AP® Chemistry

Course Planning and Pacing Guide 4

Armand Amoranto
Oceanside High School
Oceanside, California

About the College Board

The College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, the College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, the College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success — including the SAT® and the Advanced Placement Program™. The organization also serves the education community through research and advocacy on behalf of students, educators and schools.

For further information, visit **www.collegeboard.org**.

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® Chemistry Course Planning and Pacing Guides

This guide is one of four course planning and pacing guides designed for AP® Chemistry 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 Chemistry Curriculum Framework* — the learning objectives, big ideas, 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, laboratory investigations, and 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 Chemistry teachers. Additionally, each author explicitly explains how he or she manages course breadth and increases depth for each unit of instruction.

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

Oceanside High School
Oceanside, California

School	Oceanside High School is a public school that serves grades 9–12. It is located in a suburb of San Diego and is near Marine Corps Base Camp Pendleton. The school's mission statement is as follows: "The mission of Oceanside High School is to ensure every member of the school community is achieving in a challenging and comprehensive environment as determined by state and district standards. Support systems will assure students maximum preparation for their postsecondary pursuits."
Student population	Total enrollment of 2,400 students: • 63 percent Hispanic/Latino • 21 percent Caucasian • 9 percent African American • 5 percent Asian • 3 percent Pacific Islander
	• 54 percent of students qualify for free or reduced-price lunch • About 41 percent of juniors and seniors take and complete AP® courses and exams; 40 percent of students pass their AP Exams with a score of 3 or higher • 26 percent of graduates meet the University of California or California State University minimum application requirements • About 60 percent of our graduates move on to postsecondary education in traditional colleges and universities, military, or technical schools
Instructional time	Our school year starts on the Thursday before the last full week of August. We have 180 instructional days. Our schedule provides for AP Chemistry: • one 55-minute period a day, five days a week, for a total of 275 minutes a week • 30 weeks of instruction before the AP Chemistry Exam, which includes two weeks of review for the exam

Student preparation	Our school offers open enrollment for all of the AP courses. Though students at any grade level can take AP Chemistry, most take the course in grades 10–12. Because our school does not offer an honors chemistry course as a prerequisite, students either take AP Chemistry as a second course following general or regular chemistry or as their first high school chemistry course.
Textbooks and lab manuals	Zumdahl, Steven S., and Susan A. Zumdahl. *Chemistry*. 7th ed. Boston: Houghton Mifflin, 2007. Bilash, Borislaw, II, George R. Gross, and John K. Koob. *A Demo a Day: A Year of Chemical Demonstrations*. 2nd ed. Batavia, IL: Flinn Scientific, 2006. Randall, Jack. *Advanced Chemistry with Vernier*. Beaverton, OR: Vernier Software & Technology, 2004. Vonderbrink, Sally Ann. *Laboratory Experiments for Advanced Placement Chemistry*. Batavia, IL: Flinn Scientific, 2001.

Overview of the Course

The students in my classes are considered novices at science problem solving, demonstrating scientific reasoning, and designing labs. In addition, my class sizes typically range between 35 and 45 students. To overcome these challenges, I take a balanced approach of direct instruction, modeling techniques for thinking out loud to solve problems, and demonstrating proper lab technique for traditional as well as guided-inquiry labs (see resources). Direct instruction is provided through in-class lessons and vodcasts (online videos I create to show students how to solve a problem or to review chemistry concepts) that serve as previews for in-class instruction. I record additional vodcast lessons as extra examples for students to watch at home.

Many of my students need to master skills such as conversions, stoichiometry, or knowledge of first-year chemistry concepts, which I call "the standards." Formative assessments with feedback improve learning of such standards. I provide these standards assessments via Moodle, creating quizzes that cover each area or topic. Each assessment provides students with different levels of feedback to help them correct their mistakes, such as a hint in a step to solve a problem or a link to a full video lesson demonstrating how to solve a problem. The formative assessments help students evaluate their own learning through timely feedback about their progress toward proficiency on a particular learning objective. They also inform my decisions about whether to alter my instruction to ensure that students understand the six big ideas.

With greater emphasis on science practices and models in the new curriculum, I expect students to demonstrate their understanding using two methods: concept questions answered on a Moodle Workshop module and guided-inquiry labs. I have adapted techniques to help students develop models that are critical to scientific reasoning. Communication skills and peer evaluation are critical to mastering the science practices. Using Moodle's Workshop module, students explain their reasoning in support of their chosen answers. Skills such as justifying responses with evidence and comparing/contrasting information with reasoning skills are emphasized in the course. Students also learn to critically read their peers' responses and use a rubric to assess their own and other students' work. I train my students to identify instances when their peers' responses lack justification; this helps develop their capacity to justify and reason, as well as to engage in error analyses in the lab setting.

Twenty-five percent of all class time is spent engaging in hands-on laboratory work. For each hands-on laboratory experience, students submit a complete report including a hypothesis, procedure, observations/data, calculations, and a conclusion. These reports are kept in laboratory notebooks for students to present to the colleges of their choice. For the guided-inquiry labs, students are presented with a problem to solve. I use the guided-inquiry lab not as a preview to the unit but as a form of summative assessment within the unit. I use Socratic questioning to train my students to focus on identifying the data that need to be collected in order to solve the problem. We have whole-class discussions along with live-feed Moodle forums to ensure all students have an opportunity to participate in the process. Once we have identified the data that need to be collected, I help my students practice the techniques that chemists use to collect data, such as developing proficiency with instrumentation, learning to prepare the equipment, attending to safety protocols, and understanding the reasons behind the techniques used. After the data are collected and analyzed, students engage in error analysis. During error analysis, students identify errors in calculation and equipment use; they then perform the labs again, modifying procedures and correcting their errors. Finally, students submit their lab reports and use a rubric to evaluate one another's work in a Moodle Workshop module.

Big Ideas and Science Practices

AP Chemistry Big Ideas

Big Idea 1: The chemical elements are fundamental building materials of matter, and all matter can be understood in terms of arrangements of atoms. These atoms retain their identity in chemical reactions.

Big Idea 2: Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.

Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.

Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.

Big Idea 6: Any bond or intermolecular attraction that can be formed can be broken. These two processes are in a dynamic competition, sensitive to initial conditions and external perturbations.

Science Practices for AP Chemistry

A practice is a way to coordinate knowledge and skills in order to accomplish a goal or task. The science practices enable students to establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. These science practices capture important aspects of the work that scientists engage in, at the level of competence expected of AP Chemistry students.

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

1.1 The student can *create representations and models* of natural or man-made phenomena and systems in the domain.

1.2 The student can *describe representations and models* of natural or man-made phenomena and systems in the domain.

1.3 The student can *refine representations and models* of natural or man-made phenomena and systems in the domain.

1.4 The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively.

1.5 The student can *re-express key elements* of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately.

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

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

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

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

3.1 The student can *pose scientific questions*.

3.2 The student can *refine scientific questions*.

3.3 The student can *evaluate scientific questions.*

Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question.

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

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

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

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

Science Practice 5: The student can perform data analysis and evaluation of evidence.

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

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

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

Science Practice 6: The student can work with scientific explanations and theories.

6.1 The student can *justify claims with evidence*.

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

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

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

6.5 The student can *evaluate alternative scientific explanations*.

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

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

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

Managing Breadth and Increasing Depth

Unit	Managing Breadth	Increasing Depth
Unit 1: Lab Safety, Matter, and Measurement	The topics covered are a review of basic skills (not content) that students need to be successful in the AP Chemistry course. Therefore, there is no reduction of breadth in this unit as a result of the redesigned curriculum framework.	However, the decrease in the breadth of the overall course content allows me more time to evaluate and strengthen students' basic calculations skills necessary for chemistry and to develop students' proficiency in creating particulate models of atoms and compounds in the context of phases and density.
Unit 2: Internal Structure of the Atom	Students are no longer required to know quantum numbers to label the electrons in an atom. This saves two days of instruction time.	I use the extra two days to help students understand Coulomb's Law and how to apply it in microscopic interactions of particles. Students must understand the direct relationship between the force of attraction and the magnitude of the charge. More important, students must know the inverse relationship between force and the square of the distance to understand how models of atomic structure lead to periodic trends.
Unit 3: Bonding: Interactions Between Atoms to Form Molecules	Due to a decreased focus on equation writing isolated from context, less time will be spent on memorizing reaction types and associated equations. Instead, students will learn nomenclature and equation writing in the context of bonding, equilibrium, and thermodynamics. By combining my nomenclature unit with my bonding unit, I hope to save at least five days.	With the extra five days, I spend more time strengthening my students' skills in creating representations of the particulate nature of matter. Students are expected to draw, label, and explain the microscopic interaction of particles to create bonds and the macroscopic observations that should follow.
Unit 4: Qualitative and Quantitative Chemistry: Counting Atoms and Molecules	Colligative properties are no longer assessed in the redesigned course. As a consequence, molality does not need to be taught. Also, there is less emphasis on organic reactions, so time will be saved by not specifically teaching an organic unit even though examples of organic reactions will still be provided in the context of stoichiometry. In addition, there is less emphasis on the solubility rules. Students will be given the rules if necessary and do not have to memorize them. The removal of Lewis acids and bases means a de-emphasis on transition metal reactions. All of these changes should save at least 10 days.	With the 10 days gained by the decrease in breadth, I focus on interparticle interactions with solutions. I take time to ensure that students understand how to justify and reason to support macroscopic observations based on models that guide the microscopic interactions. The additional time also allows me to include more labs in which students make macroscopic observations and develop associated particulate representations.
Unit 5: Thermochemistry: Energy of Interacting Atoms and Molecules	This unit is essentially the same as before except that students must use the term "thermodynamically favored" instead of "spontaneous." However, to ensure that students understand thermochemistry in context, I am combining the gas unit with the energy unit, since many of the concepts in the redesigned curriculum framework emphasize the description of gas behavior from an energy perspective.	Energy is what drives the interaction of particles in chemistry. Students are expected to strengthen understanding of how energy is transferred from one system to another. Accordingly, $P\Delta V$ work diagrams are now part of the curriculum to improve students' skill in translating between observations, organized data, and particulate representations of intermolecular forces.
Unit 6: Kinetics: Factors That Affect Reaction Rates	The content in this unit has not been changed in the redesigned curriculum framework. However, to strengthen students' reasoning pertaining to the connection of kinetic molecular theory, thermodynamics, and equilibrium, I teach this unit prior to my equilibrium unit.	The skills of analyzing rate graphs, calculating rates, and calculating rate constants are still used in the redesigned course. However, students must deepen their conceptual and particulate view of how kinetics connects to thermodynamics and equilibrium and know how to use such understanding to explain macroscopic-level observations in the laboratory setting.

Unit	Managing Breadth	Increasing Depth
Unit 7: Equilibrium: Application of Kinetics	The breadth of content pertaining to equilibrium has not changed much in the redesigned course. However, since computing the change in pH resulting from the addition of an acid or a base to a buffer is not a required skill in the course, I can spend more time on strengthening students' particulate view of what is happening during equilibrium.	Students will be expected to explain macroscopic observations of equilibrium using particulate-level reasoning. We start with the macroscopic observations; I teach Le Chatelier's principle first, and students apply the teachings to an inquiry lab. Then we move toward understanding the kinetics behind equilibrium. To develop the depth of understanding necessary, I address equilibrium from a collision model by starting with gas equilibrium (K_p) and the importance of how pressure and temperature affect equilibrium for gases. I then address solutions (K_c) and the importance of how concentration and temperature affect equilibrium using the collision model. Once those models are developed, we study solubility equilibrium and focus on why solids have no affect on equilibrium. Lastly, we apply the equilibrium concepts to acids and bases.
Unit 8: Electrochemistry: Applications to Redox Reactions	Though students are not required to label the positive and negative electrodes in a galvanic cell, I still teach it. I feel it helps my students understand the flow of electrons and fits their understanding of the electrode as the place where reduction and oxidation occur. I save two days by not emphasizing the Nernst equation.	The time saved by not teaching the Nernst equation is spent on a guided-inquiry lab in which students design at least three galvanic cells and analyze the difference in the predicted values from the standard potential tables and what they measure. Students then explain the interparticle interactions in the redox reaction and justify it with the data they obtained.

Unit 1: Lab Safety, Matter, and Measurement

Laboratory Investigations:

- Floating Lemons and Sinking Limes *(guided inquiry)*
- Identifying the Dyes in M&Ms Using Chromatography *(guided inquiry)*

Estimated Time:

8 days

Essential Questions: ▼ What are the implications of students not following safety rules in an AP Chemistry course or other college-level general chemistry courses? ▼ What macroscopic clues can be used to determine whether a physical or chemical change has occurred? ▼ Why is it important to be able to separate mixtures, and how do chemists achieve such separation?

Learning Objectives	Materials	Instructional Activities and Assessments
	Bilash, Gross, and Koob, "A Simulated 'Acid in Your Eye' Accident"; "Contact Lens Demo"; and "Fire Extinguisher Demo" **Web** Baruch's Chemistry Lab Safety Tutorial	**Instructional Activity:** Students tour a virtual chemistry lab, identifying lab safety equipment and defining their application to safety. The demonstrations give students a visual of the potential dangers of getting acids in their eyes and wearing contacts in the lab. The fire extinguisher demo shows students the proper way to use a fire extinguisher.
	Moodle	**Formative Assessment:** Standard 1.0 Lab Safety Rules Practice Quiz on Moodle Students demonstrate knowledge of safety rules and proper use of lab safety equipment. There are 30 multiple-choice questions in the practice quiz.
	Moodle	**Summative Assessment:** Lab Safety Rules Final Quiz on Moodle: Students demonstrate knowledge of safety rules and proper use of lab safety equipment.
	Zumdahl and Zumdahl, Chapter 1: "Chemical Foundations," Sections 1.1–1.8 Bilash, Gross, and Koob, "Nitric Acid Acts Upon Copper — The First Demo"	**Instructional Activity:** Students watch a teacher-created vodcast defining matter, elements, compounds, units of measurement, and significant figure rules prior to engaging in a whole-class discussion about how to calculate different units using dimensional analysis and calculate temperature conversions and density. Students relate the particulate models of the different phases of matter for particular compounds and elements to calculated values of densities.
	Web "Floating Lemons and Sinking Limes"	**Instructional Activity:** Floating Lemons and Sinking Limes (guided-inquiry lab): I show students a clear tub filled with water that contains three lemons and three limes of equal size. The lemons float and the limes sink. Students are guided to develop their own hypotheses, data collection procedures, and anticipated calculations to explain this observed phenomenon.

The practice quiz provides feedback to my students and me about their understanding of safety procedures. The results from the assessment will guide how much I review prior to the summative assessment.

This assessment addresses the essential question, What are the implications of students not following safety rules in an AP Chemistry course or other college-level general chemistry courses? *About 15 of my students each year are first-year chemistry students. I require that my students earn at least 90 percent on the summative assessment to qualify for lab work. They are allowed to retake the quiz as many times as they need to in order to pass.*

This activity not only reinforces students' observation, recording, and calculation skills but also introduces them to guided inquiry in the AP Chemistry setting by using a simple concept like density.

Essential Questions: ▼ What are the implications of students not following safety rules in an AP Chemistry course or other college-level general chemistry courses? ▼ What macroscopic clues can be used to determine whether a physical or chemical change has occurred? ▼ Why is it important to be able to separate mixtures, and how do chemists achieve such separation?

Learning Objectives	Materials	Instructional Activities and Assessments
	Moodle	**Formative Assessment:** Students practice using physical data and appropriate units of measurement to calculate density on the following Moodle assessments: • Standard 1.1 Matter, Elements, and Compounds: Students identify different states of matter and compare and contrast elements and compounds. • Standard 1.2 Scientific Notation: Students translate or convert between numbers in scientific notation and regular decimals. • Standard 1.3 Significant Figures: Students calculate numbers and apply significant figure rules to their answers. • Standard 1.4 Conversions: Students use dimensional analysis to convert between different units of chemical quantities. • Standard 1.5 Density: Students calculate density, mass, or volume from lab data and relate it to the different particulate models for the different phases of matter.
Translate among macroscopic observations of change, chemical equations, and particle views. [LO 3.1, SP 1.5, SP 7.1] Support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [LO 5.10, SP 5.1]	Zumdahl and Zumdahl, Chapter 1: "Chemical Foundations," Section 1.9 Teacher-created demonstrations: copper (II) sulfate solution and aluminum metal; sodium metal in water	**Instructional Activity:** Matter Classification: Upon watching the copper (II) sulfate solution and aluminum and the sodium metal in water teacher demonstrations, students classify the states of matter, pure substances versus mixtures, and differentiate between physical and chemical changes.

Each standard is a Moodle quiz containing six to eight questions that test student comprehension of the topics listed. These standards are completed over two days. Students' responses inform my decisions about any reteaching that may be necessary.

Essential Questions: ▼ What are the implications of students not following safety rules in an AP Chemistry course or other college-level general chemistry courses? ▼ What macroscopic clues can be used to determine whether a physical or chemical change has occurred? ▼ Why is it important to be able to separate mixtures, and how do chemists achieve such separation?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain how solutes can be separated by chromatography based on intermolecular interactions. [LO 2.7, SP 6.2] Design and/or interpret the results of a separation experiment (filtration, paper chromatography, column chromatography, or distillation) in terms of the relative strength of interactions among and between the components. [LO 2.10, SP 4.2, SP 5.1, SP 6.4]		**Instructional Activity:** Students are shown a solid mixture of different colored powdered drink mixes; a mixture of sand, pebbles, and water; a liquid mixture of acetone and isopropyl alcohol; a plastic bag filled with air gathered by waving it in the air and then tying the ends together; and a solid piece of brass. Students work in groups to review different separation techniques and then determine which technique would be used to separate each of the shown mixtures: distillation, filtration, or chromatography. Students come up with an explanation for why a chemist would implement particular separation techniques to identify the components of a mixture.
Translate among macroscopic observations of change, chemical equations, and particle views. [LO 3.1, SP 1.5, SP 7.1] Support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [LO 5.10, SP 5.1]	Moodle	**Formative Assessment:** Students practice translating among macroscopic observations and particulate representations with the following Moodle assessments: • Standard 1.5 Physical and Chemical Changes: Students identify a picture as demonstrating a physical or chemical change. • Standard 1.6 Heterogeneous and Homogeneous Mixtures: Looking at pictures, students determine whether a mixture is homogeneous or heterogeneous. • Standard 1.7 Mixture Separation: Students identify the best technique to separate a mixture in different scenarios.
Design and/or interpret the results of a separation experiment (filtration, paper chromatography, column chromatography, or distillation) in terms of the relative strength of interactions among and between the components. [LO 2.10, SP 4.2, SP 5.1, SP 6.4]	M&Ms, capillary tubes, 1000 mL and 50 mL beakers, chromatography paper, sticks, tape, pencil, water, food coloring	**Instructional Activity:** Identifying the Dyes in M&Ms Using Chromatography (guided-inquiry lab): Students use chromatography techniques to measure, calculate, and compare the food coloring dyes provided with those in the different M&M colors. Students are expected to calculate the R_f value for each color from the food coloring dyes and the M&Ms. Students design the procedures to determine the calculations necessary to solve the problem. In the conclusion of the lab report, students calculate the percent error for their R_f values after they identify the dyes and identify the incorrect procedure or calculation that caused the error.

It's important to expose students to the various types of mixtures and separation techniques to strengthen their understanding of intermolecular forces, homogeneous and heterogeneous mixtures, and good lab techniques.

The results of these assessments let my students and me know which topics require more instruction and inform my decisions about adapting the next guided-inquiry lab.

The biggest issue with this lab is that students find it hard to get concentrated dye from the M&Ms, making it difficult for them to read the data. To solve this problem, lead students to use small beakers with minimal water and add the M&Ms. Phase it so they add five to 10 at a time, pull the M&Ms out when the dye is gone, and repeat until they get a nice dark color.

Essential Questions: ▼ What are the implications of students not following safety rules in an AP Chemistry course or other college-level general chemistry courses? ▼ What macroscopic clues can be used to determine whether a physical or chemical change has occurred? ▼ Why is it important to be able to separate mixtures, and how do chemists achieve such separation?

Learning Objectives	Materials	Instructional Activities and Assessments
	Moodle	**Summative Assessment:** In a 55-minute quiz, students answer 25 multiple-choice questions on Edusoft and one free-response question. The multiple-choice questions focus on the concepts learned from the Moodle 1.1 to 1.7 Standards, along with mixture separation. The free-response question requires students to choose methods to separate different mixtures, justify their choices, and develop lab procedures to accomplish the separation.

This assessment addresses the following essential questions:

- What macroscopic clues can be used to determine whether a physical or chemical change has occurred?
- Why is it important to be able to separate mixtures, and how do chemists achieve such separation?

Laboratory Investigations:

- Identifying the Elements Using the Bright Line Spectrum *(guided inquiry)*

Estimated Time: *13 days*

Essential Questions: ▼ How does Coulomb's Law explain the structure of the atom and the periodic trends? ▼ What data can be collected that give insight into the internal structure of the atom? ▼ How can the quantum mechanical model of energy levels in conjunction with Coulomb's Law explain the periodic trends?

Learning Objectives	Materials	Instructional Activities and Assessments
Apply Coulomb's Law qualitatively (including using representations) to describe the interactions of ions, and the attractions between ions and solvents to explain the factors that contribute to the solubility of ionic compounds. [LO 2.14, SP 1.4, SP 6.4]	Van de Graaf generator, pith balls attached to string, electroscopes	**Instructional Activity:** Students watch a vodcast introducing them to Coulomb's Law and the roles that variables of distance and charge play in the magnitude of the force of attraction. Students then make observations and analyze forces of interactions using a Van de Graaf generator with pith balls attached to string and electroscopes. Students are required to use the observations made to explain the connection between Coulomb's Law, atomic structure, and periodic trends.
	iPad, ShowMe app, Moodle	**Formative Assessment:** Students use the iPad ShowMe app (or another video-creating program) to create a vodcast explaining their understanding of Coulomb's Law. Specifically, they demonstrate their conceptual understanding of what happens to the force when the distance changes between the charged particles, and how the change in the magnitude of the charge changes the magnitude of the force as well. Students submit their vodcasts to a Moodle Workshop module and peer assess one another's work using a rubric the next day.
Explain the distribution of electrons in an atom or ion based upon data. [LO 1.5, SP 1.5, SP 6.2] Analyze data relating to electron energies for patterns and relationships. [LO 1.6, SP 5.1]	Zumdahl and Zumdahl, Chapter 7: "Atomic Structure and Periodicity," Sections 7.1–7.4 **Web** "Models of the Hydrogen Atom"	**Instructional Activity:** Students use the PhET simulation, "Models of the Hydrogen Atom." When the list of different atomic models appears, students click each model to watch what the atomic model theorist predicted would happen to the subatomic particles as white light was beamed at the atom. Students select the Bohr model and then explain the connection between the movement of the electron in the atom when hit with white light and the observation seen by the spectrometer.

This activity addresses the physics topic of Coulomb's Law to ensure that students understand the fundamental particle interactions. This learning objective will be revisited when discussing ions and solutions.

When students assess their own and their peers' work, they generate a list of topics or concepts they want me to revisit to strengthen their understanding of Coulomb's Law and its connection to atomic structure and periodic trends.

Essential Questions: ▼ How does Coulomb's Law explain the structure of the atom and the periodic trends? ▼ What data can be collected that give insight into the internal structure of the atom? ▼ How can the quantum mechanical model of energy levels in conjunction with Coulomb's Law explain the periodic trends?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain the distribution of electrons in an atom or ion based upon data. [LO 1.5, SP 1.5, SP 6.2] Analyze data relating to electron energies for patterns and relationships. [LO 1.6, SP 5.1]	Moodle	**Formative Assessment:** Students practice the content and skills involved in connecting the Bohr model to data relating to electron energies and periodic trends using the following Moodle assessments: • Standard 2.0 Wavelength and Frequency: Students apply the formula $c = \nu \lambda$ to calculate the wavelength and frequency pertaining to electromagnetic radiation. • Standard 2.1 Bohr and Energy Levels: Students apply the formula $E_n = -2.18 \times 10^{-18} (1^2/n^2)$ to calculate the energy released or absorbed as electrons transition between energy levels in the hydrogen atom.
Explain the distribution of electrons in an atom or ion based upon data. [LO 1.5, SP 1.5, SP 6.2] Analyze data relating to electron energies for patterns and relationships. [LO 1.6, SP 5.1] Describe the electronic structure of the atom, using PES data, ionization energy data, and/or Coulomb's Law to construct explanations of how the energies of electrons within shells in atoms vary. [LO 1.7, SP 5.1, SP 6.2] Explain the distribution of electrons using Coulomb's Law to analyze measured energies. [LO 1.8, SP 6.2] Justify the selection of a particular type of spectroscopy to measure properties associated with vibrational or electronic motions of molecules. [LO 1.15, SP 4.1, SP 6.4]	6 spectrum analysis power supplies, bulbs (H, He, Ne, Ar, Hg, N_2), 6 spectroscopes	**Instructional Activity:** Identify the Elements Using the Bright Line Spectrum (guided-inquiry lab): Students watch a vodcast introducing them to a spectrometer and a spectroscope, then engage in a whole-class discussion about how to design the procedures to collect the data necessary to identify specific elements using the bright line spectra. Students collect line spectra data from six different element spectral tubes. They measure the wavelength of the bright line spectra and use their data to determine the element in each of the tubes. In the lab report conclusion, students communicate the knowledge and skills necessary to analyze the data required to solve the problem in the lab. They also provide an error analysis, discussing the limitations of the spectroscope and how it increases the difficulty in identifying the unknown element.

Students connect the observations made in the PhET simulation with the calculations performed in the Moodle assessments. Students' performance in this set of standards informs my decision on how to modify the Identify the Elements Using the Bright Line Spectrum guided-inquiry lab to strengthen student understanding of connecting observations to calculations, to atomic theory, and to associated atomic models.

Essential Questions: ▼ How does Coulomb's Law explain the structure of the atom and the periodic trends? ▼ What data can be collected that give insight into the internal structure of the atom? ▼ How can the quantum mechanical model of energy levels in conjunction with Coulomb's Law explain the periodic trends?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain why a given set of data suggests, or does not suggest, the need to refine the atomic model from a classical shell model with the quantum mechanical model. [LO 1.12, SP 6.3] Given information about a particular model of the atom, determine if the model is consistent with specified evidence. [LO 1.13, SP 5.3]	Zumdahl and Zumdahl, Chapter 7: "Atomic Structure and Periodicity," Sections 7.5–7.9	**Instructional Activity:** Prior to class, students watch a vodcast lesson introducing them to the wave and particle nature of the electron and connect that nature to the quantum mechanical model. In class, the lesson focuses on the quantum mechanical model of the atom: energy, orbital shapes, electron spin, and electron configuration. Students relate this information to data from the Identify the Elements Using the Bright Line Spectrum guided-inquiry lab. Students use the lab data to justify the quantum mechanical model.
		Formative Assessment: Students work in groups to generate an explanation of how the quantum mechanical model builds upon the Bohr model of the atom. They connect the data that allowed for such a revision of the Bohr model into the quantum mechanical model. Students also ensure their explanation relates to our current use of electron configurations to describe the structure of an atom and explain how older models for atomic structure needed to be refined based on given limitations for each model.
		Summative Assessment: In this 30-minute, mid-unit quiz, students answer 10 multiple-choice questions on Edusoft and one free-response question. The multiple-choice questions focus on the quantum mechanical model and Coulomb's Law. The free-response question focuses on Bohr's model and how it changes for elements with more than one proton.
Predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model. [LO 1.9, SP 6.4]	Zumdahl and Zumdahl, Chapter 7: "Atomic Structure and Periodicity," Sections 7.12–7.13	**Instructional Activity:** Students watch a vodcast defining the different periodic trends: atomic/ionic radius, ionization energy. They are also given various graphs and data tables displaying the periodic trends. Students then (in groups) develop a series of statements about the periodic and group trends with a rationale for each trend. They demonstrate their understanding of the reasons behind the trends by using Z (effective nuclear charge), energy levels, shielding, and Coulomb's Law in their explanations.

We use the results of the lab to focus a discussion of how certain elements, such as neon, have many bright lines. I ask students how the quantum mechanical model explains the plethora of bright lines in neon, as opposed to hydrogen's four bright lines.

After hearing the groups' explanations of how the atomic models have changed and still show limitations, I am able to identify gaps in their understanding and develop a reteach-and-review session.

This assessment addresses the essential question, What data can be collected that give insight into the internal structure of the atom?

Essential Questions: ▼ How does Coulomb's Law explain the structure of the atom and the periodic trends? ▼ What data can be collected that give insight into the internal structure of the atom? ▼ How can the quantum mechanical model of energy levels in conjunction with Coulomb's Law explain the periodic trends?

Learning Objectives	Materials	Instructional Activities and Assessments
Predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model. [LO 1.9, SP 6.4]	Moodle	**Formative Assessment:** Students use the following teacher-created Moodle assessments to practice the content and skills related to reasoning about and identifying periodic trends: • 2.6 Atomic Radius Trend: Students answer concept questions regarding their knowledge of the atomic radius trend. • 2.7 Ion Radius Trend: Students answer concept questions regarding their knowledge of the ion radius trend. • 2.8 Ionization Energy Trend: Students answer concept questions regarding their knowledge of the ionization energy trend. • Workshop 2.2: Students answer concept questions regarding their knowledge of the trends and explain the reason behind each trend using Z (effective charge), energy levels, electron shielding, and Coulomb's Law to justify their reasoning.
Justify with evidence the arrangement of the periodic table and apply periodic properties to chemical reactivity. [LO 1.10, SP 6.1] Analyze data, based on periodicity and the properties of binary compounds, to identify patterns and generate hypotheses related to the molecular design of compounds for which data are not supplied. [LO 1.11, SP 3.1, SP 5.1]	Zumdahl and Zumdahl, Chapter 8: "Bonding: General Concepts," Sections 8.1–8.2	**Instructional Activity:** Students watch a vodcast defining electronegativity and types of bonding (metallic, covalent, and ionic) prior to engaging in a whole-class discussion about the periodic trend of electronegativity and how knowledge of electronegativity values help them determine the types of bonds formed. Students calculate differences between electronegativity values to identify dipole moments, overall dipole moments, and the type of bond formed in several compounds and molecules.
		Summative Assessment: In this 55-minute assessment, students answer 14 multiple-choice questions using Edusoft and two free-response questions. The multiple-choice questions focus on the quantum mechanical model, Coulomb's Law, periodic trends, and types of bonds. The first free-response question focuses on periodic trends and analyzing data, and the second focuses on calculations of energy, frequency, and wavelength. Students are asked to explain the differences in values of energy using Coulomb's Law.

Moodle formative assessments 2.6–2.7 test students' knowledge of the trends and let me see whether they can sort them from least to greatest or vice versa. This will guide my approach to the workshop activity and determine whether I need to reteach certain topics.

This assessment addresses the following essential questions:
- How does Coulomb's Law explain the structure of the atom and the periodic trends?
- What data can be collected that give insight into the internal structure of the atom?
- How can the quantum mechanical model of energy levels in conjunction with Coulomb's Law explain the periodic trends?

Laboratory Investigations:

- Lewis Structures Activity Lab
- Identifying Unknowns by Connecting Macroscopic Observations to Intermolecular Forces *(guided inquiry)*

Estimated Time: *22 days*

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain how a bonding model involving delocalized electrons is consistent with macroscopic properties of metals (e.g., conductivity, malleability, ductility, and low volatility) and the shell model of the atom. [LO 2.20, SP 6.2, SP 7.1, *connects to* 2.D.2] Compare the properties of metal alloys with their constituent elements to determine if an alloy has formed, identify the type of alloy formed, and explain the differences in properties using particulate level reasoning. [LO 2.25, SP 1.4, SP 7.2] Use the electron sea model of metallic bonding to predict or make claims about the macroscopic properties of metals or alloys. [LO 2.26, SP 6.4, SP 7.1] Create a representation of a metallic solid that shows essential characteristics of the structure and interactions present in the substance. [LO 2.27, SP 1.1] Explain a representation that connects properties of a metallic solid to its structural attributes and to the interactions present at the atomic level. [LO 2.28, SP 1.1, SP 6.2, SP 7.1]	Zumdahl and Zumdahl, Chapter 10: "Liquids and Solids," Section 10.4	**Instructional Activity:** After reviewing the definition of a metallic bond and the role Coulomb's Law plays in metallic bonding, as well as viewing several images of metallic solids, students draw particulate-level depictions of the crystal structure of metals for metallic bonds. Students analyze the drawings and use Coulomb's Law to justify the macroscopic properties of metals: conductivity, malleability, ductility, and low volatility.

Metallic bonding is not typically taught before ionic bonding. Given the importance of understanding the particulate nature of matter, I decided to start with the simplest model. Though the attraction between the sea of electrons is more complicated than ionic attraction, the particle structures of metals are easier to visualize.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Compare the properties of metal alloys with their constituent elements to determine if an alloy has formed, identify the type of alloy formed, and explain the differences in properties using particulate level reasoning. [LO 2.25, SP 1.4, SP 7.2] Use the electron sea model of metallic bonding to predict or make claims about the macroscopic properties of metals or alloys. [LO 2.26, SP 6.4, SP 7.1]		**Instructional Activity:** Students develop particulate representations of three alloys and then connect specific particulate structures of the alloys, which yield the macroscopic properties of those alloys. Students predict how adding impurities to metals/alloys produces changes in the solid structure and is used in the design of new materials, as well as how the properties can be "tuned" by varying the amount of impurity.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain how a bonding model involving delocalized electrons is consistent with macroscopic properties of metals (e.g., conductivity, malleability, ductility, and low volatility) and the shell model of the atom. [LO 2.20, SP 6.2, SP 7.1, *connects to* 2.D.2] Compare the properties of metal alloys with their constituent elements to determine if an alloy has formed, identify the type of alloy formed, and explain the differences in properties using particulate level reasoning. [LO 2.25, SP 1.4, SP 7.2] Use the electron sea model of metallic bonding to predict or make claims about the macroscopic properties of metals or alloys. [LO 2.26, SP 6.4, SP 7.1] Create a representation of a metallic solid that shows essential characteristics of the structure and interactions present in the substance. [LO 2.27, SP 1.1] Explain a representation that connects properties of a metallic solid to its structural attributes and to the interactions present at the atomic level. [LO 2.28, SP 1.1, SP 6.2, SP 7.1]	iPad, ShowMe app, and Moodle	**Formative Assessment:** Students can choose to perform the Nitinol presentation or Moodle Workshop 3.1 below: Nitinol Presentation: Students research a particular shape memory alloy (nitinol) and then create a presentation to show how the particulate structure of nitinol translates to the macroscopic observations of how nitinol can be reshaped at low temperatures but will return to its original shape at high temperatures. Students also connect the characteristics of nitinol to the benefits such a material provides to technology and society. Workshop 3.1: Questions focus on students' conceptual understanding of the particulate-level reasoning about the electron sea model and alloy formation in metallic bonding. They upload student-made images of particulate representations of alloys along with vodcasts (created with the ShowMe app or other video-creating software) demonstrating their conceptual understanding of the microscopic structure and macroscopic properties of alloys. Presentations are evaluated by peers using a rubric.

Due to the conceptual nature of the learning objectives, I use Moodle Workshop 3.1 so that students can communicate their ideas in pictures. Students receive feedback through peer-to-peer evaluations using provided rubrics on either the vodcasts or presentations.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Predict the type of bonding present between two atoms in a binary compound based on position in the periodic table and the electronegativity of the elements. [LO 2.17, SP 6.4] Create visual representations of ionic substances that connect the microscopic structure to macroscopic properties, and/or use representations to connect the microscopic structure to macroscopic properties (e.g., boiling point, solubility, hardness, brittleness, low volatility, lack of malleability, ductility, or conductivity). [LO 2.19, SP 1.1, SP 1.4, SP 7.1, *connects to* 2.D.1, 2.D.2] Create a representation of an ionic solid that shows essential characteristics of the structure and interactions present in the substance. [LO 2.23, SP 1.1] Explain a representation that connects properties of an ionic solid to its structural attributes and to the interactions present at the atomic level. [LO 2.24, SP 1.1, SP 6.2, SP 7.1]	Zumdahl and Zumdahl, Chapter 2: "Atoms, Molecules, and Ions," Sections 2.6–2.8 and Chapter 10: "Liquids and Solids," Section 10.7	**Instructional Activity:** After reviewing ionic bond formation and nomenclature rules for Type I and Type II binary compounds, students translate names of compounds into the compound formulae. For each formula written, students draw a picture of the structure of ionic compounds. Students then use the structure of ionic compounds to justify the macroscopic properties: boiling point, solubility, brittleness, ductility, or conductivity.

The review of nomenclature is inserted here so students can understand that the formula is a simplification of the lattice of the ionic solid.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [LO 2.1, SP 6.4, SP 7.1] Predict the type of bonding present between two atoms in a binary compound based on position in the periodic table and the electronegativity of the elements. [LO 2.17, SP 6.4] Create visual representations of ionic substances that connect the microscopic structure to macroscopic properties, and/or use representations to connect the microscopic structure to macroscopic properties (e.g., boiling point, solubility, hardness, brittleness, low volatility, lack of malleability, ductility, or conductivity). [LO 2.19, SP 1.1, SP 1.4, SP 7.1, *connects to* 2.D.1, 2.D.2] Create a representation of an ionic solid that shows essential characteristics of the structure and interactions present in the substance. [LO 2.23, SP 1.1] Explain a representation that connects properties of an ionic solid to its structural attributes and to the interactions present at the atomic level. [LO 2.24, SP 1.1, SP 6.2, SP 7.1]	Moodle	**Formative Assessment:** Students use the following Moodle assessments to practice the content and skills learned in previous activities: • Standard 3.2 Ionic Compound Properties: Students answer multiple-choice questions about properties of ionic compounds. • Standard 3.3 Type I Nomenclature: Short-answer questions focus on Type I Nomenclature. • Standard 3.4 Type II Nomenclature: Short-answer questions focus on Type II Nomenclature. • Standard 3.5 Type I and II Nomenclature: Short-answer questions focus on a mixture of nomenclature and polyatomic ions. • Workshop 3.6: Students analyze and draw lattice structures of ionic compounds and justify the properties of ionic compounds, comparing and contrasting them with metal properties. Responses are evaluated by peers using a rubric.

I emphasize learning nomenclature. I encourage my students to be responsible for their learning by focusing on understanding when to use Type I or Type II rules. Students' responses to the Moodle assessments inform my decisions about any reteaching that may be necessary.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Analyze data, based on periodicity and the properties of binary compounds, to identify patterns and generate hypotheses related to the molecular design of compounds for which data are not supplied. [LO 1.11, SP 3.1, SP 5.1] Predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [LO 2.1, SP 6.4, SP 7.1] Predict the type of bonding present between two atoms in a binary compound based on position in the periodic table and the electronegativity of the elements. [LO 2.17, SP 6.4] Rank and justify the ranking of bond polarity on the basis of the locations of the bonded atoms in the periodic table. [LO 2.18, SP 6.1] Use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [LO 2.21, SP 1.4]	Zumdahl and Zumdahl, Chapter 2: "Atoms, Molecules and Ions," Section 2.8; Chapter 8: "Bonding: General Concepts," Section 8.10–8.13; and Chapter 9: "Covalent Bonding: Orbitals," Section 9.1	**Instructional Activity:** After reviewing types of covalent bonds, structures, and nomenclature, students practice naming, writing formulae, and drawing the Lewis structures for several molecules. Students identify the polarity of such molecules and apply VSEPR theory to predict the geometry and hybridization of the molecules.
Predict the type of bonding present between two atoms in a binary compound based on position in the periodic table and the electronegativity of the elements. [LO 2.17, SP 6.4] Rank and justify the ranking of bond polarity on the basis of the locations of the bonded atoms in the periodic table. [LO 2.18, SP 6.1]	Moodle	**Formative Assessment:** Students use the following Moodle assessments to practice the content and skills learned in the preceding activities: • Standard 3.7 Type III Nomenclature: Short-answer questions focus on naming covalent compounds. • Standard 3.8 Type I, II, and III Nomenclature: Short-answer questions focus on naming a mixture of ionic and covalent compounds.

When teaching hybridization, keep in mind that only sp, sp^2, and sp^3 will be assessed; d orbital hybridization isn't addressed in the course. Time might also be spent teaching about the Bond Triangle to summarize the differences between metallic, ionic, and covalent bonding.

Students' responses to the Moodle assessments inform my decisions about any reteaching that may be necessary.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain the trends in properties and/or predict properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces. [LO 2.11, SP 6.2, SP 6.4] Describe the relationships between the structural features of polar molecules and the forces of attraction between the particles. [LO 2.13, SP 1.4, SP 6.4] Explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces. [LO 2.16, SP 6.2] Use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [LO 2.21, SP 1.4] Identify the noncovalent interactions within and between large molecules, and/or connect the shape and function of the large molecule to the presence and magnitude of these interactions. [LO 5.11, SP 7.2]	Zumdahl and Zumdahl, Chapter 10: "Liquids and Solids," Sections 10.1–10.2	**Instructional Activity:** After reviewing intermolecular forces (London dispersion, dipole-dipole, and hydrogen bonds) and intramolecular forces, students are presented with a series of unknown solutions. As a class, they then perform a full analysis of covalent molecules: Lewis structures, polar/nonpolar covalent bonds, VSEPR, polar/nonpolar molecules and how they lead to determining the intermolecular force between molecules. Students analyze the Coulombic attraction between molecules and justify how they translate to macroscopic properties of boiling point, solubility, volatility, etc.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain the trends in properties and/or predict properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces. [LO 2.11, SP 6.2, SP 6.4] Describe the relationships between the structural features of polar molecules and the forces of attraction between the particles. [LO 2.13, SP 1.4, SP 6.4] Use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [LO 2.21, SP 1.4]	Molecular model kits	**Formative Assessment:** Lewis Structures Activity Lab: Students generate models of molecules and polyatomic ions, draw Lewis dot structures, describe the molecular geometry, and predict their polarity using VSEPR theory. Students also predict the intermolecular forces between like molecules as well as other molecules within the list of molecules they will create using the molecule-building kit.

I walk around the room assessing students' models and confirming that they have correctly identified the molecular geometry and polarity in each case. If needed, I do on-the-spot reteaching and reviewing.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Design or evaluate a plan to collect and/or interpret data needed to deduce the type of bonding in a sample of a solid. [LO 2.22, SP 4.2, SP 6.4] Create a representation of a covalent solid that shows essential characteristics of the structure and interactions present in the substance. [LO 2.29, SP 1.1]	Zumdahl and Zumdahl, Chapter 10: "Liquids and Solids," Sections 10.5–10.6	**Instructional Activity:** Students watch a vodcast introducing them to the definitions of *covalent solid* and *molecular solid*, then work together as a class to draw and analyze the structural difference between covalent and molecular solids. Students draw representations of both and describe how the microscopic differences translate to macroscopic property differences in melting points, hardness, solubility, etc. As a review, students compare and contrast covalent solids and molecular solids with ionic solids and metals.
Explain a representation that connects properties of a covalent solid to its structural attributes and to the interactions present at the atomic level. [LO 2.30, SP 1.1, SP 6.2, SP 7.1] Create a representation of a molecular solid that shows essential characteristics of the structure and interactions present in the substance. [LO 2.31, SP 1.1] Explain a representation that connects properties of a molecular solid to its structural attributes and to the interactions present at the atomic level. [LO 2.32, SP 1.1, SP 6.2, SP 7.1] Make claims and/or predictions regarding relative magnitudes of the forces acting within collections of interacting molecules based on the distribution of electrons within the molecules and the types of intermolecular forces through which the molecules interact. [LO 5.9, SP 6.4]		**Formative Assessment:** Identifying Unknowns by Connecting Macroscopic Observations to Intermolecular Forces (guided-inquiry lab): Pre- and postlab questions focus on evaluating students' particulate-level reasoning pertaining to intermolecular forces by contrasting the characteristics of molecular and covalent solids and translating between particulate views and macroscopic characteristics. Some questions also focus on contrasting the differences between metal, ionic solids, molecular solids, and covalent solids. Students are expected to correctly identify the unknown solids in the lab and to justify their identifications with evidence from a series of tests performed to uncover macroscopic properties and identify intermolecular forces associated with the unknown substances.

Students' correct identification and justification with evidence of the unknown substances in the lab help me understand the level of proficiency they have gained with the associated learning objectives. Students who incorrectly identified the unknown substances will be given the correct identity and required to write an explanation of their incorrect identification and how to correct their misconceptions or errors.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Express the law of conservation of mass quantitatively and qualitatively using symbolic representations and particulate drawings. [LO 1.17, SP 1.5] Apply conservation of atoms to the rearrangement of atoms in various processes. [LO 1.18, SP 1.4] Translate among macroscopic observations of change, chemical equations, and particle views. [LO 3.1, SP 1.5, SP 7.1] Translate an observed chemical change into a balanced chemical equation and justify the choice of equation type (molecular, ionic, or net ionic) in terms of utility for the given circumstances. [LO 3.2, SP 1.5, SP 7.1]	Zumdahl and Zumdahl, Chapter 3: "Stoichiometry," Sections 3.6–3.7	**Instructional Activity:** Students are given a series of common reactions associated with general reaction types (synthesis, combustion, redox) and draw and write both a particle view and chemical symbol view of these chemical reactions. Students are required to apply the law of conservation of matter when writing balancing equations for these reactions and have to justify the best way to write the equation to accurately represent what's happening (molecular, ionic, and net ionic).
		Formative Assessment: After practicing the writing of chemical equations in the previous instructional activity, students are shown several reaction demonstrations, make observations, and write balanced chemical equations (using and justifying the most appropriate equation type) based on the observed demonstrations.

In the new curriculum, there is less emphasis on writing equations in isolation of the context of lab data associated with the reaction equation. Instead, equation writing will be emphasized within the context of problems. As with earlier units, I focus on strengthening students' mental models of particle views.

After each demonstration, I walk around the room and spot-check students' proficiency with translating macroscopic observations into chemical equations. I reteach and review as needed after each demonstration and equation-writing task.

Essential Questions: ▼ What models help us to understand the differences between ionic, covalent, and metallic bonding? ▼ How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Learning Objectives	Materials	Instructional Activities and Assessments
Evaluate the classification of a process as a physical change, chemical change, or ambiguous change based on both macroscopic observations and the distinction between rearrangement of covalent interactions and noncovalent interactions. [LO 3.10, SP 1.4, SP 6.1, *connects to* 5.D.2] Support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [LO 5.10, SP 5.1]		**Instructional Activity:** After reviewing the definitions of physical and chemical changes, students observe demonstrated chemical reactions and determine whether a chemical or physical change occurred. Students justify their identification of a change as physical or chemical by noting the change in intramolecular versus intermolecular interactions. Students also compare and contrast physical/chemical/nuclear reactions in terms of energy, conservation of mass, and identity of the atoms.
	Moodle	**Formative Assessment:** Students use the following Moodle workshop to practice the content and skills related to identifying and representing a process as a chemical or physical change through explanations and drawings of inter- and intramolecular forces: Workshop 3.13: Questions focus on students' ability to analyze interparticle relationships in physical and chemical changes. Students draw and explain the particle-level interactions to identify whether a change is chemical or physical. Students will peer-evaluate one another's responses based on a rubric.
		Summative Assessment: In this 55-minute assessment, students answer 20 multiple-choice questions using Edusoft and two free-response questions. The multiple-choice questions focus on conceptual questions regarding ionic, covalent, and metallic bonds. They also cover reactions and conservation of matter. The first free-response question focuses on Lewis structures, molecular shapes, polarity, and intermolecular forces. The second free-response question focuses on drawing and justifying the similarities and differences between the properties of ionic, metallic, and covalent solids. Students must be able to explain how the microscopic interparticle interactions lead to the macroscopic properties observed during chemical reactions.

The use of symbolic and particulate drawings to represent these differences will help students construct deeper understanding.

Students' evaluations of one another's work help strengthen their abilities to critically review their own responses. I review the students' responses and evaluations and reteach as necessary.

This assessment addresses the following essential questions:

- What models help us to understand the differences between ionic, covalent, and metallic bonding?
- How do we use Lewis diagrams and the VSEPR model to help predict the geometry, hybridization, polarity, and intermolecular forces of molecules?

Unit 4: Qualitative and Quantitative Chemistry: Counting Atoms and Molecules

Laboratory Investigations:

- Gravimetric Analysis *(guided inquiry)*
- Physical and Chemical Properties of a Substance *(guided inquiry)*
- Beer's Law
- Determining Molarity Using Titration
- Conductimetric Titration and Gravimetric Determination of a Precipitate *(guided inquiry)*
- Redox Titration *(guided inquiry)*

Estimated Time:

30 days

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Use data from mass spectrometry to identify the elements and the masses of individual atoms of a specific element. [LO 1.14, SP 1.4, SP 1.5]	Zumdahl and Zumdahl, Chapter 3: "Stoichiometry," Section 3.1	**Instructional Activity:** I introduce students to the instrumentation involved in mass spectrometry and the science behind it prior to engaging them in a whole-class discussion about identification of elements from mass spectrometer data. Students then analyze given mass spectrometry data and identify elements and the masses of individual atoms of a specific element in compounds.
Justify the observation that the ratio of the masses of the constituent elements in any pure sample of that compound is always identical on the basis of the atomic molecular theory. [LO 1.1, SP 6.1] Select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures. [LO 1.2, SP 2.2] Connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively. [LO 1.4, SP 7.1] Relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [LO 3.4, SP 2.2, SP 5.1, SP 6.4]	Zumdahl and Zumdahl, Chapter 3: "Stoichiometry," Sections 3.2–3.5 and 3.8–3.9	**Instructional Activity:** Students watch a vodcast introducing them to counting by mass or volume; the concepts behind molar mass, molar volume, and Avogadro's number; and the use of balanced chemical reactions to obtain stoichiometric ratios between compounds and elements. Students work in groups to practice calculating conversions between particles, volume, moles, and mass; evaluate scenarios with limiting reactants; perform calculations to identify the limiting reactant; and compute percent yield. The student groups compare their calculations and solutions with other groups as a method of peer review and informal formative assessment.

Each year, I have 10 to 15 first-year chemistry students who are not familiar with this skill, hence the focus here.

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Select and apply mathematical relationships to mass data in order to justify a claim regarding the identity and/or estimated purity of a substance. [LO 1.3, SP 2.2, SP 6.1] Use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [LO 3.3, SP 2.2, SP 5.1] Relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [LO 3.4, SP 2.2, SP 5.1, SP 6.4] Design a plan in order to collect data on the synthesis or decomposition of a compound to confirm the conservation of matter and the law of definite proportions. [LO 3.5, SP 2.1, SP 4.2, SP 6.4] Use data from synthesis or decomposition of a compound to confirm the conservation of matter and the law of definite proportions. [LO 3.6, SP 2.2, SP 6.1]	Bunsen burner, striker, test tube, test tube tongs, copper (II) sulfate pentahydrate	**Formative Assessment:** Gravimetric Analysis (guided-inquiry lab): As a class, students design the procedures to determine the data and associated calculations necessary to identify the formula for a hydrate. Once the students know what type of data should be collected, I teach them techniques that chemists use to collect data. Afterward, students write their final procedures. In the lab report conclusion, students include an error analysis to calculate the percent error, analyze the directional nature of the error, and identify the error in their procedure, justifying it with calculations.

The initial focus of the discussion is to determine the data necessary to solve this problem. I use Socratic dialogue to elicit ideas from students, such as asking, "What can we do to the hydrate to obtain the data?" Through the review of the lab report, I can determine the extent to which students have mastered stoichiometric calculations. Students who perform poorly on this lab report are required to redo the Moodle standards tasks that address these skills.

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion. [LO 3.4, SP 2.2, SP 5.1, SP 6.4]	Moodle	**Alternate Formative Assessment:** Students practice using the following Moodle assessments: • Standard 4.6 Stoichiometry: Students calculate stoichiometric conversions from moles, mass, volume, or number of particles of one substance into moles, mass, volume, or number of particles of another substance using the stoichiometric ratios. • Standard 4.7 Limiting Reactant: Students analyze data to determine the limiting reactants in given scenarios and calculate the products produced.

If students performed poorly on the gravimetric analysis lab, they are required to complete this formative assessment. I provide feedback to the students through the Moodle platform on their performance and suggest additional tutorials or workshops to strengthen student content knowledge and skills. My evaluation also helps me decide whether to review and reteach this content for the whole class or in small groups after school.

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Draw and/or interpret representations of solutions that show the interactions between the solute and solvent. [LO 2.8, SP 1.1, SP 1.2, SP 6.4] Create or interpret representations that link the concept of molarity with particle views of solutions. [LO 2.9, SP 1.1, SP 1.4] Apply Coulomb's Law qualitatively (including using representations) to describe the interactions of ions, and the attractions between ions and solvents to explain the factors that contribute to the solubility of ionic compounds. [LO 2.14, SP 1.4, SP 6.4] Explain observations regarding the solubility of ionic solids and molecules in water and other solvents on the basis of particle views that include intermolecular interactions and entropic effects. [LO 2.15, SP 1.4, SP 6.2, *connects to* 5.E.1] Support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [LO 5.10, SP 5.1]	Zumdahl and Zumdahl, Chapter 4: "Types of Chemical Reactions and Solution Stoichiometry," Sections 4.1–4.3, and Chapter 11: "Properties of Solutions," Sections 11.1–11.3	**Instructional Activity:** Using solubility data, chemical formulae, and molecular structure, students analyze the solubility of solvents and determine whether the solution creation for ionic compounds is a chemical or physical process. They justify their answers by providing particulate drawings of what happens when ionic solids dissolve. Students also determine whether solution creation for polar covalent compounds (such as sugar) is a physical or chemical process, justifying their responses by providing particulate drawings of what happens when covalent solids dissolve. Students also draw representations of solutions that relate to the molarity of the solute in the solvent.
		Formative Assessment: Students make three solutions and draw the particle/interparticle representations for each. Students explain the particle-level interactions in solutions and peer-evaluate one another's responses based on a rubric.

I provide on-the-spot reteaching and reviewing as I look at students' representations of the solutions and their explanations.

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Evaluate the classification of a process as a physical change, chemical change, or ambiguous change based on both macroscopic observations and the distinction between rearrangement of covalent interactions and noncovalent interactions. [LO 3.10, SP 1.4, SP 6.1, *connects to* 5.D.2] Support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [LO 5.10, SP 5.1]		**Instructional Activity:** Physical and Chemical Properties of a Substance (guided-inquiry lab): Students analyze a generic acetaminophen tablet's physical and chemical properties to determine the components and purity of the tablet. Based on possible combinations of substances within the tablet, students are guided in techniques chemists would use to identify components of the Quick Ache Relief substance that are associated with consumer complaints.
Design and/or interpret the results of an experiment regarding the absorption of light to determine the concentration of an absorbing species in a solution. [LO 1.16, SP 4.2, SP 5.1] Draw and/or interpret representations of solutions that show the interactions between the solute and solvent. [LO 2.8, SP 1.1, SP 1.2, SP 6.4] Create or interpret representations that link the concept of molarity with particle views of solutions. [LO 2.9, SP 1.1, SP 1.4]	Randall, Experiment 17: "Determining the Concentration of a Solution: Beer's Law"	**Instructional Activity:** Students gather data from an experiment in which they standardize a solution of known molarity using a colorimeter. From the data they obtain, they determine the concentration of a solution of unknown molarity. In the conclusion of the lab report, students must show the appropriate use of mathematical routine and organization of data to compute the concentration of the solution of unknown molarity. Students must also provide an explanation as to how light was used to collect such data and show the particulate representation of the solution interacting with light to associate with the data collected.

I have the students use the copper (II) sulfate from the gravimetric analysis lab to create the solution with unknown molarity. As an extra analysis, I have them calculate the amount of water that reattached to the copper (II) sulfate. I often need to remind the students to determine the mass of copper (II) sulfate · Xhydrate before they mix their solutions.

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [LO 2.2, SP 7.2, *connects to* Big Idea 5, Big Idea 6] Identify compounds as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, using proton-transfer reactions to justify the identification. [LO 3.7, SP 6.1]	Zumdahl and Zumdahl, Chapter 4: "Types of Chemical Reactions and Solution Stoichiometry," Section 4.8, and Chapter 14: "Acids and Bases," Section 14.1	**Instructional Activity:** Students analyze several acid-base reactions, using Brønsted-Lowry's definition to determine the acid, base, and the conjugate acid-base pairs. They justify their claims by analyzing the proton transfer within the reaction. Students then work in groups to develop an explanation as to the relative strengths of common acids and bases based on molecular structure and interparticle forces. Students also determine the pH of a given series of acid and base solutions and connect the pH to their explanations of the strength of an acid or a base.
	Moodle	**Formative Assessment:** Students will use the following Moodle assessments to practice the content and skills learned in preceding activities: • Standard 4.9 Acid Base ID: Students identify compounds as acids or bases using the Brønsted-Lowry definition. • Standard 4.10 Conjugate Acid-Base ID: Students identify the conjugate acid-base pairs in a neutralization acid-base reaction. • Standard 4.11 Acid-Base pH: Students calculate concentrations of H+ and OH- based on pH and determine the strength of the acid or base from the pH values.
Design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution. [LO 1.20, SP 4.2, SP 5.1, SP 6.4] Translate among macroscopic observations of change, chemical equations, and particle views. [LO 3.1, SP 1.5, SP 7.1]	Buret, buret clamp, ring stand, 250 mL Erlenmeyer flasks, KHP, 0.1 M NaOH, unknown molarity of HCl, funnel, 250 mL beakers Zumdahl and Zumdahl, Chapter 4: "Types of Chemical Reactions and Solution Stoichiometry," Section 4.8	**Instructional Activity:** Determining Molarity Using Titration (guided-inquiry lab): Students work in groups to determine a procedure to identify the molarity of an unknown monoprotic acid. Groups then report their procedures back to the whole class and engage in a discussion about designing the procedures to determine the data and associated calculations necessary to identify the molarity of a solution. Students implement their designed procedures to collect data and then ensure that they show appropriate data collection procedures and correct calculation of molarity of the unknown monoprotic acid.

Students' responses inform my decisions about any reteaching that may be necessary.

The initial focus of the discussion is on the information needed to calculate the molarity of the acid. I use Socratic dialogue to elicit ideas from students. Since moles of acid can't be obtained directly, I remind students about titration technique and how we can use it before they write their procedures.

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Design, and/or interpret data from, an experiment that uses gravimetric analysis to determine the concentration of an analyte in a solution. [LO 1.19, SP 4.2, SP 5.1, SP 6.4] Translate among macroscopic observations of change, chemical equations, and particle views. [LO 3.1, SP 1.5, SP 7.1]	Randall, Experiment 16: "Conductimetric Titration and Gravimetric Determination of a Precipitate"	**Instructional Activity:** Students review common precipitation reactions and watch a vodcast on making observations about precipitation reactions. Students collect data regarding the conductivity of ionic solutions prior to mixing them. They also collect conductivity data after the precipitation reaction occurs. The precipitate is also collected and the mass is measured. Student lab reports must include particulate-level drawings to represent the precipitation reaction and connecting the conductivity data to such representations.
Identify redox reactions and justify the identification in terms of electron transfer. [LO 3.8, SP 6.1]	Zumdahl and Zumdahl, Chapter 4: "Types of Chemical Reactions and Solution Stoichiometry," Sections 4.9–4.10	**Instructional Activity:** Students watch a vodcast introducing them to oxidation, reduction, and redox reactions prior to engaging in a whole-class discussion about analyzing compounds to determine the oxidation number of each element. Students then analyze redox reactions to determine which element or compounds are oxidized and reduced.
Select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures. [LO 1.2, SP 2.2] Translate among macroscopic observations of change, chemical equations, and particle views. [LO 3.1, SP 1.5, SP 7.1] Design and/or interpret the results of an experiment involving a redox titration. [LO 3.9, SP 4.2, SP 5.1]		**Formative Assessment:** Redox Titration (guided-inquiry lab): Students watch a vodcast about potassium permanganate as an oxidizer, then participate in a whole-class discussion about designing procedures to determine the data necessary to perform the calculations required to determine the formula of a hydrate. Students implement their designed procedures and then, in the conclusion of the lab report, provide the net ionic redox reaction occurring in the titration and provide the particulate-level view of what is happening during the titration. Students must also show the appropriate mathematical routine to use stoichiometry and data gathered during the titration to correctly identify the formula of the hydrate. Since moles of iron (II) sulfate can't be measured directly, I remind them about titration technique and how we can use it.

If students perform poorly on the lab report, they will be required to attend a small group review-and-reteach session to identify misconceptions and strengthen their understanding. They will then repeat the experiment using a different redox titration reaction.

Essential Questions: ▼ How do chemists use the law of conservation of mass to design lab experiments? ▼ How do chemists use stoichiometry to verify lab results? ▼ For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Learning Objectives	Materials	Instructional Activities and Assessments
Identify redox reactions and justify the identification in terms of electron transfer. [LO 3.8, SP 6.1]	Moodle	**Alternate Formative Assessment:** Students use the following Moodle assessments to practice the content and skills learned in preceding activities: • Standard 4.12 Oxidation Number ID: Students identify the oxidation number of the elements in a compound. • Standard 4.13 Oxidized/Reduced ID: Students identify the element or compound oxidized or reduced.
		Summative Assessment: In this 55-minute assessment, students answer 20 multiple-choice questions using Edusoft and two free-response questions. The multiple-choice section includes both conceptual and calculation questions regarding all topics covered in this unit. The first free-response question focuses on a mixture of the concepts and calculations of two of the labs. Students will be required to analyze error and justify their reasons for the directional nature of the error. The second free-response question focuses on drawing the particle nature of solutions. Students justify their analysis of the solubility of chosen molecules using drawings and Coulomb's Law.

Students who incorrectly determine the formula of a hydrate in the previous lab will have to perform this Moodle standards practices session and associated formative assessment and then repeat the lab using a different unknown hydrate.

This assessment addresses the following essential questions:
- How do chemists use the law of conservation of mass to design lab experiments?
- How do chemists use stoichiometry to verify lab results?
- For which situations is it best to use gravimetric analysis, spectroscopy, or titration in a lab setting?

Thermochemistry: Energy of Interacting Atoms and Molecules

Laboratory Investigations:

- **Determine the Molar Enthalpy of a Neutralization Reaction Between NaOH and HCl *(guided inquiry)***
- **Determine the Specific Heat of an Unknown Metal *(guided inquiry)***

Estimated Time:

20 days

Essential Questions: ▼ How does energy play a role in bonding, phase changes, and heat transfers? ▼ What models do chemists use to visualize particles in the solid, liquid, and gas phases?

Learning Objectives	Materials	Instructional Activities and Assessments
Create or use graphical representations in order to connect the dependence of potential energy to the distance between atoms and factors, such as bond order (for covalent interactions) and polarity (for intermolecular interactions), which influence the interaction strength. [LO 5.1, SP 1.1, SP 1.4, SP 7.2, *connects to* Big Idea 2] Draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds. [LO 5.8, SP 2.3, SP 7.1, SP 7.2]	Zumdahl and Zumdahl, Chapter 8: "Bonding: General Concepts," Sections 8.1, 8.5, and 8.8	**Instructional Activity:** Students analyze different potential energy diagrams and compare and contrast the different energies with bond order. Students also note how the shorter distances of higher bond orders increase the bond energy. They describe enthalpy changes as the difference in energy released when new bonds form in products and the difference in energy required to break the old bonds in the reactants. Students also practice calculations with heats of formation and bond energies prior to engaging in the calorimetry lab experience toward the end of this unit.
Use aspects of particulate models (i.e., particle spacing, motion, and forces of attraction) to reason about observed differences between solid and liquid phases and among solid and liquid materials. [LO 2.3, SP 6.4, SP 7.1] Make claims and/or predictions regarding relative magnitudes of the forces acting within collections of interacting molecules based on the distribution of electrons within the molecules and the types of intermolecular forces through which the molecules interact. [LO 5.9, SP 6.4] Support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [LO 5.10, SP 5.1]	**Web** "States of Matter"	**Instructional Activity:** Students analyze the PhET simulation, noting how solid, liquid, and gas phases differ in motion. Students then engage in a whole-class discussion, analyzing claims regarding relative magnitudes of the forces between particles of different phases. Students explain the energy necessary to overcome the forces of different phases and identify phase changes as physical changes. **Formative Assessment:** Students make additional observations about the PhET simulation pertaining to different phases and how the particles move differently in those phases. Students also draw conclusions regarding the macroscopic observations based on the microscopic analysis of the simulation.

Before having students analyze potential energy diagrams, I usually review covalent bonding and how to determine enthalpy for a reaction. We then engage in whole-class discussion about the potential energy diagrams for the bonding and calculate the enthalpy of a reaction by breaking and forming bonds.

Students' conclusions show me how well they understand the concepts and skills in the associated learning objectives. If students demonstrate a lack of understanding in this simulation, they will be required to attend a small-group review-and-reteach session to identify misconceptions and strengthen concept understanding.

Essential Questions: ▼ How does energy play a role in bonding, phase changes, and heat transfers? ▼ What models do chemists use to visualize particles in the solid, liquid, and gas phases?

Learning Objectives	Materials	Instructional Activities and Assessments
Use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors. [LO 2.4, SP 1.4, SP 6.4] Refine multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes in macroscopic properties on the sample. [LO 2.5, SP 1.3, SP 6.4, SP 7.2]	Zumdahl and Zumdahl, Chapter 5: "Gases," Sections 5.1–5.6 **Web** "Gas Properties"	**Instructional Activity:** Students alter variables such as concentration, temperature, and volume in the PhET simulation, noting the differences in how temperature, particle mass, and pressure affect gas behaviors and associated macroscopic properties. Students then engage in a whole-class discussion about the kinetic molecular theory. Students use the kinetic molecular theory to make predictions about the macroscopic properties of gases for both ideal and nonideal gases.
	Web "Gas Properties"	**Formative Assessment:** Students analyze multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes such as temperature, pressure, and volume in macroscopic properties of the gas. Students are also given macroscopic observations of gases and must draw associated particulate representations of such interactions (pertaining to intermolecular forces) between the gas molecules.
Apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [LO 2.6, SP 2.2, SP 2.3] Qualitatively analyze data regarding real gases to identify deviations from ideal behavior and relate these to molecular interactions. [LO 2.12, SP 5.1, SP 6.5, *connects to* 2.A.2] Use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work. [LO 5.6, SP 2.2, SP 2.3]	Zumdahl and Zumdahl, Chapter 5: "Gases," Sections 5.1–5.6, and Chapter 6: "Thermochemistry," Section 6.2	**Instructional Activity:** In small groups, students are given a series of problems requiring them to calculate macroscopic variables for ideal gases. They first analyze problems to determine which gas law to apply, then compare the gas law chosen and the mathematical routine used to come to the correct value of the variable within the problem. The assigned problems will require students to differentiate between ideal and nonideal gases and qualitatively analyze data to identify aspects of the microscopic interactions that result in the data shown.

During the assessment, I informally assess students' proficiency in accurately representing the particulate nature of matter with gases associated with observations. I provide assistance to students who are struggling with this activity.

I review the gas laws, combined gas law, and ideal gas law prior to students engaging in this activity.

Essential Questions: ▼ How does energy play a role in bonding, phase changes, and heat transfers? ▼ What models do chemists use to visualize particles in the solid, liquid, and gas phases?

Learning Objectives	Materials	Instructional Activities and Assessments
Apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [LO 2.6, SP 2.2, SP 2.3] Qualitatively analyze data regarding real gases to identify deviations from ideal behavior and relate these to molecular interactions. [LO 2.12, SP 5.1, SP 6.5, *connects to* 2.A.2] Use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work. [LO 5.6, SP 2.2, SP 2.3]	Moodle	**Formative Assessment:** Students use the following Moodle assessments to practice the content and skills learned in preceding activities: • Standard 5.6 Gas Laws: Students calculate for unknown variables using the appropriate gas laws. • Standard 5.7 Ideal Gas Law and Gas Stoichiometry: Students apply the Ideal gas law to solve problems requiring stoichiometry. • Standard 5.8 Pressure and Volume (PV) Diagrams: Students answer concept questions, solve problems analyzing the PV diagram of a gas, and calculate the work done.
Interpret observations regarding macroscopic energy changes associated with a reaction or process to generate a relevant symbolic and/or graphical representation of the energy changes. [LO 3.11, SP 1.5, SP 4.4] Generate explanations or make predictions about the transfer of thermal energy between systems based on this transfer being due to a kinetic energy transfer between systems arising from molecular collisions. [LO 5.3, SP 7.1] Use conservation of energy to relate the magnitudes of the energy changes occurring in two or more interacting systems, including identification of the systems, the type (heat versus work), or the direction of energy flow. [LO 5.4, SP 1.4, SP 2.2, *connects to* 5.B.1, 5.B.2]	Zumdahl and Zumdahl, Chapter 6: "Thermochemistry," Sections 6.1–6.2	**Instructional Activity:** Students analyze problems to determine which systems are exothermic and endothermic. In small groups, students then draw energy diagrams for the endothermic and exothermic reactions in the problems, including the activation energy. Students provide explanations with their diagrams to show how heat is transferred through microscopic interactions with collisions. Students also calculate the enthalpy change in the problems using standard enthalpy values and Hess's Law.

Students' responses inform my decisions about any reteaching that may be necessary.

Essential Questions: ▼ How does energy play a role in bonding, phase changes, and heat transfers? ▼ What models do chemists use to visualize particles in the solid, liquid, and gas phases?

Learning Objectives	Materials	Instructional Activities and Assessments
Use conservation of energy to relate the magnitudes of the energy changes when two nonreacting substances are mixed or brought into contact with one another. [LO 5.5, SP 2.2, *connects to* 5.B.1, 5.B.2] Use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work. [LO 5.6, SP 2.2, SP 2.3]	Zumdahl and Zumdahl, Chapter 10: "Liquids and Solids," Section 10.8	**Instructional Activity:** Students watch a vodcast introducing the heating and cooling curves of a pure substance and point out the constant temperature during phase changes. Students then engage in a whole-class discussion about heat of vaporization and fusion. Students analyze problems to determine which systems are exothermic and endothermic and calculate the energy released or absorbed using the heats of vaporization and fusion. Students use the law of conservation of matter for ice melting in water in conjunction with $q = mc\Delta T$.
Design and/or interpret the results of an experiment in which calorimetry is used to determine the change in enthalpy of a chemical process (heating/cooling, phase transition, or chemical reaction) at constant pressure. [LO 5.7, SP 4.2, SP 5.1, SP 6.4]	Calorimeter cups, 1 M NaOH, 1M HCl, beakers, thermometers Zumdahl and Zumdahl, Chapter 6: "Thermochemistry," Sections 6.3–6.4	**Formative Assessment:** Determine the Molar Enthalpy of a Neutralization Reaction Between NaOH and HCl (guided-inquiry lab): In small groups, students determine the data needed and the procedure to collect such data to calculate the molar enthalpy of the naturalization reaction between HCl and aqueous NaOH. Student group lab reports must include observations of the temperature of the system before and after the neutralization reaction occurs, calculations of the change in temperature for the system, and the appropriate use of the temperature change and heat capacities for the calorimeter and aqueous solution to calculate the molar enthalpy of neutralization.

If student lab reports do not represent proficient student understanding of calorimetry procedures and calculations for determining molar enthalpy, those students will be required to attend a small-group review-and-reteach session to identify misconceptions and strengthen concept understanding of molar enthalpy.

Essential Questions: ▼ How does energy play a role in bonding, phase changes, and heat transfers? ▼ What models do chemists use to visualize particles in the solid, liquid, and gas phases?

Learning Objectives	Materials	Instructional Activities and Assessments
Use conservation of energy to relate the magnitudes of the energy changes when two nonreacting substances are mixed or brought into contact with one another. [LO 5.5, SP 2.2, *connects to* 5.B.1, 5.B.2] Design and/or interpret the results of an experiment in which calorimetry is used to determine the change in enthalpy of a chemical process (heating/cooling, phase transition, or chemical reaction) at constant pressure. [LO 5.7, SP 4.2, SP 5.1, SP 6.4]	Beakers, boiling water bath, unknown metals (copper, aluminum, etc.), crucible tongs, calorimeter cups, thermometers Zumdahl and Zumdahl, Chapter 6: “Thermochemistry,” Sections 6.1–6.2	**Instructional Activity:** Determine the Specific Heat of an Unknown Metal (guided-inquiry lab): Student groups determine the data needed to identify the specific heat of an unknown metal and the procedure needed to collect such data. They also conduct research to identify the metal once the specific heat has been calculated for the unknown metal. Student lab reports must show the proper collection and organization of data as well as the use of the appropriate mathematical routine and error analysis to compute the specific heat and identify the unknown metal.
Use representations and models to predict the sign and relative magnitude of the entropy change associated with chemical or physical processes. [LO 5.12, SP 1.4] Predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both $\Delta H°$ and $\Delta S°$, and calculation or estimation of $\Delta G°$ when needed. [LO 5.13, SP 2.2, SP 2.3, SP 6.4, *connects to* 5.E.3] Determine whether a chemical or physical process is thermodynamically favorable by calculating the change in standard Gibbs free energy. [LO 5.14, SP 2.2, *connects to* 5.E.2]	Zumdahl and Zumdahl, Chapter 16: “Spontaneity, Entropy, and Free Energy,” Sections 16.1–16.5, 16.4, and 16.6–16.9	**Instructional Activity:** Prior to engaging in this activity, students watch a vodcast defining entropy and enthalpy as well as the sign for the change in entropy and enthalpy and their connections to determining the thermodynamic favorability of a process. Students are then given a series of observations pertaining to physical or chemical reactions and look qualitatively at chemical and physical changes to determine the sign of the changes in enthalpy and entropy. Using these qualitative assessments, students should be able to make predictions about thermodynamic favorability of the processes.

Essential Questions: ▼ How does energy play a role in bonding, phase changes, and heat transfers? ▼ What models do chemists use to visualize particles in the solid, liquid, and gas phases?

Learning Objectives	Materials	Instructional Activities and Assessments
		Summative Assessment: In this 55-minute assessment, students answer 20 multiple-choice questions and two free-response questions. The multiple-choice section includes both conceptual and calculation questions regarding all topics covered in this unit. The first free-response question focuses on students' ability to calculate ΔH from either lab data, standard enthalpy values, or bond energies. Students calculate ΔS and estimate the sign of ΔG at a given temperature. The analysis focuses on determining whether a reaction is thermodynamically favored. The second free-response question requires students to draw the particle nature of gases and liquids and describe the differences in energy and interparticle forces. Students calculate the amount of water vapor produced from the combustion as well as the energy released when the water condenses back to a liquid.

This assessment addresses the following essential questions:

- How does energy play a role in bonding, phase changes, and heat transfers?
- What models do chemists use to visualize particles in the solid, liquid, and gas phases?

Kinetics: Factors That Affect Reaction Rates

Laboratory Investigations:

- Identifying Factors That Affect the Rate of Reaction *(guided inquiry)*
- Determining the Rate Law of the Reaction Between Crystal Violet with Sodium Hydroxide *(guided inquiry)*

Estimated Time:

13 days

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect reaction rates? ▼ How do we analyze rate law data to determine the order of a reaction? ▼ How do energy and statistics play a part in the rate of a reaction?

Learning Objectives	Materials	Instructional Activities and Assessments
Explain the difference between collisions that convert reactants to products and those that do not in terms of energy distributions and molecular orientation. [LO 4.5, SP 6.2] Use representations of the energy profile for an elementary reaction (from the reactants, through the transition state, to the products) to make qualitative predictions regarding the relative temperature dependence of the reaction rate. [LO 4.6, SP 1.4, SP 6.4] Relate temperature to the motions of particles, either via particulate representations, such as drawings of particles with arrows indicating velocities, and/or via representations of average kinetic energy and distribution of kinetic energies of the particles, such as plots of the Maxwell-Boltzmann distribution. [LO 5.2, SP 1.1, SP 1.4, SP 7.1]	Zumdahl and Zumdahl, Chapter 12: "Chemical Kinetics," Sections 12.7–12.8 **Web** "Reactions & Rates"	**Instructional Activity:** Students watch a vodcast that explains the factors that affect the rate of a reaction and helps students visualize the collision model for chemical reactions pertaining to molecules requiring sufficient energy and proper orientation for effective collisions. Students view the "Reactions & Rates" simulation in class and draw representations of the energy profile of an elementary reaction. Students use the Maxwell-Boltzmann distributions, energy diagrams, and particulate representations to justify how the rate of reaction increases when the temperature is increased.
		Formative Assessment: Working in groups, students answer multiple-choice questions regarding the factors that affect reaction rates. They justify their responses with evidence from macroscopic observations and particulate-level drawings. Students are given free-response questions on interpreting energy profile diagrams and particulate representations and justifying their interpretation of the diagrams.
Translate among reaction energy profile representations, particulate representations, and symbolic representations (chemical equations) of a chemical reaction occurring in the presence and absence of a catalyst. [LO 4.8, SP 1.5] Explain changes in reaction rates arising from the use of acid-base catalysts, surface catalysts, or enzyme catalysts, including selecting appropriate mechanisms with or without the catalyst present. [LO 4.9, SP 6.2, SP 7.2]		**Instructional Activity:** Students are given energy profiles of reactions that use a catalyst and reactions that do not use a catalyst. They generate an explanation about what a catalyst actually does to the reaction rate. Students are given macroscopic observations of reactions using and not using a catalyst of various types (acid-base, surface, and enzyme). They draw energy profile representations for the noncatalyzed and catalyzed reactions before and after a catalyst is added. Students compare and contrast the mechanism by which different catalysts lower the activation energy of the reaction.

The PhET simulation is used in both the vodcast and in class. The goal is to help students visualize the collision model both in a static and an animated view.

Student groups share their answers with the class and peer-evaluate one another's responses in a whole-group discussion. If the entire class got a problem wrong, I will reteach and review.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect reaction rates? ▼ How do we analyze rate law data to determine the order of a reaction? ▼ How do energy and statistics play a part in the rate of a reaction?

Learning Objectives	Materials	Instructional Activities and Assessments
The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction. [LO 4.1, SP 4.2, SP 5.1]		**Instructional Activity:** Identifying Factors That Affect the Rate of Reaction (guided-inquiry lab): Students watch a vodcast that defines rate of reaction and introduces them to the technique to calculate the rate of reaction. As a class, they decide how to collect the data necessary for a particular reaction to graph the relationship between time and volume of CO_2 produced. Using the graphs students generate from their collected data, they calculate the rate of production of CO_2 for their chosen variables (temperature, concentration, or surface area).
Analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. [LO 4.2, SP 5.1, SP 6.4, *connects to* 4.A.3] Connect the half-life of a reaction to the rate constant of a first-order reaction, and justify the use of this relation in terms of the reaction being a first-order reaction. [LO 4.3, SP 2.1, SP 2.2] Connect the rate law for an elementary reaction to the frequency and success of molecular collisions, including connecting the frequency and success to the order and rate constant, respectively. [LO 4.4, SP 7.1, *connects to* 4.A.3, 4.B.2]	Zumdahl and Zumdahl, Chapter 12: "Chemical Kinetics," Sections 12.1–12.5	**Instructional Activity:** Students analyze graphs to determine the order of chemical reaction when concentration is graphed versus time and calculate the rate constant or the rate from data. Students are also given problems that ask them to calculate the half-life of a reaction from the rate constant and from data. Students derive the integrated rate law from concentration versus time data.
Analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. [LO 4.2, SP 5.1, SP 6.4, *connects to* 4.A.3]	Zumdahl and Zumdahl, Chapter 12: "Chemical Kinetics," Sections 12.1–12.5	**Formative Assessment:** Determining the Rate Law of the Reaction Between Crystal Violet with Sodium Hydroxide (guided-inquiry lab): As a class, students design the procedures they need to collect the concentration versus time data. (They may need to be reminded of Beer's law and how to use a colorimeter.) Students collect data from three trials to eliminate error. In each trial, they analyze the data and determine whether the rate law is zero, first, or second order.

The initial focus of the discussion is on the data necessary to solve the problem: How do we calculate the rate of a reaction? I lead a Socratic dialogue to elicit ideas from students. Once the data are known, I teach them techniques that chemists use to collect data needed to graph the relationship between the volume of CO_2 and time.

If student lab reports reveal miscalculations, inappropriate choice of mathematical routines, or misidentification of the rate law, students will be required to attend a small-group review-and-reteach session to identify misconceptions and strengthen concept understanding.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect reaction rates? ▼ How do we analyze rate law data to determine the order of a reaction? ▼ How do energy and statistics play a part in the rate of a reaction?

Learning Objectives	Materials	Instructional Activities and Assessments
Evaluate alternative explanations, as expressed by reaction mechanisms, to determine which are consistent with data regarding the overall rate of a reaction, and data that can be used to infer the presence of a reaction intermediate. [LO 4.7, SP 6.5, *connects to* 4.C.1, 4.C.2, 4.C.3]	Zumdahl and Zumdahl, Chapter 12: "Chemical Kinetics," Section 12.6 **Web** "Mechanisms of a Chemical Reaction"	**Instructional Activity:** Students use the "Mechanisms of a Chemical Reaction" simulation, choose Mechanism A, and select the "enable reactions" button to display molecular-level interactions and formations of reaction intermediates in a mechanism. Students then engage in a whole-class discussion about the analysis of reaction mechanisms. I show students how to derive the order of a reaction from the reaction mechanism and how to identify the reaction intermediate, evaluate the rate law, and ensure that it is consistent with the overall rate of a reaction. Students solve a series of problems involving reaction-rate data, rate law, or stepwise equations to identify the mechanism, the rate law, or the order.
	Moodle	**Formative Assessment:** Students use the following Moodle assessment to practice the content and skills learned in preceding activities: Standard 6.7 Rate Mechanisms: Students evaluate the reaction mechanism, determine the overall rate of the reaction, and ensure it is consistent with the overall data.
		Summative Assessment: In this 55-minute summative assessment, students answer two free-response questions that focus on their ability to evaluate data and determine the rate law for an elementary reaction. Students calculate rate constant from given data and analyze a concentration versus time graph. They determine the order of the reaction and calculate the average rate of a reaction for a given time period. A graph of the energy profile of the graph will be given, and students will calculate the enthalpy change.

Students' responses inform my decisions about any reteaching that may be necessary.

This assessment addresses all the essential questions in this unit:
- What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect reaction rates?
- How do we analyze rate law data to determine the order of a reaction?
- How do energy and statistics play a part in the rate of a reaction?

Equilibrium: Application of Kinetics

Laboratory Investigations:

- Determining the Factors That Will Cause a Shift in an Equilibrium Reaction *(guided inquiry)*
- Connecting the Structure of an Acid or Base to the Resulting pH of the Solution *(guided inquiry)*
- Designing and Testing Effective Buffers *(guided inquiry)*

Estimated Time:

30 days

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions. [LO 6.3, SP 7.2] Use Le Chatelier's principle to predict the direction of the shift resulting from various possible stresses on a system at chemical equilibrium. [LO 6.8, SP 1.4, SP 6.4] Connect Le Chatelier's principle to the comparison of *Q* to *K* by explaining the effects of the stress on *Q* and *K*. [LO 6.10, SP 1.4, SP 7.2]	Zumdahl and Zumdahl, Chapter 13: "Chemical Equilibrium," Sections 13.1 and 13.7	**Instructional Activity:** Each student group writes a general statement of how the concepts of rates of reaction connect to the concepts of equilibrium. Groups share their statements and then refine them after viewing a reaction that is stressed back and forth, yielding observable results of the reaction producing reactants and then yielding products as a result of the stress. Students are shown a different reaction and qualitatively predict the direction of the shift using Le Chatelier's principle. As a class, we discuss connecting kinetics to equilibrium as the reasoning in Le Chatelier's principle and infer the relative rates of the forward and reverse reactions.
Use Le Chatelier's principle to design a set of conditions that will optimize a desired outcome, such as product yield. [LO 6.9, SP 4.2]	Solution with $[Co(H_2O)_6]^{2+}(aq) + 4Cl^{-}(aq) \rightarrow [CoCl_4]^{2-}(aq) + 6\,H_2O(l)$ all in equilibrium, water baths (hot and cold), ethanol, 6 M HCl, 1 M $AgNO_3$, distilled water, test tubes, test tube racks	**Formative Assessment:** Determining the Factors That Will Cause a Shift in an Equilibrium Reaction (guided-inquiry lab): Students design a set of procedures to test and observe Le Chatelier's principle. Using the list of equipment, students create procedures and make predictions of the direction the reaction will shift, based on stresses they design for the reaction.
Given a set of experimental observations regarding physical, chemical, biological, or environmental processes that are reversible, construct an explanation that connects the observations to the reversibility of the underlying chemical reactions or processes. [LO 6.1, SP 6.2] Given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, *K*. [LO 6.5, SP 2.2]	Zumdahl and Zumdahl: Chapter 13, "Chemical Equilibrium," Sections 13.3–13.4	**Instructional Activity:** Given gas-based equilibrium reactions, students predict the effects of changes in temperature and pressure on the collision of gases of the forward and reverse reactions. Students then apply the same concepts to solutions and predict how temperature and concentration affect collision of the particles in the solution and the kinetics of the forward and reverse reactions. Upon completing this set of predictions, students write equilibrium expressions from balanced chemical reactions and calculate the equilibrium constant (*K*) for gas-based and solution-based equilibrium reactions.

Prior to engaging in this activity, students will watch a vodcast introducing them to reversible chemical reactions, the idea of dynamic equilibrium, and Le Chatelier's principle. They then engage in a whole-class discussion, comparing reactions that go to completion with chemical reactions that are in dynamic equilibrium.

Student lab reports must correctly indicate the factors that affect the direction of the reaction as well as indicate proper lab procedure and recording of observations. If students perform poorly on the lab report, they will be given a short reteach-and-review session and then conduct the lab again, using a different reaction.

I will review with students the difference between K_{sp}, K_p, and K prior to engaging in this activity.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Given a set of experimental observations regarding physical, chemical, biological, or environmental processes that are reversible, construct an explanation that connects the observations to the reversibility of the underlying chemical reactions or processes. [LO 6.1, SP 6.2] Connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions. [LO 6.3, SP 7.2]	Moodle	**Formative Assessment:** Students use the following Moodle assessments and workshop to practice the content and skills learned in preceding activities: • Standard 7.3 Equilibrium Constant Expressions: Students write equilibrium constant expressions from balanced chemical reactions. • Standard 7.4 Calculate Equilibrium Constants: Students calculate equilibrium constant expressions from equilibrium concentration and pressure values. • Workshop 7.5: Questions focus on students' ability to explain the concept of equilibrium from a set of experimental observations regarding physical, chemical, biological, or environmental processes.
Given a manipulation of a chemical reaction or set of reactions (e.g., reversal of reaction or addition of two reactions), determine the effects of that manipulation on *Q* or *K*. [LO 6.2, SP 2.2] Given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, *K*, use the tendency of *Q* to approach *K* to predict and justify the prediction as to whether the reaction will proceed toward products or reactants as equilibrium is approached. [LO 6.4, SP 2.2, SP 6.4] For a reversible reaction that has a large or small *K*, determine which chemical species will have very large versus very small concentrations at equilibrium. [LO 6.7, SP 2.2, SP 2.3]	Zumdahl and Zumdahl, Chapter 13: "Chemical Equilibrium," Sections 13.1–13.5	**Instructional Activity:** After reviewing how the reaction quotient, *Q*, differs from but is connected to *K*, students analyze a set of reactions with initial concentrations, calculating *Q* and justifying the prediction as to whether the reaction will proceed toward products or reactants as equilibrium is approached. Students compare reactions that go to completion with chemical reactions that are in dynamic equilibrium. Students also analyze scenarios where *K* is either very large or very small to determine which chemical species will have very large or very small concentrations at equilibrium.

Students' responses inform my decisions about any reteaching that may be necessary.

LO 6.2 focuses on changing pressures and concentrations so students have a mathematical basis for understanding shifts in K *and* Q.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, *K*, use stoichiometric relationships and the law of mass action (*Q* equals *K* at equilibrium) to determine qualitatively and/or quantitatively the conditions at equilibrium for a system involving a single reversible reaction. [LO 6.6, SP 2.2, SP 6.4]	Zumdahl and Zumdahl, Chapter 13: "Chemical Equilibrium," Sections 13.5–13.6	**Instructional Activity:** Students work in groups to develop a way to organize initial concentration, change in concentration, and final concentration of species in a chemical reaction to calculate *Q* and *K* in order to make predictions. After groups share their results, I show students how to develop and use an ICE table. Students use the ICE tables in a set of problems to analyze initial conditions (concentrations and partial pressure) and use *K* to calculate the concentrations or partial pressures when equilibrium is established. Students also use stoichiometric relationships in the ICE tables to account for the unknown variables in the reaction problems.
		Formative Assessment: Students are given a set of problems that require them to use initial conditions, *K*, and stoichiometric relationships to calculate the concentrations of both products and reactants at equilibrium.
Express the equilibrium constant in terms of $\Delta G°$ and *RT* and use this relationship to estimate the magnitude of *K* and, consequently, the thermodynamic favorability of the process. [LO 6.25, SP 2.3] Explain how the application of external energy sources or the coupling of favorable with unfavorable reactions can be used to cause processes that are not thermodynamically favorable to become favorable. [LO 5.15, SP 6.2] Explain why a thermodynamically favored chemical reaction may not produce large amounts of product (based on consideration of both initial conditions and kinetic effects), or why a thermodynamically unfavored chemical reaction can produce large amounts of product for certain sets of initial conditions. [LO 5.18, SP 1.3, SP 7.2, *connects to* 6.D.1]	Zumdahl and Zumdahl, Chapter 16: "Spontaneity, Entropy, and Free Energy," Sections 16.8–16.9	**Instructional Activity:** Students watch a vodcast that introduces them to the formula $\Delta G° = RTlnK$ and to the concept of natural log. As a class, they use the formula to estimate the magnitude of *K*. Students spend time deriving the algebraic steps to solve for *K*. By analyzing $\Delta G°$, students determine whether the reaction is thermodynamically favorable or not. Students explain why the thermodynamically favorable or nonfavorable reaction affects the amounts of products produced and how adding or removing heat can cause an unfavorable reaction to become favorable.

Students peer-review one another's papers and use of the ICE table to solve the problems, then report back to the whole group the common mistakes they find. I reteach and review to address such common mistakes.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Use Le Chatelier's principle to make qualitative predictions for systems in which coupled reactions that share a common intermediate drive formation of a product. [LO 5.16, SP 6.4, *connects to* 6.B.1] Make quantitative predictions for systems involving coupled reactions that share a common intermediate, based on the equilibrium constant for the combined reaction. [LO 5.17, SP 6.4, *connects to* 6.A.2]	Moodle	**Formative Assessment:** Students use the following Moodle assessment and workshop to practice the content and skills learned in preceding activities: • Standard 7.13 Coupled Reactions: Students calculate K values from the coupling of two reactions with common intermediates. Students then calculate $\Delta G°$ using $\Delta G° = RT\ln K$ to determine whether a reaction is thermodynamically favored or not favored. • Workshop 7.14: Questions focus on students' ability to couple reactions with common intermediates and use Le Chatelier's principle to predict the shift in the coupled reaction.
		Summative Assessment: In this 30-minute assessment, students answer 10 multiple-choice questions using Edusoft and one free-response question. The multiple-choice questions focus on basics of equilibrium and kinetics. The free-response question focuses on students' ability to calculate both K and Q, compare and contrast the two, and determine in which direction a reaction will shift.
Predict the solubility of a salt, or rank the solubility of salts, given the relevant K_{sp} values. [LO 6.21, SP 2.2, SP 2.3, SP 6.4] Interpret data regarding solubility of salts to determine, or rank, the relevant K_{sp} values. [LO 6.22, SP 2.2, SP 2.3, SP 6.4] Interpret data regarding the relative solubility of salts in terms of factors (common ions, pH) that influence the solubility. [LO 6.23, SP 5.1, SP 6.4] Analyze the enthalpic and entropic changes associated with the dissolution of a salt, using particulate level interactions and representations. [LO 6.24, SP 1.4, SP 7.1, *connects to* 5.E]	Zumdahl and Zumdahl, Chapter 15: "Applications of Aqueous Equilibria," Sections 15.6–15.7	**Instructional Activity:** Given K_{sp} values for a variety of salts, students interpret data to rank the solubility of the salts based on their K_{sp} values. Conversely, students interpret data of the relative solubility of salts and then calculate K_{sp} values according to data given associated with such salts. The lesson also focuses on why solids do not impact equilibrium and on how to identify the enthalpic and entropic changes involved in the dissolution of a salt. **Formative Assessment:** Students calculate K_{sp} values from solubility concentrations and rank the solubility from K_{sp} values. Students also apply ICE tables and stoichiometric ratios to calculate concentrations at equilibrium. Students analyze solutions with different factors such as common ions and pH and explain with justification how they affect the solubility of a solution.

Students' responses inform my decisions about any reteaching that may be necessary.

This assessment addresses the essential question, What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions?

I review the different K *values in equilibrium with the students prior to this activity.*

Students' responses inform my decisions about any reteaching that may be necessary.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Generate or use a particulate representation of an acid (strong or weak or polyprotic) and a strong base to explain the species that will have large versus small concentrations at equilibrium. [LO 6.11, SP 1.1, SP 1.4, SP 2.3] Reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration. [LO 6.12, SP 1.4, SP 6.4, *connects to* 1.E.2] Based on the dependence of K_w on temperature, reason that neutrality requires [H+] = $[OH^-]$ as opposed to requiring pH = 7, including especially the applications to biological systems. [LO 6.14, SP 2.2, SP 6.2]		**Instructional Activity:** Students practice drawing particulate representations of specific concentrations of strong and weak acids and bases in solution. Such drawings should represent percent ionization as well as concentration and interaction with water. Students then work in groups on an assigned concentration of an acid and base and use $[H^+]$ and $[OH^-]$ to explain pH and calculate the amount of assigned base needed to reach the equivalence point in a titration with the assigned acid. Students share their results with the class.

Prior to this activity, I review with students K_w and how neutrality is based on $[H^+]$ = [OH] as opposed to requiring pH = 7.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Generate or use a particulate representation of an acid (strong or weak or polyprotic) and a strong base to explain the species that will have large versus small concentrations at equilibrium. [LO 6.11, SP 1.1, SP 1.4, SP 2.3] Reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration. [LO 6.12, SP 1.4, SP 6.4, *connects to* 1.E.2] Identify a given solution as containing a mixture of strong acids and/or bases and calculate or estimate the pH (and concentrations of all chemical species) in the resulting solution. [LO 6.15, SP 2.2, SP 2.3, SP 6.4] Relate the predominant form of a chemical species involving a labile proton (i.e., protonated/deprotonated form of a weak acid) to the pH of a solution and the pK_a associated with the labile proton. [LO 6.19, SP 2.3, SP 5.1, SP 6.4]	Zumdahl and Zumdahl, Chapter 14: "Acids and Bases," Sections 14.1–14.6, and Chapter 15: "Applications of Aqueous Equilibria," Sections 15.4–15.5	**Instructional Activity:** Students watch a vodcast that introduces them to acid-base equilibrium prior to drawing a particulate representation of strong or weak or polyprotic acids and strong bases. Students then engage in a whole-class discussion to develop an explanation about the main difference between strong and weak acids and bases and calculate pH and percent ionizations for weak acids. Students use ICE tables and stoichiometric ratios to calculate concentrations needed to achieve a specific pH or the equivalence point.

Essential Question: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Generate or use a particulate representation of an acid (strong or weak or polyprotic) and a strong base to explain the species that will have large versus small concentrations at equilibrium. [LO 6.11, SP 1.1, SP 1.4, SP 2.3] Reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration. [LO 6.12, SP 1.4, SP 6.4, *connects to* 1.E.2] Identify a given solution as containing a mixture of strong acids and/or bases and calculate or estimate the pH (and concentrations of all chemical species) in the resulting solution. [LO 6.15, SP 2.2, SP 2.3, SP 6.4] Identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base), calculate the pH and concentration of all species in the solution and/or infer the relative strengths of the weak acids or bases from given equilibrium concentrations. [LO 6.16, SP 2.2, SP 6.4] Given an arbitrary mixture of weak and strong acids and bases (including polyprotic systems), determine which species will react strongly with one another (i.e., with K>1), and what species will be present in large concentrations at equilibrium. [LO 6.17, SP 6.4]		**Formative Assessment:** Students analyze particulate representations with data of acids with bases and determine which will have large versus small concentrations at equilibrium. Students justify their analyses with calculations.

Students peer-review one another's analyses and calculations and then, as a class, identify common mistakes and misconceptions. I reteach and review at this time to address such mistakes.

Essential Questions: ▼ What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions? ▼ What are some real-life applications of buffer systems? ▼ How does the ocean act as a buffer?

Learning Objectives	Materials	Instructional Activities and Assessments
Interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the pK_a for a weak acid, or the pK_b for a weak base. [LO 6.13, SP 5.1, SP 6.4, *connects to* 1.E.2]		**Instructional Activity:** Connecting the Structure of an Acid or Base to the Resulting pH of the Solution (guided-inquiry lab): Students design a procedure to solve a question of their choosing about how the structure of an acid or base affects the pH and mechanism of the neutralization reaction during a titration. Students draw models of how the atoms in the reaction are rearranged during different parts of the titration and connect such models to their developed titration curves. They draw Lewis structures of the acids to analyze acid strength and explain the choice of equations to use to solve for an unknown molarity during a titration, the pH, and K_a of the acid.
Design a buffer solution with a target pH and buffer capacity by selecting an appropriate conjugate acid-base pair and estimating the concentrations needed to achieve the desired capacity. [LO 6.18, SP 2.3, SP 4.2, SP 6.4] Identify a solution as being a buffer solution, and explain the buffer mechanism in terms of the reactions that would occur on addition of acid or base. [LO 6.20, SP 6.4]	Zumdahl and Zumdahl, Chapter 15: "Applications of Aqueous Equilibria," Sections 15.1–15.5	**Formative Assessment:** Designing and Testing Effective Buffers (guided-inquiry lab): Students (in groups) prepare a specific buffer, titrate the buffer, and use a pH meter to analyze the buffer capacity of the buffer. Students then verify mathematically the buffer capacity and compare it to the given design specifications.
		Summative Assessment: In this 55-minute assessment, students answer 15 multiple-choice questions and two free-response questions. The multiple-choice section includes both conceptual and calculation questions regarding all topics covered in this unit. The first free-response question addresses students' ability to evaluate data and determine the Q and K_{sp} value at equilibrium. Students generate particulate views of a solution and explain with justification how temperature, pressure, or common ions will affect the shift in equilibrium. The second free-response question requires students to analyze a pH graph for a titration of a strong base with a polyprotic acid. Students determine the number of H^+ ions attached to the anion from the data and calculate the pH and pK_a values for each equilibrium point.

Students who do not correctly design their assigned buffer will be required to participate in a short review-and-reteach session and then choose a different buffer to design and perform the lab again.

This assessment addresses the following essential questions:
- What happens at the microscopic level that helps us understand that concentration, temperature, surface area, and catalysts affect rates of reactions?
- What are some real-life applications of buffer systems?
- How does the ocean act as a buffer?

Laboratory Investigations:

- Which Combination of Half-Cells Creates the Greatest Positive Voltage? *(guided inquiry)*

Estimated Time: *10 days*

Essential Question:

- What is the chemistry involved in making electrical current from batteries?

Learning Objectives	Materials	Instructional Activities and Assessments
Identify redox reactions and justify the identification in terms of electron transfer. [LO 3.8, SP 6.1]	Zumdahl and Zumdahl, Chapter 4: "Types of Chemical Reactions and Solution Stoichiometry," Sections 4.9–4.10	**Instructional Activity:** Working in small groups, students generate a statement of how redox reactions differ or are similar to other chemical reactions such as synthesis, combustion, and acid-base. Student groups determine criteria for identifying a reaction as a redox reaction, and the groups then report back to the whole class to agree on such criteria. Students are given a series of four redox reactions for which they identify the element that is reduced or oxidized by analyzing the oxidation states of each element. Students are given a list of reactions and must identify whether each reaction is or is not a redox reaction. Students justify their answers by identifying the transfer of electrons from the oxidized element to the reduced element.
Translate among macroscopic observations of change, chemical equations, and particle views. [LO 3.1, SP 1.5, SP 7.1] Make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws. [LO 3.12, SP 2.2, SP 2.3, SP 6.4] Analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions. [LO 3.13, SP 5.1]	Zumdahl and Zumdahl, Chapter 17: "Electrochemistry," Sections 17.1–17.8	**Instructional Activity:** Students research ways redox reactions are used to create electricity, the common types of redox reactions, and household equipment or products that we use with such reactions. Students share their findings. I teach students to draw and analyze galvanic cells, labeling the anode and cathode, and displaying the flow of electrons from the redox reaction. Students then choose a reaction they researched, write the associated half reactions, and combine them into a redox reaction. They calculate cell potential using standard potentials from the combination of half-cells. From current readings and other lab data, students use Faraday's law and constants to calculate mass or electrons transferred from stoichiometric ratios. Students also calculate $\Delta G°$ from the equation $\Delta G° = nFE°$ to determine whether the reaction is thermodynamically favored.

Essential Question:

- What is the chemistry involved in making electrical current from batteries?

Learning Objectives	Materials	Instructional Activities and Assessments
Make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws. [LO 3.12, SP 2.2, SP 2.3, SP 6.4] Analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions. [LO 3.13, SP 5.1]	Metals (iron, copper, zinc, and lead), salt bridge, test tubes, alligator clips, voltmeter, 1 M solutions of the following: $Fe(NO_3)_3$, $Cu(NO_3)_2$, $Zn(NO_3)_2$, and $Pb(NO_3)_2$	**Formative Assessment:** Which Combination of Half-Cells Creates the Greatest Positive Voltage? (guided-inquiry lab): Students design at least three galvanic cells from the half cells that can be created from the list of equipment. Students measure the voltage for each galvanic cell and analyze why the values of the standard potential do not match the predicted values.
		Summative Assessment: In this 35-minute assessment, students answer 15 multiple-choice questions using Edusoft and one free-response question. The multiple-choice section focuses on both conceptual and calculation questions regarding all topics covered in this unit, and at least five multiple-choice questions will focus on past units. The free-response question will focus on students' ability to draw a galvanic cell and label the parts of the cell and the flow of electrons. Students also calculate the standard potential. The second part of the problem uses Faraday's constant for a circuit and asks students to calculate the change in mass in the electrodes.

Students who cannot accurately depict the galvanic cell and calculate the predicted voltage and associated net ionic equation with each cell will participate in a short reteach-and-review session and then perform this lab again with three different galvanic cells.

This assessment addresses the essential question, What is the chemistry involved in making electrical current from batteries?

Resources

General Resources

Textbook

Zumdahl, Steven S., and Susan A. Zumdahl. *Chemistry*. 7th ed. Boston: Houghton Mifflin, 2007.

Demonstration Manuals

Bilash, Borislaw, II, George R. Gross, and John K. Koob. *A Demo a Day: A Year of Chemical Demonstrations*. 2nd ed. Batavia, IL: Flinn Scientific, 2006.

Bilash, Borislaw, II, George R. Gross, and John K. Koob. *A Demo a Day Volume 2: Another Year of Chemical Demonstrations*. Batavia, IL: Flinn Scientific, 1998.

Laboratory Manuals

Randall, Jack. *Advanced Chemistry with Vernier*. Beaverton, OR: Vernier Software & Technology, 2004.

Vonderbrink, Sally Ann. *Laboratory Experiments for Advanced Placement Chemistry*. Batavia, IL: Flinn Scientific, 2001.

Online Resources

"AP Chemistry Course Home Page." AP Central®. The College Board. Accessed October 16, 2012. http://apcentral.collegeboard.com/apc/public/courses/teachers_corner/2119.html.

Edusoft. Accessed October 16, 2012. http://edusoft.com/login.jsp.

"Interactive Simulations." PhET. University of Colorado at Boulder. Accessed October 16, 2012. http://phet.colorado.edu.

Moodle. Accessed October 16, 2012. https://moodle.org/.

ShowMe. iPad app. Accessed October 15, 2012. http://www.showme.com/.

Supplementary Resources

"A Level Introduction to Mass Spectrometry." Doc Brown's Chemistry Online. Accessed October 16, 2012. http://www.docbrown.info/page04/4_71atomMSintro.htm.

Cauley, Kathleen M., and James H. McMillan. "Formative Assessment Techniques to Support Student Motivation and Achievement." *Clearing House* 83, no. 1 (2010): 1–6.

Clark, Richard E., Paul A. Kirschner, and John Sweller. "Putting Students on the Path to Learning: The Case for Fully Guided Instruction." *American Educator* 36, no. 1 (Spring 2012): 6–11. http://www.aft.org/pdfs/americaneducator/spring2012/Clark.pdf.

"Modeling Instruction — Legacy Site." Arizona State University. Accessed October 16, 2012. http://modeling.asu.edu/.

Spencer, James N. "New Approaches to Process and Content in Introductory Chemistry." AP Central. http://apcentral.collegeboard.com/apc/members/courses/teachers_corner/26065.html. (Use this to teach the Bond Triangle: a new way to teach the differences between metallic, ionic, and covalent bonding.)

Unit 1 (Lab Safety, Matter, and Measurement) Resources

Baruch's Chemistry Lab Safety Tutorial. (Requires Flash.) Accessed October 11, 2012. http://www.baruch.cuny.edu/tutorials/weissman/chemlab/.

"Floating Lemons and Sinking Limes." Steve Spangler Science. Accessed October 11, 2012. http://www.stevespanglerscience.com/experiment/floating-lemons-and-sinking-limes.

Unit 2 (Internal Structure of the Atom) Resources

"Models of the Hydrogen Atom." PhET. University of Colorado at Boulder. Accessed October 15, 2012. http://phet.colorado.edu/en/simulation/hydrogen-atom.

Unit 3 (Bonding: Interactions Between Atoms to Form Molecules) Resources

No unit-specific resources

Unit 4 (Qualitative and Quantitative Chemistry: Counting Atoms and Molecules) Resources

No unit-specific resources

Unit 5 (Thermochemistry: Energy of Interacting Atoms and Molecules) Resources

"Gas Properties." PhET. University of Colorado at Boulder. Accessed October 16, 2012. http://phet.colorado.edu/en/simulation/gas-properties.

"States of Matter." PhET. University of Colorado at Boulder. Accessed October 16, 2012. http://phet.colorado.edu/en/simulation/states-of-matter.

Unit 6 (Kinetics: Factors That Affect Reaction Rates) Resources

"Mechanisms of a Chemical Reaction." MoLE Project. Accessed October 16, 2012. http://genchem1.chem.okstate.edu/CCLI/CCLIDefault.html. (Select "Web-based simulations" from the left-hand menu, then scroll down to the first Kinetics simulation and select "Mechanism A.")

"Reactions & Rates." PhET. University of Colorado at Boulder. Accessed October 16, 2012. http://phet.colorado.edu/en/simulation/reactions-and-rates.

Unit 7 (Equilibrium: Application of Kinetics) Resources

No unit-specific resources

Unit 8 (Electrochemistry: Applications to Redox Reactions) Resources

No unit-specific resources