AP® Chemistry

Course Planning and Pacing Guide 3

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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

Syracuse High School
Syracuse, Utah

School	Suburban public school serving grades 9–12
Student population	Total enrollment is 1,909 students (962 female, 947 male) • 85.91 percent Caucasian • 8.31 percent Hispanic • 2.20 percent Asian • 1.26 percent African American • .84 percent Pacific Islander • .47 percent American Indian
	• 22.1 percent of students receive free or reduced-price lunch • Average class sizes: English: 29.9; math: 25.4; science: 34.2 • Number of students taking AP courses: 429 • Percentage of students on reading level: 10th grade: 86.4 percent; 11th grade: 88.7 percent
Instructional time	The school year starts the last week of August and has 180 school days. There are approximately 80 class periods per year for each class. The school follows an A/B block schedule with 90 minutes per block.
Student preparation	AP Chemistry is recommended as a second-year chemistry course that is taken in the junior or senior year. Students should come to the course prepared with a basic knowledge of atomic structure, the periodic table, bonding theory, and the mole. Students may take AP Chemistry as their first course, but most students have completed a first-year course (regular or honors chemistry) with a grade of C or better. I have found that a one-to-one recruitment style works best. During lab activities in my first-year chemistry classes, I like to walk around and talk to students about the possibility of taking AP Chemistry next year.

Textbooks and lab manuals, and software	Zumdahl, Steven S., and Susan A. Zumdahl. *Chemistry*. 7th ed. Boston: Houghton Mifflin, 2007. Hostage, David, and Martin Fossett. *Laboratory Investigations: AP* Chemistry*. Saddle Brook, NJ: Peoples Education, 2006. Vonderbrink, Sally Ann. *Laboratory Experiments for Advanced Placement Chemistry*. Batavia, IL: Flinn Scientific, 1995. Hnatow, John, and Ketan Trivedi. *High School Chemistry for AP Achievement: An Interactive Multimedia Course on DVD-ROM*. Blacksburg, VA: Trivedi Chemistry, 2012.

Overview of the Course

Course Outline: The traditional approach to teaching AP Chemistry is to follow the sequence of the chosen textbook. I have adopted an alternative approach. (In the alternative approach, the numbers refer to the units in the course planning and pacing section that follows.)

Traditional	Alternative
1 – Review Nomenclature and Stoichiometry	0 – Review Nomenclature and Stoichiometry
2 – Reaction Products	1 – Gas Laws
3 – Thermochemistry	2 – Kinetics
4 – Atomic Structure	3 – Equilibrium, Acid-Base Equilibria, Solubility Equilibria
5 – Periodic Table	4 – Thermodynamics, Thermochemistry, Electrochemistry
6 – Chemical Bonding	5 – Atomic Structure, Periodic Table
7 – Molecular Geometry and Hybridization	6 – Chemical Bonding, Molecular Geometry, and Hybridization
8 – Intermolecular Forces	7 – Intermolecular Forces, Solution Properties, Reaction Products
9 – Solution Properties	8 – Review; Exam – Beginning of May
10 – Gas Laws	
11 – Kinetic	
12 – Equilibrium	
13 – Acid-Base Equilibria	
14 – Solubility Equilibria	
15 – Thermodynamics	
16 – Electrochemistry	
17 – Review; Exam – Beginning of May	

My alternative approach is based on two observations. First, the second half of the school year has many more interruptions in the normal daily schedule than the first half. Second, students have the most difficulty with the mathematical topics. Covering the mathematical topics early allows more time for their mastery.

Laboratory: I use labs at the very beginning of a unit to generate interest and to pose questions that will be answered as the unit evolves. The revised AP course requires students to engage in 16 laboratory investigations, six of which must be in guided-inquiry format. These hands-on lab experiences for students make up 25 percent of my course. For each and every lab, I require my students to use a structured lab report format that must be in a bound quad-ruled notebook. Colleges and universities may or may not give lab credit to AP Chemistry students. Different rules apply, but most require some proof of the lab experience students had in high school.

Formative Assessments: Formative assessments are important quick checks to determine what my students know and what misconceptions they may have. I like to use warm-up questions and short, specific quizzes. Laboratory investigations are also a great formative assessment tool. The results of the assessments are used to determine whether the students understood the previous activity or further instruction is needed. Based on the assessment results, the post-assessment activity may be a simple review of the problems and the application of the rubric used, or one or more topics may need to be retaught. Occasionally, a follow-up assessment may be necessary. I have found this to be the best way to practice the type of problems that will be on the AP Chemistry Exam.

Take-Home Exam: This is a whole-unit formative assessment designed to take about two hours to complete. I suggest the students form small work groups (three to five members) and allow them to use any resources they wish during the assessment. The exams are usually a mix of multiple-choice and free-response questions from released AP Exams.

In-Class Summative Assessment: For the in-class assessment, I also use previous AP Chemistry Exam questions. I suggest grading and scoring the free-response questions as an AP Exam Reader would: Use the College Board scoring rubric or a similar rubric that you create. I also include questions from previous units. I ensure that students use only the College Board–released equation tables and periodic table. Familiarization with these pages will help students when they take the exam in May.

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 0: Review of Stoichiometry and Nomenclature *(This is a review of first-year topics. It could be used as a summer assignment.)*	The elimination of the calculation of molality, percent by mass, and percent by volume will simplify the review of these first-year topics.	The relationships between the number of particles in a solution and in a solid and how these particles are rearranged in a chemical reaction can now be explored in greater depth. Emphasis is placed on the ratio between reactants and products as particles and their respective masses.
Unit 1: Gas Laws	No significant reductions have been made in the curriculum. The deviation of the ideal gas law now emphasizes the qualitative influence of the volume of gas particles and how they interact with one another.	The use of the kinetic molecular theory to describe the motion of particles in a gas is critical in the student's understanding of the properties of gases. Models are very useful in helping the students to visualize gas particles. The use of the ideal gas equation to determine molar mass and the density of a gas addresses the emphasis of Science Practice 2: *The student can use mathematics appropriately.*
Unit 2: Kinetics	The elimination of calculations involving the Arrhenius equation and of the collection of data pertaining to the experimental detection of a reaction intermediate will save 30–40 minutes of one class period.	Orders other than zero, one, and two need to be examined. Students should be able to determine what is meant, at the particulate level, when a reactant is one-half order. Mechanisms, as they relate to the rate law expression and the stoichiometry of the reaction, are important in the understanding of how and why some stresses will affect the rate of a reaction. Related to this, intermediates and collision theory need to be examined regarding what makes a mechanism or a step probable.
Unit 3: Equilibrium	This unit has the largest number of reductions or eliminations. The following are no longer included in the curriculum: • Lewis acid-base concepts and the numerical computation of the concentration of each species present in the titration curve for polyprotic acids • Computing the change in pH resulting from the addition of an acid or base to a buffer • The production of the Henderson-Hasselbalch equation by algebraic manipulation of the relevant equilibrium constant expression • Memorization of the "solubility rules" • Computation of solubility as a function of pH These changes will save three or four class periods.	With the reduction of breadth, more emphasis may be placed on topics that give students a better understanding of equilibrium: • The relationship of kinetics to equilibrium • The importance of having a model that describes the macroscopic and microscopic view of equilibrium • The dynamic and the static models of equilibrium • The relationship of the shape of the titration curve to the concentration of the molecules and ions in solution is critical in the overall understanding of buffers, salts, and equivalence This unit covers solution, gas phase, acid, base, solubility, and complex ion equilibria. The unit focus should be that all equilibria describe the same process.
Unit 4: Thermodynamics and Electrochemistry	The elimination from the curriculum framework of students having to label chemical species as the reducing agent or oxidizing agent will save very little time. The biggest gain is seen with the removal of the Nernst equation. A total of two days will be saved from the classroom and lab time.	Thermochemistry is included in this unit because students need to have a deep qualitative and quantitative understanding of enthalpy, entropy, and Gibbs free energy. Students understand the connections among the first four units when the relationship between equilibrium, thermodynamics, and electrochemistry is explored.
Unit 5: Atomic Structure and the Periodic Table	With the elimination of the memorization of the Aufbau principle and the assignment of quantum numbers to electrons, two instructional periods may be saved.	Modern chemical analysis techniques of mass spectrometry and photoelectron spectroscopy are now included. Chemical analysis provides a method for determining relative numbers of atoms in a substance, which can be used to identify the substance or determine its purity.

Unit	Managing Breadth	Increasing Depth
Unit 6: Bonding	The bonding unit also has many reductions. The following are no longer required: • Knowledge of specific types of crystal structures • The use of formal charge to explain why certain molecules do not obey the octet rule • Learning how to defend Lewis models based on assumptions about the limitations of the models • An understanding of the deviation and depiction of these orbitals (only include sp, sp^2, and sp^3 due to controversy that hybridization involving d-orbital exists) • Aspects of molecular orbital theory such as recall or filling of molecular orbital diagrams • The study of specific varieties of crystal lattices for ionic compounds These changes will save two class periods.	The addition of metallic bonds described as an array of positively charged metal cores surrounded by a sea of mobile valence electrons will further student understanding of the relationship between the atom's nucleus and its electrons. It will also allow students to refine their personal model of atomic structure. Added are the properties of metallic solids (i.e., they are good conductors of heat and electricity; have a wide range of melting points; are shiny, malleable, and ductile; and are readily alloyed). With the properties of ionic compounds, covalent compounds, and covalent networks, students will have a deeper understanding of why compounds have specific properties.
Unit 7: Solutions and Intermolecular Forces	With the removal of phase diagrams and the study of colligative properties, one day of classroom discussion and one day of lab time may be saved. I still incorporate a colligative-properties lab in my curriculum. As we are located in the Salt Lake City area, the relevancy of salt in our society and environment is important to our students. It is also worth the time because it shows a microscale lab technique.	The past AP Chemistry Exams have shown that students either do not understand the concept of intermolecular forces or they do not know how to formulate an acceptable answer on this topic. Deeper exploration of the concepts and the proper language is possible due to the reduced breadth. Writing net ionic reactions from a statement of what reactants are added and the conditions of the reaction is the summary of the course. Students use all of their knowledge from previous units and the labs that have been completed. Students predict products and are able to describe potential results and/or different physical and chemical properties of the reactant and products (e.g., oxidation states, acid-base properties, solubility).

Review of Stoichiometry and Nomenclature

Laboratory Investigations:

- Finding the Ratio of Moles of Reactants in a Chemical Reaction (or Job's Method of Continuous Variation)
- Analysis of a Silver Alloy

Estimated Time:

10 days

Essential Questions: ▼ Brass was used in ancient times for currency and in art. The composition of the alloy can help archeologists determine the age and its creator. How is the composition determined? ▼ How do chemical engineers ensure that expensive reactants are completely used in a manufacturing process?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	Vonderbrink, Experiment 2: "Finding the Ratio of Moles of Reactants in a Chemical Reaction" Zumdahl and Zumdahl, Chapter 3: "Stoichiometry"	**Instructional Activity:** In small groups, students use a Job's plot to determine the stoichiometric relationship between different reactions. Vonderbrink's lab has students react one of the following three reactants with sodium hypochlorite (household bleach): KI, $Na_2S_2O_3$, and Na_2SO_3. Students then determine the stoichiometric relationship between the reactants and the products. Next, students graphically determine the number of molecules of each reactant. By the end of this lab, students understand the concept of particles interacting. This concept will be a key element of this course.
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]		**Instructional Activity:** Student groups present their findings from the previous laboratory activity to the entire class. Students examine data and graphs for each reaction, and I encourage group discussions on the collective results. **Formative Assessment:** Students write a summary of their lab results and the other lab results presented. In their summaries, students address the data that was obtained, the graph of the data used to determine the stoichiometric relationship, and the balanced equation for the reaction. It is important for students to understand the underlying principle of limiting reactants before we proceed.

I like to have my students do a lab as soon as possible to help them see that AP Chemistry is a rigorous laboratory course.

An alternate activity to consider is Job's Method of Continuous Variation, Experiment 7 in Hostage and Fossett's Laboratory Investigations: AP* Chemistry. *Hostage and Fosset offer the option of using the height of a precipitate, pH, absorbance, temperature change, and the mass of precipitate to determine the ratio of reactants.*

I use the reports to check for student understanding of limiting reactants. If students are having difficulty, I provide further review of the concept of limiting reactants.

Essential Questions: ▼ Brass was used in ancient times for currency and in art. The composition of the alloy can help archeologists determine the age and its creator. How is the composition determined? ▼ How do chemical engineers ensure that expensive reactants are completely used in a manufacturing process?

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] 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] 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] 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]	Vonderbrink, Experiment 1: "Analysis of a Silver Alloy"	**Instructional Activity:** Students dissolve a sample of a given silver alloy. The solution is then selectively precipitated by the addition of chloride ions. Students create a procedure and formulate a data table. They determine the original percentage of silver in the alloy that was given to them. Optional extension: Students are given a sample of the same alloy that was used in the first procedure. The alloy is dissolved in the same manner, but with a piece of Cu (wire or sheet) added to the solution. Solid silver will be produced.
		Formative Assessment: Students work in groups to trace the silver that was recovered back to the original alloy. They perform the necessary calculation to determine the composition of the alloy and describe the process in a nonmathematical method. Students may use pictures, graphs, etc. Error analyses must be incorporated in their summaries.

Do not be afraid of the word silver. *Silver jewelry is my first choice of an alloy. I have picked up pieces at garage sales, students have brought in old jewelry, and I have gone to a jewelry store. One small bracelet will last you for many years. Chemical companies also sell alloys at reasonable prices.*

The percent error that students obtain is not important. What is important is the process of determining the percentage of silver within the compound. I identify any incorrect processes used by the groups, and groups revise their processes as needed.

Essential Questions: ▼ Brass was used in ancient times for currency and in art. The composition of the alloy can help archeologists determine the age and its creator. How is the composition determined? ▼ How do chemical engineers ensure that expensive reactants are completely used in a manufacturing process?

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]	Hnatow and Trivedi, Chapter 1: "Atoms, Molecules, and Ions," Sections 1.19–1.47 Zumdahl and Zumdahl, Chapter 2: "Atoms, Molecules, and Ions," Section 2.8	**Instructional Activity:** Students practice balancing equations, identifying mole ratios, and limiting reactants as well as identifying and writing the nomenclature of ionic and covalent molecules.
		Summative Assessment: Students take a unit exam that emphasizes stoichiometric principles and nomenclature. The underlying theme of particles reacting is also assessed. Students are asked to draw a particle model of a reaction.

These topics should be covered in a first-year regular chemistry or honors chemistry course. However, you cannot rely on the students having complete recall of these basic but very important topics.

This assessment addresses the essential question, How do chemical engineers ensure that expensive reactants are completely used in a manufacturing process? *More specifically, students determine, given an expensive reactant, what procedures they would incorporate to be sure that the chemical process is the most cost-efficient.*

Laboratory Investigations:

- Molecular Mass of a Volatile Liquid
- Graham's Law: Determination of Molar Mass

Estimated Time: *12 days*

Essential Questions: ▼ We can model the motion of gases as individual particles. When does the model most accurately represent nature? ▼ When a scuba diver stays underwater for an extended time and then surfaces quickly, he or she may experience the bends. What are the cause and the cure? ▼ Why do some packaged foods have different cooking instructions for different locations?

Learning Objectives	Materials	Instructional Activities and Assessments
Connect the number of particles, moles, mass, and the volume of substances to one another, both qualitatively and quantitatively. [LO 1.4, SP 7.1]	Vonderbrink, Experiment 7: "Molecular Mass of a Volatile Liquid" (Modified) Zumdahl and Zumdahl, Chapter 5: "Gases," Sections 5.1–5.4 Hnatow and Trivedi, Chapter 5: "Gases," Sections 5.1–5.2 and 5.17–5.18	**Instructional Activity:** This lab procedure has been streamlined by utilizing a microscale setup and using Parafilm instead of aluminum foil. Students gather pressure, volume, mass, and temperature data; manipulate the data; and critically examine their calculated molecular mass.
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] Apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [LO 2.6, SP 2.2, SP 2.3]	Hnatow and Trivedi, Chapter 5: "Gases," Sections 5.15–5.16	**Instructional Activity:** A review of the previous day's lab is important. As a class, we go over the lab's procedure and the data that was obtained. I then introduce PV = nRT and algebraic manipulation of the ideal gas law with the mass to mole relationship. I also show how molecular mass and density may be derived. Students are asked to propose a model of a gas from their laboratory experience and classroom discussions.
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]		**Formative Assessment:** Lab groups answer four short free-response questions based on the Molecular Mass of a Volatile Liquid lab. The classroom comes together to discuss students' individual responses and the purpose of the activity. Student groups are also asked to describe their model of a gas, and the class gives feedback as I monitor the discussion and provide feedback of my own. The models are combined to form a working representation of a gas.

I find that when students do the labs before we have any formal presentation, it allows them to form questions and makes them eager to know the "real story" behind the activity.

What do you do if you do not have an analytical balance? The mass of the gas that is normally calculated is approximately .01 grams. Instruct your students that the mass is .01 +/- .005 grams. Have them calculate the molecular weight with a mass of .015 and .005 grams. This process helps students to understand the importance of the precision of the instrumentation as well as how important it is for them to record all of the digits presented.

Essential Questions: ▼ We can model the motion of gases as individual particles. When does the model most accurately represent nature? ▼ When a scuba diver stays underwater for an extended time and then surfaces quickly, he or she may experience the bends. What are the cause and the cure? ▼ Why do some packaged foods have different cooking instructions for different locations?

Learning Objectives	Materials	Instructional Activities and Assessments
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] Apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [LO 2.6, SP 2.2, SP 2.3]	Zumdahl and Zumdahl, Chapter 5: "Gases," Sections 5.1–5.4 Hnatow and Trivedi, Chapter 5: "Gases," Sections 5.3–5.10 **Web** "Gas Properties"	**Instructional Activity:** I review the mathematical and graphical relationships of P, V, and T. Students use the PhET "Gas Properties" simulation to explore a visual representation of the kinetic molecular theory and the relationships that exist among P, V, and T.
		Formative Assessment: Short quiz covering the ideal gas law, unit conversions, and the techniques used in the Molecular Mass of a Volatile Liquid lab.
Use KMT and the 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]		**Instructional Activity:** As a class, we discuss deviation of the ideal gas law and the kinetic molecular theory. We also discuss the Van der Waals equation as an attempt to make corrections for the volume and interaction of gas particles. Students predict under which conditions real gases deviate most from ideal gases.
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] 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 5: "Gases," Sections 5.5–5.8 Hnatow and Trivedi, Chapter 5: "Gases," Sections 5.23–5.34	**Instructional Activity:** The Graham's Law lab is a microscale adaption of a popular demonstration; teacher supervision is critical. Students place droplets of concentrated HCl and NH_4OH on either end of a clear soda straw. The product of an NH_4Cl ring within the clear straw becomes obvious within a few seconds. Students then draw a particle model of the lab showing relative velocities of the gases. The lab produces the signature NH_4Cl ring, but because of the scale used, there is a result that the larger demonstration does not exhibit: The formed ring will move. The vapor pressure of the two reactants can be compared. Students will get different results from the predicted 35 g/mol for the molecular mass of NH_4OH because the gas that is produced is NH_3.
		Formative Assessment: Students write lab summaries in which they address the kinetic molecular theory. Students are asked to describe a model of a gas and then to answer questions related to that model. We discuss individual student responses as a class.

It is important that students understand the "basics." I provide feedback to students on their understanding of these concepts and skills. Depending on the results of the assessment, additional group or individual work may be necessary.

The actual math that can be done should be minimized. Emphasis should be placed on how the Van der Waals equation correlates with the kinetic molecular theory as it pertains to gases.

I guide the discussion and provide feedback to the students on their summaries. Depending on the results, group or individual work may be necessary.

Essential Questions: ▼ We can model the motion of gases as individual particles. When does the model most accurately represent nature? ▼ When a scuba diver stays underwater for an extended time and then surfaces quickly, he or she may experience the bends. What are the cause and the cure? ▼ Why do some packaged foods have different cooking instructions for different locations?

Learning Objectives	Materials	Instructional Activities and Assessments
		Formative Assessment: Students are given a take-home exam and associated rubric that covers the concepts of the entire unit. Common misconceptions are explained after students return the exams.
		Summative Assessment: In-class exam (timed: 60 minutes) consisting of multiple-choice and free-response questions. Part of the assessment poses different models of gases to the students. Students change the values of the P, V, and T variables to examine the effects of each change on the model.

Reviewing the common misconceptions will help your students perform well on the final assessment. Make note of these misconceptions for the next time you teach the gases.

This assessment addresses the following essential questions:

- We can model the motion of gases as individual particles. When does the model most accurately represent nature?
- When a scuba diver stays underwater for an extended time and then surfaces quickly, he or she may experience the bends. What are the cause and the cure?
- Why do some packaged foods have different cooking instructions for different locations?

Laboratory Investigations:

- Integrated Rate Law, Zero Order
- Integrated Rate Law, First Order
- Integrated Rate law, Second Order
- Sulfur Clock Reaction
- Investigating the Kinetics of Acid Rain Reacting with Marble Statues *(guided inquiry)*
- Study of the Kinetics of a Reaction

Estimated Time:

24 days

Essential Questions: ▼ The stoichiometry and the kinetics of a reaction are determined from laboratory investigations. How is a mechanism determined? ▼ When two different collisions occur between two particles, why does only one result in the formation of a product? ▼ A chemical engineer needs to remove hydrogen peroxide from a solution. What would be the advantages and disadvantages of using a heterogeneous catalyst over a homogeneous catalyst?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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 –12.2 Hnatow and Trivedi, Chapter 13: "Chemical Kinetics," Sections 13.1–13.2 and 13.13–13.19	**Instructional Activity:** In pairs, students are assigned one of three lab activities to begin the study of kinetics. Zero-, first-, and second-order reactions are simulated. At the end of the period, students who worked on the same lab activities are grouped together to compare data. Each group must have the following graphs prepared for the next class meeting: • Amount versus Time • Log (Amount) versus Time • 1/Amount versus Time
		Formative Assessment: Students write summaries of their own labs and the other labs presented. In their summaries, they address the order of a reaction and the rate law expression.
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]	Zumdahl and Zumdahl, Chapter 12: "Chemical Kinetics," Sections 12.1, 12.2, 12.4, and 12.5 Hnatow and Trivedi, Chapter 13: "Chemical Kinetics," Sections 13.1–13.6 and 13.13–13.19	**Instructional Activity:** Students are organized into three groups according to which lab activity they were assigned. Each group is asked to pick two spokespeople to discuss their lab activity. Each lab is then presented. The spokespeople explain the lab activity and the data collected and show the three graphs. Students will explain how their graphs show zero-, first-, and second-order kinetics and how the integrated rate laws are derived from the students' graphs.
		Formative Assessment: Students answer six short-answer questions related to the lab activity that they performed.

I examine students' rate law expressions and provide feedback on their understanding of the concept. Depending on the results, additional group or individual work may be necessary.

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

Essential Questions: ▼ The stoichiometry and the kinetics of a reaction are determined from laboratory investigations. How is a mechanism determined? ▼ When two different collisions occur between two particles, why does only one result in the formation of a product? ▼ A chemical engineer needs to remove hydrogen peroxide from a solution. What would be the advantages and disadvantages of using a heterogeneous catalyst over a homogeneous catalyst?

Learning Objectives	Materials	Instructional Activities and Assessments
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, 12.2, 12.4, and 12.5 Hnatow and Trivedi, Chapter 13: "Chemical Kinetics," Sections 13.1–13.6 and 13.13–13.19	**Instructional Activity:** As a class, we examine the integrated rate law for zero-, first-, and second-order reactions and explore the use of the equations to predict the amount of reactant or product as a function of time. We also explore the concept of a *half-life* for zero-, first-, and second-order reactions. Students are asked to draw a particle model of the recently conducted lab showing relative numbers and collisions.
Analyze concentration vs. time data to determine the rate law for a zeroth-, first-, and second-order reaction. [LO 4.2, SP 5.1, SP 6.4, *connects to* 4.A.3]	Zumdahl and Zumdahl, Chapter 12: "Chemical Kinetics," Section 12.3 Hnatow and Trivedi, Chapter 13: "Chemical Kinetics," Sections 13.7–13.12	**Instructional Activity:** The precipitation of sulfur by the reaction of HCl and $Na_2S_2O_3$ (sulfur clock reaction) is examined using the differential laboratory method. Students prepare and mix different concentrations of HCl and $Na_2S_2O_3$. The reaction is complete when a predrawn *X* on white paper disappears. The differential method for determining the rate law expression is explored. Using the data gathered during the lab, students determine the order of the HCl and the $Na_2S_2O_3$. Most students will obtain data that allow them to easily determine the rate law expression and determine the rate constant (k).
		Formative Assessment: Student groups answer eight short-answer questions related to the previous lab activity. The class then discusses the data and calculations as a group.
		Instructional Activity: Investigating the Kinetics of Acid Rain Reacting with Marble Statues: By first constructing, then testing, a hypothesis, students investigate how the speed of the chemical reaction between solid calcium carbonate and a solution of hydrochloric acid is affected by changing variables relating to the two reactants.

The simplicity of this lab makes it a great way to strengthen students' understanding of kinetics. There are few ways in which students may make mistakes. Counting drops and timing the formation of sulfur are easy procedures that most students can master very quickly. When mechanisms are introduced, the results of this lab may be used by the students to offer a possible series of steps.

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

Kinetics

(continued)

Essential Questions: ▼ The stoichiometry and the kinetics of a reaction are determined from laboratory investigations. How is a mechanism determined? ▼ When two different collisions occur between two particles, why does only one result in the formation of a product? ▼ A chemical engineer needs to remove hydrogen peroxide from a solution. What would be the advantages and disadvantages of using a heterogeneous catalyst over a homogeneous catalyst?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Vonderbrink, Experiment 12: "Study of the Kinetics of a Reaction" Hostage and Fossett, Experiment 13: "Kinetics: Differential and the Integrated Rate Laws"	**Instructional Activity:** The Vonderbrink lab is difficult to set up and students must be sure that the reaction vessels are very clean for each trial. Students will perform calculations to determine the rate law expression. The Hostage and Fossett lab has students examine the effects of concentration and the type and size of catalyst on a reaction rate.
Analyze concentration vs. time data to determine the rate law for a zeroth-, first-, and 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 12.6–12.8 Hnatow and Trivedi, Chapter 13: "Chemical Kinetics," Sections 13.20–13.23 **Web** "Reactions & Rates"	**Instructional Activity:** The Arrhenius equation and the determination of Ea are always associated with a graph. Students do the following: 1. Label the *x* and *y* axes of a graph used to determine the Ea. 2. Sketch a line that represents the Ea/R relationship. 3. Given a graph, explain what the slope of the graph represents. (The particle model that we have been developing is modified to address collisions and their efficiency.) The PhET "Reactions & Rates" simulation offers a good visualization of the kinetic molecular theory. The use of graphs to show the energy of the system is useful for introducing the concept of Ea. Students can make predictions about how certain actions may affect the rate of a reaction.
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]	Hnatow and Trivedi, Chapter 13: "Chemical Kinetics," Sections 13.24–13.28 Zumdahl and Zumdahl, Chapter 12: "Chemical Kinetics," Sections 12.6–12.8 **TV clip** *I Love Lucy*, "Job Switching"	**Instructional Activity:** Students determine the ingredients, the amount of each ingredient, and the steps that would be necessary to prepare ice cream sundaes; this becomes a discussion of the stoichiometry of an ice cream sundae. Once the class is in agreement, the process is divided into three to four stations. Students agree on what should happen at each station, then assign themselves to one of these stations, and start to perform their step in the sundae-making mechanism. Once the process is established and running smoothly, a change is made. The person working at one of the stations is hindered from producing at the same rate. The station at which the change was made becomes the rate-determining step station.

This lab examines the effects of concentration and temperature. Students find the Vonderbrink lab to be one of their favorites and say that they "really understand" what they were doing in both the lab and the calculations. The Hostage and Fossett lab is a fun lab to set up and perform. It does require special equipment. What this lab offers over the other labs in this unit is the introduction of the concepts of homogenous and heterogeneous catalysts.

Traditionally, the Arrhenius equation has been looked at through the lens of the graph associated with this equation. The slope of the linear relationship needs to be explained to show how the Ea may be determined. Once again, the PhET simulation is an excellent visualization tool to demonstrate the kinetic molecular theory.

The most important statement that I make to my students about mechanisms is, "A mechanism may be possible if it meets the requirements of the stoichiometry and the rate law expression. Then only experimentation can determine if what is proposed is the true mechanism."

Essential Questions: ▼ The stoichiometry and the kinetics of a reaction are determined from laboratory investigations. How is a mechanism determined? ▼ When two different collisions occur between two particles, why does only one result in the formation of a product? ▼ A chemical engineer needs to remove hydrogen peroxide from a solution. What would be the advantages and disadvantages of using a heterogeneous catalyst over a homogeneous catalyst?

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] 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] Analyze concentration vs. time data to determine the rate law for a zeroth-, first-, and second-order reaction. [LO 4.2, SP 5.1, SP 6.4, *connects to* 4.A.3]		**Formative Assessment:** Follow the above activity with a real reaction, such as the Sulfur Clock Reaction. Small groups propose a mechanism that they then perform. Each mechanism is examined by the class as a whole.
		Formative Assessment: Students are given a take-home exam and associated rubric that covers the concepts of the entire unit. Common misconceptions are explained after students return the exams.
		Summative Assessment: In-class exam (timed: 90 minutes) consisting of multiple-choice and free-response questions are posed pertaining to chemical reactions, rates of reaction, kinetic molecular theory, and molecular collisions.

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

Reviewing the common misconceptions will help your students perform well on the final assessment. It is also helpful in your growth as a teacher. The take-home assessment and its review are a review strategy.

This assessment addresses the essential question, When two different collisions occur between two particles, why does only one result in the formation of a product?

Laboratory Investigations:

- Dueling Graduated Cylinders *(guided inquiry)*
- Determination of Equilibrium Constant
- Determination of Equivalent Mass and pK_a of an Unknown Acid *or* Mass Percent of Acetic Acid in Vinegar
- Preparation of a Buffer Solution *(guided inquiry)*
- Dissociation Constant of Weak Acids *(guided inquiry)*
- Solubility Product of an Ionic Compound
- Solubility Product Constant of Calcium Hydroxide

Estimated Time:
46 days

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
Use LeChatelier's principle to design a set of conditions that will optimize a desired outcome, such as product yield. [LO 6.9, SP 4.2] 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] Use LeChatelier'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 LeChatelier'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]	**Web** "Dueling Aquariums: An Equilibrium Demonstration"	**Instructional Activity:** I guide students through a modification of the "Dueling Aquariums" demonstration. Using similar graduated cylinders and straws, student groups collect data and look for a point of balance. When a point of balance has been reached, students stress their system by either changing the length of a straw or the volume in one of the cylinders. Before they apply the stress, they predict what their action will do to their point of balance. Students continue the activity until another point of balance has been reached. Lab groups present their data in the next class period. The concept of *Q* is introduced at the two points of balance by examining the volume of the left and right cylinders.

I never use the term equilibrium *until the lab is complete and we are discussing it as a group. As I walk around the lab, I use the phrase* point of balance. *The stress that I apply is usually cutting a straw, adding water, or removing water. A graph of volume versus exchange is the best way for students to see the point of balance, and it is the best way for me to spark discussion.*

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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 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] Connect kinetics to equilibrium by using reasoning about equilibrium, such as LeChatelier's principle, to infer the relative rates of the forward and reverse reactions. [LO 6.3, SP 7.2] 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, 6.4]	Zumdahl and Zumdahl, Chapter 13: "Chemical Equilibrium," Sections 13.1–13.2 Hnatow and Trivedi, Chapter 14: "Chemical Equilibrium," Sections 14.1–14.7	**Instructional Activity:** The data from each lab group are examined. The following observations may be made: • Each group will reach a point of balance before and after the stress is applied. • Adding or subtracting water will create a large change in the volume/exchange in the graph. • Changing the straw will make a very small change in the volume/exchange. Students are asked to assume the following reaction: **Left Volume → Right Volume** From this aspect, students qualitatively (graph of volumes) and quantitatively (ratio of volumes) describe their understanding of the point of balance.

This is the best activity that I have used to address the misconception that at equilibrium the volumes in the graduated cylinders will be the same. The determination of K allows you to introduce what K_{eq} means:

$K_{eq} = k_f/k_r$

So, equilibrium is a special point where the rate constant of the forward reaction is equal to the rate constant of the reverse reaction. Tying equilibrium back to kinetics makes the point of balance understandable for many students.

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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]		**Formative Assessment:** From the numeric and graphical information, students evaluate the equilibrium constant before and after the stress is imposed. Students then determine if the stress their system experienced changed the value of the equilibrium constant and, if it did, whether the forward or reverse reaction rate was affected.
Use LeChatelier'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]	**Web** "Salts & Solubility"	**Instructional Activity:** The concept of equilibrium having two components (macroscopic and microscopic) is shown with this simulation. I use it as a demonstration tool. As NaCl is added to a very small volume of water, dissociation is first observed. Adding more NaCl eventually creates a saturated solution. Students can see the Na^+ and Cl^- ions leaving and entering the crystalline structure. The simulation also quantifies the number of dissolved and bound ions. Students use LeChatelier's principle to describe the stresses and shifts on the system as evidenced by the simulation.
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] 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]		**Instructional Activity:** As a class, we discuss K_{eq} problems that address the quantitative and qualitative aspects of equilibrium. The process of setting up the problems and determining the answers is explored. Whenever possible, I refer back to the lab recently performed (Dueling Graduated Cylinders).

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

I use this as a demonstration to explore the point of equilibrium. Later, I will use the same simulation as a classroom activity when we discuss solubility equilibrium.

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Learning Objectives	Materials	Instructional Activities and Assessments
Use LeChatelier'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]	Zumdahl and Zumdahl, Chapter 13: "Chemical Equilibrium," Sections 13.3–13.7 Hnatow and Trivedi, Chapter 14: "Chemical Equilibrium," Sections 14.8–14.22	**Instructional Activity:** I demonstrate the following equilibrium reaction: $Fe^{3+} + SCN^- \leftrightarrow FeSCN^{2+}$ Using an overhead projector, I show students that the color of the $FeSCN^{2+}$ solution may be observed as different stresses are applied. Students are asked to predict how adding KSCN, $Fe(NO_3)_3$, and Na_2HPO_4 (s) will shift/drive a reaction. In the final part of the demonstration, I place a $CoCl_4^{2-}$ beral pipette into cold and hot water. Students explore and explain the effect of temperature on an existing equilibrium: $CoCl_4^{2-} + 6\ H_20 \leftrightarrow Co(H_20)_6^{2-} + 4Cl^-$
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] 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]	Vonderbrink, Experiment 14: "Determination of the Equilibrium Constant for the formation of $FeSCN^{2+}$" Hostage and Fossett, Experiment 11: "Determination of Equilibrium Constant of an Indicator"	**Instructional Activity:** Depending on your personal approach and the equipment that your school may have, select one of the two lab activities, both of which introduce Beer's law. Students prepare solutions and calculate the value of K_{eq} for the given reaction. Each lab requires 90 minutes to complete. **Formative Assessment:** From the data gathered by one of the two methods above, a value of the K_{eq} is determined. Students are again asked to describe their results in a particle model.

The Vonderbrink lab uses the same reaction that was examined in Equilibrium I
$Fe^{3+} + SCN^- \leftrightarrow FeSCN^{2+}$

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

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]	Zumdahl and Zumdahl, Chapter 14: "Acids and Bases," Sections 14.1–14.4 Hnatow and Trivedi, Chapter 15: "Acids and Bases," Sections 15.1–15.6	**Instructional Activity:** Students develop definitions and particulate representations of acids and bases. They define pH as a measure of the [H+] and derive the equations that relate pH, pOH, $[H^+]$, and $[OH^-]$ from the K_w.

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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]	Vonderbrink, Experiment 16: "Determination of the Equivalent Mass and pK_a of an Unknown Acid" Hostage and Fossett, Experiment 8: "Finding the Mass Percent of Acetic Acid in Vinegar" Zumdahl and Zumdahl, Chapter 14: "Acids and Bases," Sections 14.5–14.7 Hnatow and Trivedi, Chapter 15: "Acids and Bases," Sections 15.7–15.10, and Chapter 16: "Acid Base Equilibria," Sections 16.12–16.18	**Instructional Activity:** Select one of the suggested lab activities. Each activity will have the students prepare a solution, standardize the solution, and then use that solution to determine the K_a of a weak acid or the mass percentage of vinegar. (30 minutes) Prepare NaOH solution (90 minutes) Standardization (90 minutes) K_a or mass percentage determination
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, *connects to* 1.E.2]		**Formative Assessment:** Students are asked to prepare a specific concentration of NaOH and then determine the actual concentration through titration. The K_a of a weak acid is determined from the previously determined concentration of base. Students' preparations of solutions and titration skills are assessed.

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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 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] 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] 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]	Zumdahl and Zumdahl, Chapter 14: "Acids and Bases," Sections 14.8–14.12 Hnatow and Trivedi, Chapter 15: "Acids and Bases," Sections 15.11–15.20	**Instructional Activity:** I define weak acids and bases and draw their molecular structures on the board to explain their relative strengths. Students see that salts are a product of an acid reacting with a base. Starting with a weak acid and strong base titration, students determine the concentrations of the acid, salt, and base. This is repeated for weak base and strong acid titrations.

One of the connections that I most like to make between topics is that between the K_a of a weak acid and the percent dissociation. Using acetic acid (K_a = 1.8 x 10^{-5}), calculate the percent dissociation. This explains why we use the terms weak *and* strong *when we talk about acids (and bases).*

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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 15.1–15.2 Hnatow and Trivedi, Chapter 16: "Acid Base Equilibria," Sections 16.1–16.6	**Instructional Activity:** Define what a buffer is and what it is used for in real-life applications. Ask students to bring in examples of buffers from their kitchens and homes. Students then find the components of their examples that make them buffers.
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]	Hostage and Fossett, Experiment 12: "Preparation of a Buffer Solution at a Given pH" Zumdahl and Zumdahl, Chapter 15: "Applications of Aqueous Equilibria," Sections 15.1–15.2 Hnatow and Trivedi, Chapter 16: "Acid Base Equilibria," Sections 16.1–16.6	**Instructional Activity:** In the class period before the lab, students use dice to create a buffer of a given pH. Students roll the dice, determine what buffer they need to create, and are given a list of chemicals that they may use. Students come into class the next period prepared to mix and test their buffer.

Buffers are everywhere. Instant lemonade and contact lens solution are good places to start. Bring in samples to show before students bring in their own items.

This is a great lab activity that students look forward to. It requires a good supply of weak acids and salts. Before the lab, prepare a list of available chemicals and predetermine what buffers can or cannot be made.

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Vonderbrink, Experiment 15: "Determination of the Dissociation Constant of Weak Acids"	**Summative Assessment:** This experiment is used to evaluate students' knowledge of titrations, buffer mechanisms, and weak acids. Each student is asked to determine the K_a of a weak acid, given the following set of equipment and chemicals: 50 mL volumetric flask 25 mL graduated cylinder two Beral pipettes two 100 mL beakers Scoopula pH meter .2 g of a solid unknown weak acid Phenolphthalein solution 100 mL of .1 M(approx.) NaOH(aq) Students prepare a detailed procedure, explain the theory behind their approach, and show all calculations.

This assessment addresses the essential question, At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Students are not given the lab procedure, but are given the task of determining the K_a *of an unknown weak acid given a very limited set of equipment.*

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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]	Vonderbrink, Experiment 13: “Determination of the Solubility Product of an Ionic Compound” Hostage and Fossett, Experiment 18: “Determining the Solubility Product Constant of Calcium Hydroxide” Hnatow and Trivedi, Chapter 17: “Solubility Equilibria,” Sections 17.1–17.8 Zumdahl and Zumdahl, Chapter 15: “Applications of Aqueous Equilibria,” Sections 15.6–15.7	**Instructional Activity:** Three separate lab activities examine how the stoichiometry of a reaction influences the point of equilibrium: $\mathbf{Ca(OH)_2\,(s) \leftrightarrow Ca^{2+} + 2\,OH^-}$ $\mathbf{K_{sp} = [Ca^{2+}][OH^-]^2}$ In each one, calcium hydroxide is used to explore how the stoichiometric ratios of the reactants and products affect the value of the K_{sp}. Activity 1: Students determine the amount of solute ($Ca(OH)_2$) that will dissolve in a given volume. (Hostage and Fosset Method 1) Activity 2: Students determine the pH of a saturated Ca(OH)2 solution. (Hostage and Fosset Method 2) Activity 3: Students perform a set of serial dilutions. (Vonderbrink)
	Web “Salts & Solubility”	**Instructional Activity:** This simulation was used at the beginning of this unit and is revisited here. If possible, students should work in pairs and explore the solubility of salts and the factors that influence the solubility by varying the parameters of the variables within the simulation.

Activity 1 has the students evaporate a saturated solution. Emphasis needs to be placed on the concentration of the calcium hydroxide that will dissolve.

$[Ca(OH)_2]_{diss} = [Ca^{2+}]$

$2[Ca(OH)_2]_{diss} = [OH^-]$

Activity 2 has the students relate pH to pOH.

$[OH^-] = 10^{-pOH}$

$[Ca^{2+}] = 1/2[OH^-]$

Activity 3 has the students perform two sets of serial dilutions. One keeps the $[Ca^{2+}]$ constant and varies the $[OH^-]$. The second keeps the $[OH^-]$ constant and varies the $[Ca^{2+}]$.

This is an excellent way to bring back the idea that the concept of solubility is simply a form of equilibrium. This is a long unit. The tieback really helps the students understand that we are still talking about the same topic that we started 20+ class periods ago.

Essential Questions: ▼ Hydrofluoric acid (HF) is banned from high school chemistry storerooms. If it is so dangerous, why is it classified as a weak acid? ▼ A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface? ▼ The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium? ▼ At the equivalence point of a weak acid–strong base titration, what three amounts are equal?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]	Zumdahl and Zumdahl, Chapter 15: "Applications of Aqueous Equilibria," Sections 15.6–15.7 Hnatow and Trivedi, Chapter 17: "Solubility Equilibria," Sections 17.1–17.8	**Instructional Activity:** Solubility equilibrium problems are posed and solved in class. I start with stoichiometric relationships of the ions that are 1:1 and then introduce problems in which the ratio is not 1:1. Mass of solute that will dissolve in a given volume, the maximum concentration that can be achieved, and the question of whether a precipitate will form if two soluble salts are mixed need to be addressed. Students connect factors such as pH, common ions, intermolecular forces, and entropy pertaining to the factors' effects on equilibrium through explanations or solutions to the problems worked on in class.
		Formative Assessment: Students are given a take-home exam and associated rubric that covers the concepts of the entire unit. Common misconceptions are explained after students return the exams.
		Summative Assessment: In-class exam (timed: 45 minutes) consisting of multiple-choice and free-response questions pertaining to solubility of salts, intermolecular interactions, and buffer mechanisms.

This assessment addresses the following essential questions:

- A sealed bottle of a saturated solution of calcium hydroxide ($Ca(OH)_2$) sits on a shelf, unchanging for one month. Why, when the seal is broken, does a thin white layer appear on the surface?
- The clear liquid above a saturated solution of copper sulfate ($CuSO_4$) is removed and placed in a test tube. Is the solution in the test tube at equilibrium?

Unit 4: Thermodynamics and Electrochemistry

Laboratory Investigations:

- Thermochemistry and Hess's Law
- Thermodynamics of a Rubber Band *(guided inquiry)*
- Electrochemical Cells *(guided inquiry)*
- Analysis of a Commercial Bleach

Estimated Time:

18 days

Essential Questions: ▼ When an auto mechanic informs you that your car battery is "dead," what does that mean at the molecular level? ▼ If we say a reaction "takes place," what factors make that happen? ▼ If you have metal fillings in your teeth, why does biting on aluminum foil cause so much pain? ▼ Why do saltwater fishermen place Zn plates on their boats' engines?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] 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] 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]	Vonderbrink, Experiment 6: "Thermochemistry and Hess's Law" Zumdahl and Zumdahl, Chapter 6: "Thermochemistry," Sections 6.1–6.3 Hnatow and Trivedi, Chapter 6: "Thermochemistry," Sections 6.1–6.8	**Instructional Activity:** Students perform a laboratory investigation to determine the enthalpy of the following reaction: **NH3 (aq) + HCl (aq) → NH4Cl (aq)** This is a nontraditional approach. It uses the algebraic sum of the heat of reaction of two reactions to determine the heat of reaction of a third. Part I: Students determine the heat capacity of a calorimeter that they make. Part II: Students determine the heat of reactions.

Of all the labs that I have my students perform, this one requires the greatest amount of solid chemicals. Separation of this lab into two parts is important to emphasize the concept of heat capacity. Heat capacity is often overlooked when performing a calorimetric determination of the enthalpy of a reaction. Separating the topics and requiring separate lab write-ups for each helps students see the importance of heat capacity.

Essential Questions: ▼ When an auto mechanic informs you that your car battery is "dead," what does that mean at the molecular level? ▼ If we say a reaction "takes place," what factors make that happen? ▼ If you have metal fillings in your teeth, why does biting on aluminum foil cause so much pain? ▼ Why do saltwater fishermen place Zn plates on their boats' engines?

Learning Objectives	Materials	Instructional Activities and Assessments
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 6: "Thermochemistry," Sections 6.1–6.3 Hnatow and Trivedi, Chapter 6: "Thermochemistry," Sections 6.1–6.8 and 6.9–6.18	**Instructional Activity:** As a class, we examine student data from the previous class meeting. In groups, students determine the enthalpy of the reactions.
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] 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]	Zumdahl and Zumdahl, Chapter 16: "Spontaneity, Entropy, and Free Energy," Sections 16.1–16.6 Hnatow and Trivedi, Chapter 18: "Spontaneity and Chemical Change," Sections 18.1–18.5 and 18.12	**Instructional Activity:** I introduce the following equation: $\boldsymbol{\Delta G = \Delta H - T\Delta S}$ As a class, we examine qualitatively the two tendencies in nature: 1. The tendency to lose energy 2. The tendency to go toward more disorder I emphasize the signs of $\boldsymbol{\Delta H}$ and $\boldsymbol{\Delta S}$, noting that a spontaneous reaction has a $\boldsymbol{-\Delta G}$. Students are asked to connect the above equation to the following reactions: • Room temperature water is cooled to ice • Room temperature water is converted to steam I place isopropyl alcohol on the back of a student volunteer's hand and the other students share their observations.

Students should place emphasis on the relationship between the heat production shown by the use of a calorimeter and the heat capacity of that calorimeter.

I like to look at the pluses and minuses. For example:

$\boldsymbol{\Delta G = \Delta H - T\Delta S}$

(-) -T(+)

Once the students have correctly identified the signs of ΔH and ΔS, we begin varying the temperature. Students see that increasing or decreasing the temperature may affect the spontaneity of a reaction. Students realize that many properties (such as freezing-point temperature) may be described as a temperature when the $\boldsymbol{\Delta G < 0}$.

Essential Questions: ▼ When an auto mechanic informs you that your car battery is "dead," what does that mean at the molecular level? ▼ If we say a reaction "takes place," what factors make that happen? ▼ If you have metal fillings in your teeth, why does biting on aluminum foil cause so much pain? ▼ Why do saltwater fishermen place Zn plates on their boats' engines?

Learning Objectives	Materials	Instructional Activities and Assessments
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]		**Formative Assessment:** A student mixes equal amounts of solid barium hydroxide octahydrate and solid ammonium nitrate in a 250 mL Erlenmeyer flask. The flask is swirled vigorously, and I solicit observations from the class. In a take-home assessment, students explain their observations in terms of ΔG, ΔH, and ΔS. This assessment is used to determine the students' level of understanding of these basic concepts.
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]	Zumdahl and Zumdahl, Chapter 16: "Spontaneity, Entropy, and Free Energy," Sections 16.1–16.6 Hnatow and Trivedi, Chapter 18: "Spontaneity and Chemical Change," Sections 18.1–18.5, 18.12, and 18.6–18.11	**Instructional Activity:** The relaxation of a stretched rubber band is a spontaneous reaction. Students are asked to make observations regarding the change in temperature of a relaxing rubber band. They then determine the enthalpy and entropy of the reaction. Pairs of students pose a question related to the thermodynamics of a stretched rubber band, then design and carry out an investigation to answer the question. Pairs present their questions, investigations, and associated results to the rest of the class.
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] 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]	Zumdahl and Zumdahl, Chapter 16: "Spontaneity, Entropy, and Free Energy," Sections 16.7–16.9 Hnatow and Trivedi, Chapter 18: "Spontaneity and Chemical Change," Sections 18.13–18.19	**Instructional Activity:** Students review qualitative and quantitative descriptions of chemical reactions and physical changes, using previous laboratory activities and previous AP test questions. Students connect these descriptions to enthalpic and entropic changes.

Wide rubber bands should be used for this activity. To show how heat affects the relaxation of the rubber band, set up a ring stand with a utility clamp. Place a heated rubber band over the clamp, and support a large mass from the rubber band. The mass should only stretch the rubber band 70%–90% of the maximum.

Essential Questions: ▼ When an auto mechanic informs you that your car battery is "dead," what does that mean at the molecular level? ▼ If we say a reaction "takes place," what factors make that happen? ▼ If you have metal fillings in your teeth, why does biting on aluminum foil cause so much pain? ▼ Why do saltwater fishermen place Zn plates on their boats' engines?

Learning Objectives	Materials	Instructional Activities and Assessments
		Summative Assessment: In-class exam (timed: 45 minutes) consisting of multiple-choice and free-response questions related to qualitative and quantitative aspects of thermodynamics.
Identify redox reactions, and justify the identification in terms of electron transfer. [LO 3.8, SP 6.1]		**Instructional Activity:** I begin with two beakers. Different cells are constructed by adding different electrodes, different solutions, a salt bridge, and a voltmeter. Students identify the redox reactions within the galvanic cells. Next, students identify the anode and cathode of the cells and the reactions that occur at each electrode. They also calculate the total voltage within the cells.
Identify redox reactions, and justify the identification in terms of electron transfer. [LO 3.8, SP 6.1] 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]	Vonderbrink, Experiment 18: "Electrochemical Cells" Zumdahl and Zumdahl, Chapter 17: "Electrochemistry," Sections 17.1–17.5 Hnatow and Trivedi, Chapter 19: "Electrochemistry," Sections 19.1–19.6	**Instructional Activity:** Students use metals and their corresponding metallic ions prepared as 1 M nitrate solutions. They create simple cells in well plates and measure the resulting voltage. From this data, a reduction potential series is established. Students then design an investigation to determine how a change in the concentration of one of the metallic ions or a change in temperature affects the voltage of a cell.
Design and/or interpret the results of an experiment involving a redox titration. [LO 3.9, SP 4.2, SP 5.1]	Vonderbrink, Experiment 10: "Analysis of a Commercial Bleach"	**Instructional Activity:** Students use the technique of redox titration to determine the concentration of commercial bleach.

This assessment addresses the essential question, If we say a reaction "takes place," what factors make that happen?

Normally I like to start a new topic with a lab activity, but a description of the parts of an electrochemical cell and the determination of the total voltage is important before students enter the lab.

Preparation for this lab is very important. The strips of metal must be cut, 1 M solutions must be made, and strips of filter paper must be cut. I have my students prepare these components the day before. Students need to have many experiences preparing a lab.

Essential Questions: ▼ When an auto mechanic informs you that your car battery is "dead," what does that mean at the molecular level? ▼ If we say a reaction "takes place," what factors make that happen? ▼ If you have metal fillings in your teeth, why does biting on aluminum foil cause so much pain? ▼ Why do saltwater fishermen place Zn plates on their boats' engines?

Learning Objectives	Materials	Instructional Activities and Assessments
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 17.6–17.8 Hnatow and Trivedi, Chapter 19: "Electrochemistry," Sections 19.17–19.20	**Instructional Activity:** When students enter the classroom, I begin two demonstrations: Demo 1: (Requires a fume hood) A solution of $CuBr_2$ is placed in a large U-tube. Electrodes are placed in each end. A DC power supply is attached and turned on. Demo 2: A metal spoon or fork is used as an electrode and is placed into a large container that contains a solution of $AgNO_3$. A piece of silver is used as the second electrode. A DC power supply is connected with an ammeter connected in series. The mass of the spoon is given to the students and the time when the power supply is turned on is noted. The current is periodically noted.
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]	Hnatow and Trivedi, Chapter 19: "Electrochemistry," Sections 19.11–19.15	**Instructional Activity:** Thermodynamic and electrochemistry problems are reviewed. We examine Gibbs free energy equation, the relationship between E_{total} and the free energy, and the relationship between the free energy and the equilibrium constant. Previous AP test questions are examined and worked out in small groups and as a class.
		Formative Assessment: Students are given a take-home exam and associated rubric that covers the concepts of the entire unit. Common misconceptions are explained after students return the exams. The take-home exam also provides students with the opportunity to qualitatively and quantitatively evaluate spontaneous and nonspontaneous electrochemical cells.
		Summative Assessment: In-class exam (timed: 45 minutes) consisting of multiple-choice and free-response questions pertaining to galvanic and electrolytic cells as well as the underlying redox reactions.

Students will potentially see a color change in each demonstration and should be able to explain what happens at each electrode.

Reviewing the common misconceptions will help your students perform well on the final assessment. It is also helpful in your growth as a teacher. Make notes of these misconceptions for the next time you teach thermodynamics and electrochemistry.

This assessment addresses the following essential questions:

- When an auto mechanic informs you that your car battery is "dead," what does that mean at the molecular level?
- If you have metal fillings in your teeth, why does biting on aluminum foil cause so much pain?

Atomic Structure and the Periodic Table

Laboratory Investigations:

- Bohr's Atom: Hydrogen's Bright-line Spectrum
- An Activity Series

Estimated Time:

14 days

Essential Questions: ▼ Why do Mylar balloons that are filled with hydrogen gas keep their pressure longer than balloons filled with helium gas? ▼ How does the arrangement of the outer electrons in an atom determine how the atom bonds to others and forms materials?

Learning Objectives	Materials	Instructional Activities and Assessments
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," Section 7.1 Hnatow and Trivedi, Chapter 7: "Atomic Structure and the Periodic Table," Section 7.1 **Web** "Microwaves" "Waves on a String"	**Instructional Activity:** Part I: I place a large milk chocolate candy bar in a microwave. The carousel of the microwave has been removed. The microwave is turned on until small areas of melted chocolate have been observed. Part II: I replace the candy bar with small marshmallows in a shallow Pyrex dish. When the microwave is turned on, the marshmallows will begin to rise. The distance between the areas of unmelted and melted chocolate and between the areas of unraised and raised marshmallows is one-half of a wavelength of the microwave. Students use this information to determine the frequency of the microwave. Students can use either of the PhET simulations to explain the wave characteristics of light and to connect the interaction of the microwaves with the matter in the demonstration.
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]		**Instructional Activity:** Students calculate the average mass of an atom using isotopic data. Students also use $E = mc^2$ to explain the conservation of mass for nuclear transformations.
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] 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]	Zumdahl and Zumdahl, Chapter 7: "Atomic Structure and Periodicity," Section 7.2 Hnatow and Trivedi, Chapter 7: "Atomic Structure and the Periodic Table," Section 7.24 **Web** "Photoelectric Effect"	**Instructional Activity:** Students use the PhET simulation to explain the model of the photoelectric effect. I then discuss the theory behind photoelectron spectroscopy (PES) and show students how to analyze typical data. The Hnatow and Trivedi DVD provides sample data for students to analyze and to use to describe the electronic structure of a particular atom.

Only one demonstration needs to be done, but I like to do both. Students enjoy the unusual scientific application of a kitchen appliance.

This is a first-year topic. The addition of the $E = mc^2$ equation puts the lesson at a higher level. This is not part of the AP Chemistry curriculum, but students should be exposed to it.

PES data are examined. Students need to understand how PES data are collected and what the limitations are to using PES data to describe the electronic structure of an atom.

Essential Questions: ▼ Why do Mylar balloons that are filled with hydrogen gas keep their pressure longer than balloons filled with helium gas? ▼ How does the arrangement of the outer electrons in an atom determine how the atom bonds to others and forms materials?

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]		**Instructional Activity:** The Balmer series of the hydrogen atom is viewed and the three most prominent bright lines (red, green, and blue) are measured and their wavelengths and frequencies are determined. Students place the diffraction grating at one end of a 2-meter stick and a hydrogen tube is placed at the other end. A 1-meter stick is placed perpendicular to the 2-meter stick next to the hydrogen tube. Looking through the diffraction grating, students locate the bright lines of hydrogen (or other gases) and develop their explanations of the distribution of the electrons in an atom through the data gathered in these observations. **Formative Assessment:** Students calculate the wavelength and frequency of the three main bright lines for hydrogen. Given the accepted values, students reflect on their results and determine whether they are accurate.
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] Explain the distribution of electrons using Coulomb's Law to analyze measured energies. [LO 1.8, SP 6.2] 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 7.3–7.8 Hnatow and Trivedi, Chapter 7: "Atomic Structure and the Periodic Table," Sections 7.5–7.13	**Instructional Activity:** After reviewing the Bohr's model of the atom, students use texts on modern atomic theory to refine their understanding of the quantum mechanics model. Focus topics should include electron configuration, orbital notation, paramagnetism, and diamagnetism. In groups, students analyze data associated with the above focus topics to create an explanation as to why the data suggest a need to refine the atomic model from the classic shell model to the quantum mechanical model.

I use a 2-meter stick, a 1-meter stick, a diffraction grating, and a hydrogen spectrum tube (or other gas tubes) in a discharge apparatus.

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

This should be a review of the first-year course content, except for paramagnetism and diamagnetism. Quantum numbers have been removed from the new curriculum, but I find their inclusion helps the students to understand the different orbitals.

Essential Questions: ▼ Why do Mylar balloons that are filled with hydrogen gas keep their pressure longer than balloons filled with helium gas? ▼ How does the arrangement of the outer electrons in an atom determine how the atom bonds to others and forms materials?

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] 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 7: "Atomic Structure and Periodicity," Sections 7.10–7.13 Hnatow and Trivedi, Chapter 7: "Atomic Structure and the Periodic Table," Sections 7.15–7.21	**Instructional Activity:** Students tie the explanation of effective nuclear charge to the observed periodic table trends. Students will be able to describe trends in atomic properties based on the number of protons and the arrangement of the electrons.
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]	Vonderbrink, Experiment 5: "An Activity Series"	**Instructional Activity:** Students investigate the comparable reactivity of a select group of metals and the comparable reactivity of a select group of halogens. Different combinations of metals followed by different combinations of halogens are reacted. The results are used to create a reactivity series for metals and the halogens.
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]		**Formative Assessment:** Students create a reactivity series for a select group of metals and halogens. Students then compare their results to the reduction table that is part of the AP Chemistry Exam.

Students need to know what shielding is and why the trends behave the way they do. When describing periodic trends, simply using the phrase "Shielding says . . ." is similar to using the term LeChatelier's *to describe the effects of a stress on equilibrium. Rubrics are written to assess the student's understanding of the basic principles.*

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

Essential Questions: ▼ Why do Mylar balloons that are filled with hydrogen gas keep their pressure longer than balloons filled with helium gas? ▼ How does the arrangement of the outer electrons in an atom determine how the atom bonds to others and forms materials?

Learning Objectives	Materials	Instructional Activities and Assessments
Justify with evidence the arrangement of the periodic table and apply periodic properties to chemical reactivity. [LO 1.10, SP 6.1]	Hnatow and Trivedi, Chapter 7: "Atomic Structure and the Periodic Table," Sections 7.22–7.24	**Instructional Activity:** Pairs of students pick a property from the periodic table and plot that property versus atomic number. On the graph, students draw vertical lines at the end of each period.
		Formative Assessment: Students look at the general shape of their graphs within a period and from period to period. They provide a claim as to whether or not a trend exists within a period or between periods for a particular property.
		Instructional Activity: Students share their graphs from the previous activity with the class. This is followed by a discussion of the trends based on the plotted data. Students summarize each of the presentations by describing the horizontal and vertical trends on the periodic table.
		Formative Assessment: Students are given a take-home exam and associated rubric that covers the concepts of the entire unit. Common misconceptions are explained after students return the exams.
		Summative Assessment: In-class exam (timed: 45 minutes) consisting of multiple-choice and free-response questions. Emphasis should be placed on the periodic table and the trends. Student responses are scored with a rubric that is at a difficulty level similar to those used to grade the AP Exam.

I provide feedback to students based on their responses. Depending on the results, additional group or individual work may be necessary.

Reviewing the common misconceptions will help your students perform well on the final assessment. It is also helpful in your growth as a teacher. Make notes of these misconceptions for the next time you teach atomic structure/ the periodic table.

This assessment addresses the essential question, How does the arrangement of the outer electrons in an atom determine how the atom bonds to others and forms materials?

Laboratory Investigations:

- Building Covalent Molecules
- Investigation of Ionic, Covalent, and Metallic Bonds: The Mystery of the Unlabeled Chemicals and How They Can Be Identified *(guided inquiry)*

Estimated Time: *16 days*

Essential Questions: ▼ When tested in the laboratory, how can two hydrocarbons labeled C_3H_6O differ in properties? ▼ How can there be so many different kinds of things if there are only 92 naturally occurring elements? ▼ What makes carbon the perfect atom for the center of almost every organic molecule? ▼ What would life based on silicon be like?

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] 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 8: "Bonding: General Concepts," Sections 8.1–8.6 Hnatow and Trivedi, Chapter 8: "Chemical Bonding," Sections 8.1–8.3	**Instructional Activity:** Beginning with the concepts of oxidation and reduction, students develop their own models of an ionic crystal. After Coulomb's Law is introduced to relate the charge of the ions to the lattice energy and the concept of different cations and anions is used to calculate the force between ions, students apply Coulomb's Law to describe the interactions and attractions between ions and solvents and connect properties such as boiling point and solubility to representations of the ionic crystals dissolved in water.

This is a first-year topic, except for the addition of Coulomb's Law. With the rearrangement of topics, ionic bonding is easier for students to grasp. Atoms losing and gaining electrons was explained in the electrochemistry unit. It is important to stress that there is no bond with 100 percent ionic character.

Essential Questions: ▼ When tested in the laboratory, how can two hydrocarbons labeled C_3H_6O differ in properties? ▼ How can there be so many different kinds of things if there are only 92 naturally occurring elements? ▼ What makes carbon the perfect atom for the center of almost every organic molecule? ▼ What would life based on silicon be like?

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] 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]		**Instructional Activity:** The sea of electrons model to represent a metal is developed through a series of demonstrations: Demonstrations: • A wire will conduct electricity. • A metal will conduct heat. • A 9-volt battery will ignite a piece of steel wool. • A small piece of Na metal reacts with water to form a base. • A metal is malleable. Students use observations made during the demonstrations to explain the flow of a single electron through a wire. They discuss how imperfections in the wire act as resistance to the flow. Additionally, students create a representation of metallic solids to show the flow of electrons and connect structure to properties such as malleability and conductivity.
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]	Zumdahl and Zumdahl, Chapter 8: "Bonding: General Concepts," Sections 8.7–8.13 Hnatow and Trivedi, Chapter 8: "Chemical Bonding," Sections 8.4–8.13 **Web** "Molecule Shapes"	**Instructional Activity:** Covalent bonding is introduced with Trivedi's AP Achievement DVD and PhET's "Molecule Shapes" simulation. Both offer exceptional visualizations that are easy to follow. Beginning with a carbon atom, hydrogen atoms are added to create methane. From there, students combine different atoms to create a variety of Lewis diagrams and molecular models for hydrocarbons.

From physics, the actual rate of flow of electrons is introduced to remove the misconception of electrons going from point A to B instantaneously.

Essential Questions: ▼ When tested in the laboratory, how can two hydrocarbons labeled C_3H_6O differ in properties? ▼ How can there be so many different kinds of things if there are only 92 naturally occurring elements? ▼ What makes carbon the perfect atom for the center of almost every organic molecule? ▼ What would life based on silicon be like?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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]		**Instructional Activity:** Covalent molecules are built using kits that may be purchased from most vendors. Students build a variety of molecules, draw their Lewis dot diagrams, determine their molecular shape, and describe their bond angles. Students use the VSEPR model to determine the molecular shapes.

Most kits do not allow you to show molecules that use an expanded octet. Octahedral molecular shapes are not possible. Choices would be to purchase kits that do allow this, use software to show a 2-D representation, or use gum balls and toothpicks to make these structures. These shapes are part of the curriculum and should be shown to your students.

Essential Questions: ▼ When tested in the laboratory, how can two hydrocarbons labeled C_3H_6O differ in properties? ▼ How can there be so many different kinds of things if there are only 92 naturally occurring elements? ▼ What makes carbon the perfect atom for the center of almost every organic molecule? ▼ What would life based on silicon be like?

Learning Objectives	Materials	Instructional Activities and Assessments
Use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [LO 2.21, SP 1.4] 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] 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]	Zumdahl and Zumdahl, Chapter 9: "Covalent Bonding: Orbitals," Sections 9.1–9.2 Hnatow and Trivedi, Chapter 9: "Molecular Geometry and Hybridization of Atomic Orbitals," Sections 9.1–9.12	**Instructional Activity:** Hybridization, resonance, and molecular orbital theory. The Hnatow and Trivedi DVD is used to show how molecular orbitals hybridize to allow for more bonds. Resonance is explained by looking at the different possible structures that SO_3 may form. Molecular orbital theory is explained as a parallel to atomic theory developed in Unit 5. Students compare and contrast molecular orbitals with atomic orbitals. Additionally, students draw resonance structures and identify hybridization on such structures.
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]		**Instructional Activity:** Investigation of Ionic, Covalent, and Metallic Bonds: The Mystery of the Unlabeled Chemicals and How They Can Be Identified: Students design a method that can provide data for the determination of the identity or type of chemicals of unlabeled bottles from the chemical storeroom.

Bonding

(continued)

Essential Questions: ▼ When tested in the laboratory, how can two hydrocarbons labeled C_3H_6O differ in properties? ▼ How can there be so many different kinds of things if there are only 92 naturally occurring elements? ▼ What makes carbon the perfect atom for the center of almost every organic molecule? ▼ What would life based on silicon be like?

Learning Objectives	Materials	Instructional Activities and Assessments
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]		**Instructional Activity:** As a class, we discuss the process for the determination of the enthalpy of a reaction using bond energies. Then, using bond energy data, we determine the enthalpy of a reaction. Students then work in pairs to calculate the enthalpy of a reaction that they randomly pull out of a container.
		Formative Assessment: Students are given a take-home exam and associated rubric that covers the concepts of the entire unit. Common misconceptions are explained after students return their exams.
		Summative Assessment: In-class exam (timed: 60 minutes) consisting of multiple-choice and free-response questions. Students must be able to represent a chemical bond in a diagram, calculate the bond energies, and describe a bond in an essay.

This is a simple topic, but many students do not correctly calculate the enthalpy correctly. Two misconceptions are common:
(1) Students do not recognize the importance of the stoichiometry of the reaction.
(2) When the enthalpy is determined using Hess's law, students learn "products-reactants."
Many students therefore use this to incorrectly calculate the enthalpy.

Reviewing the common misconceptions will help your students perform well on the final assessment. It is also helpful in your growth as a teacher. Make notes of these misconceptions for the next time you teach bonding.

This assessment addresses the essential question, What makes carbon the perfect atom for the center of almost every organic molecule?

Unit 7: Solutions and Intermolecular Forces

Laboratory Investigations:

- Molecular Mass by Freezing Point Depression
- An Investigation of Chemical and Physical Properties *(guided inquiry)*
- Chromatography of a Popular Consumer Beverage *(guided inquiry)*

Estimated Time:

12 days

Essential Questions: ▼ How can a nonpolar substance have a higher melting point than a polar substance? ▼ How are solutions formed?

Learning Objectives	Materials	Instructional Activities and Assessments
	Vonderbrink, Experiment 8: "Molecular Mass by Freezing Point Depression"	**Instructional Activity:** Although colligative properties have been removed from the AP Chemistry curriculum, the Molecular Mass by Freezing Point Depression lab is worth the time to show a microscale lab technique.
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] 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] 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] ***(learning objectives continue)***	Zumdahl and Zumdahl, Chapter 10: "Liquids and Solids," Sections 10.1–10.2 and 10.8–10.9, and Chapter 11: "Properties of Solutions," Sections 11.4–11.5 and 11.7–11.8 Hnatow and Trivedi, Chapter 10: "Intermolecular Forces and Liquid Properties," Sections 10.1–10.5	**Instructional Activity:** Intermolecular forces in all phases of matter need to be examined. I start by explaining what causes an intermolecular force and what factors influence the strength of these forces. After the concept of intermolecular forces has been discussed, I stress their importance in explaining observed properties. Students write responses to prior exam questions in class and as homework. I emphasize that the mass of atoms is not to be used in the discussion of these forces.

Students need to be exposed to the style of questions and the type of response expected on the AP Exam. More so than with other topics, the use of the proper terms and the complete explanation of concepts is critical when discussing intermolecular forces. Having your students write responses to many essay questions is a good strategy. Help your students see what the question is asking and what is expected in a "good" answer.

Essential Questions: ▼ How can a nonpolar substance have a higher melting point than a polar substance? ▼ How are solutions formed?

Learning Objectives	Materials	Instructional Activities and Assessments
(continued) 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]		
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]		**Instructional Activity:** Students design an appropriate flowchart to accurately depict an experimental procedure and design for making macroscopic observations to infer whether chemical or physical changes have occurred during a separation experiment for determining the composition of an imaginary pharmaceutical drug. Students also describe and create particulate-level representations of these changes using concepts of solubility, boiling point, and chemical reactivity.
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] 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] Identify redox reactions and justify the identification in terms of electron transfer. [LO 3.8, SP 6.1] 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]		**Instructional Activity:** Students practice using the colors of ions and the most common oxidation states of specific elements to determine the products of a reaction. Given the reactants of a reaction, the class works on determining the product(s).

Prior to reorganizing the curriculum, I would spend a week at the beginning of the course on this topic. Now, covering this at the end, time is saved and it is a great review of the entire course.

Essential Questions: ▼ How can a nonpolar substance have a higher melting point than a polar substance? ▼ How are solutions formed?

Learning Objectives	Materials	Instructional Activities and Assessments
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] 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] Explain how solutes can be separated by chromatography based on intermolecular interactions. [LO 2.7, SP 6.2]	Hostage and Fossett, Experiment 15: "Chromatography of a Popular Consumer Beverage"	**Instructional Activity:** Students begin by separating the dye in the coating of an M&M candy. Students are allowed to experiment with different solvents. After the technique has been explored, students select a beverage that they would like to investigate.
		Formative Assessment: Students are given a take-home exam and associated rubric that covers the concepts of the entire unit. Common misconceptions are explained after students return their exams.
		Summative Assessment: In-class exam (timed: 60 minutes) consisting of multiple-choice and free-response questions. Emphasis should be placed on the difference between intermolecular and intramolecular forces, and the proper use of terminology in the essay responses should be stressed.

This fun lab activity allows students to investigate the dyes found in common foods. Chromatography is often a topic for the first-year chemistry course. This lab activity is a unique way to look at consumer chemistry.

Reviewing the common misconceptions will help your students perform well on the final assessment. It is also helpful in your growth as a teacher. Make notes of these misconceptions for the next time you teach solutions and intermolecular forces.

This assessment addresses the essential question, How are solutions formed?

Resources

General Resources

Textbook

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

Laboratory Manuals

Hostage, David, and Martin Fossett. *Laboratory Investigations: AP* Chemistry*. Saddle Brook, NJ: Peoples Education, 2006.

Vonderbrink, Sally Ann. *Laboratory Experiments for Advanced Placement Chemistry*. Batavia, IL: Flinn Scientific, 1995.

DVDs and Online Simulations

Hnatow, John, and Ketan Trivedi. *High School Chemistry for AP Achievement: An Interactive Multimedia Course on DVD-ROM*. Blacksburg, VA: Trivedi Chemistry, 2012.

"Simulations: Chemistry." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://phet.colorado.edu/en/simulations/category/chemistry.

Unit 0 (Review of Stoichiometry and Nomenclature) Resources

No unit-specific resources

Unit 1 (Gas Laws) Resources

"Gas Properties." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://phet.colorado.edu/en/simulation/gas-properties.

Unit 2 (Kinetics) Resources

"Job Switching." *I Love Lucy*, Season 2, Episode 4. Directed by William Asher. Written by J. Oppenheimer, M. Davis. Produced by Desi Arnaz. First aired September 15, 1952. *I Love Lucy: The Complete Second Season*. Paramount, 2004. DVD.

"Reactions & Rates." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://PhET.colorado.edu/en/simulation/reactions-and-rates.

Unit 3 (Equilibrium) Resources

"Dueling Aquariums: An Equilibrium Demonstration" (Publication No. 211). Chem-Fax. Flinn Scientific. Batavia, IL: Flinn Scientific, 1995. Accessed June 14, 2012. http://www.svusd.org/hp_images/3313/D18544-aquariumequilibrium.pdf.

"Salts & Solubility." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://PhET.colorado.edu/en/simulation/soluble-salts.

Unit 4 (Thermodynamics and Electrochemistry) Resources

No unit-specific resources

Unit 5 (Atomic Structure and the Periodic Table) Resource

"Microwaves." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://phet.colorado.edu/en/simulation/microwaves.

"Photoelectric Effect." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://phet.colorado.edu/en/simulation/photoelectric.

"Waves on a String." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://phet.colorado.edu/en/simulation/wave-on-a-string.

Unit 6 (Bonding) Resources

"Molecule Shapes." PhET. University of Colorado at Boulder. Accessed June 14, 2012. http://phet.colorado.edu/en/simulation/molecule-shapes.

Unit 7 (Solutions and Intermolecular Forces) Resources

No unit-specific resources