given previous year

Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment)
Buoyancy Lab (if not completed during AP Physics 1/UConn 1201Q)
Balloons and Buoyancy PhET Simulation Lab
Flow Rate PhET Simulation Lab

LEARNING PLAN COMPONENTS

- Identify those components that the district expects will provide the basis for major learning activities in the lesson designs that staff create:
  - Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6
  - Reference textbooks: College-level textbooks as selected by teacher
  - AP Central – AP Physics 2 Course Homepage Resources
  - Quest Learning and Assessment, Minds On Physics, and/or other similar online homework submission site
  - PhET Interactive Simulations https://phet.colorado.edu

Unit Name: Light and Optics Est. # of Weeks: 5 weeks 2nd semester

Synopsis: This unit builds upon knowledge of wave behavior first learned in AP Physics 1, with students differentiating between electromagnetic waves (light) and mechanical waves (sound). The dual nature of light is introduced. While the study of the formation of images by lenses and mirrors (geometric optics) is done through the application of ray approximation (i.e. light travels in straight lines), students will learn that the phenomena of light interference, diffraction, and polarization can't adequately be explained with ray optics, but can be understood using the wave model of light.

STUDENT LEARNING GOALS

AP Physics Big Ideas (College Board Curriculum Framework)	**AP Physics Enduring Understandings (College Board Curriculum Framework)**
• 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. (BI6)	**6.A:** A wave is a traveling disturbance that transfers energy and momentum. **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.C:** Only waves exhibit interference and diffraction. **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.F:** Electromagnetic radiation can be modeled as waves or as fundamental particles.
	Key Vocabulary absorption concave constructive interference converging convex critical angle destructive interference diffraction grating diverging Doppler effect double-slit interference electromagnetic spectrum electromagnetic wave flat/plane mirror focal length focal point frequency gamma ray height Huygens' principle image index of refraction infrared radiation intensity inverted lateral magnification law of Malus

	law of reflection lens light linear polarized magnified medium microwaves mirror/thin-lens equation normal object order number pathlength pathlength difference phase polarization polarizer principle axis radio waves radius of curvature ray approximation ray diagram real reduced reflection refraction single-slit diffraction Snell's law of refraction spherical mirror thin film total internal reflection transmission transmission axis ultraviolet radiation unpolarized upright virtual wavelength x-ray
AP Physics Essential Knowledge (College Board Curriculum Framework) **6.A.1:** Waves can propagate via different oscillation modes such as transverse and longitudinal. 1. Mechanical waves can be either transverse or longitudinal. Examples should include waves	**Guiding Questions (College Board Course Planning Guides)** How are waves an energy transport phenomena? How can we explore wave boundary behavior?

on a stretched string and sound waves. 2. Electromagnetic waves are transverse waves. 3. Transverse waves may be polarized. **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. **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. **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. **6.C.2:** When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed. **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. **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. **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.) **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. **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. 1. Snell's law relates the angles of incidence and refraction to the indices of refraction, with the ratio of the indices of refraction inversely proportional to the ratio of the speeds of propagation in the two media. 2. When light travels from an optically slower substance into an optically faster substance, it bends away from the perpendicular. 3. At the critical angle, the light bends far enough away from the perpendicular that it skims the surface of the material. 4. Beyond the critical angle, all of the light is internally reflected. **6.E.4:** The reflection of light from surfaces can be used	How do the basic optic phenomena of reflection and refraction explain the formation of images by mirrors and lenses? How does light interference demonstrate the wave nature of light?

to form images.

1. Ray diagrams are very useful for showing how and
   where images of objects are formed for different mirrors and how this depends upon the placement of the object. Concave and convex mirror examples should be included.
2. They are also useful for determining the size of the resulting image compared to the size of the object.
3. Plane mirrors, convex spherical mirrors, and concave spherical mirrors are part of this course. The construction of these ray diagrams and comparison with direct experiences are necessary.

6.E.5: The refraction of light as it travels from one transparent medium to another can be used to form images.

a. Ray diagrams are used to determine the relative size of object and image, the location of object and image relative to the lens, the focal length, and the real or virtual nature of the image. Converging and diverging lenses should be included as examples.

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.

6.F.2: Electromagnetic waves can transmit energy through a medium and through a vacuum.

1. Electromagnetic waves are transverse waves composed of mutually perpendicular electric and magnetic fields that can propagate through a vacuum.
2. The planes of these transverse waves are both perpendicular to the direction of propagation.

AP Physics Learning Objectives (College Board Curriculum Framework)

6.A.1.2:
The student is able to describe representations of transverse and longitudinal waves. [See **Science Practice 1.2**]

6.A.1.3:
The student is able to analyze data (or a visual representation) to identify patterns that indicate that a particular wave is polarized and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation. [See **Science Practices 5.1 and 6.2**]

6.A.2.2:
The student is able to contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. [See **Science Practices 6.4 and 7.2**]

6.B.3.1:
The student is able to construct an equation relating the wavelength and amplitude of a wave from a graphical representation of the electric or magnetic field value as a function of position at a given time instant and vice versa, or construct an equation relating the frequency or period and amplitude of a wave from a graphical representation of the electric or magnetic field value at a given position as a function of time and vice versa. [See **Science Practice 1.5**]

6.C.1.1:
The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. [See **Science Practices 6.4 and 7.2**]
6.C.1.2:
The student is able to construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [See **Science Practice 1.4**]
6.C.2.1:
The student is able to make claims about the diffraction pattern produced when a wave passes through a small opening and to qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. [See **Science Practices 1.4**, **6.4**, **and 7.2**]
6.C.3.1:
The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small, but larger than the wavelength. [See **Science Practices 1.4 and 6.4**]
6.C.4.1:
The student is able to predict and explain, using representations and models, the ability or inability of waves to transfer energy around corners and behind obstacles in terms of the diffraction property of waves in situations involving various kinds of wave phenomena, including sound and light. [See **Science Practices 6.4 and 7.2**]
6.E.1.1:
The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [See **Science Practices 6.4 and 7.2**]
6.E.2.1:
The student is able to make predictions about the locations of object and image relative to the location of a reflecting surface. The prediction should be based on the model of specular reflection with all angles measured relative to the normal to the surface. [See **Science Practices 6.4 and 7.2**]
6.E.3.1:
The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. [See **Science Practices 1.1 and 1.4**]
6.E.3.2:
The student is able to plan data collection strategies as well as perform data analysis and evaluation of the evidence for finding the relationship between the angle of incidence and the angle of refraction for light crossing boundaries from one transparent material to another (Snell's law). [See **Science Practices 4.1**, **5.1**, **5.2**, **and 5.3**]
6.E.3.3:
The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [See **Science Practices 6.4 and 7.2**]
6.E.4.1:
The student is able to plan data collection strategies and perform data analysis and evaluation of evidence about the formation of images due to reflection of light from curved spherical mirrors. [See **Science Practices 3.2**, **4.1**, **5.1**, **5.2**, **and 5.3**]
6.E.4.2:
The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the reflection of light from surfaces. [See **Science Practices 1.4 and 2.2**]
6.E.5.1:
The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the refraction of light through thin lenses. [See **Science Practices 1.4 and 2.2**]
6.E.5.2:
The student is able to plan data collection strategies, perform data analysis and evaluation of evidence, and refine scientific questions about the formation of images due to refraction for thin lenses. [See **Science Practices 3.2**, **4.1**, **5.1**, **5.2**, **and 5.3**]
6.F.1.1:
The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [See **Science Practices 6.4 and 7.2**]
6.F.2.1:
The student is able to describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. [See **Science Practice 1.1**]

ASSESSMENT PLAN

Summative Assessment(s)	Formative and Diagnostic Assessment(s)
• Teacher designed quizzes and unit test aligned to Essential Knowledge • UConn PHYS 1202 Q Exit Exam (to be provided each year by UConn Physics Department)	• AP Physics 2 practice exam • Teacher designed homework problem sets

Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment)

Snell's Law Lab
Plane (Flat) Mirror Lab
Lens Lab
AP Physics 2 Sample Lab #2

LEARNING PLAN COMPONENTS

- Identify those components that the district expects will provide the basis for major learning activities in the lesson designs that staff create:
  - Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6
  - Reference textbooks: College-level textbooks as selected by teacher
  - AP Central – AP Physics 2 Course Homepage Resources
  - Quest Learning and Assessment, Minds On Physics, and/or other similar online homework submission site
  - PhET Interactive Simulations https://phet.colorado.edu

Unit Name: Modern Physics **Est. # of Weeks:** 5 weeks 2^{nd} semester

Synopsis: This unit explores the underlying ideas of quantum theory and the wave/particle nature of both light and matter. The hydrogen atom is examined from the viewpoint of quantum mechanics and the quantum numbers that characterize various atomic states. The basic properties and structure of the atomic nucleus is introduced. Radioactivity, nuclear reactions, and nuclear decay processes are explored.

STUDENT LEARNING GOALS

AP Physics Big Ideas (College Board Curriculum Framework)	**AP Physics Enduring Understandings (College Board Curriculum Framework)**
• Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1) • The interactions of an object with other objects can be described by forces. (BI3) • Interactions between systems can result in changes in those systems. (BI4) • Changes that occur as a result of interactions are constrained by conservation laws. (BI5) • 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. (BI6) • The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems. (BI7)	**1.A:** The internal structure of a system determines many properties of the system. **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.D:** Classical mechanics cannot describe all properties of objects. **3.G:** Certain types of forces are considered fundamental. **4.C:** Interactions with other objects or systems can change the total energy of a system. **5.B:** The energy of a system is conserved. **5.C:** The electric charge of a system is conserved. **5.D:** The linear momentum of a system is conserved. **5.G:** Nucleon number is conserved. **6.F:** Electromagnetic radiation can be modeled as waves or as fundamental particles. **6.G:** All matter can be modeled as waves or as particles. **7.C:** At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world. **Key Vocabulary** absorption alpha particle atomic number beta particle binding energy Bohr model for energy levels Compton effect de Broglie wavelength decay constant decay rate emission endothermic reaction equivalence of mass and energy ether excited state exothermic reaction fission fusion gamma ray ground state

	half-life ionization energy isotope length contraction mass number neutrino neutron number nuclear force nuclear reaction nucleus photoelectric effect photoelectron photon Planck's constant positron probability quantum number quark radioactivity special relativity spontaneous emission stimulated absorption stimulated emission stopping potential time dilation unified atomic mass unit wave function work function

AP Physics Essential Knowledge (College Board Curriculum Framework)	**Guiding Questions (College Board Course Planning Guides)**
1.A.2: Fundamental particles have no internal structure. 1. Electrons, neutrinos, photons, and quarks are examples of fundamental particles. 2. Neutrons and protons are composed of quarks. 3. 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. **1.A.3:** Nuclei have internal structures that determine their properties. 1. The number of protons identifies the element. 2. The number of neutrons together with the number of protons identifies the isotope. 3. There are different types of radioactive	What unsolved problems in classical physics led to the development of quantum mechanics? How are the concepts of momentum and energy in collisions applied to the scattering of photons by electrons? How are mass–energy equivalence and charge and nucleon conservation laws applied to nuclear reactions? What are the major implications of the theory of relativity?

emissions from the nucleus. 4. The rate of decay of any radioactive isotope is specified by its half-life. **1.A.4:** Atoms have internal structures that determine their properties. 1. The number of protons in the nucleus determines the number of electrons in a neutral atom. 2. The number and arrangements of electrons cause elements to have different properties. 3. 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). 4. Discrete energy state transitions lead to spectra. **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*. **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. **1.D.1:** Objects classically thought of as particles can exhibit properties of waves. 1. This wavelike behavior of particles has been observed, e.g., in a double-slit experiment using elementary particles. 2. The classical models of objects do not describe their wave nature. These models break down when observing objects in small dimensions. **1.D.2:** Certain phenomena classically thought of as waves can exhibit properties of particles. 1. The classical models of waves do not describe the nature of a photon. 2. Momentum and energy of a photon can be related to its frequency and wavelength. **1.D.3:** Properties of space and time cannot always be treated as absolute. 1. 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. 2. Measurements of length and time depend on speed. (Qualitative treatment only.) **3.G.1:** Gravitational forces are exerted at all scales and	

dominate at the largest distance and mass scales. **3.G.2:** Electromagnetic forces are exerted at all scales and can dominate at the human scale. **3.G.3:** The strong force is exerted at nuclear scales and dominates the interactions of nucleons. **4.C.4:** Mass can be converted into energy, and energy can be converted into mass. 1. Mass and energy are interrelated by $E = mc^2$. 2. Significant amounts of energy can be released in nuclear processes. **5.B.8:** Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei. 1. Transitions between two given energy states of an atom correspond to the absorption or emission of a photon of a given frequency (and hence, a given wavelength). 2. An emission spectrum can be used to determine the elements in a source of light. **5.B.11:** Beyond the classical approximation, mass is actually part of the internal energy of an object or system with $E = mc^2$. a. $E = mc^2$ can be used to calculate the mass equivalent for a given amount of energy transfer or an energy equivalent for a given amount of mass change (e.g., fission and fusion reactions). **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. **5.D.1:** In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after. 1. In an isolated system, the linear momentum is constant throughout the collision. 2. In an isolated system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision. **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. 1. In an isolated system, the linear momentum is constant throughout the collision. 2. In an isolated system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision. **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] 1. The center of mass of a system depends upon the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change. 2. When objects in a system collide, the velocity	

of the center of mass of the system will not change unless an external force is exerted on the system. **5.G.1:** The possible nuclear reactions are constrained by the law of conservation of nucleon number. **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. 1. In the quantum model of electromagnetic radiation, the energy is emitted or absorbed in discrete energy packets called photons. Discrete spectral lines should be included as an example. 2. For the short-wavelength portion of the electromagnetic spectrum, the energy per photon can be observed by direct measurement when electron emissions from matter result from the absorption of radiant energy. 3. Evidence for discrete energy packets is provided by a frequency threshold for electron emission. Above the threshold, maximum kinetic energy of the emitted electrons increases with the frequency and not the intensity of absorbed radiation. The photoelectric effect should be included as an example. **6.F.4:** The nature of light requires that different models of light are most appropriate at different scales. 1. The particle-like properties of electromagnetic radiation are more readily observed when the energy transported during the time of the measurement is comparable to E_{photon} . 2. The wavelike properties of electromagnetic radiation are more readily observed when the scale of the objects it interacts with is comparable to or larger than the wavelength of the radiation. **6.G.1:** Under certain regimes of energy or distance, matter can be modeled as a classical particle. **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. 1. A wave model of matter is quantified by the de Broglie wavelength that increases as the momentum of the particle decreases. 2. The wave property of matter was experimentally confirmed by the diffraction of electrons in the experiments of Clinton Joseph Davisson, Lester Germer, and George Paget Thomson. **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.) **7.C.2:** The allowed states for an electron in an atom can be calculated from the wave model of an electron. 1. The allowed electron energy states of an atom are modeled as standing waves. Transitions between these levels, due to emission or absorption of photons, are observable as discrete spectral lines. 2. The de Broglie wavelength of an electron can be calculated from its momentum, and a wave representation can be used to model discrete transitions between energy states as transitions between standing waves. **7.C.3:** The spontaneous radioactive decay of an individual nucleus is described by probability. 1. In radioactive decay processes, we cannot predict when any one nucleus will undergo a change; we can only predict what happens on the average to a large number of identical nuclei. 2. In radioactive decay, mass and energy are interrelated, and energy is released in nuclear processes as kinetic energy of the products or as electromagnetic energy. 3. The time for half of a given number of radioactive nuclei to decay is called the half-life. 4. Different unstable elements and isotopes have vastly different half-lives, ranging from small fractions of a second to billions of years. **7.C.4:** Photon emission and absorption processes are described by probability. 1. An atom in a given energy state may absorb a photon of the right energy and move to a higher energy state (stimulated absorption). 2. An atom in an excited energy state may jump spontaneously to a lower energy state with the emission of a photon (spontaneous emission). 3. Spontaneous transitions to higher energy states have a very low probability but can be stimulated to occur. Spontaneous transitions to lower energy states are highly probable. 4. When a photon of the right energy interacts with an atom in an excited energy state, it may stimulate the atom to make a transition to a lower energy state with the emission of a photon (stimulated emission). In this case, both photons have the same energy and are in phase and moving in the same direction.	
AP Physics Learning Objectives (College Board Curriculum Framework) **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**]
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**]
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**]
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**]
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**]
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**]
3.G.1.2 :
The student is able to connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength to other types of forces. [See **Science Practice 7.1**]
3.G.2.1:
The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [See **Science Practice 7.1**]
3.G.3.1:
The student is able to identify the strong force as the force that is responsible for holding the nucleus together. [See **Science Practice 7.2**]
4.C.4.1:
The student is able to apply mathematical routines to describe the relationship between mass and energy and apply this concept across domains of scale. [See **Science Practices 2.2**, **2.3**, **and 7.2**]
5.B.8.1:
The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed. [See **Science Practices 1.2 and 7.2**]
5.B.11.1:
The student is able to apply conservation of mass and conservation of energy concepts to a natural phenomenon and use the equation $E = mc^2$ to make a related calculation. [See **Science Practices 2.2 and 7.2**]
5.C.1.1:
The student is able to analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge. [See **Science Practices 6.4 and 7.2**]
5.D.1.6:
The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. [See **Science Practice 6.4**]
5.D.1.7:
The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [See **Science Practices 2.1 and 2.2**]
5.D.2.5:
The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [See **Science Practices 2.1 and 2.2**]

5.D.2.6:
The student is able to apply the conservation of linear momentum to an isolated system of objects involved in an inelastic collision to predict the change in kinetic energy. [See **Science Practices 6.4 and 7.2**]
5.D.3.2:
The student is able to make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. [See **Science Practice 6.4**]
5.D.3.3:
The student is able to make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. [See **Science Practice 6.4**]
5.G.1.1:
The student is able to apply conservation of nucleon number and conservation of electric charge to make predictions about nuclear reactions and decays such as fission, fusion, alpha decay, beta decay, or gamma decay. [See **Science Practice 6.4**]
6.F.3.1:
The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. [See **Science Practice 6.4**]
6.F.4.1:
The student is able to select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. [See **Science Practices 6.4 and 7.1**]
6.G.1.1:
The student is able to make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. [See **Science Practices 6.4 and 7.1**]
6.G.2.1:
The student is able to articulate the evidence supporting the claim that a wave model of matter is appropriate to explain the diffraction of matter interacting with a crystal, given conditions where a particle of matter has momentum corresponding to a de Broglie wavelength smaller than the separation between adjacent atoms in the crystal. [See **Science Practice 6.1**]
6.G.2.2:
The student is able to predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima) based upon the particle speed and de Broglie wavelength of electrons in an electron beam interacting with a crystal. (de Broglie wavelength need not be given, so students may need to obtain it.) [See **Science Practice 6.4**]
7.C.1.1:
The student is able to use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region. [See **Science Practice 1.4**]
7.C.2.1:
The student is able to use a standing wave model in which an electron orbit circumference is an integer multiple of the de Broglie wavelength to give a qualitative explanation that accounts for the existence of specific allowed energy states of an electron in an atom. [See **Science Practice 1.4**]
7.C.3.1:
The student is able to predict the number of radioactive nuclei remaining in a sample after a certain period of time, and also predict the missing species (alpha, beta, gamma) in a radioactive decay. [See **Science Practice 6.4**]
7.C.4.1:
The student is able to construct or interpret representations of transitions between atomic energy states involving the emission and absorption of photons. [For questions addressing stimulated emission, students will not be expected to recall the details of the process, such as the fact that the emitted photons have the same frequency and phase as the incident photon; but given a representation of the process, students are expected to make inferences such as figuring out from energy conservation that since the atom loses energy in the process, the emitted photons taken together must carry more energy than the incident photon.] [See **Science Practices 1.1 and 1.2**]

ASSESSMENT PLAN

Summative Assessment(s)	**Formative and Diagnostic Assessment(s)**
• Teacher designed quizzes and unit test aligned to Essential Knowledge • UConn PHYS 1202 Q Exit Exam (to be provided each year by UConn Physics Department)	• AP Physics 2 practice exam • Teacher designed homework problem sets

Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment)
Plank's Constant Lab
Photoelectric Effect PhET Simulation Lab

Alpha and/or Beta Decay PhET Simulation Lab
Davisson-Germer Electron Diffraction PhET Simulation Lab

LEARNING PLAN COMPONENTS

- Identify those components that the district expects will provide the basis for major learning activities in the lesson designs that staff create:
  - Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6
  - Reference textbooks: College-level textbooks as selected by teacher
  - AP Central – AP Physics 2 Course Homepage Resources
  - Quest Learning and Assessment, Minds On Physics, and/or other similar online homework submission site
  - PhET Interactive Simulations https://phet.colorado.edu

Unit Name: AC Circuits **Est. # of Weeks:** 2 weeks 2nd semester

Synopsis: This topic is specific to UConn Physics 1202Q and will be taught after the AP Physics 2 exam to the level necessitated by the exit exam provided by the UConn Physics department. The study of AC circuits begins by examining the characteristics of a circuit containing a source of emf and one other circuit element: a resistor, a capacitor, or an inductor. Then circuits where combinations of these elements are connected in series are examined. Applications of AC circuits to long-distance electric power transmission are explored through the study of transformers.

STUDENT LEARNING GOALS

AP Physics Big Ideas (College Board Curriculum Framework)

• Objects and systems have properties such as mass and charge. Systems may have internal structure. (BI1)

• Interactions between systems can result in changes in those systems. (BI4)

• Changes that occur as a result of interactions are constrained by conservation laws. (BI5)

AP Physics Enduring Understandings (College Board Curriculum Framework)

1.B: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.
1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.
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.
5.B: The energy of a system is conserved.
5.C: The electric charge of a system is conserved.

Key Vocabulary

Emf
Faraday's law
henry
impedance
inductance
inductor
mutual inductance (*M*)
primary
reactance
resonance
root-mean-square (rms)
secondary
self inductance (*L*)
time constant (τ)
transformer

Essential Knowledge

1202Q.1: When the current in a coil changes with time, an emf is induced in the coil according to Faraday's law. This self-induced emf is defined by the expression $\xi = -L\ \Delta I/\Delta t$.

1202Q.2: The inductance from a coil can be found from the expression $L = N\phi_B/I$.

1202Q.3: If a resistor and inductor are connected in series to a battery and a switch is closed at t=0, the current in the circuit doesn't rise instantly to its maximum value. After one time constant $\tau = L/R$, the current in the circuit is 63.2% of its final value ξ/R. As the current approaches its maximum value, the voltage drop across the inductor approaches zero.

Guiding Questions

What qualitative effect does the presence of a capacitor have upon the transient behavior of a circuit which also contains batteries, resistors, and a switch?

In what manner do inductors and capacitors behave like resistors, when driven with a sinusoidal voltage source?

What analogies may be drawn between inductors and masses?

What ramifications does conservation of power have upon the design of a national power-delivery system?

1202Q.4: In an AC circuit consisting of a generator and a resistor, the current in the circuit is in phase with the voltage.

1202Q.5: The rms voltage across a resistor is related to the rms current in the resistor by Ohm's Law

1202Q.6: In an AC circuit consisting of a generator and a capacitor, the voltage lags behind the current by 90 degrees, thus reaching its maximum ¼ of a period after the current reaches its maximum

1202Q.7: In an AC circuit consisting of a generator and an inductor, the voltage leads the current by 90 degrees, thus reaching its maximum ¼ of a period before the current reaches its maximum

1202Q.8: In an *RLC* series AC circuit, the maximum applied voltage is related to the maximum voltage across the resistor, capacitor, and inductor by $\sqrt{[\Delta V_r^2 + (\Delta V_L - \Delta V_c)^2]}$

1202Q.9: In an AC circuit consisting of a resistor, and inductor, and a capacitor connected in series, the limit placed on the current is given by the impedance *Z* of the circuit.

1202Q.10: The relationship between the maximum voltage supplied to an *RLC* series AC circuit and the maximum current in the circuit is $\Delta V_{max} = I_{max}Z$

1202Q.11: In an *RLC* series AC circuit, the applied rms voltage and current are out of phase by a phase angle ϕ

1202Q.12: The average power delivered by the voltage source in *RLC* series AC circuit is $P_{avg} = I_{rms}\Delta V_{rms}\cos\phi$

1202Q.13: In an *RLC* circuit the current has its maximum value when the impedance has its minimum value. The frequency at which this happens is called the resonance frequency of the circuit

1202Q.14: If the primary winding of a transformer has N_1 turns, then if an input AC voltage ΔV_1 is applied to the primary, the induced voltage in the secondary winding is given by $\Delta V_2 = (N_2/N_1)\Delta V_1$

AP Physics Learning Objectives

LO1: The student can explain the process of self-inductance and its relationship to inductance, and perform quantitative calculations of each

LO2: The student can qualitatively and quantitatively describe an RL circuit and calculate a time constant, relating it to current

LO3: The student is able to explain the characteristics of alternating current and how it is generated

LO4: The student is able to demonstrate an understanding of the difference between AC and DC circuits through written expression of ideas and quantitative calculations related to voltage, current, and power.

LO5: The student is able to explain the purpose of step-up and step-down transformers and perform related calculations

ASSESSMENT PLAN	
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Possible Laboratory Work (teacher to select from list based on individual needs, facility, and equipment) *RLC* Series AC Circuit Lab	

LEARNING PLAN COMPONENTS

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  - Primary textbook: Serway/Faughn (2006). College Physics, 7th ed. Thomson Brooks/Cole. ISBN 0-534-99723-6
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