

## AP Physics 2

<b>Curriculum/Content Area:</b> Science	<b>Course Length:</b> 2 Terms
<b>Course Title:</b> AP Physics 2	<b>Date last reviewed:</b> 2018
<b>Prerequisites:</b> None	<b>Board approval date:</b> May 2018
<b>Primary Resource:</b> Giancoli, Douglas C. (2005) Physics : principles with applications Upper Saddle River, N.J. : Pearson/Prentice Hall, Urone, P., & Hinrichs, R. (2016). College Physics. Houston, Texas: OpenStax College.	

## Desired Results

**Course description and purpose:** AP Physics 2 is the equivalent to a second-semester algebra- based college physics course. The course covers fluid mechanics; thermodynamics; electricity and magnetism; optics and atomic and nuclear physics. The ability to develop and use physics knowledge by using scientific inquiry and reasoning is at the heart of this course. Students interested in Engineering and the physical science should follow this course with AP Physics C: Calculus-Based.

AP Physics Big Ideas
<b>Big Idea 1:</b> Objects and systems have properties such as mass and charge. Systems may have internal structure.
<b>Big Idea 2:</b> Fields existing in space can be used to explain interactions.
<b>Big Idea 3:</b> The interactions of an object with other objects can be described by forces.
<b>Big Idea 4:</b> Interactions between systems can result in changes in those systems.
<b>Big Idea 5:</b> Changes that occur as a result of interactions are constrained by conservation laws.
<b>Big Idea 6:</b> 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.
<b>Big Idea 7:</b> The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

## Fluids

### **AP Big Ideas**

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

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

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

### **Standards:**

#### **AP Physics Enduring Understandings**

**EU1.A** The internal structure of a system determines many properties of the system.

**EU1.E** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the materia

**EU3.A** All forces share certain common characteristics when considered by observers in inertial reference frames.

**EU3B** Classically, the acceleration of an object interacting with other objects can be predicted by using

**EU3.C** At the macroscopic level, forces can be categorized as either long-range (action-at-a- distance) forces or contact forces.

**EU5.B** The energy of a system is conserved.

**EU5.F** Classically, the mass of a system is conserved.

#### **Advanced Placement Science Practices**

**SP2** The student can use mathematics appropriately.

**SP4** The student can plan and implement data collection strategies in relation to a particular scientific question. (Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction and/or archived data.)

**SP6** The student can work with scientific explanations and theories.

**SP7** The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.

### **Learning Targets:**

### Big Idea 1

- I can 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, 6]**
- I can select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. **[SP 4, 6]**

### Big Idea 3

- I can make claims about various contact forces between objects based on the microscopic cause of those forces. **[SP 6]**
- I can explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. **[SP 6]**

### Big Idea 5

- I can use Bernoulli's equation to make calculations related to a moving fluid. **[SP 2]**
- I can use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid. **[SP 2]**
- I can use Bernoulli's equation and the continuity equation to make calculations related to a moving fluid. **[SP 2]**
- I can construct an explanation of Bernoulli's equation in terms of the conservation of energy. **[SP 6]**
- I can make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). **[SP 2,7]**

### Assessment Evidence

#### Performance Assessment Options

*May include, but are not limited to the following:*

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#### Other assessment options

*May include, but are not limited to the following:*

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### Digital Tools & Supplementary Resources

[Suggested AP Physics 2 Lab Investigations](#)

[Teacher's Lab Manual](#)

[Fluid Simulations - Phet](#)

[Fluid Simulations - oPhysics](#)

## Thermodynamics

### **AP Big Ideas**

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

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

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

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

**Big Idea 7:** The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

## Standards

### **AP Physics Enduring Understandings**

**EU1.A:** The internal structure of a system determines many properties of the system.

**EU1.E:** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

**EU3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames.

**EU3B:** Classically, the acceleration of an object interacting with other objects can be predicted by using

**EU3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

**EU4.C:** Interactions with other objects or systems can change the total energy of a system.

**EU5.B:** The energy of a system is conserved.

**EU5.D:** The linear momentum of a system is conserved.

**EU7.A:** The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure.

**EU7.B:** The tendency of isolated systems to move toward states with higher disorder is described by probability.

### **AP Physics Science Practices**

**SP1:** The student can use representations and models to communicate scientific phenomena and solve scientific problems.

**SP2:** The student can use mathematics appropriately.

**SP3:** The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

**SP4:** The student can plan and implement data collection strategies in relation to a particular scientific question. (Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction and/or archived data.)

**SP5:** The student can perform data analysis and evaluation of evidence.

**SP6:** The student can work with scientific explanations and theories.

**SP7:** The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.

## Learning Targets

### Big Idea 1

- I can design an experiment and analyze data from it to examine thermal conductivity. [SP 4, 5]

### Big Idea 4

- I can make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [SP 6]

### Big Idea 5

- I can define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. [SP 6, 7]
- I can describe and make predictions about the internal energy of systems. [SP 6, 7]
- I can calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [SP 1, 2]
- I can 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, 7]
- I can 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, 6]
- I can 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, 5]
- I can 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]

- I can 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, 7]**
- I can create a plot of pressure versus volume for a thermodynamic process from given data. **[SP 1]**
- I can use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics). **[SP 1, 2]**

### Big Idea 7

- I can 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, 7]**
- I can qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. **[SP 7]**
- I can connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes. **[SP 7]**
- I can 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, 7]**
- I can design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and amount of an ideal gas, and to refine a scientific question concerning a proposed incorrect relationship between the variables. **[SP 3, 4]**
- I can 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]**
- I can 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, 7]**
- I can 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]**

### Assessment Evidence

#### Performance Assessment Options

*May include, but are not limited to the following:*

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#### Other assessment options

*May include, but are not limited to the following:*

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### Digital Tools & Supplementary Resources

*Tools and resources that can augment the learning experience for students*

[Suggested AP Physics 2 Lab Investigations](#)

[Teacher's Lab Manual](#)

[Thermodynamics Simulations - PhET](#)

## Electric Forces, Field, and Potential

### AP Big Ideas

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

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

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

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

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

### Standards

#### AP Physics Enduring Understandings

**EU1.A:** The internal structure of a system determines many properties of the system.

**EU1.B:** Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.

**EU1.E:** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

**EU2.A:** A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur

**EU2.C:** An electric field is caused by an object with electric charge.

**EU2.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.

**EU3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames.

**EU3B:** Classically, the acceleration of an object interacting with other objects can be predicted by using

**EU3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

**EU3G:** Certain types of forces are considered fundamental.

**EU4.E:** The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

**EU5.B:** The energy of a system is conserved.

**EU5.C:** The electric charge of a system is conserved.

### **Advanced Placement Science Practices**

**SP1:** The student can use representations and models to communicate scientific phenomena and solve scientific problems.

**SP2:** The student can use mathematics appropriately.

**SP3:** The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

**SP4:** The student can plan and implement data collection strategies in relation to a particular scientific question. (Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction and/or archived data.)

**SP5:** The student can perform data analysis and evaluation of evidence.

**SP6:** The student can work with scientific explanations and theories.

**SP7:** The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.

### **Learning Targets**

#### **Big Idea 1**

- I can make claims about natural phenomena based on conservation of electric charge. **[SP 6]**
- I can 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, 7]**
- I can make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. **[SP 6, 7]**
- I can challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. **[SP 6]**
- I can challenge the claim that an electric charge smaller than the elementary charge has been isolated. **[SP 1, 6, 7]**



## Big Idea 2

- I can 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, 7]
- I can 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]
- I can qualitatively and semi-quantitatively apply the vector relationship between the electric field and the net electric charge creating that field. [SP 2, 6]
- I can explain the inverse square dependence of the electric field surrounding a spherically symmetric electrically charged object. [SP 6]
- I can 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, 6, 7]
- I can apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (2–4) of point charges, and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points. [SP 1, 2]
- I can create representations of the magnitude and direction of the electric field at various distances (small compared to plate size) from two electrically charged plates of equal magnitude and opposite signs, and is able to recognize that the assumption of uniform field is not appropriate near edges of plates. [SP 1, 2]
- I can 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]
- I can represent the motion of an electrically charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in the Earth's gravitational field. [SP 1, 2, 7]
- I can 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, 6, 7]
- I can determine the structure of isolines of electric potential by constructing them in a given electric field. [SP 6, 7]
- I can 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, 7]

- I can qualitatively use the concept of isolines to construct isolines of electric potential in an electric field and determine the effect of that field on electrically charged objects. **[SP 1]**
- I can 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]**
- I can 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, 6]**

### **Big Idea 3**

- I can represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1]**
- I can challenge a claim that an object can exert a force on itself. **[SP 6]**
- I can describe a force as an interaction between two objects and identify both objects for any force. **[SP 1]**
- I can make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge. **[SP 6]**
- I can 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, 6]**
- I can use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. **[SP 6, 7]**
- I can 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]**
- I can reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. **[SP 1, 2]**
- I can 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, 7]**
- I can create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. **[SP 1, 2]**
- I can use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. **[SP 2, 6]**
- I can connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. **[SP 7]**
- I can use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situations of high symmetry). **[SP 2]**

- I can connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength to other types of forces. **[SP 7]**
- I can 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]**

#### **Big Idea 4**

- I can make predictions about the redistribution of charge during charging by friction, conduction, and induction. **[SP 6]**
- I can make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. **[SP 6, 7]**
- I can construct a representation of the distribution of fixed and mobile charge in insulators and conductors. **[SP 1, 6]**
- I can 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. **[SP 1, 6]**
- I can plan and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or is able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure. **[SP 3, 4, 5]**

#### **Big Idea 5**

- I can define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. **[SP 6, 7]**
- I can calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. **[SP 1, 2]**
- I can predict electric charges on objects within a system by application of the principle of charge conservation within a system. **[SP 6]**
- I can 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, 5]**
- I can justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects. **[SP 4]**

#### **Assessment Evidence**

##### **Performance Assessment Options**

*May include, but are not limited to the following:*

##### **Other assessment options**

*May include, but are not limited to the following:*

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<b>Digital Tools &amp; Supplementary Resources</b>	
<a href="#">Suggested AP Physics 2 Lab Investigations</a> <a href="#">Teacher's Lab Manual</a> <a href="#">Electricity Simulations - PhET</a> <a href="#">Electricity Simulations - oPhysics</a>	

<b>Electric Circuits</b>
<p><b>AP Big Ideas</b></p> <p><b>Big Idea 1:</b> Objects and systems have properties such as mass and charge. Systems may have internal structure.</p> <p><b>Big Idea 4:</b> Interactions between systems can result in changes in those systems.</p> <p><b>Big Idea 5:</b> Changes that occur as a result of interactions are constrained by conservation laws.</p>
<b>Standards</b>
<p><b>AP Physics Enduring Understandings</b></p> <p><b>EU1.B:</b> Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.</p> <p><b>EU1.E:</b> Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.</p> <p><b>EU4.E:</b> The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.</p> <p><b>EU5.B:</b> The energy of a system is conserved.</p> <p><b>EU5.C:</b> The electric charge of a system is conserved.</p> <p><b>Advanced Placement Science Practices</b></p> <p><b>SP1:</b> The student can use representations and models to communicate scientific phenomena and solve scientific problems.</p> <p><b>SP2:</b> The student can use mathematics appropriately.</p> <p><b>SP4:</b> The student can plan and implement data collection strategies in relation to a particular scientific question. (Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction and/or archived data.)</p>

**SP5:** The student can perform data analysis and evaluation of evidence.

**SP6:** The student can work with scientific explanations and theories.

**SP7:** The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.

## Learning Targets

### Big Idea 1

- I can choose and justify the selection of data needed to determine resistivity for a given material. **[SP 4]**

### Big Idea 4

- I can 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, 6]**
- I can design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. **[SP 4]**
- I can 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]**
- I can 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, 6]**
- I can 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]**
- I can 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, 4, 5]**

### Big Idea 5

- I can analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule. **[SP 5]**
- I can use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. **[SP 6]**

- I can 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]**
- I can 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, 5]**
- I can translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. **[SP 1]**
- I can predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. **[SP 6, 7]**
- I can 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, 2]**
- I can 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, 2]**
- I can 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, 2]**

#### Assessment Evidence

##### Performance Assessment Options

*May include, but are not limited to the following:*

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##### Other assessment options

*May include, but are not limited to the following:*

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#### Digital Tools & Supplementary Resources

[Suggested AP Physics 2 Lab Investigations](#)

[Teacher's Lab Manual](#)

[Electricity Simulations - PhET](#)

[Electricity Simulations - oPhysics](#)

#### Magnetism and Electromagnetic Induction

##### AP Big Ideas

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

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

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

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

## Standards

### **AP Physics Enduring Understandings**

**EU1.A:** The internal structure of a system determines many properties of the system.

**EU1.E:** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

**EU2.A:** A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur

**EU2.C:** An electric field is caused by an object with electric charge.

**EU2.D:** A magnetic field is caused by a magnet or a moving electrically charged object. Magnetic fields observed in nature always seem to

**EU3.A:** All forces share certain common characteristics when considered by observers in inertial reference frames.

**EU3B:** Classically, the acceleration of an object interacting with other objects can be predicted by using

**EU3.C:** At the macroscopic level, forces can be categorized as either long-range (action-at-a- distance) forces or contact forces.

**EU3G:** Certain types of forces are considered fundamental.

**EU4.E:** The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

### **Advanced Placement Science Practices**

**SP1:** The student can use representations and models to communicate scientific phenomena and solve scientific problems.

**SP2:** The student can use mathematics appropriately.

**SP3:** The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

**SP4:** The student can plan and implement data collection strategies in relation to a particular scientific question. (Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction and/or archived data.)

**SP5:** The student can perform data analysis and evaluation of evidence.

**SP6:** The student can work with scientific explanations and theories.

**SP7:** The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.

## Learning Targets

### Big Idea 2

- I can 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, 6, 7]**
- I can apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. **[SP 2]**
- I can create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires. **[SP 1]**
- I can describe the orientation of a magnetic dipole placed in a magnetic field in general and the particular cases of a compass in the magnetic field of the Earth and iron filings surrounding a bar magnet. **[SP 1]**
- I can use the representation of magnetic domains to qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material. **[SP 1]**

### Big Idea 3

- I can represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1]**
- I can challenge a claim that an object can exert a force on itself. **[SP 6]**
- I can describe a force as an interaction between two objects and identify both objects for any force. **[SP 1]**
- I can 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, 6]**
- I can use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. **[SP 6, 7]**
- I can 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]**



- I can use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. **[SP 1]**
- I can 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, 5]**

#### Big Idea 4

- I can 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, 2]**
- I can 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]**

#### Assessment Evidence

##### Performance Assessment Options

*May include, but are not limited to the following:*

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##### Other assessment options

*May include, but are not limited to the following:*

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#### Digital Tools & Supplementary Resources

[Suggested AP Physics 2 Lab Investigations](#)

[Teacher's Lab Manual](#)

[E & M Simulations - PhET](#)

[E & M Simulations - oPhysics](#)

#### Geometric and Physics Optics

##### AP Big Ideas

**Big Idea 6:** Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

#### Standards

### **AP Physics Enduring Understandings**

**EU6.A:** A wave is a traveling disturbance that transforms energy and momentum

**EU6.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.

**EU6.C:** Only waves exhibit interference and diffraction.

**EU6E:** The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.

**EU6.F:** Electromagnetic radiation can be modeled as waves or as fundamental particles.

### **Advanced Placement Science Practices**

**SP1:** The student can use representations and models to communicate scientific phenomena and solve scientific problems.

**SP4:** The student can plan and implement data collection strategies in relation to a particular scientific question. (Note: Data can be collected from many different sources, e.g., investigations, scientific observations, the findings of others, historic reconstruction and/or archived data.)

**SP5:** The student can perform data analysis and evaluation of evidence.

**SP6:** The student can work with scientific explanations and theories.

**SP7:** The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.

### **Learning Targets**

#### **Big Idea 6**

- I can describe representations of transverse and longitudinal waves. **[SP 1]**
- I can 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, 6]**
- I can contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. **[SP 6, 7]**
- I can 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]**
- I can make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. **[SP 6, 7]**

- I can construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. **[SP 1]**
- I can make claims about the diffraction pattern produced when a wave passes through a small opening, and to qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. **[SP 1, 6, 7]**
- I can qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared to the wavelength of the waves. **[SP 1, 6]**
- I can 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, 7]**
- I can make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. **[SP 6, 7]**
- I can 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, 7]**
- I can 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]**
- I can 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, 5]**
- I can make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. **[SP 6, 7]**
- I can make qualitative comparisons of the wavelengths of types of electromagnetic radiation. **[SP 6, 7]**
- I can describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. **[SP 1]**

### Assessment Evidence

#### Performance Assessment Options

*May include, but are not limited to the following:*

#### Other assessment options

*May include, but are not limited to the following:*

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<b>Digital Tools &amp; Supplementary Resources:</b>	
<a href="#">Suggested AP Physics 2 Lab Investigations</a> <a href="#">Teacher's Lab Manual</a> <a href="#">Light Simulations - PhET</a> <a href="#">Light Simulations - oPhysics</a>	

<b>Quantum, Atomic, and Nuclear Physics</b>
<p><b>AP Big Ideas</b></p> <p><b>Big Idea 1:</b> Objects and systems have properties such as mass and charge. Systems may have internal structure.</p> <p><b>Big Idea 3:</b> The interactions of an object with other objects can be described by forces.</p> <p><b>Big Idea 4:</b> Interactions between systems can result in changes in those systems.</p> <p><b>Big Idea 5:</b> Changes that occur as a result of interactions are constrained by conservation laws.</p> <p><b>Big Idea 6:</b> 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.</p> <p><b>Big Idea 7:</b> The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.</p>
<b>Standards</b>
<p><b>AP Physics Enduring Understandings</b></p> <p><b>EU1.A:</b> The internal structure of a system determines many properties of the system.</p> <p><b>EU1.C:</b> Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.</p> <p><b>EU1.D:</b> Classical mechanics cannot describe all properties of objects.</p> <p><b>EU3G:</b> Certain types of forces are considered fundamental.</p> <p><b>EU4.C:</b> Interactions with other objects or systems can change the total energy of a system.</p> <p><b>EU5.B:</b> The energy of a system is conserved.</p> <p><b>EU5.C:</b> The electric charge of a system is conserved.</p> <p><b>EU5.D:</b> The linear momentum of a system is conserved.</p>

**EU5.G:** Nucleon number is conserved.

**EU6.C:** Only waves exhibit interference and diffraction.

**EU6.F:** Electromagnetic radiation can be modeled as waves or as fundamental particles.

**EU6.G:** All matter can be modeled as waves or as particles.

**EU7.C:** At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.

### **Advanced Placement Science Practices**

**SP1:** The student can use representations and models to communicate scientific phenomena and solve scientific problems.

**SP2:** The student can use mathematics appropriately.

**SP6:** The student can work with scientific explanations and theories.

**SP7:** The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.

### **Learning Targets**

#### **Big Idea 1**

- I can construct representations of the differences between a fundamental particle and a system composed of fundamental particles and to relate this to the properties and scales of the systems being investigated. **[SP 1, 7]**
- I can construct representations of the energy-level structure of an electron in an atom and to relate this to the properties and scales of the systems being investigated. **[SP 1, 7]**
- I can articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass-energy. **[SP 6]**
- I can 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]**
- I can 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, 7]**

### Big Idea 3

- I can identify the strong force as the force that is responsible for holding the nucleus together. **[SP 7]**

### Big Idea 4

- I can apply mathematical routines to describe the relationship between mass and energy and apply this concept across domains of scale. **[SP 2, 7]**

### Big Idea 5

- I can 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, 7]**
- I can 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, 7]**
- I can analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge. **[SP 6, 7]**
- I can 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]**
- I can 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]**
- I can 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]**
- I can 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, 7]**
- I can make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. **[SP 6]**
- I can make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. **[SP 6]**
- I can 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]**

### Big Idea 6

- I can support the photon model of radiant energy with evidence provided by the photoelectric effect. **[SP 6]**
- I can select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. **[SP 6, 7]**
- I can make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. **[SP 6, 7]**
- I can articulate the evidence supporting the claim that a wave model of matter is appropriate to explain the diffraction of matter interacting with a crystal, given conditions where a particle of matter has momentum corresponding to a de Broglie wavelength smaller than the separation between adjacent atoms in the crystal. **[SP 6]**
- I can predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima), based upon the particle speed and de Broglie wavelength of electrons in an electron beam interacting with a crystal. (de Broglie wavelength need not be given, so students may need to obtain it.) **[SP 6]**

### Big Idea 7

- I can 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]**
- I can 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]**
- I can 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]**
- I can 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]**

### Assessment Evidence

#### Performance Assessment Options

*May include, but are not limited to the following:*

#### Other assessment options

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<b>Digital Tools &amp; Supplementary Resources:</b> <i>Tools and resources that can augment the learning experience for students</i>	
<a href="#"><u>Suggested AP Physics 2 Lab Investigations</u></a> <a href="#"><u>Teacher's Lab Manual</u></a> <a href="#"><u>Modern Physics Simulations - PhET</u></a> <a href="#"><u>Modern Physics Simulations - oPhysics</u></a>	