# AP® Physics 2: Algebra-Based

## Course Planning and Pacing Guide

Lance Argano-Rush
Viewpoint School
Calabasas, California

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## AP Equity and Access Policy

The College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial and socioeconomic groups that have been traditionally underserved. Schools should make every effort to ensure their AP classes reflect the diversity of their student population. The College Board also believes that all students should have access to academically challenging course work before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

## Welcome to the AP® Physics Course Planning and Pacing Guides

This guide is one of four course planning and pacing guides designed for AP® Physics 2 teachers. Each provides an example of how to design instruction for the AP course based on the author's teaching context (e.g., demographics, schedule, school type, setting).

These course planning and pacing guides highlight how the components of the *AP Physics Curriculum Framework* — the learning objectives, conceptual understandings, and science practices — are addressed in the course. Each guide also provides valuable suggestions for teaching the course, including the selection of resources, instructional activities such as laboratory investigations, and formative and summative assessments. The authors have offered insight into the *why* and *how* behind their instructional choices — displayed in boxes along the right side of the individual unit plans — to aid in course planning for AP Physics teachers.

The primary purpose of these comprehensive guides is to model approaches for planning and pacing curriculum throughout the school year. However, they can also help with syllabus development when used in conjunction with the resources created to support the AP Course Audit: the Syllabus Development Guide and the four Annotated Sample Syllabi. These resources include samples of evidence and illustrate a variety of strategies for meeting curricular requirements.

# Contents

# Instructional Setting

## Viewpoint School
## Calabasas, California

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|---|---|
| School | Situated on a 25-acre campus, Viewpoint School is an independent, coeducational, college-preparatory day school with kindergarten through grade 12. |
| Student population | Our students represent a variety of ethnic, religious, socioeconomic, and cultural backgrounds. There are 15 different languages spoken in the homes of our families. The school's enrollment is 1,200, and nearly 20 percent of the student body receives financial aid. The racial/ethnic demographics of the school are as follows:<br>• 71 percent Caucasian<br>• 12 percent Asian Pacific or South Asian<br>• 6 percent Hispanic<br>• 5 percent African American<br>• 5 percent Middle Eastern<br>• 1 percent multiracial |
| Instructional time | Viewpoint operates on a modified block schedule, run on a six-day cycle. The AP Physics 2 course meets on four out of the six days, one of which is a double block (the double block is 110 minutes). Our academic year begins in September and there are 35 weeks of instruction; typically, 30 of the weeks occur prior to AP exams. |
| Student preparation | Students take AP Physics 2 as a second-year course; as a prerequisite, students may take AP Physics 1 or another year-long introductory physics course. The math requirement for the AP Physics 2 course is Algebra II/Trigonometry. The first-year physics course, such as AP Physics 1, is expected to provide students with a strong conceptual background in algebra-based mechanics and introductory waves and circuits through inquiry-based experiences. Students matriculating from AP Physics 1 will also have a fundamental understanding of waves and sound. |
| Primary planning resources | Serway, Raymond A., and Chris Vuille. *College Physics*. 9th ed. Boston: Brooks/Cole, 2012. This book provides end-of-chapter, multiple-choice items especially designed for the AP curriculum. |

# Overview of the Course

## Guiding Principles

The primary goal of this course is to connect fundamental physics principles to everyday experiences in the students' lives. When the laws of nature leave the text and become visible and tangible to students, as they trip a circuit breaker in their house or float one too many people on a raft in the pool, then I believe the course was effective. This goal is addressed by providing students with opportunities to engage in real-world scenarios and practical laboratory investigations. I strive to make the examples as real as possible (e.g., citing statistics for modern vehicles and voltages for typical household electronics), and I bring articles to class that relate new experiments in physics to course content. Students' questions often lead the discussion into new material or bring up sample problems that are more relevant to them. Many of the best lessons are ones in which student-led questions take the class down a different path than the one I intended.

Laboratory investigations are instrumental in building students' conceptual understandings and are balanced between three general styles: (1) classical experiments used to reinforce the principles being studied and to provide exposure to new instrumentation; (2) open-ended, student-centered, inquiry-based investigations into new topics; and (3) practical assessments (or laboratory practicals) in which an unknown or a target event is desired and measurable error can be obtained. Students spend no less than 25% of class time participating in laboratory investigations. The course emphasizes the laboratory practice of recording, analyzing, and evaluating data, and students are required to report on all laboratory experiences. These reports include components not limited to purpose, procedure, and conclusion. These reports are maintained in a required lab notebook.

The recurring theme in lab, lecture, and assessments is the question, "Is this a reasonable outcome or value?" Students are exposed to the full spectrum of scientific equipment, from nontechnical stopwatches and metersticks to more complex computer-interface probes. I also find online PhET simulations and *The Video Encyclopedia of Physics Demonstrations* DVD set to be useful supplements to physical investigations when equipment is either too expensive, too dangerous, or does not fit the classroom setting.

## Formative and Summative Assessments

Students are aware that any work done in the course may be collected and assessed for accuracy by me, because anything worth doing is worth doing well. The bulk of the assessments follow traditional methodologies with minor alterations. Homework is assigned and collected in a bound, un-ruled composition book on the day of the exam. The same book is maintained all year so the students have a collective body of work to refer to as the year progresses. This way they can also evaluate how problem-solving strategies have evolved during the course. Quizzes are assigned via the online platform WebAssign; by doing so, I gain 20 percent more instructional time, which allows for more inquiry-based laboratory time. For each quiz, students are initially given four opportunities in WebAssign to submit answers to problems with randomized values; they may obtain extra submissions up to the deadline. Group work, classroom questions, and academic assistance are all acceptable and advisable for solving problems. Collaborative learning and time-management skills have improved as a direct result of this style of assessment. Requests for extra submissions clearly demonstrate to me when students do not understand a concept. One question taken directly from the WebAssign assignments is used in every exam and distinguishes students who are utilizing this instructional supplement appropriately from those who are not. WebAssign also tracks the time a student spends on an assessment and can provide guidance regarding topics with which students struggle or find success easily. Each semester contains six traditional exams that often model AP-style structure and questioning. As the AP Exam approaches, review questions from prior AP Exams found on the AP Central website are critical to students' final preparation.

# Unit 1: Lab Practices and Data Analysis

## Laboratory Investigations:

- Back and Forth Motion Investigation
- Factors Affecting Electrical Resistance Investigation

## Estimated Time:

*1 week*

**Guiding Questions:** ▼ How do you recognize mathematical trends in laboratory data? ▼ How do you linearize nonlinear trends in data, and what is the significance of the slope of the line? ▼ What is the error associated with an instrument, and how does this affect the graphs produced?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Make predictions about the properties of resistors in a simple circuit, based on length and diameter. [LO 4.E.4.1, SP 2.2, SP 6.4]<br><br>Choose and justify the selection of data needed to determine resistivity for a given material. [LO 1.E.2.1, SP 4.1] | | **Instructional Activity: Graphing Practice**<br><br>The whole class discusses an example of a lab performed in a previous physics class, such as period of a pendulum or accelerating cart on a ramp. The class constructs a dry lab experiment, carefully choosing the equipment and noting the strengths and weaknesses of each tool used in a measurement. I distribute sample data so that the class can create and analyze graphical trends. In small groups, students create linear graphs from curved data and deliberate on the meaning of the slope. |
| | Appel et al., "Back and Forth Motion" (modified for inquiry-based learning)<br><br>**Supplies**<br>String, set of masses, timers, metersticks | **Formative Assessment: Back and Forth Motion Investigation**<br><br>Working in small groups, students collect position-versus-time data for a swinging pendulum. They evaluate the data and graphs created by the motion detector. In Excel, students record period versus length of string, and they construct graphs to linearize the period of motion. The whole class then discusses their results and the meaning of the slope of the linear graph. |
| | Dukerich, "Factors Affecting Electrical Resistance" (modified for inquiry-based learning) | **Summative Assessment: Factors Affecting Electrical Resistance Investigation**<br><br>In this guided-inquiry lab, students work individually to perform a quantitative investigation of the effect of length on resistance and current, given a fixed DC voltage source. Students complete lab reports in which they evaluate their predictions based on the empirical results. I require students to complete the graphing portion of the lab before leaving class to ensure their data and graphing skills allow them to draw reasonable conclusions. |

*This exercise allows me to review graphing techniques, set standards for graphs and data tables, review "best fit" lines, and compare a handmade graph to one produced in Microsoft Excel.*

*I monitor students' results to ensure that they have successfully linearized their data. Through group discussion, I check their interpretation of the slope of the data. I project other scientific examples of linearized data from concepts covered in a first-year physics course to see if they can predict, using prior physics knowledge, the appropriate assessment of the slopes shown. I provide further instruction on this topic to students who demonstrate a need for it.*

*This assessment addresses all of the guiding questions in this unit.*

## Laboratory Investigations:

- Buoyancy Playground Investigation
- Buoyancy and Density Investigation
- Don't Sink It! Investigation

**Estimated Time:**
*3 weeks*

**Guiding Questions:** ▼ Why can a person lie on a bed of nails without getting pierced? ▼ How does a concrete canoe not sink? ▼ How does an airplane wing create lift?

| Learning Objectives | Materials | Instructional Activities and Assessments |
| --- | --- | --- |
| Make claims about various contact forces between objects based on the microscopic cause of those forces. [LO 3.C.4.1, SP 6.1]<br><br>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]<br><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. [LO 3.A.4.1, SP 1.4, SP 6.2]<br><br>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2] | Serway and Vuille, Chapter 9: "Solids and Fluids"<br><br>**Video**<br>"Pressure: The Bed of Nails" | **Instructional Activity: Bed of Nails**<br><br>After watching the video, the students form small groups to discuss why the person on the bed of nails was not injured. Each group lists contributing factors important to the outcome. I circulate around the room facilitating group discussions. The groups then share their lists with the class, and we compile a master list on the board. |
| Re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [LO 3.B.1.3, SP 1.5, SP 2.2]<br><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. [LO 3.B.1.4, SP 6.4, SP 7.2] | **Web**<br>"Buoyancy Playground" | **Formative Assessment: Buoyancy Playground Investigation**<br><br>Working individually, students use the scenarios presented by the PhET simulation to make predictions about the following:<br><br>1. The scale reading of the bricks under water<br>2. The level/volume the water will rise to when the wood is added<br>3. The density of the oil<br><br>Students then check their answers with a peer for any discrepancies prior to turning in their work. |
| Use Newton's third law to make claims and predictions about the action–reaction pairs of forces when two objects interact. [LO 3.A.4.2, SP 6.4, SP 7.2]<br><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. [LO 3.A.4.3, SP 1.4] | **Supplies**<br>Demonstration spring scale, mass, bucket of water | **Instructional Activity: Weigh Submerged Block**<br><br>I hang a mass from the bottom of a demonstration spring scale. The mass is slowly lowered into a bucket of water, and the students observe the change in weight on the scale. I ask the class why there is a change in the spring scale and what factors the change could be dependent on. |

*For this activity, I collect students' graphs and provide written feedback. I also address misconceptions as needed during a follow-up class discussion.*

**Guiding Questions:** ▼ Why can a person lie on a bed of nails without getting pierced? ▼ How does a concrete canoe not sink? ▼ How does an airplane wing create lift?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction. [LO 1.E.1.1, SP 4.2, SP 6.4]<br><br>Select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [LO 1.E.1.2, SP 4.1, SP 6.4]<br><br>Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [LO 3.C.4.2, SP 6.2] | **Supplies**<br>Irregularly shaped objects, graduated cylinders, digital force probes, water, two other fluids of varying density (e.g., oil and vinegar) | **Formative Assessment: Buoyancy and Density Investigation**<br><br>In this guided-inquiry lab, students in small groups are given an irregularly shaped object, a graduated cylinder, a digital force probe, and three fluids (water and two fluids of unknown density). Each group designs an experiment (with a purpose, procedure, and empty data table) to determine both the density of the irregularly shaped mass and the density of the two unknown liquids. Students present their process to me for approval before collecting data. I guide the groups by asking questions that reveal any holes or inconsistencies in their plans. Once a sound design is achieved, the groups proceed to data acquisition and turn in a completed lab report at the end of the period. |
| Use Bernoulli's equation to make calculations related to a moving fluid. [LO 5.B.10.1, SP 2.2]<br><br>Use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid. [LO 5.B.10.2, SP 2.2]<br><br>Use Bernoulli's equation and the continuity equation to make calculations related to a moving fluid. [LO 5.B.10.3, SP 2.2]<br><br>Construct an explanation of Bernoulli's equation in terms of the conservation of energy. [LO 5.B.10.4, SP 6.2]<br><br>Make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [LO 5.F.1.1, SP 2.1, SP 2.2, SP 7.2] | | **Instructional Activity: Fluid Flow**<br><br>As a class, we examine the properties of fluid flow and use Bernoulli's equation to make calculations and predictions. Students work through several practice problems, such as the gauge pressure or water-flow rate created by a water tower and what happens when a nozzle restricts the opening of a garden hose. |

*I provide direct feedback as groups develop the steps in their procedure and again on the documentation of the data recorded in this activity. Good lab practices require scientists to be clear and explicit. I return an evaluation sheet to each member of the group along with the group report that outlines strengths and weaknesses in their approach. Weaknesses may reveal the need for reteaching of certain topics.*

**Guiding Questions:** ▼ Why can a person lie on a bed of nails without getting pierced? ▼ How does a concrete canoe not sink? ▼ How does an airplane wing create lift?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. [LO 1.E.1.2, SP 4.1, SP 6.4] | **Supplies**<br>Washers, film containers, large beakers filled with water | **Summative Assessment: Don't Sink It! Investigation**<br><br>Students are given a small plastic container (the approximate size of a 35 mm film canister) and metal washers. They must predict the maximum number of washers that could be placed in the container and floated in a beaker of water without sinking the container. Working in pairs, students document their measurements and tools used, create data tables, draw free-body diagrams, and display equations and calculations. When a pair determines a maximum whole number of washers, they test their prediction. If the container floats, they add one more washer to see if it will sink. In the event the container sinks or the maximum number is not achieved, students add error analysis to the documentation they submit for a grade. |

*Typically, students have many personal real-world experiences with floating, and they enjoy the practical application of this assessment.*

*This assessment addresses the following guiding question:* How does a concrete canoe not sink?

# Electric Forces, Fields, and Energy

## Laboratory Investigations:

- Sticky Tape Electrostatics Investigation
- Video Analysis — Coulomb's Law Investigation
- Mapping Electric Potential Investigation

## Estimated Time:

*5 weeks*

**Guiding Questions:** ▼ Why might you get shocked when you scuff your feet on the carpet and then touch a door knob? ▼ How do classical fundamental particles interact? ▼ What effect does a charge have on a region of space? ▼ How does a capacitor store and provide energy?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Make claims about natural phenomena based on conservation of electric charge. [LO 1.B.1.1, SP 6.4]<br><br>Construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. [LO 1.B.2.1, SP 6.2] | Serway and Vuille, Chapter 15: "Electric Forces and Electric Fields"<br><br>**Supplies**<br>Transparent adhesive tape | **Instructional Activity: Sticky Tape Electrostatics Investigation**<br><br>In this guided-inquiry lab, I guide students through a series of actions involving the removal of transparent tape from the lab bench, creating static charge on the tape. Students make assertions about the number of possible fundamental charges and the attraction and/or repulsion interactions between charged and noncharged objects. |
| Make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. [LO 1.B.2.2, SP 6.4, SP 7.2]<br><br>Challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [LO 1.B.2.3, SP 6.1]<br><br>Challenge the claim that an electric charge smaller than the elementary charge has been isolated. [LO 1.B.3.1, SP 1.5, SP 6.1, SP 7.2] | **Supplies**<br>Van de Graaff generator and accessories, electroscope | **Instructional Activity: Conduction and Induction**<br><br>As a class, we briefly review the three classifications of bonds from chemistry, with special attention given to the locations of electrons and what job they perform in the atomic bond. Students write a prediction and rank the bonds in order of best to worst electrical conductivity, including a justification statement. As a class we investigate different methods of charging and discharging using a Van de Graaff generator, its accessories, and an electroscope. We allow the charge to flow through several different materials from the different bonding categories and then reconcile the predictions with the results. |
| Make predictions about the redistribution of charge during charging by friction, conduction, and induction. [LO 4.E.3.1, SP 6.4]<br><br>Make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. [LO 4.E.3.2, SP 6.4, SP 7.2]<br><br>Construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [LO 4.E.3.3, SP 1.1, SP 1.4, SP 6.4]<br><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. [LO 4.E.3.4, SP 1.1, SP 1.4, SP 6.4]<br><br>***(learning objectives continue)*** | | **Formative Assessment: Electroscopes**<br><br>In pairs, students are given a worksheet with a variety of situations (both written text and pictorial) regarding the state of static charge on an electroscope. They answer the questions posed about each situation. Each pair of students then meets with another pair, compares their answers, and provides justification for any discrepancies in answers. The class then regroups, and pairs take turns providing their answers to the class. We take time to discuss any incongruities. |

*In this activity, I find the Socrative approach particularly useful, only asking questions of the students and not providing any concrete answers. It takes a bit longer, but when students personally discover charge and come to the realization that neutral objects can be attracted, the knowledge is more meaningful.*

*I evaluate the justifications provided by students and verbally correct any inaccuracies, and I add any detail missing from the answers. From the responses I gauge the preparedness of the class to move into quantitative analysis of static charges.*

# Electric Forces, Fields, and Energy

*(continued)*

**Guiding Questions:** ▼ Why might you get shocked when you scuff your feet on the carpet and then touch a door knob? ▼ How do classical fundamental particles interact? ▼ What effect does a charge have on a region of space? ▼ How does a capacitor store and provide energy?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| ***(continued)***<br>Plan and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure. [LO 4.E.3.5, SP 3.2, SP 4.1, SP 4.2, SP 5.1, SP 5.3]<br><br>Predict electric charges on objects within a system by application of the principle of charge conservation within a system. [LO 5.C.2.1, SP 6.4]<br><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. [LO 5.C.2.2, SP 4.2, SP 5.1]<br><br>Justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects. [LO 5.C.2.3, SP 4.1] | | |

**Guiding Questions:** ▼ Why might you get shocked when you scuff your feet on the carpet and then touch a door knob? ▼ How do classical fundamental particles interact? ▼ What effect does a charge have on a region of space? ▼ How does a capacitor store and provide energy?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 2.C.1.1, SP 6.4, SP 7.2]<br><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. [LO 2.C.1.2, SP2.2]<br><br>Explain the inverse square dependence of the electric field surrounding a spherically symmetric electrically charged object. [LO 2.C.3.1, SP 6.2]<br><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. [LO 2.C.4.1, SP 2.2, SP 6.4, SP 7.2]<br><br>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1]<br><br>Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4]<br><br>Make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge. [LO 3.A.3.4, SP 6.1, SP 6.4]<br><br>***(learning objectives continue)*** | Serway and Vuille, Chapter 15: "Electric Forces and Electric Fields"<br><br>**Supplies**<br>Two pith balls (or light metal spheres) for electrostatics on a string, fur, rubber rods | **Instructional Activity: Coulomb's Law**<br><br>Students observe the demonstration of electric repulsion between two pith balls from a static charge; then they identify variables that affect the balls' charged positions. After students briefly discuss this with a peer, we debrief as a class, and I use the remainder of the time to quantitatively describe Coulomb's law. Homework exercises and in-class practice problems are excerpted from Chapter 15. |

# Electric Forces, Fields, and Energy

*(continued)*

**Guiding Questions:** ▼ Why might you get shocked when you scuff your feet on the carpet and then touch a door knob? ▼ How do classical fundamental particles interact? ▼ What effect does a charge have on a region of space? ▼ How does a capacitor store and provide energy?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| ***(continued)***<br>Challenge a claim that an object can exert a force on itself. [LO 3.A.3.2, SP 6.1]<br>Describe a force as an interaction between two objects and identify both objects for any force. [LO 3.A.3.3, SP 1.4]<br>Re-express a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [LO 3.B.1.3, SP 1.5, SP 2.2]<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. [LO 3.A.4.1, SP 1.4, SP 6.2]<br>Use Newton's third law to make claims and predictions about the action–reaction pairs of forces when two objects interact. [LO 3.A.4.2, SP 6.4, SP 7.2]<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. [LO 3.A.4.3, SP 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. [LO 3.B.1.4, SP 6.4, SP 7.2]<br>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2]<br>Use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. [LO 3.C.2.1, SP 2.2, SP 6.4]<br>***(learning objectives continue)*** | | |

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| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| ***(continued)***<br>Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [LO 3.C.2.2, SP 7.2]<br>Use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situations of high symmetry). [LO 3.C.2.3, SP 2.2]<br>Make claims about various contact forces between objects based on the microscopic cause of those forces. [LO 3.C.4.1, SP 6.1]<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 to other types of forces. [LO 3.G.1.2, SP 7.1]<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. [LO 3.G.2.1, SP 7.1] | | |
| 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. [LO 3.B.1.4, SP 6.4, SP 7.2]<br>Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [LO 3.B.2.1, SP 1.1, SP 1.4, SP 2.2] | Laws et al., "Coulomb's Law for Two Charged Spheres" | **Formative Assessment: Video Analysis — Coulomb's Law Investigation**<br>First, students use a video-analysis method to explore and describe the variables that affect Coulomb's law. Next, they develop quantitative relationships between these variables. |

*I circulate among the students, asking questions to monitor their progress. When their answers are not as in-depth or detailed as necessary, I challenge them to think more critically about a specific process by asking probing questions about their original answers.*

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| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Qualitatively and semiquantitatively apply the vector relationship between the electric field and the net electric charge creating that field. [LO 2.C.2.1, SP 2.2, SP 6.4]<br><br>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. [LO 2.C.4.2, SP 1.4, SP 2.2]<br><br>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 recognize that the assumption of uniform field is not appropriate near edges of plates. [LO 2.C.5.1, SP 1.1, SP 2.2]<br><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. [LO 2.C.5.2, SP 2.2]<br><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 the Earth's gravitational field. [LO 2.C.5.3, SP 1.1, SP 2.2, SP 7.1] | **Web**<br>"Millikan's Oil Drop Experiment to Determine Charge of an Electron" | **Instructional Activity: The Oil Drop Experiment**<br><br>A video simulating Millikan's oil drop experiment is shown to the class. Students record their observations during the video. Afterward, the class discusses the shape, strength, and other factors regarding a parallel electric field, especially its direct relationship to force. |

# Electric Forces, Fields, and Energy

*(continued)*

**Guiding Questions:** ▼ Why might you get shocked when you scuff your feet on the carpet and then touch a door knob? ▼ How do classical fundamental particles interact? ▼ What effect does a charge have on a region of space? ▼ How does a capacitor store and provide energy?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential. [LO 2.E.1.1, SP 1.4, SP 6.4, SP 7.2]<br><br>Determine the structure of isolines of electric potential by constructing them in a given electric field. [LO 2.E.2.1, SP 6.4, SP 7.2]<br><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. [LO 2.E.2.2, SP 6.4, SP 7.2]<br><br>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. [LO 2.E.2.3, SP 1.4]<br><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. [LO 2.E.3.1, SP 2.2]<br><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. [LO 2.E.3.2, SP 1.4, SP 6.4] | Dukerich, "Mapping Electric Potential" | **Instructional Activity: Mapping Electric Potential Investigation**<br><br>In groups of at least three, students create 3-D surface graphs symbolizing the electric potential on a piece of carbon paper. Measurements from a voltmeter are recorded in Excel to generate the graphs. The data collection is easier and faster if the three students perform one job each: move the probe lead, read the meter, and type into Excel. Symmetry can be applied to some graphs to reduce data collection. Students individually complete a lab report with two potential plots and experiment analysis. |

*This is a tedious experiment, as a few hundred data points are collected, but the resulting graph is the best tool I have ever seen for helping students understand this concept.*

# Electric Forces, Fields, and Energy

*(continued)*

**Guiding Questions:** ▼ Why might you get shocked when you scuff your feet on the carpet and then touch a door knob? ▼ How do classical fundamental particles interact? ▼ What effect does a charge have on a region of space? ▼ How does a capacitor store and provide energy?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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). [LO 5.B.5.4, SP 6.4, SP 7.2]<br><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. [LO 5.B.5.5, SP 2.2, SP 6.4] | Serway and Vuille, Chapter 16: "Electric Energy and Capacitance"<br><br>**Supplies**<br>Disposable camera, screw driver | **Instructional Activity: Capacitance and Electrical Energy**<br><br>A disposable camera body is opened to show the AAA battery and capacitor that run the flash. Students draw a picture of a battery and a capacitor and symbolize the charge locations in each. They list similarities and differences between the components. I charge the capacitor in the camera; then I use a screw driver to cause a short and produce a spark, flash, and loud bang. Students then get an opportunity to amend their lists. As a class, one large list is compiled, indicating the energy storage and rate of delivery by each. For homework, students write a description and create a sketch of what they think is happening during the whining sound produced when the capacitor is charging. |
| All of the learning objectives in this unit are assessed. | Teacher-produced unit assessment | **Summative Assessment: Unit Exam**<br><br>The unit exam consists of multiple-choice and free-response questions that are a mixture of point and constant-field problems. The multiple-choice items emphasize charge distributions and conduction/induction. Students are required, in the free-response items, to describe the movement of charge within a structure as well as solve free-body diagrams with electric forces as one of the components. I create free-body problems that emulate questions students had in AP Physics 1, except one of the contact forces is replaced by the electric force, to reinforce to students that these are the same types of problems they already learned to solve. |

*According to student feedback, this is one of the best demonstrations all year. It solidifies conceptual understanding with images from movies and stories they have heard about electronics. It takes some time to demystify and there are numerous questions, but the payoff is well worth the time.*

*This assessment addresses the following guiding questions:*

- *How do classical fundamental particles interact?*
- *What effect does a charge have on a region of space?*

# Unit 4: Electric Current, Resistance, Power, and Circuits

## Laboratory Investigations:

- Ohm's Law with Light Bulbs Investigation
- Series and Parallel Circuits Investigation
- Batteries in a Circuit Investigation
- Mystery Light Boxes Investigation

## Estimated Time:

*4 weeks*

**Guiding Questions:** ▼ Why doesn't a circuit lose all its energy the instant you turn it on? ▼ How does temperature affect a circuit? ▼ How does connecting a system of objects to a battery change the circuit? ▼ Does a battery supply its energy freely and at what rate? ▼ What is the purpose of placing multiple batteries in your calculator?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Choose and justify the selection of data needed to determine resistivity for a given material. [LO 1.E.2.1, SP 4.1]<br><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. [LO 4.E.4.1, SP 2.2, SP 6.4] | Serway and Vuille, Chapter 17: "Current and Resistance"<br><br>**Supplies**<br>LEDs, piezoelectric speaker, DC power (~5V), Arduino board, conductive and nonconductive dough<br><br>**Web**<br>"Squishy Circuits" | **Instructional Activity: Squishy Circuits**<br><br>Prior to class, I prepare conductive and nonconductive dough. LEDs and speakers are used to create circuits in series with the dough to investigate their conductive properties. I use a speaker, an Arduino board, and conductive dough to produce a tone proportional to the resistance of the circuit. I then squish, stretch, and fold the dough while the class observes the variations in sound produced. The class makes assertions about the physical dimensions of the dough in relationship to its resistance. |
| 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. [LO 3.C.3.2, SP 4.2, SP 5.1]<br><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. [LO 1.B.1.2, SP 6.4, SP 7.2]<br><br>Translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [LO 5.B.9.8, SP 1.5] | Appel et al., "Ohm's Law"<br><br>**Supplies**<br>Voltmeter, bulbs and holders, clip leads and wires, battery | **Formative Assessment: Ohm's Law with Light Bulbs Investigation**<br><br>In this guided-inquiry lab, groups record and graph the voltage across and current through a light bulb in the range from barely visible glow to nearing the threshold of burning out the filament. During the experiment, lab groups must justify whether they believe the graph is linear. I ask questions that help the groups understand that the resistance must be changing. In their analyses, groups must justify why the resistance of a filament changes as it gets brighter. I modify this lab to use traditional meters to measure the current and voltage; the uncertainty in measurement and time to complete the experiment increases, but it is less of a mystery for the students. |

*The Arduino board and speaker can be replaced by a small incandescent light bulb, but you must play with the quantity and shape of the dough to get the resistance just right to see the bulb dim. Other examples can be seen on the "Squishy Circuits" Web page.*

*Students are provided immediate feedback as I work with each group during the investigation. For students who only see linear trend lines, cover all but three data points at the beginning, middle, and end, and ask them to draw a trend line through the three points. Each successive trend line will increase in slope. Students must justify why there is a consistent increase in trend lines from set to set, and they are not permitted to proceed until they provide the appropriate justification.*

# Electric Current, Resistance, Power, and Circuits

*(continued)*

**Guiding Questions:** ▼ Why doesn't a circuit lose all its energy the instant you turn it on? ▼ How does temperature affect a circuit? ▼ How does connecting a system of objects to a battery change the circuit? ▼ Does a battery supply its energy freely and at what rate? ▼ What is the purpose of placing multiple batteries in your calculator?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 4.E.5.1, SP 2.2, SP 6.4]<br><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. [LO 5.C.3.6, SP 1.4, SP 2.2]<br><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. [LO 5.C.3.7, SP 1.4, SP 2.2] | Serway and Vuille, Chapter 18: "Direct-Current Circuits"<br><br>**Supplies**<br>Demonstration bulb board, DC power supply | **Instructional Activity: Bulb Board**<br><br>I set up a demonstration light-bulb board with three identical bulbs. One bulb is lit using a DC power supply to obtain a reference intensity of light. Pairs of students are given a worksheet of guiding questions about what will happen to the intensity of the light of the bulbs when various combinations are created. The pairs discuss the questions and predict answers. They must provide an energy justification with each answer. I ask a group to share a prediction and then the circuit is created. Predictions are reconciled with the observation, and a list of physical properties of the system is put on the board. |

# Electric Current, Resistance, Power, and Circuits

*(continued)*

**Guiding Questions:** ▼ Why doesn't a circuit lose all its energy the instant you turn it on? ▼ How does temperature affect a circuit? ▼ How does connecting a system of objects to a battery change the circuit? ▼ Does a battery supply its energy freely and at what rate? ▼ What is the purpose of placing multiple batteries in your calculator?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 4.E.4.2, SP 4.1, SP 4.2]<br><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. [LO 4.E.4.3, SP 5.1]<br><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. [LO 4.E.5.2, SP 6.1, SP 6.4]<br><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. [LO 4.E.5.3, SP 2.2, SP 4.2, SP 5.1] | **Supplies**<br>Bulbs and holders, resistors, clip leads and wires, batteries, multimeters | **Formative Assessment: Series and Parallel Circuits Investigation**<br><br>In small groups, students are provided circuit diagrams. Each group must build the circuits provided, and I check their wiring before they turn on the circuit. When the circuit is correctly assembled, the group collects data and analyzes the voltage and power supplied versus consumed. I circulate among the groups, asking students to justify and verify conservation of energy using their data. |

*In constructing the circuits, students will undoubtedly make mistakes, and these are wonderful teachable moments to strengthen understanding of series, parallel, open, and short circuits. I circulate among the groups, probing individual student's knowledge. This allows for immediate feedback on the concepts at hand. It also helps me identify any area that may need reteaching or one-on-one instruction for a specific student.*

**Guiding Questions:** ▼ Why doesn't a circuit lose all its energy the instant you turn it on? ▼ How does temperature affect a circuit? ▼ How does connecting a system of objects to a battery change the circuit? ▼ Does a battery supply its energy freely and at what rate? ▼ What is the purpose of placing multiple batteries in your calculator?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 5.B.9.7, SP 4.1, SP 4.2, SP 5.1, SP 5.3]<br><br>Analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule ( $\sum \Delta V = 0$ ) [LO 5.B.9.4, SP 5.1]<br><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. [LO 5.B.9.6, SP 2.1, SP 2.2]<br><br>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. [LO 5.B.9.5, SP 6.4] | **Supplies**<br>Flashlights, calculators, hand-held fans | **Instructional Activity: Batteries in a Circuit Investigation**<br><br>In this guided-inquiry lab, we inspect and compare the quantity, orientation, and size of batteries in common electric devices such as a calculator, flashlight, and hand-held fan. Rough sketches of the batteries in the circuits are drawn on the board. In small groups, students make claims explaining why the various styles were chosen. We reassemble as a large group and create a master list. In group discussion, we further students' conceptual models of batteries in series and parallel with matching polarity. For homework, students make claims postulating why batteries would ever be connected with opposing polarities. |

# Electric Current, Resistance, Power, and Circuits

*(continued)*

**Guiding Questions:** ▼ Why doesn't a circuit lose all its energy the instant you turn it on? ▼ How does temperature affect a circuit? ▼ How does connecting a system of objects to a battery change the circuit? ▼ Does a battery supply its energy freely and at what rate? ▼ What is the purpose of placing multiple batteries in your calculator?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 5.C.3.4, SP 6.4, SP 7.2]<br><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. [LO 5.C.3.5, SP 1.4, SP 2.2]<br><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. [LO 5.C.3.6, SP 1.4, SP 2.2]<br><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. [LO 5.C.3.7, SP 1.4, SP 2.2] | **Supplies**<br>Teacher-produced project boxes, each consisting of four-bulb circuits with concealed wiring | **Summative Assessment: Mystery Light Boxes Investigation**<br><br>I use a guided-inquiry approach for this investigation. The assessment uses a set of project boxes with four light bulbs in each. The wiring circuit is hidden inside the box. The boxes are set up as stations around the classroom, and students move from station to station attempting to determine what the circuit diagram is by unplugging bulbs and watching the changes in the resulting circuit. Students submit a labeled circuit diagram for each of the stations. |

*This is one of the students' favorite assessments and it is widely discussed throughout the school from year to year.*

*This assessment addresses all of the guiding questions in this unit.*

# Unit 5: Magnetism and Induction

## Laboratory Investigations:

- Mapping a Magnetic Field Investigation
- The Magnetic Field in a Coil Investigation
- Making a DC Motor Investigation
- Faraday's Law Investigation

## Estimated Time:

*5 weeks*

**Guiding Questions:** ▼ What causes a magnetic field and specifically the Earth's magnetic field? ▼ How does a compass work? ▼ What is an electromagnet and how do you make one? ▼ How do an electric motor and hand-crank generator work?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 2.D.3.1, SP 1.2]<br><br>Use the representation of magnetic domains to qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material. [LO 2.D.4.1, SP 1.4] | **Supplies**<br>Compasses, bar and horseshoe magnets, blank paper | **Instructional Activity: Mapping a Magnetic Field Investigation**<br><br>Each student is supplied a compass, blank paper, a bar magnet, and a horseshoe magnet. I tell students that the compass points in the direction of the magnetic field vector and tangential to the magnetic field line at a point. I instruct them to place the magnet in the center of the paper and trace small tangential vectors in the region around the magnet. Once the region is filled, students insert magnetic field lines connecting series of tangential vectors. After students produce two different field maps, the class discusses the similarities between the magnetic and electric field lines, noting the similarity between the bar magnetic and two point charges, while the inside of the horseshoe magnet resembles a parallel-plate capacitor. |
| 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. [LO 3.C.3.1, SP 1.4]<br><br>Create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires. [LO 2.D.2.1, SP 1.1]<br><br>Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [LO 3.A.2.1, SP 1.1] | Serway and Vuille, Chapter 19: "Magnetism" | **Instructional Activity: Introduction to Magnetic Fields**<br><br>In large-group discussion, we debrief from drawing B-fields and compare and contrast the gravitational, electric, and magnetic field. I point out that the magnetic field is the only one that does not have a monopole. This leads the discussion into the development of a magnetic field and the right-hand rule for vector orientation. Many board examples are done as a group until the class is confident with the right-hand rule and 3-D notations. Homework exercises and in-class practice problems are excerpted from Chapter 19. |

*Significant time should be given to learning 3-D notation and the right-hand rule, as it is most likely the first time students have ever really had to work with this concept in three-dimensional space.*

# Magnetism and Induction

*(continued)*

**Guiding Questions:** ▼ What causes a magnetic field and specifically the Earth's magnetic field? ▼ How does a compass work? ▼ What is an electromagnet and how do you make one? ▼ How do an electric motor and hand-crank generator work?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 4.E.1.1, SP1.1, SP 1.4, SP 2.2] | **Supplies**<br>Paper clips, 9V batteries, wires, nails | **Instructional Activity: Making Electromagnets**<br>In groups of three, students make an electromagnet by wrapping a current-carrying wire around an iron nail. They record their observations to share in a whole-class discussion after the activity. |
| | Appel et al., "The Magnetic Field in a Coil"<br>**Supplies**<br>Wires, cardboard box, batteries, multimeter | **Instructional Activity: The Magnetic Field in a Coil Investigation**<br>I use a guided-inquiry approach for this investigation. Students wind loops of wire around a cardboard box. By sending current through the wire, they can investigate the relationship between the number of coils and the magnetic field produced. Students also discover that the Earth's magnetic field must be taken into consideration. |
| Apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [LO 2.D.1.1, SP 2.2] | Serway and Vuille, Chapter 19: "Magnetism" | **Instructional Activity: Force on a Moving Charge in a Magnetic Field**<br>In small groups, students discuss the question, *If a moving charge creates a B-field and a second moving charge flies by the first with its own B-field, how do the two particles affect each other?* The small groups share their assertions with the class and develop a conceptual model of magnetic force on a moving charge in a B-field. Homework exercises and in-class practice problems are excerpted from Chapter 19. |

*I highlight and emphasize the difference between creating a magnetic field and the effects a preexisting B-field has on a second moving charge. This is the single most confusing topic in all of magnetism for my students when they are solving problems.*

**Guiding Questions:** ▼ What causes a magnetic field and specifically the Earth's magnetic field? ▼ How does a compass work? ▼ What is an electromagnet and how do you make one? ▼ How do an electric motor and hand-crank generator work?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 4.E.2.1, SP 6.4] | Serway and Vuille, Chapter 20: "Induced Voltages and Inductance"<br><br>**Supplies**<br>Genco hand-crank generator, DC battery (6V or 9V), light bulb | **Instructional Activity: Exploring Generators**<br><br>I demonstrate the use of a Genco hand-crank generator and reference emergency hand-crank radios and lights that students may have at home. First the DC battery is hooked up to the crank and the system runs like a toy-car motor. Then the crank is attached to a light bulb and turned by hand to produce light. I lead a whole-class discussion on what phenomena are occurring and the reversibility of the process. |
| | **Supplies**<br>D-cell batteries, paper clips, enameled wires, magnets, rubber bands | **Formative Assessment: Making a DC Motor Investigation**<br><br>This lab involves both guided-inquiry and open-inquiry components. Students are supplied with a D-cell battery, paper clips, rubber bands, a loop of wire, and a magnet to construct a rough DC motor. After several students have operating spinning coils, the class discusses key concepts, and students record the list on their lab handouts.<br><br>Students discuss factors that had positive and negative impacts on the operation of the device. Students then refine and work on the motors again, trying to improve the spin. Students who create successful motors are encouraged to assist others having difficulty until the entire class has spinning devices. Students then suggest changes to the device that would create faster, more powerful, and more efficient motors. The list of suggestions is added to the lab handout. |
| All of the learning objectives in this unit are assessed. | Dukerich, "Faraday's Law: Moving Magnet"<br><br>Teacher-produced unit assessment<br><br>**Supplies**<br>Neodymium magnets, copper wire, ammeter, batteries | **Summative Assessment: Faraday's Law Investigation and Unit Exam**<br><br>In this unit, I give a two-part summative assessment. First, students create the fundamentals of a generator by building a solenoid and dropping a neodymium magnet through the coil. They report the collected data, analysis, and a conclusion in a formal lab report.<br><br>For the second part, I give a traditional unit exam consisting of multiple-choice and free-response questions. Students are required to articulate, in both written explanations and with figures and diagrams, how magnetic fields are produced, as well as how induced current is created. |

*This activity takes the mystery away from the magic box of a DC motor. Students can then apply this concept to the function of toy cars, cell phone vibrators, and eventually reversing the system and creating a generator.*

*During the activity, I monitor the students' lists of factors impacting their device. I provide direct guidance to students needing help and also address any recurring misconceptions about motors with the entire class.*

*This assessment addresses all of the guiding questions in this unit.*

# Unit 6: Thermodynamics

## Laboratory Investigations:

- Temperature and Energy Transfer Investigation
- Behavior of a Gas Investigation
- Heat Engine Investigation

## Estimated Time:

*4 weeks*

**Guiding Questions:** ▼ Why do some doors stick when sunlight heats them up? ▼ What happens to the temperature of an ice cube as it melts? ▼ How does the gas in a car engine move the piston? ▼ How does a refrigerator cool its contents?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Design an experiment and analyze data from it to examine thermal conductivity. [LO 1.E.3.1, SP 4.1, SP 4.2, SP 5.1] | Serway and Vuille, Chapter 10: "Thermal Physics"<br><br>**Supplies**<br>Ball and ring set, bimetallic strips | **Instructional Activity: Thermal Expansion**<br><br>To provide students with a sense of the importance and magnitude of thermal expansion, a ball and ring and bimetallic demonstration apparatus are used. This activity is followed with images of expansion gaps in modern bridge roadways and a sample problem where students estimate the linear expansion of a steel bridge and discuss how these concepts inform bridge designs. |
| Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [LO 1.A.5.2, SP 1.1, SP 1.4, SP 7.1]<br><br>Make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [LO 4.C.3.1, SP 6.4]<br><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. [LO 5.B.2.1, SP 1.4, SP 2.1] | **Supplies**<br>Temperature probes, Logger Pro software, paraffin wax, hot- and cold-water baths, test tubes and stoppers | **Instructional Activity: Temperature and Energy Transfer Investigation**<br><br>Working in small groups, students heat wax in a test tube to past its melting point. A temperature probe is inserted into the test tube and temperature recording begins. The wax-filled tube is then placed in an ice bath and the wax cools, solidifies, and cools more. The time–temperature chart emulates the phase-change graph. In pairs, students identify what they believe is happening during the flat portions of the graph. They justify their thoughts using energy and atomic structure arguments. |

*For a contrast, a second setup with an ice bath can simultaneously be heating to see the phase change go in the opposite direction, giving a sense of reversibility of the process.*

# Thermodynamics

*(continued)*

**Guiding Questions:** ▼ Why do some doors stick when sunlight heats them up? ▼ What happens to the temperature of an ice cube as it melts? ▼ How does the gas in a car engine move the piston? ▼ How does a refrigerator cool its contents?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system. [LO 7.A.1.1, SP 6.4, SP 7.2]<br><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. [LO 7.A.1.2, SP 1.4, SP 2.2]<br><br>Qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. [LO 7.A.2.1, SP 7.1]<br><br>Connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes. [LO 7.A.2.2, SP 7.1] | Serway and Vuille, Chapter 11: "Energy in Thermal Processes"<br><br>**Web**<br>"Gas Properties" | **Instructional Activity: Introduction to Ideal Gasses**<br><br>After reviewing fundamental principles of ideal gasses and kinetic theory, students view the PhET simulation, which provides a helpful visual representation. Students manipulate the simulation and write four concrete observations. When the class regroups, students' observations are shared with the class. |

*I believe that models and simulations are extremely important when the topics become microscopic. For example, gas behavior is a topic with which students may struggle, and the use of a simulation can help them better understand the concepts.*

**Guiding Questions:** ▼ Why do some doors stick when sunlight heats them up? ▼ What happens to the temperature of an ice cube as it melts? ▼ How does the gas in a car engine move the piston? ▼ How does a refrigerator cool its contents?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| Design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and amount of an ideal gas, and refine a scientific question concerning a proposed incorrect relationship between the variables. [LO 7.A.3.2, SP 3.2, SP 4.2]<br><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 $PV = nRT$. [LO 7.A.3.3, SP 5.1]<br><br>Describe and make predictions about the internal energy of systems. [LO 5.B.4.1, SP 6.4, SP 7.2]<br><br>Calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. [LO 5.B.4.2, SP 1.4, SP 2.1, SP 2.2]<br><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. [LO 7.A.3.1, SP 6.4, SP 7.2] | Dukerich, "Behavior of a Gas"<br><br>**Supplies**<br>Erlenmeyer flasks, beakers, gas pressure sensors, ice- and hot-water baths, temperature probes | **Instructional Activity: Behavior of a Gas Investigation**<br><br>In this experiment, students develop quantitative relationships between pressure, temperature, and volume. By the end of this activity, students identify and explain the variables that affect the pressure of a gas in a container. |

*This activity is modified from its original format in the Vernier manual to model a more inquiry-based approach, as the concepts are not unfamiliar to students with their previous experience in chemistry.*

**Guiding Questions:** ▼ Why do some doors stick when sunlight heats them up? ▼ What happens to the temperature of an ice cube as it melts? ▼ How does the gas in a car engine move the piston? ▼ How does a refrigerator cool its contents?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 5.B.5.6, SP 4.2, SP 5.1]<br><br>Create a plot of pressure versus volume for a thermodynamic process from given data. [LO 5.B.7.2, SP 1.1]<br><br>Use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics). [LO 5.B.7.3, SP 1.1, SP 1.4, SP 2.2]<br><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. [LO 5.B.5.5, SP 2.2, SP 6.4]<br><br>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. [LO 5.B.6.1, SP 1.2]<br><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. [LO 5.B.7.1, SP 6.4, SP 7.2]<br><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). [LO 5.B.5.4, SP 6.4, SP 7.2]<br><br>***(learning objectives continue)*** | Serway and Vuille, Chapter 12: "The Laws of Thermodynamics"<br><br>Dukerich, "Heat Engines" | **Formative Assessment: Heat Engine Investigation**<br><br>Often, students can become mechanical with P–V diagrams, and the subject starts to lose meaning. This activity is a two-day sequence. The first day requires a worksheet with detailed questions about each segment of a four-step thermodynamic cycle. Students attempt to answer the questions on their own, and then they discuss their answers with a peer. At the end of class, I review the responses with the class as a whole.<br><br>On day two, lab groups perform the "Heat Engines" experiment. As they are in the process of taking data, I circulate among the groups and ask questions relating to the prior day's worksheet, requiring students to link the physical steps of the experiment to the calculations and concepts previously encountered. |

*I provide direct feedback to students as I circulate from group to group, asking questions for assessment of student knowledge during the experiment.*

**Guiding Questions:** ▼ Why do some doors stick when sunlight heats them up? ▼ What happens to the temperature of an ice cube as it melts? ▼ How does the gas in a car engine move the piston? ▼ How does a refrigerator cool its contents?

| Learning Objectives | Materials | Instructional Activities and Assessments |
| --- | --- | --- |
| ***(continued)***<br>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. [LO 7.B.1.1, SP 6.2]<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. [LO 7.B.2.1, SP 7.1] | | |
| 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. [LO 7.B.1.1, SP 6.2]<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. [LO 7.B.2.1, SP 7.1] | Sokoloff, Laws, and Thornton, Lab 2: "Energy Transfer and Temperature Change" | **Summative Assessment: Energy Transfer and Temperature Change**<br>Student lab groups use selections from this experiment to analyze how electrical energy is converted into thermal energy via an immersion heater. Students complete a formal lab report. |

*This assessment brings electrical concepts back into the curriculum for review and clearly demonstrates how energy is a major unifying theme throughout the course.*

*This assessment addresses all of the guiding questions in this unit.*

# Unit 7: Light and Geometric Optics

## Laboratory Investigations:

- Ray Tracing Investigation
- Determining Focal Length Investigation
- Diffraction Patterns Investigation

**Estimated Time:** *5 weeks*

**Guiding Questions:** ▼ How do magnifying glasses and telescopes work? ▼ What causes an object viewed in a car's passenger-side mirror to appear farther away than it actually is? ▼ What makes fiber optics work? ▼ Why does light bend around the corner of a solid object like a doorway?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 6.E.3.1, SP 1.1, SP 1.4] | Serway and Vuille, Chapter 22: "Reflection and Refraction of Light"<br><br>**Supplies**<br>Light box or laser and slit, optics box: plane mirror, concave and convex mirror, converging and diverging lens, triangular prism | **Instructional Activity: Ray Tracing Investigation**<br><br>I use a guided-inquiry approach for this investigation. Each student applies ray-tracing techniques to each of the fundamental optical elements: plane mirror, concave and convex mirror, converging and diverging lens, and refracted triangular prism. I circulate among the students, checking their work for proper arrows and dashed-versus-solid lines showing real-versus-virtual rays. |
| 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. [LO 6.E.2.1, SP 6.4, SP 7.2]<br><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. [LO 6.E.4.1, SP 3.2, SP 4.1, SP 5.1, SP 5.2, SP 5.3]<br><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. [LO 6.E.4.2, SP 1.4, SP 2.2] | Serway and Vuille, Chapter 23: "Mirrors and Lenses"<br><br>**Supplies**<br>Demonstration-sized concave and convex mirrors | **Instructional Activity: Mirrors**<br><br>I use large concave and convex mirrors to distinguish between real and virtual images. I darken the room and have a student stand outside in the sunlight. Students observe the image of the person outside in both mirrors, noting approximate size and orientation. I then project the image from the concave mirror onto a wall or poster board to show real imaging. Students predict what will happen when the mirror is changed to a convex shape. The mirror is changed, and the class discusses why no imaging occurred. |

*I find this activity instrumental in forming a solid foundation for all geometric optics to follow. When subsequent ray tracing of images is taught, the students do not get confused about where the rays go, and the depth of student understanding about concepts in optics increases.*

*Most students do not truly understand the difference between real and virtual images until this activity. Concave mirrors projecting an image seems logical to them, but they have a difficult time accepting that a convex mirror cannot accomplish the same task.*

**Guiding Questions:** ▼ How do magnifying glasses and telescopes work? ▼ What causes an object viewed in a car's passenger-side mirror to appear farther away than it actually is? ▼ What makes fiber optics work? ▼ Why does light bend around the corner of a solid object like a doorway?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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). [LO 6.E.3.2, SP 4.1, SP 5.1, SP 5.2, SP 5.3]<br><br>Describe representations of transverse and longitudinal waves. [LO 6.A.1.2, SP 1.2]<br><br>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. [LO 6.E.1.1, SP 6.4, SP 7.2]<br><br>Make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [LO 6.F.1.1, SP 6.4, SP 7.2] | **Supplies**<br>Demonstration-sized plastic block or prism, laser | **Instructional Activity: Refraction**<br><br>In a teacher-led demonstration, a laser is shined normally on the plastic–air boundary and at small angles. Each situation is traced on the board. Students sketch what they believe will happen when the plastic–air boundary is rotated to an increasingly larger incident angle. In a whole-class discussion, the concept of refraction and the critical angle is developed. |
| 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. [LO 6.E.5.1, SP 1.4, SP 2.2]<br><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. [LO 6.E.5.2, SP 3.2, SP 4.1, SP 5.1, SP 5.2, SP 5.3] | **Supplies**<br>Candles or light boxes, small lenses of known focal lengths, metersticks | **Formative Assessment: Determining Focal Length Investigation**<br><br>I use a guided-inquiry approach for this investigation. In pairs, students are given a light source and three small unknown lenses. Their objective is to determine the type and focal distances of the unknown lenses. Students must create a procedure, indicate measurements, and make observations for single- and double-lens systems. As I circulate among the pairs, they show me which lenses are converging and diverging, explaining how they arrived at this conclusion. Numerical results are recorded and checked in the formal report. |

*Students' explanations will indicate the class's readiness to move forward with the material.*

# Light and Geometric Optics

*(continued)*

**Guiding Questions:** ▼ How do magnifying glasses and telescopes work? ▼ What causes an object viewed in a car's passenger-side mirror to appear farther away than it actually is? ▼ What makes fiber optics work? ▼ Why does light bend around the corner of a solid object like a doorway?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 1.D.1.1, SP 6.3]<br><br>Contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. [LO 6.A.2.2, SP 6.4, SP 7.2]<br><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. [LO 6.B.3.1, SP 1.5]<br><br>Make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. [LO 6.C.1.1, SP 6.4, SP 7.2]<br><br>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. [LO 6.E.3.3, SP 6.4, SP 7.2]<br><br>Describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. [LO 6.F.2.1, SP 1.1] | Serway and Vuille, Chapter 24: "Wave Optics" | **Instructional Activity: Properties of Light**<br><br>In small groups, students discuss common observations regarding properties of light such as reflection from mirrors, fuzzy borders on shadows, and the apparent shifting of positions of objects in water. From their discussion, groups draw a conclusion on the nature of light being more like a wave or a particle. As a class, the tricky wave–particle duality of light is described and discussed. |

**Guiding Questions:** ▼ How do magnifying glasses and telescopes work? ▼ What causes an object viewed in a car's passenger-side mirror to appear farther away than it actually is? ▼ What makes fiber optics work? ▼ Why does light bend around the corner of a solid object like a doorway?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 6.A.1.3, SP 5.1, SP 6.2]<br><br>Construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [LO 6.C.1.2, SP 1.4]<br><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. [LO 6.C.2.1, SP 1.4, SP 6.4, SP 7.2]<br><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, but larger than the wavelength. [LO 6.C.3.1, SP 1.4, SP 6.4]<br><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. [LO 6.C.4.1, SP 6.4, SP 7.2] | **Supplies**<br>Lasers, single slits, double slits, diffraction gratings, holographic glasses<br><br>**Video**<br>"Demo 23-02: Single Slit Diffraction" and "Demo 23-08: Knife Edge Diffraction" | **Instructional Activity: Diffraction Patterns Investigation**<br><br>I use a guided-inquiry approach for this investigation. I set up lasers to create diffraction patterns for double slits, single slits, and a diffraction grating. Students sketch each of the patterns, providing written descriptions of the characteristics under each sketch. They then watch two short videos on diffraction that show the wave patterns. Students graph intensities and describe the pattern they see. At the end of each video, students can amend the written descriptions under their personal sketches. The class concludes with a mathematical proof of constructive and destructive interference, showing half- and full-wave minima and maxima. |

# Light and Geometric Optics
*(continued)*

**Guiding Questions:** ▼ How do magnifying glasses and telescopes work? ▼ What causes an object viewed in a car's passenger-side mirror to appear farther away than it actually is? ▼ What makes fiber optics work? ▼ Why does light bend around the corner of a solid object like a doorway?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| All of the learning objectives in this unit are assessed. | Teacher-produced unit assessment | **Summative Assessment: Unit Exam**<br><br>The unit exam consists of multiple-choice and free-response questions that require students to make and support claims using ray tracing, formulas, and logical verbal justifications. Students must reconcile the observations made in the class and labs with the academic justifications. Free-response questions will require students to choose and describe how to construct optical systems to produce a desired result. |

*This assessment addresses all of the guiding questions in this unit, with extra emphasis placed on single lens and mirror problems.*

# Unit 8: Atomic Physics

## Laboratory Investigations:
- Photoelectric Effect Investigation
- Planck's Constant Investigation
- Neon Lights and Other Discharge Lamps Investigation
- Nuclear Decay Investigation

**Estimated Time:** *3 weeks*

**Guiding Questions:** ▼ Why are some elements radioactive and why do they exhibit decay? ▼ Waves exhibit particle-like behaviors; do particles exhibit wave-like behaviors? ▼ Are protons, neutrons, and electrons the fundamental building blocks of all matter?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 1.D.3.1, SP 6.3, SP 7.1]<br><br>Apply mathematical routines to describe the relationship between mass and energy and apply this concept across domains of scale. [LO 4.C.4.1, SP 2.2, SP 2.3, SP 7.2]<br><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. [LO 5.B.11.1, SP 2.2, SP 7.2]<br><br>Make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. [LO 6.G.1.1, SP 6.4, SP 7.1]<br><br>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. [LO 6.G.2.1, SP 6.1]<br><br>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. [LO 6.G.2.2, SP 6.4]<br><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. [LO 1.A.2.1, SP 1.1, SP 7.1]<br><br>***(learning objectives continue)*** | Serway and Vuille, Chapter 27: "Quantum Physics" | **Instructional Activity: History of Quantum Physics**<br><br>Students are presented with an in-depth background on the historical need for and significance of experimentation conducted between 1890 and 1920. This includes, but is not limited to, the photoelectric effect, Compton scattering, and Planck's development of the energy of a photon. Homework exercises and in-class practice problems are excerpted from Chapter 27. The historical background provides students with perspective showing that classical Newtonian physics principles are a subset of "modern physics." This helps students determine when classical approaches are appropriate. |

*This period marks the birth of "modern physics," and it is important because our perception of the universe and the structure of matter changed. During this activity, students will often enthusiastically ask about recent topics such as the Higgs boson particle.*

**Guiding Questions:** ▼ Why are some elements radioactive and why do they exhibit decay? ▼ Waves exhibit particle-like behaviors; do particles exhibit wave-like behaviors? ▼ Are protons, neutrons, and electrons the fundamental building blocks of all matter?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| ***(continued)***<br>Articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass-energy. [LO 1.C.4.1, SP 6.3]<br>Use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region. [LO 7.C.1.1, SP 1.4]<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. [LO 7.C.2.1, SP 1.4]<br>Construct or interpret representations of transitions between atomic energy states involving the emission and absorption of photons. [LO 7.C.4.1, SP 1.1, SP 1.2]<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. [LO 5.D.2.6, SP 6.4, SP 7.2]<br>Make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. [LO 5.D.3.2, SP 6.4]<br>Make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. [LO 5.D.3.3, SP 6.4] | | |

**Guiding Questions:** ▼ Why are some elements radioactive and why do they exhibit decay? ▼ Waves exhibit particle-like behaviors; do particles exhibit wave-like behaviors? ▼ Are protons, neutrons, and electrons the fundamental building blocks of all matter?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| 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. [LO 5.B.8.1, SP 1.2, SP 7.2]<br><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. [LO 5.D.1.6, SP 6.4]<br><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. [LO 5.D.1.7, SP 2.1, SP 2.2]<br><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. [LO 5.D.2.5, SP 2.1, SP 2.2]<br><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. [LO 5.D.2.6, SP 6.4, SP 7.2]<br><br>Make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [LO 6.F.1.1, SP 6.4, SP 7.2]<br><br>Select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. [LO 6.F.4.1, SP 6.4, SP 7.1] | Serway and Vuille, Chapter 29: "Nuclear Physics"<br><br>**Web**<br>"Photoelectric Effect" | **Instructional Activity: Photoelectric Effect Investigation**<br><br>I use a guided-inquiry approach for this investigation. Working in pairs, students are given guiding questions to experiment with the photoelectric effect through an online PhET simulation. After making observations, the class regroups and students share their findings. The discussion is facilitated to ensure that students grasp the significance of intercepts and slope. I add appropriate terminology and definitions. |
| | Dukerich, "Planck's Constant"<br><br>**Supplies**<br>Current probes, voltage probes, power amplifiers, 10–15 Ω resistors, four or five LEDs | **Formative Assessment: Planck's Constant Investigation**<br><br>Students use LEDs to recognize that a forward bias is required to make electrons jump from the n-type material to the p-type material in a diode. Students collect and analyze current and voltage to estimate the energy required to excite each LED. The students measure the photon energy and peak frequency. The resulting data is used to plot energy versus frequency. Students discover that the slope of the plot yields Planck's constant. |

*This PhET simulation is important, as it gives context and meaning to the subsequent lab. Without the animation, it is difficult for some students to conceptualize what is happening on the atomic scale.*

*I circulate among the students as they are working and provide leading questions or redirect their discussions as needed. I consider the strength of student understanding to decide whether extra class discussion is needed the following day.*

**Guiding Questions:** ▼ Why are some elements radioactive and why do they exhibit decay? ▼ Waves exhibit particle-like behaviors; do particles exhibit wave-like behaviors? ▼ Are protons, neutrons, and electrons the fundamental building blocks of all matter?

| Learning Objectives | Materials | Instructional Activities and Assessments |
| --- | --- | --- |
| Support the photon model of radiant energy with evidence provided by the photoelectric effect. [LO 6.F.3.1, SP 6.4]<br><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. [LO 1.A.4.1, SP 1.1, SP 7.1] | Serway and Vuille, Chapter 28: "Atomic Physics"<br><br>**Web**<br>"Neon Lights & Other Discharge Lamps" | **Instructional Activity: Neon Lights and Other Discharge Lamps Investigation**<br><br>As a demonstration, I show students the "Neon Lights & Other Discharge Lamps" simulation. I indicate the nonobvious controls of the simulator, drawing a connection to the energy-band jumps made by the electrons. The activity culminates in the creation of a custom element with controllable energy levels. I ask for students' input in creating the atom, and before running the simulation I ask them to predict the outcome. |
| 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. [LO 7.C.3.1, SP 6.4]<br><br>Analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge. [LO 5.C.1.1, SP 6.4, SP 7.2]<br><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. [LO 5.G.1.1, SP 6.4]<br><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 to other types of forces. [LO 3.G.1.2, SP 7.1]<br><br>Identify the strong force as the force that is responsible for holding the nucleus together. [LO 3.G.3.1, SP 7.2] | | **Instructional Activity: Nuclear Decay Investigation**<br><br>In pairs, students are presented with common questions with guiding principles that stem from atomic structure and nuclear decay. For example: *When you get an X-ray, why do they choose lead as the material to create the shielding cover?* or *Why can't we run a nuclear reactor off of simple items like a banana peel?*<br><br>As a large group we discuss the size, structure, forces, and stability of the atom. I emphasize the stability of atoms whose atomic number and number of neutrons have nearly a one-to-one ratio. We look at the different nuclear-decay types to identify conditions under which atoms are unstable. |

*Students enjoy making a custom element, and it normally winds up being a crazy structure with many electron transitions. This creates more work and also makes it tough for them when I ask them to predict the outcome. Often, students realize, simpler is better.*

**Guiding Questions:** ▼ Why are some elements radioactive and why do they exhibit decay? ▼ Waves exhibit particle-like behaviors; do particles exhibit wave-like behaviors? ▼ Are protons, neutrons, and electrons the fundamental building blocks of all matter?

| Learning Objectives | Materials | Instructional Activities and Assessments |
|---|---|---|
| All of the learning objectives in this unit are assessed. | Teacher-produced unit assessment | **Summative Assessment: Unit Exam**<br><br>The unit exam consists of multiple-choice and free-response questions that require students to articulate the relationship between energy, particles, and waves. I create a claim asserted by a fictitious experimenter and ask students to support or reject the claim with facts from the unit. Students are expected to make claims and justify the implications of the major experiments described in this unit. The free-response items require students to express their thoughts in a variety of forms: written text, illustrations/images, graphs, and data tables. |

*This assessment addresses all of the guiding questions in this unit.*

# Resources

## General Resources

Appel, Kenneth, Clarence Bakken, John Gastineau, and David Vernier. *Physics with Vernier.* Beaverton, OR: Vernier Software & Technology, 2010.

Dukerich, Larry. *Advanced Physics with Vernier - Beyond Mechanics.* Beaverton, OR: Vernier Software & Technology, 2012.

Laws, Priscilla W., Robert B. Teese, Maxine C. Willis, and Patrick J. Cooney. *Physics with Video Analysis.* Beaverton, OR: Vernier Software & Technology, 2009.

Serway, Raymond A., and Chris Vuille. *College Physics*. 9th ed. Boston: Brooks/Cole, 2012.

## Unit 1 (Lab Practices and Data Analysis) Resources

*No unit-specific resources.*

## Unit 2 (Fluids) Resources

"Buoyancy Playground." PhET. University of Colorado at Boulder. Accessed December 3, 2013. http://phet.colorado.edu/sims/density-and-buoyancy/buoyancy_en.html.

"Pressure: The Bed of Nails." On *Best from Conceptual Physics Alive* (Disc 1) by Paul G. Hewitt. Arbor Scientific. DVD.

## Unit 3 (Electric Forces, Fields, and Energy) Resources

"Millikan's Oil Drop Experiment to Determine Charge of an Electron." elearnin. Video, 1:59. Accessed December 3, 2013. http://www.youtube.com/watch?v=UFiPWv03f6g.

## Unit 4 (Electric Current, Resistance, Power, and Circuits) Resources

"Squishy Circuits." Thomas Lab, University of St. Thomas. Accessed December 3, 2013. http://courseweb.stthomas.edu/apthomas/SquishyCircuits/buildingCircuits.htm.

## Unit 5 (Magnetism and Induction) Resources

*No unit-specific resources.*

## Unit 6 (Thermodynamics) Resources

"Gas Properties" PhET. University of Colorado at Boulder. Accessed December 3, 2013. http://phet.colorado.edu/en/simulation/gas-properties.

Sokoloff, David R., Priscilla W. Laws, and Ronald K. Thornton. *RealTime Physics: Active Learning Laboratories, Module 2: Heat & Thermodynamics.* Hoboken, NJ: John Wiley & Sons, Inc., 2011.

## Unit 7 (Light and Geometric Optics) Resources

"Demo 23-02: Single Slit Diffraction" and "Demo 23-08: Knife Edge Diffraction." On *The Video Encyclopedia of Physics Demonstrations*. Los Angeles, CA: The Education Group, 2005. DVD.

## Unit 8 (Atomic Physics) Resources

"Photoelectric Effect." PhET. University of Colorado at Boulder. Accessed December 3, 2013. http://phet.colorado.edu/en/simulation/photoelectric.

"Neon Lights & Other Discharge Lamps" PhET. University of Colorado at Boulder. Accessed December 3, 2013. http://phet.colorado.edu/en/simulation/discharge-lamps.

All links to online resources were verified before publication. In cases where links are no longer working, we suggest that you try to find the resource by doing a keyword Web search.