

PUBLIC SCHOOLS OF EDISON TOWNSHIP
OFFICE OF CURRICULUM AND INSTRUCTION



AP Physics 2

Length of Course:	Term
Elective/Required:	Elective/Required
Schools:	High School
Eligibility:	Grade 12
Credit Value:	7 Credits
Date Approved:	August 25, 2014 (Curriculum) August 15, 2023 (Credit Value)

TABLE OF CONTENTS

Statement of Purpose	3
Unit 1: Thermodynamics	4
Unit 2: Fluids	10
Unit 3: Electrostatics and Circuits	13
Unit 4: Magnetism	27
Unit 5: Geometric and Physical Optics	37
Unit 6: Quantum Physics, Atomic, and Nuclear Physics	39

Modifications will be made to accommodate IEP mandates for classified students.

STATEMENT OF PURPOSE

The AP Physics 2 curriculum was written in accordance to College Board requirements. The course is designed to be the equivalent of the first semester college algebra-based physics course.

The course covers fluid mechanics; thermodynamics; electricity and magnetism; optics; and atomic and nuclear physics. The course is focused on a series of learning objectives that clarify the knowledge and skills students should demonstrate to qualify for college credit and placement. Each learning objective combines physics content with one or more of seven foundational science practices.

- The student can use representations and models to communicate scientific phenomena and solve scientific problems.
- The student can use mathematics appropriately.
- The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
- The student can plan and implement data collection strategies in relation to a particular scientific question.
- The student can perform data analysis and evaluation of evidence.
- The student can work with scientific explanations and theories.
- The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.)

The curriculum guide was created by:

William McMullen (JPS)
Kruthi Singh (EHS).

Science Supervisors: Hope Benson and Laurie Maier

Unit One -Thermodynamics	Pacing: 4 Weeks
Big Ideas: 1. Objects and systems have properties such as mass and charge. Systems may have internal structure. 4. Interactions between systems can result in changes in those systems. 5. Changes that occur as a result of interactions are constrained by conservation laws. 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 Understandings: 1E Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up materials. 4C Interactions with other objects or systems can change the total energy of a system. 5B The energy of a system is conserved. 7A 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.	
Targeted Next Generation Science Standards and/or Common Core Standards: HS-PS: 3-5	

Learning Objectives (should reference College Board Framework)	Essential Knowledge <i>What students will know.</i>	Activities/Strategies Technology Implementation/ Interdisciplinary Connections
Temperature: LO 4.C.3.1 (SP 6.4) The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level.	4.C.3.: Energy is transferred from spontaneously from a high temperature system to a lower temperature system. The process through which energy is transferred between systems at different temperatures is called heat.	Thermodynamics – Energy Transfer (100 min) Use the Electrical Equivalent of Heat basic apparatus to design an experiment to determine the electrical equivalent of heat. Discuss how energy loss to the environment was limited.
LO 5.B.6.1 (SP 1.2) 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	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	Thermodynamics – Ideal Gas Equation (100 min) Guided-Inquiry [CR6b] Use the pressure/volume syringe or the Pasco pressure/volume interface to design an experiment related to the ideal gas equation.

LO 7.A.3.1 (SP 6.4 and 7.2) 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. Pressure: LO 7.A.1.1 (SP 6.4 and 7.2) 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. LO 7.A.1.2 (SP 1.4 and 2.2) 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.3.: In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV=nkT$. 7.A.1.: The pressure of the system determines the force the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just on the walls of the container	Thermodynamics – Thermal Conductivity (50 min) Select a material and design an experiment to determine its thermal conductivity.
Heat and Energy: LO 4.C.3.1 (SP 6.4) The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction.	4.C.3.: Energy is transferred from spontaneously from a high temperature system to a lower temperature system. The process through which energy is transferred between systems at different temperatures is called heat	
LO 5.B.6.1 (SP 1.2) 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.	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	

Ideal Gases:

LO 7.A.3.1 (SP 6.4 and 7.2) 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.

LO 7.A.3.2 (SP 3.2 and 4.2) 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.

LO 7.A.3.3 (SP 5.1) 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 $PV = nRT$.

Kinetic Theory:

LO 7.A.2.1 (SP 7.1) The student is able to qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system.

LO 7.A.2.2 (SP 7.1) The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic

Laws of Thermodynamics:

LO 5.B.7.1 (SP 6.4 and 7.2) 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.

7.A.3.: In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV=nkT$.

7.A.2.: The temperature of a system characterizes the average kinetic energy of its molecules.

5.B.7.: The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams – isovolumetric process, isothermal process, isobaric process, adiabatic process. No calculations of heat or internal energy from temperature change; and in

Entropy: LO 7.B.2.1 (SP 7.1) 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 PV Diagrams: LO 5.B.7.2 (SP 1.1) The student is able to create a plot of pressure versus volume for a thermodynamic process from given data. LO 5.B.7.3 (SP 1.1, 1.4, and 2.2) 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). LO 5.B.5.6 (SP 4.2 and 5.1) 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	this course, examples of these relationships are qualitative and/or semi-quantitative. 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. 5.B.7.: The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams – isovolumetric process, - isothermal process, isobaric process, adiabatic process. No calculations of heat or internal energy from temperature change; and in this course, examples of these relationships are qualitative and/or semi-quantitative. 5.B.6.: Energy can be transferred by thermal processes involving differences in temperature;
---	---

work done on or by the object or system. Probability and Thermal Equilibrium: LO 7.B.1.1 (SP 6.2) 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. Activities: LO 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: <i>conduction, convection, and radiation.</i> [SP 1.2] LO 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. [SP 3.2 and 4.2] LO 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 $PV = nRT$. [SP 5.1] LO 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-	the amount of energy transferred in this process of transfer is called heat. 7.B.1.: The approach to thermal equilibrium is a probability process. 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 7.A.3.: In an ideal gas, the macroscopic (average) pressure (P), temperature (T) and volume (V), are related to $PV=nkT$ 5.B.5.: Energy can be transferred by an external force exerted on an object or
---	--

volume curve are needed to determine the work done on or by the object or system. [SP 4.2 and 5.1] LO 1.E.3.1: The student is able to design an experiment and analyze data from it to examine thermal conductivity. [SP 4.1, 4.2, 5.1]	system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. ¹ .E.3.: Matter has a property called thermal conductivity	
Assessment Check Points (What is the authentic evidence that students have achieved the targeted standards/unit objectives? Formative, Summative and Performance Based) Formative Assessments: Diagnostic re- and post-assessments, class discussions, worksheets with teacher feedback, drafts of lab reports with teacher feedback Summative Assessments: Quizzes, tests, performance assessments/laboratory investigations, research/lab reports		
Resources: Essential Materials, Supplementary Materials, Links to Best Practices Giancoli, Douglas C. <u>Physics Principles with Applications</u>. AP Edition Seventh Edition, Pearson Prentice Hall, 2014	Instructional Adjustments: Modifications, student difficulties, possible misunderstandings	

Unit Two: Fluids		Pacing: 3 Weeks
Big Ideas: 1. Objects and systems have properties such as mass and charge. Systems may have internal structure. 3. The interactions of an object with other objects can be described by forces. 5. Changes that occur as a result of interactions are constrained by conservation laws.		
Enduring Understandings: 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.C. At the macroscopic level, forces can be categorized as either long range forces or contact forces. 5.B. The energy of a system is conserved. 5.F. Classically, the mass of a system is conserved.		
Targeted Next Generation Science Standards and/or Common Core Standards: HS-PS: 1-1, 3-1, 3-2, 3-3		

Learning Objectives (should reference College Board Framework)	Essential Knowledge <i>What students will know.</i>	Activities/Strategies Technology Implementation/ Interdisciplinary Connections
Hydrostatic Pressure and Pascal's Principle: LO 5.B.10.1 (SP 2.2) The student is able to use Bernoulli's equation to make calculations related to a moving fluid.	5.B.10.: Bernoulli's equation describes the conservation of energy in fluid flow.	Fluids – Static Fluids (100 min) Guided-Inquiry [CR6b] Design an experiment that uses fluid pressure to determine the density of an unknown oil.
Buoyancy (Archimedes' Principle): LO 3.C.4.1 (SP 6.1) The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. LO 3.C.4.2 SP 6.2) The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from	3.C.4.: Contact forces result from the interactions of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, spring and buoyant.	Fluids – Static Fluids (100 min) Using the balanced forces on a hovering helium-filled balloon, determine the density of helium.

interatomic electric forces and that they therefore have certain directions. Fluid Flow Continuity: LO 5.F.1.1 (SP 2.1, 2.2, and 7.2) The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). Conservation of Energy and Bernoulli's Principle: LO 5.B.10.1 (SP 2.2) The student is able to use Bernoulli's equation to make calculations related to a moving fluid. LO 5.B.10.2 (SP 2.2) 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 LO 5.B.10.3 (SP 2.2) The student is able to use Bernoulli's equation and the continuity equation to make calculations related to a moving fluid. LO 5.B.10.4 (SP 6.2) The student is able to construct an explanation of Bernoulli's equation in terms of the conservation of energy Activities: LO 1.E.1.2: The student is able to select from experimental data the information necessary to determine	5.F.1.: The continuity equation describes conservation of mass flow rate in fluids. Examples should include rate of flow, mass rate of flow. 5.B.10.: Bernoulli's equation describes the conservation of energy in fluid flow. 1.E.1.: Matter has property called density.	
--	---	--

the density of an object and/or compare densities of several objects. [SP 4.1 and 6.4] LO1.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. [SP 4.2 and 6.4] LO 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. [SP 4.1 and 6.4] LO 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. [SP 1.1]	3.A.2.: Forces are described by vectors.	
Assessment Check Points (What is the authentic evidence that students have achieved the targeted standards/unit objectives? Formative, Summative and Performance Based) Formative Assessments: Diagnostic re- and post-assessments, class discussions, worksheets with teacher feedback, drafts of lab reports with teacher feedback Summative Assessments: Quizzes, tests, performance assessments/laboratory investigations, research/lab reports		
Resources: Essential Materials, Supplementary Materials, Links to Best Practices Giancoli, Douglas C. <u>Physics Principles with Applications</u>, AP Edition Seventh Edition, Pearson Prentice Hall, 2014		Instructional Adjustments: Modifications, student difficulties, possible misunderstandings

Unit 3: Electrostatics and Circuits		Pacing: 13 Weeks
Big Ideas: 1. Objects and systems have properties such as mass and charge. Systems may have internal structure. 2. Fields existing in space can be used to explain interactions. 3. The interactions of an object with other objects can be described by forces. 4. Interactions between systems can result in changes in those systems. 5. Changes that occur as a result of interactions are constrained by conservation laws. Enduring Understandings: 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 others or systems containing charge. 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 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. 4.E. The electric and magnetic properties of a system can change in response to the presence of, or charges in, other objects or systems 5.B. The energy of a system is conserved. 5.C. The electric charge of a system is conserved. Targeted Next Generation Science Standards and/or Common Core Standards: HS-PS: 2-4, 2-5, 3-5		

Learning Objectives (should reference College Board Framework)	Essential Knowledge <i>What students will know.</i>	Activities/Strategies Technology Implementation/ Interdisciplinary Connections
Elementary Charges and Fundamental Particles: LO 1.A.2.1 (SP 1.1 and 7.1) 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.	1.A.2.: Fundamental particles have no internal structure.	Electricity – Charge Transfer (50 min) Guided-Inquiry [CR6b] Design an experiment to determine the type of charge on a surface, using a process involving at least two steps. Electricity - Equipotentials and Fields (100 min) Mapping Equipotentials and Electric Fields. Electricity – Circuits (50 min) "What's Watt?" Teacher led examination of bulbs in series and parallel circuits.

LO 1.A.5.2 (SP 1.1, 1.4, and 7.1) The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures. LO 1.B.2.1 (SP 6.2) The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. LO 1.B.2.2 (SP 6.4 and 7.2) 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. LO 1.B.2.3 (SP 6.1) 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. LO 1.B.3.1 (SP 1.5, 6.1, and 7.2) The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. Charging and Redistribution of Charge: LO 4.E.3.1 (SP 6.4) The student is able to make predictions about the	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 <i>object</i>. 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. 1.B.3.: The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge. 4.E.3.: The charge distribution in a system can be altered by the effects of electric	Electricity – Circuits (100 min) Guided-Inquiry [CR6b] Design an experiment to determine the internal resistance of a battery. Electricity – Capacitors (100 min) Guided-Inquiry [CR6b] Design an experiment to test the marked value of capacitance for a capacitor. Background should include derivation of the mathematical functions and analysis of the graphical relationships for potential difference, charge, and current as functions of time. Electricity – Circuits (100 min) Guided-Inquiry [CR6b] Circuit Boards and Breadboards: Design an Experiment to Qualitatively Compare Components in Different Arrangements in Series and Parallel. Electricity/Magnetism – Induction (50 min) Guided-Inquiry [CR6b] Measuring Input and Output Current and Voltage for a Small Transformer.
---	--	---

redistribution of charge during charging by friction, conduction, and induction. LO 4.E.3.2 (SP 6.4 and 7.2) 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. LO 4.E.3.3 (SP 1.1, 1.4, and 6.4) The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. LO 4.E.3.4 (SP 1.1, 1.4, and 6.4) 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. LO 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. Electric Force and Electric Field: LO 2.C.1.1 (SP 6.4 and 7.2) 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	forces produced by a charged object. 5.C.2.: The exchange of electric charges among a set of objects in a system conserves electric charge. 2.C.1.: The magnitude of the electric force F exerted on an object with electric charge q by an electric field E is $F=qE$. 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
--	---

electric field: $F=qE$; a vector relation. LO 2.C.1.2 (SP 2.2) EK 2.C.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. LO 2.C.2.1 (SP 2.2 and 6.4) The student is able to qualitatively and semi-quantitatively apply the vector relationship between the electric field and the net electric charge creating that field. LO 3.C.2.1 (SP 2.2 and 6.4) The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. LO 3.C.2.2 (SP 7.2) The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. LO 3.C.2.3 (SP 2.2) 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). LO 2.C.3.1 (SP 6.2) The student is able to explain the inverse square dependence of the electric field surrounding a spherically symmetric	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. 3.C.2.: Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.	
	2.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	

electrically charged object. LO 2.C.4.1 (SP 2.2, 6.4, and 7.2) 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.	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.	
LO 2.C.4.2 (SP 1.4 and 2.2) 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.	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.	
LO 2.C.5.1 (SP 1.1 and 2.2) 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.		

LO 2.C.5.2 (SP 2.2) 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. Electric Potential, Potential Difference, and Potential Energy: LO 2.E.3.1 (SP 2.2) 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.	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.	
LO 2.E.3.2 (SP 1.4 and 6.4) 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.	2.E.3.: Isolines in a region where an electric field exists represent lines of equal electric potential referred to as equipotential lines.	
LO 5.B.2.1 (SP 1.4 and 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	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.	

internal structure because the object is actually a system. Equipotentials: LO 2.E.1.1 (SP 1.4, 6.4, and 7.2) 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. LO 2.E.2.1 (SP 6.4 and 7.2) The student is able to determine the structure of isolines of electric potential by constructing them in a given electric field. LO 2.E.2.2 (SP 6.4 and 7.2) 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. LO 2.E.2.3 (SP 1.4) 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. Electric Dipoles: LO 2.C.4.1 (SP 2.2, 6.4, and 7.2) The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of	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.	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
---	---	--

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.	field of each individual object. Electric dipoles are treated qualitatively in this course as a teaching analogy to facilitate student understanding of magnetic dipoles.	
Electric Current Simple DC Circuits (Ohm's Law / Kirchhoff's Laws) Steady State RC Circuits: LO 4.E.5.1 (SP 2.2 and 6.4) 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.	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.	
LO 4.E.5.2 (SP 6.1 and 6.4) 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.		
LO 4.E.5.3 (SP 2.2, 4.2, and 5.1)		

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. LO 5.B.9.5 (SP 6.4) 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.	5.B.9.: Kirchhoff's loop rule describes conservation of energy in electrical circuits.	
LO 5.B.9.8 (SP 1.5) 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. LO 5.C.2.1 (SP 6.4 and 7.2) The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system.	5.C.2.: The exchange of electric charges among a set of objects in a system conserves electric charge.	
LO 5.C.2.2 (SP 4.1, 4.2, and 5.1) 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. LO 5.C.2.3 (SP 1.4 and 2.2) 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. LO 5.C.3.4 (SP 6.4 and 7.2) 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.	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.	
LO 5.C.3.5 (SP 1.4 and 2.2) 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.		
LO 5.C.3.6 (SP 1.4 and 2.2) 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.		
LO 5.C.3.7 (SP 1.4 and 2.2) 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.		
Activities: LO 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. [SP 4.2 and 5.1]	5.C.2.: The exchange of electric charges among a set of objects in a system conserves electric charge.	
LO 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. [SP 4.1]	4.E.3.: The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.	
LO 4.E.3.5: The student is able to plan 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. [SP 3.2, 4.1, 4.2, 5.1, 5.3]	2.E.2.: Isolines in a region where an electric field exists represent lines of equal electric potential referred to as equipotential lines.	
LO 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. [SP 6.4 and 7.2]	5.B.9.: Kirchhoff's loop rule describes conservation of energy in electrical circuits.	
LO 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. [SP 1.5] LO 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 non-ohmic resistor. [SP 4.1, 4.2, 5.1, 5.3] LO 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. [SP 4.1, 4.2] LO 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. [SP 5.1] LO 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		
	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.	
	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,	

differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [SP 2.2, 4.2, and 5.1] LO 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. [SP 5.1] LO 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 non-ohmic resistor. [SP4.1, 4.2, 5.1,5.3] LO 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. [SP 1.5] LO 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. [SP4.1,4.2]	and capacitors. 5.B.9.: Kirchhoff's loop rule describes conservation of energy in electrical circuits. 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.	
--	--	--

LO 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. [SP 5.1] LO 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. [SP 2.2, 4.2, and 5.1] LO 4.E.3.5: The student is able to plan 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. [SP 3.2, 4.1, 4.2, 5.1, 5.3]	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. 4.E.3.: The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.	
Assessment Check Points (What is the authentic evidence that students have achieved the targeted standards/unit objectives? Formative, Summative and Performance Based) Formative Assessments: Diagnostic re- and post-assessments, class discussions, worksheets with teacher feedback, drafts of lab reports with teacher feedback Summative Assessments: Quizzes, tests, performance assessments/laboratory investigations, research/lab reports		
Resources: Essential Materials, Supplementary Materials, Links to Best Practices Giancoli, Douglas C. <i>Physics Principles with Applications</i>, AP Edition Seventh Edition, Pearson Prentice Hall, 2014		Instructional Adjustments: Modifications, student difficulties, possible misunderstandings

Unit 4 - Magnetism		Pacing: 4-5 weeks
Essential Questions: How can we describe a magnetic field? How does a motor work? How does magnet influence the movement of charged particles? How does the presence of a magnetic field generate a current in a conductive material? How can a magnet induce current in a wire? Big Ideas: 1. Objects and systems have properties such as mass and charge. Systems may have internal structure. 2. Fields existing in space can be used to explain interactions. 3. The interactions of an object with other objects can be described by forces. 4. Interactions between systems can result in changes in those systems. Enduring Understandings: 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.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.C At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. 3.E A force exerted on an object can change the kinetic energy of the object 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 Targeted Next Generation Science Standards and/or Common Core Standards: HS-PS2-5; HS-PS3-2; HS-PS3-5, RST.11-12.8		
Learning Objectives (should reference College Board Framework)	Essential Knowledge <i>What students will know.</i>	Activities/Strategies Technology Implementation/ Interdisciplinary Connections
2.D.1.1 Apply mathematical routines to express the force exerted on a moving charged object by a magnetic field.	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	Activity: Behavior of stacked magnets - students investigate magnetic dipoles and use a compass to determine the directionality of the magnetic field. Activity: Oersted Device (force on moving charge) Class Activity: Cathode Ray Tube and Magnet (force on moving charge) Lab: Magnetic Force on Current Carrying Wire Lab: Faraday's Law Textbook: Giancoli Chapter 20 and Chapter 21

2.D.2.1 Create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires.	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. - The magnitude of the magnetic field is proportional to the magnitude of the current in a long straight wire. - 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 rule	Activity: Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections)
2.D.3.1 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.	2.D.3 A magnetic dipole placed in a magnetic field, such as the ones created by a magnet of the Earth, will tend to align with the magnetic field vector. - 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. - A compass needle is a permanent magnetic dipole. Iron filings in a magnetic field become induced magnetic dipoles. - All magnets produce a magnetic field. Examples should include magnetic field pattern of a bar magnet as detected by iron filings or small compasses. - The Earth has a magnetic field.	
3.C.3.1 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.	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. - Magnetic dipoles have "north" and "south" polarity - The magnetic dipole moment of an object has the tail of the magnetic dipole moment vector at the south end of the	

3.C.3.2 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.	object and the head of the vector at the north end of the object. c. In the presence of an external magnetic field, the magnetic dipole moment vector will align with the external magnetic field. d. 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.E.1.1 Make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves.	3.E.1 The change in kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted. a. Only the component of the net force exerted on an object parallel or antiparallel to the displacement of the object will increase (parallel) or decrease (antiparallel) the kinetic energy of the object.	
3.E.1.4 Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object.	b. The magnitude of the change in the kinetic energy is the product of the magnitude of the displacement and of the magnitude of the component of force parallel or antiparallel to the displacement. c. The component of the net force exerted on an object perpendicular to the direction of the displacement of the object can change the direction of the motion of the object without changing the kinetic energy of the object. 2.D.3 A magnetic dipole placed in a magnetic field, such as the ones created by a magnet of the Earth, will tend to align with the magnetic field vector. a. A simple magnetic dipole can be modeled by a current in a loop. The dipole is represented by a vector pointing through	

2.D.4.1 Use the representation of magnetic domains to qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material.	the loop in the direction of the field produced by the current as given by the right-hand rule. 1.E.5 Matter has a property called magnetic permeability - Free space has a constant value of the permeability that appears in physical relationships. - The permeability of matter has a value different from that of free space. 1.E.6 Matter has a property called magnetic dipole moment - Magnetic dipole moment is a fundamental source of magnetic behavior of matter and an intrinsic property of some fundamental particles such as the electron. - Permanent magnetism or induced magnetism of matter is a system property resulting from the alignment of magnetic dipole moments within the system. 2.D.4 Ferromagnetic materials contain magnetic domains that are themselves magnets. - Magnetic domains can be aligned by external magnetic fields or can spontaneously align. - 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. - 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.	
--	---	--

4.E.1.1 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.	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 vocabulary. a. Ferromagnetic materials can be permanently magnetized by an external field that causes the alignment of magnetic domains or atomic magnetic dipoles. b. 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. c. 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.2.1 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.	4.E.2 Changing magnetic flux induces an electric field that can establish an induced emf in a system. a. 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. b. 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. c. 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. d. The conservation of energy determines the direction of the induced emf relative to the change in the magnetic flux.	

3.A.2.1 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 Challenge a claim that an object can exert a force on itself. 3.A.3.3 Describe a force as an interaction between two objects and identify both objects for any force. 3.A.4.1 Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. 3.A.4.2 Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact.	3.A.2 Forces are describe 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.	
Assessment Check Points (What is the authentic evidence that students have achieved the targeted standards/unit objectives? Formative, Summative and Performance Based) Formative Assessments: Diagnostic pre- and post-assessments, class discussions, worksheets with teacher feedback, drafts of lab reports with teacher feedback Summative Assessments: Quizzes, tests, performance assessments/laboratory investigations, research/lab reports Resources: Essential Materials; Supplementary Materials; Links to Best Practices Giancoli, Douglas C. <i>Physics Principles with Applications</i>. AP Edition Seventh Edition, Pearson Prentice Hall, 2014	Instructional Adjustments: Modifications, student difficulties, possible misunderstandings	

Unit 5 – Geometric and Physical Optics		Pacing: 4-5 weeks
Essential Questions: How can transverse and longitudinal waves manifest? How are standing waves produced? How can the separation between items such as CD tracks or the thickness of a piece of hair be measured? How can the index of refraction be measured, and what is its importance in determining the purity of liquid substances?		
Big Ideas: 5. Changes that occur as a result of interactions are constrained by conservation laws 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 Understandings: 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. 5.B The energy of a system is conserved.		
Targeted Next Generation Science Standards and/or Common Core Standards: HS-PS4-1; HS-PS4-3; RST. 11.12-1; RST. 11.12-7; RST.11-12.8		

Learning Objectives (should reference College Board Framework)	Essential Knowledge <i>What students will know.</i>	Activities/Strategies Technology Implementation/ Interdisciplinary Connections
6.A.1.2 Describe representations of transverse and longitudinal waves 6.A.1.3 Analyze data (or visual representation) to identify patterns that indicate that a particular mechanical wave is polarized and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation.	6.A.1 Waves can propagate via different oscillation modes such as transverse and longitudinal a. Mechanical waves can be either transverse or longitudinal. b. Electromagnetic waves are transverse waves. c. 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	Activity: Generating Transverse and Longitudinal Waves Activity: Waves on a String: Standing Waves Lab: Measurement Using Diffraction Patterns Lab: The Index of Refraction Lab: Lenses and Mirrors and the Formation of Images Textbook: Giancoli Chapter 11, Chapter 23, Chapter 24 and Chapter 22. Optional: Chapter 25 Activity: Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections)

6.A.2.2 Contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation.	through a vacuum and sound not traveling through a vacuum.	
6.B.3.1 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.	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.1.1 Make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves.	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.1.2 Construct representations to graphically analyze situations in which two waves overlap over time using the principle of 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.2.1 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. 6.C.4.1 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. 6.E.1.1 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. 6.E.2.1 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 relative to the normal to the surface. 6.E.3.1 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. 6.E.3.2 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	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); and this law of reflection accounts for the size and location of images seen in plane 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. a. 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. b. When light travels from an optically slower substance into an optically faster	
--	---	--

transparent material to another (Snell's law).	substance, it bends away from the perpendicular.	
6.E.3.3 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.	c. At the critical angle, the light bends far enough away from the perpendicular that it skims the surface of the material. d. Beyond the critical angle, all of the light is internally reflected.	
6.E.4.1 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.	6.E.4 The reflection of light from surfaces can be used to form images. a. 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. b. They are also useful for determining the size of the resulting image compared to the size of the object. c. 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.4.2 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.		
6.E.5.1 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.	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.E.5.2 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.	6.C.3 When waves pass through a set of	

6.C.3.1 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 compared to the wavelength of the waves. 6.F.1.1 Make qualitative comparisons of the wavelengths of types of electromagnetic radiation.	opening whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference. 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.2.1 Describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. 5.B.8.1 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.	6.F.2 Electromagnetic waves can transmit energy through a medium and through a vacuum. a. Electromagnetic waves are transverse waves composed of mutually perpendicular electric and magnetic fields that can propagate through a vacuum. b. The planes of these transverse waves are both perpendicular to the direction of propagation. 5.B.8 Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei. a. 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). b. An emission spectrum can be used to determine the elements in a source of light.	
Assessment Check Points (What is the authentic evidence that students have achieved the targeted standards/unit objectives? Formative, Summative and Performance Based)		

Formative Assessments: Diagnostic pre- and post-assessments, class discussions, worksheets with teacher feedback, drafts of lab reports with teacher feedback	
Summative Assessments: Quizzes, tests, performance assessments/laboratory investigations, research/lab reports	
Resources: Essential Materials, Supplementary Materials, Links to Best Practices	Instructional Adjustments:
Giancoli, Douglas C. <u>Physics Principles with Applications</u> , AP Edition Seventh Edition, Pearson Prentice Hall, 2014	Modifications, student difficulties, possible misunderstandings

Unit 6 – Quantum Physics, Atomic, and Nuclear Physics

Pacing: 4 weeks

Essential Questions: What unsolved problems in classical physics led to the development of quantum mechanics? What behavior is exhibited by particles on the atomic scale? How do LEDs work? Why are only certain transitions between energy states of the atom allowed?

Big Ideas:

1. Objects and systems have properties such as mass and charge. Systems may have internal structure.
3. The interactions of an object with other objects can be described by forces.
4. Interactions between systems can result in changes in those systems.
5. Changes that occur as a result of interactions are constrained by conservation laws.
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.
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 Understandings:

- 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.A All forces share certain common characteristics when considered by observers in inertial reference frames.
- 3.C At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.
- 3.E A force exerted on an object can change the kinetic energy of the object.
- 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.A Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.
- 5.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.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.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.

Targeted Next Generation Science Standards and/or Common Core Standards:

HS-PS1-8, HS-PS4-4; RST.11-12.1, RST.11-12.7, RST.11-12.8

Learning Objectives (should reference College Board Framework)	Essential Knowledge <i>What students will know.</i>	Activities/Strategies Technology Implementation/ Interdisciplinary Connections
1.A.2.1 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.	1.A.1 A system is an object or a collection of objects. Objects are treated as having no internal structure. a. A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object. b. Some elementary particles are fundamental particles (e.g. electrons). Protons and neutrons are composed of fundamental particles (i.e. quarks) and might be treated as either systems or objects, depending on the question being addressed. c. The electric charges on neutrons and protons result from their quark compositions.	Activity: Blackbody Radiation (virtual) Activity: Photoelectric Effect Activity: Davisson-Germer Experiment (virtual) Textbook: Giancoli Chapter 26, Chapter 27, Chapter 28 and Chapter 30 Activity: Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections)
1.A.4.1 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.	1.A.2 Fundamental particles have no internal structure. a. Electrons, neutrinos, photons, and quarks are examples of fundamental particles. b. Neutrons and protons are composed of quarks. c. All quarks have electric charges, which are fractions of the elementary charge of the electron. Students will not be expected to know specifics of quark charge or quark composition of nucleons. 1.A.3 Nuclei have internal structures that determine their properties. a. The number of protons identifies the element.	

1.C.4.1 Articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass-energy. 1.D.1.1 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.	b. The number of neutrons together with the number of protons identifies the isotope. c. There are different types of radioactive emissions from the nucleus. d. The rate of decay of any radioactive isotope is specified by its half-life. 1.A.4 Atoms have internal structures that determine their properties. a. The number of protons in the nucleus determines the number of electrons in a neutral atom. b. The number of arrangements of electrons cause elements to have different properties. c. The Bohr model based on classical foundations was the historical representation of the atom that led to the description of the hydrogen atom in terms of discrete energy states (represented in energy diagrams by discrete energy levels). d. Discrete energy state transitions lead to spectra. 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. a. This wavelike behavior of particles has been observed, e.g., in a double-slit experiment using elementary particles. b. The classical models of objects do not describe their wave nature. These models break down when observing objects in	
---	--	--

1.D.3.1 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.]	small dimensions. 1.D.2 Certain phenomena classically thought of as waves can exhibit properties of particles. - The classical models of waves do not describe the nature of a photon. - 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. - 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. - Measurements of length and time depend on speed. (Qualitative treatment only.) 3.A.1 An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. c. A choice of reference frame determines	
--	--	--

3.G.1.1 Articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored. 3.G.1.2 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. 3.G.2.1 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.	the direction and the magnitude of each of these quantities. 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. 3.E.1 The change in kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted. 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	
--	--	--

3.G.3.1 Identify the strong force as the force that is responsible for holding the nucleus together. 4.C.4.1 Apply mathematical routines to describe the relationship between mass and energy and apply this concept across domains of scale. 5.A.2.1 Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.	interactions of nucleons. 4.C.4 Mass can be converted into energy. - Mass and energy are interrelated by $E = mc^2$. - Significant amounts of energy can be released in nuclear processes. 5.A.2 For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. 5.A.3 An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system. 5.B.3 A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. 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. 5.B.6 Energy can be transferred by thermal processes involving difference in	
--	---	--

5.B.8.1 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. 5.B.11.1 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. 5.C.1.1 Analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge.	temperature; the amount of energy transferred in this process of transfer is called heat. 5.B.8 Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei. a. 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). b. 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. a. In a closed system, the linear momentum is constant throughout the	
--	---	--

5.G.1.1 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. 6.B.5.1 Create or use a wave front diagram to demonstrate or interpret qualitatively the observed frequency of a wave, dependent upon relative motions of source and observer. 6.C.2.1 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	collision. b. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision. 5.G.1 The possible nuclear reactions are constrained by the law of conservation of nucleon number. 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.5 The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only. 6.C.2 When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed.	
---	--	--

describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave.

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.

a. Electromagnetic waves are transverse waves composed of mutually perpendicular electric and magnetic fields that can propagate through a vacuum.

6.F.3.1 Support the photon model of radiant energy with evidence provided by the photoelectric effect.

6.F.3 Photons are individual energy packets of electromagnetic waves, with $E_{\text{photon}} = hf$, where h is Planck's constant and f is the frequency of the associated light wave.

a. 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.

b. 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.

c. Evidence for discrete energy packets is provided by a frequency threshold for electron emission. Above the threshold, emission increases with the frequency and

6.F.4.1 Select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. 6.G.1.1 Make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. 6.G.2.1 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. 6.G.2.2 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	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. a. 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}. b. 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. a. A wave model of matter is quantified by the de Broglie wavelength that increases as the momentum of the particle decreases. b. The wave property of matter was experimentally confirmed by the diffraction of electron in the experiment of Clinton Joseph Davisson, Lester Germer, and George Paget Thomson.	
---	---	--

interacting with a crystal. (de Broglie wavelength need not be given, so students may need to obtain it.) 7.C.1.1 Use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region.	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.2.1 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.	7.C.2 The allowed states for an electron in an atom can be calculated from the wave model of an electron. a. 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. b. The de Broglie wavelength of an electron can be calculated from momentum, and a wave representation can be used to model discrete transitions between energy states as transitions between standing waves.	
7.C.3.1 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.	7.C.3 The spontaneous radioactive decay of an individual nucleus is described by probability. a. 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. b. In radioactive decay, mass and energy are interrelated, and energy is released in nuclear processes as kinetic energy of the	

7.C.4.1 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.]	products or as electromagnetic energy. c. The time for half of a given number of radioactive nuclei to decay is called the half-life. d. 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. a. An atom in a given energy state may absorb a photon of the right energy and move to a higher energy state (stimulated absorption). b. An atom in an excited energy state may jump spontaneously to a lower energy state with the emission of a photon (spontaneous emission). c. 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. d. 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.	
Assessment Check Points (What is the authentic evidence that students have achieved the targeted standards/unit objectives? Formative, Summative and Performance Based) Formative Assessments: Diagnostic pre- and post-assessments, class discussions, worksheets with teacher feedback, drafts of lab reports with teacher feedback Summative Assessments: Quizzes, tests, performance assessments/laboratory Investigations, research/lab reports Resources: Essential Materials, Supplementary Materials, Links to Best Practices Giancoli, Douglas C. <i>Physics: Principles with Applications</i>, AP Edition Seventh Edition, Pearson Prentice Hall, 2014		Instructional Adjustments: Modifications, student difficulties, possible misunderstandings

