# Advanced Placement (AP) Physics II - Algebra Based

Table of Contents


Course Information

Desired Results

- Overarching Big Ideas/ Enduring Understandings
- Overarching Science Practices

UNIT 1: FLUIDS
- Desired Results
- Assessment Evidence

UNIT 2: THERMODYNAMICS
- Desired Results
- Assessment Evidence

UNIT 3: ELECTRIC FORCE, FIELD, and POTENTIAL
- Desired Results
- Assessment Evidence

UNIT 4: ELECTRIC CIRCUITS
- Desired Results
- Assessment Evidence

UNIT 5:  MAGNETISM AND ELECTROMAGNETIC INDUCTION
- Desired Results
- Assessment Evidence

UNIT 6: GEOMETRIC AND PHYSICAL OPTICS
- Desired Results
- Assessment Evidence

UNIT 7: QUANTUM, ATOMIC, AND NUCLEAR PHYSICS
- Desired Results
- Assessment Evidence

# COURSE INFORMATION

| Advanced Placement (AP) Physics II Algebra Based | |
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| **CURRICULUM/CONTENT AREA** | **COURSE LENGTH** |
| SCIENCE | 2 Terms |
| **GRADE LEVEL** | **DATE LAST REVIEWED** |
| 10-12 | 2018, Program Eval 2023 |
| **PREREQUISITE(s)** ***if applicable*** | **BOARD APPROVAL DATE** |
| None | 04/2024 |

**PRIMARY RESOURCE: (if applicable)**:
AP Classroom, College Physics. Houston, Texas: OpenStax College (OpenSource)

Supplemental:
Giancoli, Douglas C. (2005) Physics : principles with applications Upper Saddle River, N.J. : Pearson/Prentice Hall, Urone, P., & Hinrichs, R. (2016).

# DESIRED RESULTS

*What students will know and be able to do*

**COURSE DESCRIPTION AND PURPOSE**

AP Physics 2 is an algebra-based, introductory college-level physics course. Students cultivate their understanding of physics through inquiry-based investigations as they explore these topics: fluids; thermodynamics; electrical force, field, and potential; electric circuits; magnetism and electromagnetic induction; geometric and physical optics; and quantum, atomic, and nuclear physics.

| **BIG IDEAS:** | **SCIENCE PRACTICES:** |
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| Crosscutting concepts that build conceptual understanding and spiral throughout the course. These serve as the foundation to create meaningful connections among concepts. | *The science practices are central to the study and practice of biology. Students should develop and apply develop and apply the described practices on a regular basis over the span of the course.* |

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| **BIG IDEA 1: SYSTEMS (SYS)**<br>Objects and systems have properties such as mass and charge. Systems may have internal structure.<br><br>**BIG IDEA 2: FIELDS (FLD)**<br>Fields existing in space can be used to explain interactions.<br><br>**BIG IDEA 3: FORCE INTERACTIONS (INT)**<br>The interactions of an object with other objects can be described by forces.<br><br>**BIG IDEA 4: CHANGE (CHA)**<br>Interactions between systems can result in changes in those systems.<br><br>**BIG IDEA 5: CONSERVATION (CON)**<br>Changes that occur as a result of interactions are constrained by conservation laws.<br><br>**BIG IDEA 6: WAVES (WAV)**<br>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.<br><br>**BIG IDEA 7: PROBABILITY (PRO)**<br>The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems. | **1 Modeling:** The student can use representations and models to communicate scientific phenomena and solve scientific problems.<br><br>**2 Mathematical Routines:** The student can use mathematics appropriately.<br><br>**3 Scientific Questioning:** The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course (not assessed on the AP Exam).<br><br>**4 Experimental Methods:** The student can plan and implement data-collection strategies in relation to a particular scientific question.<br><br>**5 Data Analysis:** The student can perform data analysis and evaluation of evidence.<br><br>**6 Argumentation:** The student can work with scientific explanations and theories.<br><br>**7 Making Connections:** The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains. |

# Unit 1: FLUIDS

In Unit 1, students will consider how a fluid's internal structure and interactions define its macroscopic characteristics and how these interactions can be studied if they can't be seen. Woven through this unit are essential AP Physics 2 principles, including an emphasis on representations and models and connecting related knowledge between fundamental ideas. Unit 1 utilizes familiar force and energy representations (free-body diagrams and energy bar charts) to describe static and dynamic fluids. As in AP Physics 1, being able to identify and describe the relationships between physical quantities—and use these relationships as evidence to justify claims—is a critical skill when answering scientific questions. Students will once again be encouraged to sharpen their understanding of mathematics and the laws of physics by being asked to reason with equations to describe a phenomenon.
Although its content is unique, Unit 1 presents thematic threads that weave throughout the course, including the interactions between systems and the conservation of fundamental quantities.

| **ENDURING UNDERSTANDING**<br>The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year. | **LEARNING OBJECTIVE**<br>Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings. | **ESSENTIAL KNOWLEDGE**<br>Statements that describe the knowledge required to perform the learning objective. |
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| TOPIC 1.1: Fluid Systems<br><br>1.A. The internal structure of a system determines many properties of the system. | 1.A.5.2<br>Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] | 1.A.5<br>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. |
| TOPIC 1.2: Density<br><br>1.E. Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. | 1.E.1.1<br>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, 6.4] | 1.E.1<br>Matter has a property called density. |

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| | 1.E.1.2<br>Select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [SP 4.1, 6.4] | |
| TOPIC 1.3: Fluids: Pressure and Forces<br><br>3.A. All forces share certain common characteristics when considered by observers in inertial reference frames. | 3.A.2.1<br>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<br>Forces are described by vectors.<br>A. Forces are detected by their influence on the motion of an object.<br>B. Forces have magnitude and direction. |
| | 3.A.3.2<br>Construct an explanation for why an object cannot exert a force on itself. [SP 6.1]<br><br>3.A.3.3 Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]<br><br>3.A.3.4 Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] | 3.A.3<br>A force exerted on an object is always due to the interaction of that object with another object.<br>A. An object cannot exert a force on itself.<br>B. Even though an object is at rest, there may be forces exerted on that object by other objects.<br>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.4.1<br>Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]<br><br>3.A.4.2<br>Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2] | 3.A.4<br>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. |

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| | 3.A.4.3 Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4] | |
| TOPIC 1.4: Fluids and Free-Body Diagrams<br><br>3.B. Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$. | 3.B.1.3<br>Re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2]<br><br>3.B.1.4<br>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. [SP 6.4, 7.2] | 3.B.1<br>If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. |
| | 3.B.2.1<br>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2] | 3.B.2<br>Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.<br>A. An object can be drawn as if it were extracted from its environment and the interactions with the environment identified.<br>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.<br>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. |

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| TOPIC 1.5: Buoyancy<br><br>3.C. At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. | 3.C.4.1<br>Make claims about various contact forces between objects based on the microscopic cause of those forces. [SP 6.1]<br><br>3.C.4.2<br>Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [SP 6.2] | 3.C.4<br>Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2). |
| TOPIC 1.6: Conservation of Energy in Fluid Flow<br><br>5.B. The energy of a system is conserved. | 5.B.10.1<br>Make calculations related to a moving fluid using Bernoulli's equation. [SP 2.2]<br><br>5.B.10.2 Make calculations related to a moving fluid using Bernoulli's equation and/or the relationship between force and pressure. [SP 2.2]<br><br>5.B.10.3<br>Make calculations related to a moving fluid using Bernoulli's equation and the continuity equation. [SP 2.2]<br><br>5.B.10.4<br>Construct an explanation of Bernoulli's equation in terms of the conservation of energy. [SP 6.2] | 5.B.10<br>Bernoulli's equation describes the conservation of energy in fluid flow. The absolute pressure (P) equals atmospheric pressure (P0 ) plus the gauge pressure (ρgh). |
| TOPIC 1.7: Conservation of Mass flow Rate in Fluids<br><br>5.F. Classically, the mass of a system is conserved. | 5.F.1.1<br>Make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [SP 2.1, 2.2, 7.2] | 5.F.1<br>The continuity equation describes conservation of mass flow rate in fluids. Examples include volume rate of flow and mass flow rate. |
| **Assessment Evidence** | | |

*Performance is evaluated in terms of...*
*Students will show their learning by...*

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 1: How are the visible properties of materials determined by parts that can't be seen?
  - BIG IDEA 3: Why do some objects float and others sink?
  - BIG IDEA 5: How can a hydraulic system be modified to do more work?
    Is it possible for energy or mass to be created or destroyed in systems involving fluids?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
  - 6 Argumentation: The student can work with scientific explanations and theories.
  - 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
- **Rubric based on AP Physics 2 Scoring Guidelines**
- **AP Classroom:**
- **Laboratory Work:**
  - **Bernoulli Straws**
  - **Pressure differential at depth lab**
  - **Archimedes Principle**

# Unit 2 : THERMODYNAMICS

In Unit 2, students will continue to investigate what they cannot see by examining heat, temperature, and thermal energy in practical contexts such as heat engines, heat pumps, and refrigerators. The focus of this unit is the study of relationships and change, so it's important that students can discuss—in addition to calculate—what happens when a physical scenario changes, such as the consequences of adding heat to, or removing heat from, a system. Throughout this unit, students will use representations and models (PV diagrams, energy bar charts, or free-body diagrams) to construct evidence-based explanations and help them make predictions and justify claims about new phenomena. These representations and models will also help students develop connections and transfer their learning across disciplinary boundaries so that they are able to link, synthesize, and apply ideas they have learned across the sciences and mathematics.

Unit 2 also acquaints students with the second law of thermodynamics, entropy, and how the behavior of complex systems can be modeled with the mathematics of probability. This will be explored further in Unit 7 to help support and explain the concepts of modern physics.

| **ENDURING UNDERSTANDING**<br>The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year. | **LEARNING OBJECTIVE**<br>Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings. | **ESSENTIAL KNOWLEDGE**<br>Statements that describe the knowledge required to perform the learning objective. |
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| TOPIC 2.1: Thermodynamic Systems<br><br>1.A. The internal structure of a system determines many properties of the system. | 1.A.5.2<br>Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] | 1.A.5<br>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. |
| TOPIC 2.2: Pressure, Thermal Equilibrium, and the Ideal Gas Law | 7.A.1.1 | 7.A.1 |

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| 7.A. The properties of an ideal gas can be explained in terms of a small number of macroscopic variables, including temperature and pressure. | 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. [SP 6.4, 7.2]<br><br>7.A.1.2<br>Treating a gas molecule as an object (i.e., ignoring its internal structure), analyze qualitatively the collisions with a container wall and determine the cause of pressure, and at thermal equilibrium, quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables. [SP 1.4, 2.2] | The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container. |
| | 7.A.2.1<br>Qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. [SP 7.1]<br><br>7.A.2.2<br>Connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and relate this to thermodynamic processes. [SP 7.1] | 7.A.2<br>The temperature of a system characterizes the average kinetic energy of its molecules.<br>A. The average kinetic energy of the system is an average of the many different speeds of the molecules in the system that can be described by a distribution curve.<br>B. 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.3.1<br>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. [SP 6.4, 7.2]<br><br>7.A.3.2 | 7.A.3<br>In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V) are related by the ideal gas law PV = nRT. |

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| | Design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and/or the amount of an ideal gas; and to refine a scientific question proposing an incorrect relationship between the variables. [SP 3.2, 4.2]<br><br>7.A.3.3<br>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] | |
| TOPIC 2.3: Thermodynamics and Forces<br><br>3.A. All forces share certain common characteristics when considered by observers in inertial reference frames. | 3.A.2.1<br>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<br>Forces are described by vectors.<br>A. Forces are detected by their influence on the motion of an object.<br>B. Forces have magnitude and direction. |
| | 3.A.3.2<br>Construct an explanation for why an object cannot exert a force on itself. [SP 6.1]<br><br>3.A.3.3<br>Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]<br><br>3.A.3.4<br>Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] | 3.A.3<br>A force exerted on an object is always due to the interaction of that object with another object.<br>A. An object cannot exert a force on itself.<br>B. Even though an object is at rest, there may be forces exerted on that object by other objects.<br>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.4.1 | 3.A.4 |

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| | Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]<br><br>3.A.4.2<br>Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2]<br><br>3.A.4.3<br>Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4] | 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. |
| TOPIC 2.4: Thermodynamics and Free-Body Diagrams<br><br>3.B. Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$. | 3.B.1.3<br>Re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2]<br><br>3.B.1.4<br>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. [SP 6.4, 7.2]<br><br>3.B.2.1<br>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2] | 3.B.1<br>If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.<br><br>3.B.2<br>Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.<br>A. An object can be drawn as if it were extracted from its environment and the interactions with the environment identified.<br>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.<br>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. |

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| TOPIC 2.5: Thermodynamics and Contact Forces<br><br>3.C. At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. | 3.C.4.1<br>Make claims about various contact forces between objects based on the microscopic cause of those forces. [SP 6.1]<br><br>3.C.4.2<br>Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [SP 6.2] | 3.C.4<br>Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2). |
| TOPIC 2.6: Heat and Energy Transfer<br><br>4.C. Interactions with other objects or systems can change the total energy of a system. | 4.C.3.1<br>Make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [SP 6.4] | 4.C.3<br>Energy is transferred spontaneously from a higher-temperature system to a lower-temperature system. The process through which energy is transferred between systems at different temperatures is called heat.<br>A. Conduction, convection, and radiation are mechanisms for this energy transfer.<br>B. At a microscopic scale, the mechanism of conduction is the transfer of kinetic energy between particles.<br>C. During average collisions between molecules, kinetic energy is transferred from faster molecules to slower molecules. |
| TOPIC 2.7: Internal Energy and Energy Transfer<br><br>5.B. The energy of a system is conserved. | 5.B.2.1<br>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, 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. [SP 1.4, 2.1] | 5.B.2<br>A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1 includes mass-spring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.] |
| | 5.B.4.1 | 5.B.4 |

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| | Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]<br><br>5.B.4.2<br>Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [SP 1.4, 2.1, 2.2] | 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.<br>A. 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.<br>B. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system. |
| | 5.B.5.4<br>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). [SP 6.4, 7.2]<br><br>5.B.5.5<br>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. [SP 2.2, 6.4]<br><br>5.B.5.6<br>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. [SP 4.2, 5.1] | 5.B.5<br>Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.]<br>The work done on a system is defined as $W = -P\Delta V$ for constant pressure or an average pressure. |
| | 5.B.6.1 | 5.B.6<br>Energy can be transferred by thermal processes involving differences in temperature; this process of transfer is called heat. |

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| | 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. [SP 1.2] | |
| | 5.B.7.1<br>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. [SP 6.4, 7.2]<br><br>5.B.7.2<br>Create a plot of pressure versus volume for a thermodynamic process from given data. [SP 1.1]<br><br>5.B.7.3<br>Make calculations of internal energy changes, heat, or work, based on conservation of energy principles (i.e., the first law of thermodynamics), using a plot of pressure versus volume for a thermodynamic process. [SP 1.1, 1.4, 2.2] | 5.B.7<br>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 include PV diagrams—isovolumetric processes, isothermal processes, isobaric processes, and adiabatic processes. No calculations of thermal energy or internal energy from temperature change are required; in this course, examples of these relationships are qualitative and/or semiquantitative. |
| TOPIC 2.8: Thermodynamics and Elastic Collisions: Conservation of Momentum<br><br>5.D. The linear momentum of a system is conserved. | 5.D.1.6<br>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. [SP 6.4] | 5.D.1<br>In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.<br>A. In a closed system, the linear momentum is constant throughout the collision.<br>B. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision. |

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| | 5.D.1.7 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. [SP 2.1, 2.2] | |
| TOPIC 2.9: Thermodynamics and Inelastic Collisions: Conservation of Momentum<br><br>5.D. The linear momentum of a system is conserved. | 5.D.2.5<br>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. [SP 2.1, 2.2]<br><br>5.D.2.6<br>Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2] | 5.D.2<br>In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.<br>A. In a closed system, the linear momentum is constant throughout the collision.<br>B. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision. |
| TOPIC 2.10: Thermal Conductivity<br><br>1.E. Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. | 1.E.3.1<br>Design an experiment, and analyze data from it to examine thermal conductivity. [SP 4.1, 4.2, 5.1] | 1.E.3<br>Matter has a property called thermal conductivity. Thermal conductivity is the measure of a material's ability to transfer thermal energy. |
| TOPIC 2.11: Probability, Thermal Equilibrium, and Entropy | 7.B.1.1 | 7.B.1<br>The approach to thermal equilibrium is a probability process. |

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| 7.B. The tendency of isolated systems to move toward states with higher disorder is described by probability. | 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. [SP 6.2] | A. The amount of thermal energy needed to change the temperature of an object depends both on the mass of the object and on the temperature change.<br>B. The details of the energy transfer depend on interactions at the molecular level.<br>C. 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 objects have the same temperature. |
| | 7.B.2.1<br>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. [SP 7.1] | 7.B.2<br>The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a qualitative treatment is considered in this course.<br>A. Entropy, like temperature, pressure, and internal energy, is a state function, the value of which depends only on the configuration of the system at a particular instant and not on how the system arrived at that configuration.<br>B. Entropy can be described as a measure of the disorder of a system, or of the unavailability of some system energy to do work.<br>C. The entropy of a closed system never decreases (i.e., it can stay the same or increase).<br>D. The total entropy of the universe is always increasing. |

**Assessment Evidence**
*Performance is evaluated in terms of…*
*Students will show their learning by…*

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 1: How is the temperature of a substance related to the energy and movement of its atoms and molecules? How can we best measure what we cannot see?
  - BIG IDEA 5: How does the direction in which a heat engine does work determine whether it is used as a refrigerator or a heat pump? How and why should we conserve energy?

When is it beneficial to remove energy from a system?
- BIG IDEA 7: How does probability help explain entropy?
  Can energy remain constant even in a closed system?

➢ **Free-response questions aligned to AP Physics 2 Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
- 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
- 2 Mathematical Routines: The student can use mathematics appropriately.
- 3 Scientific Questioning: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course (not assessed on the AP Exam).
- 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
- 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
- 6 Argumentation: The student can work with scientific explanations and theories.
- 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

➢ **Rubric based on AP Physics 2 Scoring Guidelines**

➢ **AP Classroom:**

➢ **Laboratory Work:**
- **Boyle's Law**
- **Charrel's Law**
- **Gay-Lussac's Law**

# Unit 3 : ELECTRIC FORCE, FIELD, AND POTENTIAL

Unit 3 begins the study of electromagnetic phenomena at a fundamental level, introducing students to the concepts of electric charge, electric force, and electric field and potential. Despite the shift from examining fluids and gases to examining charged particles, the foundation of this unit continues to focus on relationships, change, and developing the science practice of making connections between scales, concepts, and representations. For instance, students will use the concept of equipotential lines to visualize the electric field and make connections between the isolines on topographic maps for gravitational fields and equipotential lines for the electric field. This unit will also help students better understand that interactions between systems result in changes within those systems—allowing students to further apply energy conservation principles in later units.

Students are encouraged to apply what they know when learning about fields (gravitational and electric), how fields interact, and the complex concepts of static and dynamic electricity. This will help students better understand energy conservation principles, as well as develop the science practice of data analysis. Data analysis is essential in identifying patterns and relationships between variables and helps students become better prepared to engage in and craft scientific arguments that describe a mechanism through which a phenomenon occurs.

| **ENDURING UNDERSTANDING**<br>The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year. | **LEARNING OBJECTIVE**<br>Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings. | **ESSENTIAL KNOWLEDGE**<br>Statements that describe the knowledge required to perform the learning objective. |
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| TOPIC 3.1: Electric Systems<br><br>1.A. The internal structure of a system determines many properties of the system. | 1.A.5.2 Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] | 1.A.5<br>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. |
| TOPIC 3.2: Electric Charge<br><br>1.B. Electric charge is a property of an object or system that affects its | 1.B.1.1<br>Make claims about natural phenomena based on conservation of electric charge. [SP 6.4] | 1.B.1<br>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. |

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| interactions with other objects or systems containing charge. | 1.B.1.2<br>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. [SP 6.4, 7.2] | A. An electrical current is a movement of charge through a conductor. b. A circuit is a closed loop of electrical current. |
| | 1.B.2.1<br>Construct an explanation of the two charge model of electric charge based on evidence produced through scientific practices. [SP 6.2]<br><br>1.B.2.2<br>Make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. [SP 6.4, 7.2]<br><br>1.B.2.3<br>Challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [SP 6.1] | 1.B.2<br>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.<br>A. Like-charged objects and systems repel, and unlike-charged objects and systems attract.<br>B. Charged objects or systems may attract neutral systems by changing the distribution of charge in the neutral system. |
| | 1.B.3.1 Construct an explanation that challenges the claim that an electric charge smaller than the elementary charge has been isolated. [SP 1.5, 6.1, 7.2] | 1.B.3<br>The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.<br>A. The magnitude of the elementary charge is equal to $1.6 \times 10^{-19}$ coulombs.<br>B. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron. |
| TOPIC 3.3: Conservation of Electric Charge | 5.C.2.1<br>Predict electric charges on objects within a | 5.C.2<br>The exchange of electric charges among a set of objects in |

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| 5.C. The electric charge of a system is conserved. | system by application of the principle of charge conservation within a system. [SP 6.4]<br><br>5.C.2.2<br>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, 5.1]<br><br>5.C.2.3<br>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] | a system conserves electric charge.<br>A. Charging by conduction between objects in a system conserves the electric charge of the entire system.<br>B. Charge separation in a neutral system can be induced by an external charged object placed close to the neutral system.<br>C. Grounding involves the transfer of excess charge to another larger system (e.g., Earth). |
| TOPIC 3.4: Charge Distribution: Friction, Conduction, and Induction<br><br>4.E. The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems. | 4.E.3.1<br>Make predictions about the redistribution of charge during charging by friction, conduction, and induction. [SP 6.4]<br><br>4.E.3.2<br>Make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. [SP 6.4, 7.2]<br><br>4.E.3.3<br>Construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [SP 1.1, 1.4, 6.4]<br><br>4.E.3.4<br>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. | 4.E.3<br>The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.<br>A. Charging can take place by friction or by contact.<br>B. An induced charge separation can cause a neutral object to become polarized.<br>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. |

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| | [SP 1.1, 1.4, 6.4]<br><br>4.E.3.5<br>Plan and/or analyze the results of experiments in which electric-charge rearrangement occurs by electrostatic induction, or be 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] | |
| TOPIC 3.5: Eclectic Permittivity<br><br>1.E. Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. | [While there is no specific learning objective for it, EK 1.E.4 serves as a foundation for other learning objectives in the course.] | 1.E.4<br>Matter has a property called electric permittivity.<br>A. Free space has a constant value of the permittivity that appears in physical relationships.<br>B. The permittivity of matter has a value different from that of free space. |
| TOPIC 3.5: Introduction to Electric Forces<br><br>3.A. All forces share certain common characteristics when considered by observers in inertial reference frames. | 3.A.2.1<br>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<br>Forces are described by vectors.<br>A. Forces are detected by their influence on the motion of an object.<br>B. Forces have magnitude and direction. |
| | 3.A.3.2<br>Construct an explanation for why an object cannot exert a force on itself. [SP 6.1]<br><br>3.A.3.3<br>Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]<br><br>3.A.3.4<br>Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] | 3.A.3<br>A force exerted on an object is always due to the interaction of that object with another object.<br>A. An object cannot exert a force on itself.<br>B. Even though an object is at rest, there may be forces exerted on that object by other objects.<br>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. |

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| | 3.A.4.1<br>Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [SP 1.4, 6.2]<br><br>3.A.4.2<br>Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2]<br><br>3.A.4.3<br>Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4] | 3.A.4<br>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. |
| TOPIC 3.7: Electric Forces and Free-Body Diagrams<br><br>3.B. Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$. | 3.B.1.3<br>Re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [SP 1.5, 2.2]<br><br>3.B.1.4<br>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. [SP 6.4, 7.2] | 3.B.1<br>If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. |
| | 3.B.2.1 Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2] | 3.B.2<br>Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.<br>A. An object can be drawn as if it were extracted from its environment and the interactions with the |

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| | | environment identified.<br>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.<br>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. |
| TOPIC 3.8: Describing Electric Force<br><br>3.C. At the macroscopic level, forces can be categorized as either long-range (action-ata-distance) forces or contact forces. | 3.C.2.1<br>Make predictions about the interaction between two electric point charges, using Coulomb's law qualitatively and quantitatively. [SP 2.2, 6.4]<br><br>3.C.2.2<br>Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [SP 7.2]<br><br>3.C.2.3<br>Describe the electric force that results from the interaction of several separated point charges (generally two to four point charges, though more are permitted in situations of high symmetry) using appropriate mathematics. [SP 2.2] | 3.C.2<br>Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.<br>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 non-fundamental forces called contact forces, such as normal force, friction, and tension.<br>B. Electric forces may be attractive or repulsive, depending on the charges on the objects involved. |
| TOPIC 3.9: Gravitational and Electromagnetic Forces<br><br>3.G. Certain types of forces are considered fundamental. | 3.G.1.2<br>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 with other types of forces. [SP 7.1] | 3.G.1<br>Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales. |
| | 3.G.2.1 Connect the strength of electromagnetic | 3.G.2 |

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| | forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [SP 7.1] | Electromagnetic forces are exerted at all scales and can dominate at the human scale. |
| TOPIC 3.10: Vector and Scalar Fields<br><br>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. | [While there is no specific learning objective for it, EK 2.A.1 serves as a foundation for other learning objectives in the course.] | 2.A.1<br>A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.<br>A. Vector fields are represented by field vectors indicating direction and magnitude.<br>B. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition.<br>C. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources. |
| TOPIC 3.11: Electric Charges and Fields<br><br>2.C. An electric field is caused by an object with electric charge. | 2.C.1.1<br>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: $\vec{F} = q\vec{E}$ a vector relation. [SP 6.4, 7.2]<br><br>2.C.1.2<br>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. [SP 2.2] | 2.C.1 The magnitude of the electric force F exerted on an object with electric charge q by an electric field E is : $\vec{F} = q\vec{E}$<br>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.3.1<br>Explain the inverse square dependence of the electric field surrounding a spherically symmetric, electrically charged object. [SP 6.2] | 2.C.3<br>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 |

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| | | 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.<br>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 $\left\vert\vec{E}\right\vert = \frac{1}{4\Pi\varepsilon_0}\frac{\vert q\vert}{r^2}$.<br>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.2.1<br>Qualitatively and semi quantitatively apply the vector relationship between the electric field and the net electric charge creating that field. [SP 2.2, 6.4] | 2.C.2<br>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.3.1<br>Explain the inverse square dependence of the electric field surrounding a spherically symmetric, electrically charged object. [SP 6.2] | 2.C.3<br>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.<br>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 $\left\vert\vec{E}\right\vert = \frac{1}{4\Pi\varepsilon_0}\frac{\vert q\vert}{r^2}$.<br>B. This relation is based on a model of the space |

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| | | 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.4.1<br>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. [SP 2.2, 6.4, 7.2]<br><br>2.C.4.2<br>Apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (two to four) 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. [SP 1.4, 2.2] | 2.C.4<br>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.<br>A. When an object is small compared with 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."<br>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.5.1<br>Create representations of the magnitude and direction of the electric field at various distances (small compared with plate size) from two electrically charged plates of equal magnitude and opposite signs, and be able to recognize that the assumption of uniform field is not appropriate near edges of plates. [SP 1.1, 2.2] | 2.C.5<br>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. |

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| | 2.C.5.2<br>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. [SP 2.2]<br><br>2.C.5.3<br>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 Earth's gravitational field. [SP 1.1, 2.2, 7.1] | |
| TOPIC 3.12: Isolines and Electric Fields<br><br>2.E. Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field. | 2.E.1.1 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. [SP 1.4, 6.4, 7.2] | 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.2.1<br>Determine the structure of isolines of electric potential by constructing them in a given electric field. [SP 6.4, 7.2]<br><br>2.E.2.2<br>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. [SP 6.4, 7.2] | 2.E.2<br>Isolines in a region where an electric field exists represent lines of equal electric potential, referred to as equipotential lines.<br>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.<br>B. Since the electric potential has the same value along an isoline, there can be no component of the electric field along the isoline. |

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| | 2.E.2.3<br>Construct isolines of electric potential in an electric field, and determine the effect of that field on electrically charged objects, qualitatively using the concept of isolines. [SP 1.4] | |
| | 2.E.3.1<br>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. [SP 2.2]<br><br>2.E.3.2<br>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. [SP 1.4, 6.4] | 2.E.3<br>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. |
| TOPIC 3.13: Conservation of Electric Energy<br><br>5.B. The energy of a system is conserved. | 5.B.2.1<br>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, 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. [SP 1.4, 2.1] | 5.B.2<br>A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1 includes massspring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.] |
| | 5.B.4.1<br>Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]<br><br>5.B.4.2 | 5.B.4<br>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. |

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| | Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [SP 1.4, 2.1, 2.2] | A. 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.<br>B. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system. |
| | 5.B.5.4<br>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). [SP 6.4, 7.2]<br><br>5.B.5.5<br>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. [SP 2.2, 6.4] | 5.B.5<br>Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.] The work done on a system is defined as $W = -P\Delta V$ for constant pressure or an average pressure. |

**Assessment Evidence**
*Performance is evaluated in terms of…*
*Students will show their learning by…*

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 2: How are topographical maps connected to the ideas of electric field and potential?
    If our five senses cannot detect an electric field, how can we know it's there?
    Would you get lost in an electric field without a map? Why are some maps better than others?
  - BIG IDEA 3: How do electrical charges behave in an electric field?
  - BIG IDEA 5: Why do charges move?
    What parallels can be drawn between electric charge and energy?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.

- 3 Scientific Questioning: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course (not assessed on the AP Exam).
- 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
- 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
- 6 Argumentation: The student can work with scientific explanations and theories.
- 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

➢ **Rubric based on AP Physics 2 Scoring Guidelines**
➢ **AP Classroom:**
➢ **Laboratory Work:**
- **Coulomb's law**
- **Series and Parallel Capacitors**
- **Aluminium Foil Capacitor**

# Unit 4 : ELECTRIC CIRCUITS

Unit 4 revisits the behavior of charged particles, discussed in Unit 3, to deepen students' understanding of the law of conservation of energy and how it's applied to electric circuits. This unit will ask students to do more than calculate for the current, resistance, and voltage in a simple circuit; it will challenge them to draw connections between the interactions of systems and the changes that result from those interactions. For example, students will need to be able to articulate the impact of a light bulb being removed on a circuit consisting of several light bulbs. They will also need to design an experiment to test if a light bulb is ohmic or justify how changing the spacing of a capacitor will affect its capacitance. Using models and representations to analyze physical situations, as well as using mathematical relationships to justify claims, are critically important science practices in this unit. Unit 4 will also compel students to discover and understand the relationship between the conservation of total energy and the conservation of total electric charge in circuits. It will encourage them to use Kirchhoff's rules to describe both energy conservation and charge conservation.
Simultaneously, students will also have more opportunities in Unit 4 to expand their data collection and analysis abilities to include writing clear, concise procedural paragraphs in addition to revising their reasoning based on new data. In Unit 5, students will expand their investigations of the symmetry between electric and magnetic fields.

| **ENDURING UNDERSTANDING**<br>The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year. | **LEARNING OBJECTIVE**<br>Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings. | **ESSENTIAL KNOWLEDGE**<br>Statements that describe the knowledge required to perform the learning objective. |
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| TOPIC 4.1: Definition and Conservation of Electric Charge<br><br>1.B. Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge. | 1.B.1.1<br>Make claims about natural phenomena based on conservation of electric charge. [SP 6.4]<br><br>1.B.1.2<br>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. [SP 6.4, 7.2] | 1.B.1<br>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.<br>A. An electrical current is a movement of charge through a conductor.<br>B. A circuit is a closed loop of electrical current. |

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| | 1.B.2.1<br>Construct an explanation of the two charge model of electric charge based on evidence produced through scientific practices. [SP 6.2]<br><br>1.B.2.2<br>Make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. [SP 6.4, 7.2]<br><br>1.B.2.3<br>Challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [SP 6.1] | 1.B.2<br>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.<br>A. Like-charged objects and systems repel, and unlike-charged objects and systems attract.<br>B. Charged objects or systems may attract neutral systems by changing the distribution of charge in the neutral system. |
| TOPIC 4.2: Resistivity and Resistance<br><br>1.E. Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. | 1.E.2.1<br>Select and justify the data needed to determine resistivity for a given material. [SP 4.1] | 1.E.2<br>Matter has a property called resistivity.<br>A. The resistivity of a material depends on its molecular and atomic structure.<br>B. The resistivity depends on the temperature of the material. |
| TOPIC 4.3: Resistance and Capacitance<br><br>4.E. The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems. | 4.E.4.1<br>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. [SP 2.2, 6.4]<br><br>4.E.4.2<br>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 | 4.E.4<br>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.<br>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.<br>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 |

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| | results to the basic properties of resistors and capacitors. [SP 4.1, 4.2]<br><br>4.E.4.3<br>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] | product of the dielectric constant, κ, of the material between the plates and the electric permittivity, $\varepsilon_0$ .<br>C. The current through a resistor is equal to the potential difference across the resistor divided by its resistance.<br>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.5.1<br>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. [SP 2.2, 6.4]<br><br>4.E.5.2<br>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. [SP 6.1, 6.4]<br><br>4.E.5.3<br>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, 5.1] | 4.E.5<br>The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of individual circuit elements, such as sources of emf, resistors, and capacitors. |

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| TOPIC 4.4: Kirchhoff's Loop Rule<br><br>5.B. The energy of a system is conserved. | 5.B.9.4<br>Analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule:$\Sigma\Delta V = 0$. [SP 5.1]<br><br>5.B.9.5<br>Describe and make predictions regarding electrical potential difference, charge, and current in steadystate circuits composed of various combinations of resistors and capacitors using conservation of energy principles (Kirchhoff's loop rule). [SP 6.4]<br><br>5.B.9.6<br>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. [SP 2.1, 2.2]<br><br>5.B.9.7<br>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]<br><br>5.B.9.8<br>Translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [SP 1.5] | 5.B.9<br>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.]<br>A. Energy changes in simple electrical circuits are conveniently represented in terms of energy change per charge moving through a battery and a resistor.<br>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.<br>C. The electric potential difference across a resistor is given by the product of the current and the resistance.<br>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.<br>E. Energy conservation can be applied to combinations of resistors and capacitors in series and parallel circuits. |
| TOPIC 4.5: Kirchhoff's Junction Rule and | 5.C.3.4 | 5.C.3 |

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| the Conservation of Electric Charge<br><br>5.C. The electric charge of a system is conserved. | Predict or describe current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule, and explain the relationship of the rule to the law of charge conservation. [SP 6.4, 7.2]<br><br>5.C.3.5<br>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. [SP 1.4, 2.2]<br><br>5.C.3.6<br>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. [SP 1.4, 2.2]<br><br>5.C.3.7<br>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. [SP 1.4, 2.2] | 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 include circuits that combine resistors in series and parallel. [Physics 1 covers circuits with resistors in series, with at most one parallel branch and one battery only. Physics 2 includes capacitors in steady-state situations. For circuits with capacitors, situations should be limited to open circuit, just after circuit is closed, and a long time after the circuit is closed.] |

**Assessment Evidence**
*Performance is evaluated in terms of…*
*Students will show their learning by…*

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 1: How can what's inside affect what's outside?

How can we measure something that has no weight, mass, or temperature?

- BIG IDEA 4: How can you change the value of something just by changing its shape?
  How does the resistance and capacitance of resistors and capacitors change in response to changes in the physical geometry of the circuit element?
  Why are holiday lights usually wired in series, while house lights are usually wired in parallel?
- BIG IDEA 5: How can the electric company justify its claims that it sells "electricity"?
  What happens to the charge in a cell phone battery when it "dies"?

➢ **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*

- 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
- 2 Mathematical Routines: The student can use mathematics appropriately.
- 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
- 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
- 6 Argumentation: The student can work with scientific explanations and theories.
- 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

➢ **Rubric based on AP Physics 2 Scoring Guidelines**

➢ **AP Classroom:**

➢ **Laboratory Work:**

- **Ohm's Law**
- **Play Doh Resistivity**
- **Series & Parallel Circuits**

# Unit 5 : MAGNETISM AND ELECTROMAGNETIC INDUCTION

In Units 3 and 4, students investigated electrostatic forces and fields and how free charges can be moved through electric fields to produce currents. In Unit 5, students will supplement that knowledge by exploring the relationships between moving charges and the magnetic forces and fields they generate. Students will discover the natural symmetry between electricity and magnetism and make connections between electromagnetic induction and the underlying principles behind most of the technology in modern society, including telephones, television, computers, and the Internet.
This unit will also build on the representations presented in the previous two units by introducing the magnetic field diagram to illustrate the effects of static and dynamic magnetic fields. Students must be able to relate the content and representations that they learned in previous physics courses. Recalling this content will help students overcome misconceptions, such as the existence of a centrifugal force. While students should master how to use specific equations to calculate unknown quantities, it is more important that they are able to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. In Unit 6, the idea of electromagnetic induction is used to relate to electromagnetic waves and their oscillating electric and magnetic fields. The concepts introduced in Unit 5 are greatly expanded upon in AP Physics C: Electricity and Magnetism.

| **ENDURING UNDERSTANDING**<br>The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year. | **LEARNING OBJECTIVE**<br>Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings. | **ESSENTIAL KNOWLEDGE**<br>Statements that describe the knowledge required to perform the learning objective. |
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| TOPIC 5.1: Magnetic Systems<br><br>1.A. The internal structure of a system determines many properties of the system. | 1.A.5.2<br>Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] | 1.A.5<br>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. |
| TOPIC 5.2: Magnetic Permeability and Magnetic Dipole Moment | [While there is no specific learning objective for it, EK 1.E.5 serves as a foundation for other learning objectives in the course.] | 1.E.5<br>Matter has a property called magnetic permeability.<br>A. Free space has a constant value of the |

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| 1.E. Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. | | permeability that appears in physical relationships.<br>B. The permeability of matter has a value different from that of free space. |
| | [While there is no specific learning objective for it, EK 1.E.6 serves as a foundation for other learning objectives in the course.] | 1.E.6<br>Matter has a property called magnetic dipole moment.<br>A. Magnetic dipole moment is a fundamental source of magnetic behavior of matter and an intrinsic property of some fundamental particles, such as the electron.<br>B. Permanent magnetism or induced magnetism of matter is a system property resulting from the alignment of magnetic dipole moments within the system. |
| TOPIC 5.3: Vector and Scalar Fields<br><br>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. | [While there is no specific learning objective for it, EK 2.A.1 serves as a foundation for other learning objectives in the course.] | 2.A.1<br>A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.<br>A. Vector fields are represented by field vectors indicating direction and magnitude.<br>B. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition.<br>C. Conversely, a known vector field can be<br>D. used to make inferences about the number, relative size, and location of sources. |
| | [While there is no specific learning objective for it, EK 2.A.2 serves as a foundation for other learning objectives in the course.] | 2.A.2<br>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.<br>A. Scalar fields are represented by field values.<br>B. When more than one source object with mass or charge is present, the scalar field value can be |

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| | | determined by scalar addition.<br>C. Conversely, a known scalar field can be used to make inferences about the number, relative size, and location of sources. |
| TOPIC 5.4: Monopole and Dipole Fields<br><br>2.C. An electric field is caused by an object with electric charge. | 2.C.4.1<br>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. [SP 2.2, 6.4, 7.2] | 2.C.4<br>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.<br>A. When an object is small compared with 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."<br>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. |
| TOPIC 5.5: Magnetic Fields and Forces<br><br>2.D. A magnetic field is caused by a magnet or moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles and never by single poles. | 2.D.1.1<br>Apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [SP 2.2] | 2.D.1<br>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°, and 180° and qualitative for other angles. |

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| | 2.D.2.1<br>Create a verbal or visual representation of a magnetic field around a straight wire or a pair of parallel wires. [SP 1.1] | 2.D.2<br>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 currentcarrying wire.<br>A. The magnitude of the magnetic field is proportional to the magnitude of the current in a long, straight wire.<br>B. 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.<br>C. Determining the force due to the magnetic field from a permanent magnet is a subset of determining the force due to the magnetic field of a current-carrying wire. |
| | 2.D.3.1<br>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 Earth and iron filings surrounding a bar magnet. [SP 1.2] | 2.D.3<br>A magnetic dipole placed in a magnetic field, such as the ones created by a magnet or Earth, will tend to align with the magnetic field vector.<br>A. 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.<br>B. A compass needle is a permanent magnetic dipole. Iron filings in a magnetic field become induced magnetic dipoles.<br>C. All magnets produce a magnetic field. Examples include the magnetic field pattern of a bar magnet as detected by iron filings or small compasses.<br>D. Earth has a magnetic field. |
| | 2.D.4.1<br>Qualitatively analyze the magnetic behavior of | 2.D.4<br>Ferromagnetic materials contain magnetic domains that |

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| | a bar magnet composed of ferromagnetic material. [SP 1.4] | are themselves magnets.<br>A. Magnetic domains can be aligned by external magnetic fields or can spontaneously align.<br>B. 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.<br>C. 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. |
| TOPIC 5.6: Magnetic Forces<br><br>3.C. At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. | 3.C.3.1<br>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 currentcarrying conductor. [SP 1.4]<br><br>3.C.3.2<br>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. [SP 4.2, 5.1] | 3.C.3<br>A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or another magnet.<br>A. Magnetic dipoles have “north” and “south” polarity.<br>B. 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.<br>C. In the presence of an external magnetic field, the magnetic dipole moment vector will align with the external magnetic field.<br>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. |
| TOPIC 5.7: Forces Review | | |
| 3.A. All forces share certain common characteristics when considered by observers in inertial reference frames. | 3.A.2.1<br>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<br>Forces are described by vectors.<br>A. Forces are detected by their influence on the motion of an object.<br>B. Forces have magnitude and direction. |

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| | 3.A.3.2<br>Construct an explanation for why an object cannot exert a force on itself. [SP 6.1]<br><br>3.A.3.3<br>Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4]<br><br>3.A.3.4<br>Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] | 3.A.3<br>A force exerted on an object is always due to the interaction of that object with another object.<br>A. An object cannot exert a force on itself.<br>B. Even though an object is at rest, there may be forces exerted on that object by other objects.<br>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.4.1<br>Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of actionreaction pairs of forces. [SP 1.4, 6.2]<br><br>3.A.4.2<br>Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2]<br><br>3.A.4.3<br>Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [SP 1.4] | 3.A.4<br>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. Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$. | 3.B.1.3<br>Re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the | 3.B.1<br>If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. |

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| | object. [SP 1.5, 2.2]<br><br>3.B.1.4<br>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. [SP 6.4, 7.2] | |
| | 3.B.2.1<br>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [SP 1.1, 1.4, 2.2] | 3.B.2<br>Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.<br>A. An object can be drawn as if it were extracted from its environment and the interactions with the environment identified.<br>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.<br>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.G. Certain types of forces are considered fundamental. | 3.G.2.1<br>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. [SP 7.1] | 3.G.2<br>Electromagnetic forces are exerted at all scales and can dominate at the human scale. |
| TOPIC 5.8: Magnetic Flux<br><br>4.E. The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems. | 4.E.1.1<br>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. [SP 1.1, 1.4, 2.2] | 4.E.1<br>The magnetic properties of some materials can be affected by magnetic fields in the system. Students should focus on the underlying concepts and not the use of the vocabulary.<br>A. Ferromagnetic materials can be permanently |

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| | 4.E.2.1<br>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. [SP 6.4] | magnetized by an external field that causes the alignment of magnetic domains or atomic magnetic dipoles.<br>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.<br>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 the external magnetic field.<br><br>4.E.2<br>Changing magnetic flux induces an electric field that can establish an induced emf in a system.<br>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.<br>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.<br>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.<br>D. The conservation of energy determines the direction of the induced emf relative to the change in the magnetic flux. |

**Assessment Evidence**
*Performance is evaluated in terms of…*
*Students will show their learning by…*

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 2: How are magnetic fields both helpful and harmful?
    To what extent can you predict interactions in magnetic fields?

- BIG IDEA 3: How can currentcarrying wires exert forces on magnets and other current-carrying wires?
  What common characteristics are shared by the magnetic force and other forces?
  How can magnetic forces accelerate objects or systems?
- BIG IDEA 4: Why does a relationship exist between electrical currents

➢ **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*

- 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
- 2 Mathematical Routines: The student can use mathematics appropriately.
- 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
- 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
- 6 Argumentation: The student can work with scientific explanations and theories.
- 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

➢ **Rubric based on AP Physics 2 Scoring Guidelines**

➢ **AP Classroom:**

➢ **Laboratory Work**

- **Electromagnet nail**
- **Lens' law**
- **Hand crank generators**
- **CRT electron deflection with B Fields**

# Unit 6 : GEOMETRIC AND PHYSICAL OPTICS

Although the nature of oscillating electric and magnetic fields, explored in Unit 5, sets the foundation for this unit's fundamental topic—electromagnetic waves, or light—Unit 6 demonstrates another distinct shift in both content and the models/representations used to analyze physical scenarios. In this unit, students will be introduced to the different ways of thinking about and modeling light, but the ideas and models used in this unit are fundamentally different from those used earlier in the course, as well as those used in previous physics courses.

This unit presents new challenges for teachers and students, because it introduces many new types of representations, including ray, wave front, and interference diagrams. It is essential that students understand how to create and use these diagrams to help answer questions and to use as evidence for claims. A more complete understanding of the different ways of thinking about and modeling light will help students analyze data more effectively; they can then apply this science practice to design a process of data analysis that will help them determine if the experimental design needs to be altered to produce the needed data to justify claims.

| **ENDURING UNDERSTANDING**<br>The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year. | **LEARNING OBJECTIVE**<br>Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings. | **ESSENTIAL KNOWLEDGE**<br>Statements that describe the knowledge required to perform the learning objective. |
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| TOPIC 6.1: Waves<br><br>6.A. A wave is a traveling disturbance that transfers energy and momentum. | 6.A.1.2<br>Describe representations of transverse and longitudinal waves. [SP 1.2]<br><br>6.A.1.3<br>Analyze data (or a 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. [SP 5.1, 6.2] | 6.A.1<br>Waves can propagate via different oscillation modes, such as transverse and longitudinal.<br>A. Mechanical waves can be either transverse or longitudinal. Examples should include waves on a stretched string and sound waves.<br>B. Electromagnetic waves are transverse waves.<br>C. Transverse waves may be polarized. |
| | 6.A.2.2<br>Contrast mechanical and electromagnetic | 6.A.2<br>For propagation, mechanical waves require a medium, |

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| | waves in terms of the need for a medium in wave propagation.<br>[SP 6.4, 7.2] | while electromagnetic waves do not require a physical medium. Examples include light traveling through a vacuum and sound not traveling through a vacuum. |
| TOPIC 6.2: Electromagnetic Waves<br><br>6.F. Electromagnetic radiation can be modeled as waves or as fundamental particles. | 6.F.1.1<br>Make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [SP 6.4, 7.2] | 6.F.1<br>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<br>Describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. [SP 1.1] | 6.F.2<br>Electromagnetic waves can transmit energy through a medium and through a vacuum.<br>A. Electromagnetic waves are transverse waves composed of mutually perpendicular electric and magnetic fields that can propagate through a vacuum.<br>B. The planes of these transverse waves are both perpendicular to the direction of propagation. |
| TOPIC 6.3: Periodic Waves<br><br>6.B. A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy. | 6.B.3.1<br>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. [SP 1.5] | 6.B.3<br>A simple wave can be described by an equation involving one sine or cosine function involving the wavelength, amplitude, and frequency of the wave. |
| TOPIC 6.4: Refraction, Reflection, and Absorption | 6.E.1.1<br>Make claims using<br>connections across concepts | 6.E.1<br>When light travels from one medium to another,<br>some of the light is transmitted, some is |

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| 6.E. The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media. | 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. [SP 6.4, 7.2] | reflected, and some is absorbed (qualitative understanding only). |
| | 6.E.2.1<br>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. [SP 6.4, 7.2]<br><br>6.E.3.1<br>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. [SP 1.1, 1.4]<br><br>6.E.3.2<br>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). [SP 4.1, 5.1, 5.2, 5.3]<br><br>6.E.3.3<br>Make claims and predictions about path changes for light traveling across a boundary | 6.E.2<br>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.<br><br>6.E.3<br>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.<br>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.<br>B. When light travels from an optically slower substance into an optically faster substance, it bends away from the perpendicular.<br>C. At the critical angle, the light bends far enough away from the perpendicular that it skims the surface of the material.<br>D. Beyond the critical angle, all of the light is internally reflected. |

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| | from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. [SP 6.4, 7.2] | |
| TOPIC 6.5: Images from Lenses and Mirrors<br><br>6.E. The direction of propagation of a wave such as light may be changed when the wave encounters interface between two media. | 6.E.4.1<br>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. [SP 3.2, 4.1, 5.1, 5.2, 5.3]<br><br>6.E.4.2<br>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. [SP 1.4, 2.2]<br><br>6.E.5.1<br>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. [SP 1.4, 2.2]<br><br>6.E.5.2<br>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. [SP 3.2, 4.1, 5.1, 5.2, 5.3] | 6.E.4<br>The reflection of light from surfaces can be used to form images.<br>A. Ray diagrams are very useful for showing how and where images of objects are formed for different mirrors and how this depends on the placement of the object. Examples include concave and convex mirrors.<br>B. Ray diagrams are also useful for determining the size of the resulting image compared with the size of the object.<br>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.<br><br>6.E.5<br>The refraction of light as it travels from one transparent medium to another can be used to form images.<br>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. Examples include converging and diverging lenses. |
| TOPIC 6.6: Interference and Diffraction<br><br>6.C. Only waves exhibit interference and diffraction. | 6.C.1.1<br>Make claims and predictions about the net disturbance that occurs when two waves overlap. Examples include standing waves. [SP 6.4, 7.2] | 6.C.1<br>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 |

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| | 6.C.1.2<br>Construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [SP 1.4] | superposition. Examples include interference resulting from diffraction through slits as well as thin-film interference. |
| | 6.C.2.1<br>Make claims about the diffraction pattern produced when a wave passes through a small opening, and 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. [SP 1.4, 6.4, 7.2]<br><br>6.C.3.1<br>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 with the wavelength of the waves. [SP 1.4, 6.4] | 6.C.2 When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed.<br><br>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 include monochromatic double-slit interference. |
| | 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. [SP 6.4, 7.2] | 6.C.4 When waves pass by an edge, they can diffract into the “shadow region” behind the edge. Examples include hearing around corners but not seeing around them, and water waves bending around obstacles. |
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| **Assessment Evidence**<br>*Performance is evaluated in terms of...*<br>*Students will show their learning by...* | | |

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 6: Can we really make something invisible?
    How do household items make use of various wave properties?
  - How can an object not be where it appears to be?
  - How can electromagnetic waves be modeled?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 3 Scientific Questioning: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course (not assessed on the AP Exam).
  - 4 Experimental Methods: The student can plan and implement data-collection strategies in relation to a particular scientific question.
  - 5 Data Analysis: The student can perform data analysis and evaluation of evidence.
  - 6 Argumentation: The student can work with scientific explanations and theories.
  - 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
- **Rubric based on AP Physics 2 Scoring Guidelines**
- **AP Classroom:**
- **Laboratory Work:**
  - **Mirrors**
  - **Lens**
  - **Pinhole**
  - **Refraction (Snell's Law)**
  - **Reflection**

# Unit 7: QUANTUM, ATOMIC, AND NUCLEAR PHYSICS

Unit 7 lays the groundwork for the study of modern physics by resolving the conflicts and questions that were left unanswered by Newtonian mechanics. While new models and representations are introduced in Unit 7 (such as the electron level diagram), students will be able to make connections between the content of this unit and the fundamental principles of physics, principles of conservation, and models and representations used earlier in the course. These connections will help students make predictions about a variety of phenomena—including the rate of radioactive decay or the type of nuclear reaction—in addition to making and justifying claims with evidence about such phenomena. Students must be able to connect what they learn in this unit with the fundamental principles of physics. This is more important than being able to calculate numerical equations. For example, students will be asked to connect the photoelectric experiment to the ideas of energy conservation and the particle model of light.
Unit 7 represents only the first step into the realm of modern physics. Students who continue their study of physics in college will have the opportunity to learn about the developments in physics since the dawn of the 20th century.

| **ENDURING UNDERSTANDING**<br>The long-term takeaways related to the big ideas that leave a lasting impression. Students build and earn these understandings over time by exploring and applying course content throughout the year. | **LEARNING OBJECTIVE**<br>Define what a student needs to be able to do with content knowledge in order to progress toward the enduring understandings. | **ESSENTIAL KNOWLEDGE**<br>Statements that describe the knowledge required to perform the learning objective. |
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| TOPIC 7.1: Systems and Fundamental Forces | | |
| 1.A. The internal structure of a system determines many properties of the system. | 1.A.2.1<br>Construct representations of the differences between a fundamental particle and a system composed of fundamental particles, and relate this to the properties and scales of the systems being investigated. [SP 1.1, 7.1] | 1.A.2<br>Fundamental particles have no internal structure.<br>A. Electrons, neutrinos, photons, and quarks are examples of fundamental particles.<br>B. Neutrons and protons are composed of quarks.<br>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. |
| | [While there is no specific learning objective for it, EK 1.A.3 serves as a foundation for other | 1.A.3<br>Nuclei have internal structures that determine their |

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| | learning objectives in the course.] | properties.<br>A. The number of protons identifies the element.<br>B. The number of neutrons together with the number of protons identifies the isotope.<br>C. There are different types of radioactive emissions from the nucleus.<br>D. The rate of decay of any radioactive isotope is specified by its half-life. |
| | 1.A.4.1<br>Construct representations of the energy-level structure of an electron in an atom, and relate this to the properties and scales of the systems being investigated. [SP 1.1, 7.1] | 1.A.4<br>Atoms have internal structures that determine their properties.<br>A. The number of protons in the nucleus determines the number of electrons in a neutral atom.<br>B. The number and arrangements of electrons cause elements to have different properties.<br>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).<br>D. Discrete energy-state transitions lead to spectra. |
| 3.G. Certain types of forces are considered fundamental. | 3.G.3.1<br>Identify the strong force as the force that is responsible for holding the nucleus together. [SP 7.2] | 3.G.3<br>The strong force is exerted at nuclear scales and dominates the interactions of nucleons. |
| TOPIC 7.2 Radioactive Decay | | |
| 5.C. The electric charge of a system is conserved. | 5.C.1.1<br>Analyze electric charge conservation for nuclear and elementary particle reactions, and make predictions related to such reactions based on conservation of charge. [SP 6.4, 7.2] | 5.C.1<br>Electric charge is conserved in nuclear and elementary particle reactions, even when elementary particles are produced or destroyed. Examples include equations representing nuclear decay. |

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| 5.D. The linear momentum of a system is conserved. | 5.D.1.6<br>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. [SP 6.4]<br><br>5.D.1.7<br>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. [SP 2.1, 2.2] | 5.D.1 In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.<br>a. In a closed system, the linear momentum is constant throughout the collision. b. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision. |
| | 5.D.2.5<br>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. [SP 2.1, 2.2]<br><br>5.D.2.6<br>Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [SP 6.4, 7.2] | 5.D.2<br>In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.<br>A. In a closed system, the linear momentum is constant throughout the collision.<br>B. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision. |
| | 5.D.3.2<br>Make predictions about the velocity of the center of mass for interactions within | 5.D.3<br>The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1 |

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| | a defined one-dimensional system. [SP 6.4]<br><br>5.D.3.3 Make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. [SP 6.4] | includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]<br>A. The center of mass of a system depends on 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.<br>B. 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<br>Nucleon number is conserved. | 5.G.1.1<br>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. [SP 6.4] | 5.G.1<br>The possible nuclear reactions are constrained by the law of conservation of nucleon number. |
| TOPIC 7.3: Energy in Modern Physics (Energy in Radioactive Decay and $E = mc^2$)<br><br>5.B. The energy of a system is conserved. | 5.B.2.1<br>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, 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. [SP 1.4, 2.1]<br><br>5.B.4.1<br>Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2]<br><br>5.B.4.2 | 5.B.2<br>A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1 includes mass-spring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.]<br><br>5.B.4<br>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.<br>A. Since energy is constant in a closed system, changes in a system's potential energy can result |

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| | Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. [SP 1.4, 2.1, 2.2] | in changes to the system's kinetic energy.<br>B. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system. |
| | 5.B.5.4<br>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). [SP 6.4, 7.2] | 5.B.5<br>Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.] The work done on a system is defined as $W = -P\Delta V$ for constant pressure or an average pressure. |
| | 5.B.8.1<br>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. [SP 1.2, 7.2]<br><br>5.B.11.1<br>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. [SP 2.2, 7.2] | 5.B.8<br>Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.<br>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).<br>B. An emission spectrum can be used to determine the elements in a source of light.<br><br>5.B.11<br>Beyond the classical approximation, mass is actually part of the internal energy of an object or system with $E = mc^2$.<br>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). |

| TOPIC 7.4: Mass-Energy Equivalence | | |
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| 1.C. Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and satisfy conservation principles. | 1.C.4.1<br>Articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass–energy. [SP 6.3] | 1.C.4<br>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. |
| 4.C. Interactions with other objects or systems can change the total energy of a system. | 4.C.4.1<br>Apply mathematical routines to describe the relationship between mass and energy, and apply this concept across domains of scale. [SP 2.2, 2.3, 7.2] | 4.C.4<br>Mass can be converted into energy, and energy can be converted into mass.<br>A. Mass and energy are interrelated by $E = mc^2$.<br>B. Significant amounts of energy can be released in nuclear processes. |
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| TOPIC 7.5: Properties of Waves and Particles | | |
| 1.D<br>Classical mechanics cannot describe all properties of objects. | 1.D.1.1<br>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. [SP 6.3] | 1.D.1<br>Objects classically thought of as particles can exhibit properties of waves.<br>A. This wavelike behavior of particles has been observed (e.g., in a double-slit experiment using elementary particles).<br>B. The classical models of objects do not describe their wave nature. These models break down when observing objects in small dimensions. |
| | [While there is no specific learning objective for it, EK 1.D.2 serves as a foundation for other learning objectives in the course.] | 1.D.2<br>Certain phenomena classically thought of as waves can exhibit properties of particles.<br>A. The classical models of waves do not describe the nature of a photon.<br>B. Momentum and energy of a photon can be related to its frequency and wavelength. |
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| | 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.] [SP 6.3, 7.1] | Properties of space and time cannot always be treated as absolute.<br>A. Relativistic mass–energy equivalence is a reconceptualization of matter and energy as two manifestations of the same underlying entity, fully interconvertible, thereby rendering invalid the classically separate laws of conservation of mass and conservation of energy. Students will not be expected to know apparent mass or rest mass.<br>B. Measurements of length and time depend on speed (qualitative treatment only). |
| 6.C. Only waves exhibit interference and diffraction. | 6.C.1.1<br>Make claims and predictions about the net disturbance that occurs when two waves overlap. Examples include standing waves. [SP 6.4, 7.2]<br><br>6.C.1.2<br>Construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [SP 1.4]<br><br>6.C.2.1<br>Make claims about the diffraction pattern produced when a wave passes through a small opening, and qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose | 6.C.1<br>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. Examples include interference resulting from diffraction through slits as well as thin-film interference.<br><br>6.C.2<br>When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed. |

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| | dimensions are comparable to the wavelength of the wave. [SP 1.4, 6.4, 7.2] | |
| | 6.C.3.1<br>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 with the wavelength of the waves. | 6.C.3<br>When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples include monochromatic double-slit interference. |
| | 6.C.4.1<br>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. [SP 6.4, 7.2] | 6.C.4<br>When waves pass by an edge, they can diffract into the "shadow region" behind the edge. Examples include hearing around corners but not seeing around them, and water waves bending around obstacles. |
| 6.G<br>All matter can be modeled as waves or particles. | 6.G.1.1<br>Make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. [SP 6.4, 7.1] | 6.G.1<br>Under certain regimes of energy or distance, matter can be modeled as a classical particle. |
| | 6.G.2.1<br>Articulate the evidence supporting the claim that a wave model of matter is appropriate to explain the diffraction of matter interacting | 6.G.2<br>Under certain regimes of energy or distance, matter can be modeled as a wave. The behavior in these regimes is described by quantum mechanics. |

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| | 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. [SP 6.1]<br><br>6.G.2.2 Predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima) based on 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.) [SP 6.4] | A. A wave model of matter is quantified by the de Broglie wavelength that increases as the momentum of the particle decreases.<br>B. 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. |
| TOPIC 7.6: Photoelectric Effect<br><br>6.F<br>Electromagnetic radiation can be modeled as waves or as fundamental particles. | 6.F.3.1<br>Support the photon model of radiant energy with evidence provided by the photoelectric effect. [SP 6.4]<br><br>6.F.4.1<br>Select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. [SP 6.4, 7.1] | 6.F.3<br>Photons are individual energy packets of electromagnetic waves, with E = hf, where h is Planck's constant, and f is the frequency of the associated light wave.<br>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.<br>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.<br>C. Evidence for discrete energy packets is provided by a frequency threshold for electron emission. Above the threshold, emission increases with the frequency and not the intensity of absorbed radiation. The photoelectric effect should be included as an example.<br><br>6.F.4 |

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| | | The nature of light requires that different models of light are most appropriate at different scales.<br>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 Ephoton.<br>B. The wavelike properties of electromagnetic radiation are more readily observed when the scale of the objects with which it interacts is comparable to or larger than the wavelength of the radiation. |
| TOPIC 7.7: Wave Functions and Probability<br><br>7.C. At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world. | 7.C.1.1<br>Use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region. [SP 1.4] | 7.C.1<br>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<br>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. [SP 1.4]<br><br>7.C.3.1<br>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. [SP 6.4] | 7.C.2<br>The allowed states for an electron in an atom can be calculated from the wave model of an electron.<br>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.<br>B. 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.<br><br>7.C.3 |

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| | | The spontaneous radioactive decay of an individual nucleus is described by probability.<br>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.<br>B. 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.<br>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.4.1<br>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.] [SP 1.1, 1.2] | 7.C.4<br>Photon emission and absorption processes are described by probability.<br>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).<br>B. An atom in an excited energy state may jump spontaneously to a lower energy state with the emission of a photon (spontaneous emission).<br>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.<br>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 Evidence**
*Performance is evaluated in terms of…*
*Students will show their learning by…*

- **Checks for understanding and feedback on essential unit questions** *(Potential Quick write, Think-Pair-Share or Fishbowl):*
  - BIG IDEA 5: How can nucleon numbers be conserved when there are so many ways for an atom to split and decay?
  - BIG IDEA 6: How does the photoelectric effect support the idea of wave/particle duality?
  - BIG IDEA 7: How does probability govern the behavior of systems?
    How can we best measure/describe/represent what we cannot directly see?
- **Free-response questions aligned to AP Physics Science Practices:** *(Task verbs commonly used in free-response questions- Calculate, Construct/Draw, Describe, Determine, Evaluate, Explain, Identify, Justify, Make a claim, Predict/Make a prediction, Represent, State, Support a claim)*
  - 1 Modeling: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
  - 2 Mathematical Routines: The student can use mathematics appropriately.
  - 6 Argumentation: The student can work with scientific explanations and theories.
  - 7 Making Connections: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
- **Rubric based on AP Physics 2 Scoring Guidelines**
- **AP Classroom:**
- **Laboratory Work:**
  - **LED Photoelectric Effect**
  - **Microwave Energy Transfer**
  - **Solar Panel Energy Generation**