Main Criteria: AP Chemistry Course Description
Secondary Criteria: JoVE
Subject: Science
Grade: 9-12
Correlation Options: Show Correlated
Adopted: 2013

Outline Level 1	**AP.C.1.**	**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.**
Outline Level 2	**EU.1.A.**	**All matter is made of atoms. There are a limited number of types of atoms; these are the elements.**
Outline Level 3	**EK.1.A.1.**	**Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in differing amounts and proportions.**
Outline Level 4	**1.A.1.a.**	**The average mass of any large number of atoms of a given element is always the same for a given element.** **JoVE** • **Freezing-Point Depression to Determine an Unknown Compound** • **Introduction to Mass Spectrometry** • **MALDI-TOF Mass Spectrometry** • **Tandem Mass Spectrometry**
Outline Level 4	**1.A.1.b.**	**A pure sample contains particles (or units) of one specific atom or molecule; a mixture contains particles (or units) of more than one specific atom or molecule.** **JoVE** • **Calibration Curves** • **Capillary Electrophoresis (CE)** • **Chromatography-Based Biomolecule Purification Methods** • **Column Chromatography** • **Conducting Reactions Below Room Temperature** • **Cyclic Voltammetry (CV)** • **Degassing Liquids with Freeze-Pump-Thaw Cycling**

		• Density Gradient Ultracentrifugation • Determining the Density of a Solid and Liquid • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Ion-Exchange Chromatography • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Two-Dimensional Gel Electrophoresis
Outline Level 4	1.A.1.d.	Pairs of elements that form more than one type of molecule are nonetheless limited by their atomic nature to combine in whole number ratios. This discrete nature can be confirmed by calculating the difference in mass percent ratios between such types of molecules. JoVE • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry
Outline Level 4	LO 1.1.	The student can 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. [See SP 6.1] JoVE • Determining the Empirical Formula
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.A.	All matter is made of atoms. There are a limited number of types of atoms; these are the elements.
Outline Level 3	EK.1.A.2.	Chemical analysis provides a method for determining the relative number of atoms in a substance, which can be used to identify the substance or determine its purity.
Outline Level 4	1.A.2.a.	Because compounds are composed of atoms with known masses, there is a correspondence between the mass percent of the elements in a compound and the relative number of atoms of each element. JoVE • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry
Outline Level 4	1.A.2.b.	An empirical formula is the lowest whole number ratio of atoms in a compound. Two molecules of the same elements with identical mass percent of their constituent atoms will have identical empirical formulas. JoVE • Determining the Empirical Formula
Outline Level 4	1.A.2.c.	Because pure compounds have a specific mass percent of each element, experimental measurements of mass percents can be used to verify the purity of compounds. JoVE • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry
Outline Level 4	LO 1.2.	The student is able to select and apply mathematical routines to mass data to identify or infer the composition of pure substances and/or mixtures. [See SP 2.2] JoVE • Calibration Curves • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Introduction to Mass Spectrometry • Introduction to Titration • MALDI-TOF Mass Spectrometry

		• Method of Standard Addition • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Tandem Mass Spectrometry
Outline Level 4	LO 1.3.	The student is able to select and apply mathematical relationships to mass data in order to justify a claim regarding the identity and/or estimated purity of a substance. [See SP 2.2, 6.1] JoVE • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.A.	All matter is made of atoms. There are a limited number of types of atoms; these are the elements.
Outline Level 3	EK.1.A.3.	The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.
Outline Level 4	1.A.3.a.	Atoms and molecules interact with one another on the atomic level. Balanced chemical equations give the number of particles that react and the number of particles produced. Because of this, expressing the amount of a substance in terms of the number of particles, or moles of particles, is essential to understanding chemical processes. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells

		• Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	1.A.3.b.	Expressing the mass of an individual atom or molecule in atomic mass unit (amu) is useful because the average mass in amu of one particle (atom or molecule) of a substance will always be numerically equal to the molar mass of that substance in grams. <u>JoVE</u> • Freezing-Point Depression to Determine an Unknown Compound • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry
Outline Level 4	1.A.3.c.	Avogadro's number provides the connection between the number of moles in a pure sample of a substance and the number of constituent particles (or units) of that substance. <u>JoVE</u> • Ideal Gas Law • The Ideal Gas Law
Outline Level 4	1.A.3.d.	Thus, for any sample of a pure substance, there is a specific numerical relationship between the molar mass of the substance, the mass of the sample, and the number of particles (or units) present. <u>JoVE</u> • Freezing-Point Depression to Determine an Unknown Compound • Ideal Gas Law • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry • The Ideal Gas Law
Outline Level 4	LO 1.4.	The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively. <u>JoVE</u> • Calibration Curves • Capillary Electrophoresis (CE) • Determining Rate Laws and the Order of Reaction • Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound

		• Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Ideal Gas Law • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Photometric Protein Determination • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • The Ideal Gas Law • Understanding Concentration and Measuring Volumes
Outline Level 1	**AP.C.1.**	**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.**
Outline Level 2	**EU.1.B.**	**The atoms of each element have unique structures arising from interactions between electrons and nuclei.**
Outline Level 3	**EK.1.B.1.**	**The atom is composed of negatively charged electrons, which can leave the atom, and a positively charged nucleus that is made of protons and neutrons. The attraction of the electrons to the nucleus is the basis of the structure of the atom. Coulomb's law is qualitatively useful for understanding the structure of the atom.**
Outline Level 4	**1.B.1.d.**	**Photoelectron spectroscopy (PES) provides a useful means to engage students in the use of quantum mechanics to interpret spectroscopic data and extract information on atomic structure from such data. In particular, low-resolution PES of atoms provides direct evidence for the shell model. Light consists of photons, each of which has energy E = hν, where h is Planck's constant and ν is the frequency of the light. In the photoelectric effect, incident light ejects electrons from a material. This requires the photon to have sufficient energy to eject the electron. Photoelectron spectroscopy determines the energy needed to eject electrons from the material. Measurement of these energies provides a method to deduce the shell structure of an atom. The intensity of the photoelectron signal at a given energy is a measure of the number of electrons in that energy level.** **JoVE** • Coordination Chemistry Complexes • Förster Resonance Energy Transfer (FRET)

		• Gas Chromatography (GC) with Flame-Ionization Detection • Introduction to Fluorescence Microscopy • Introduction to the Microplate Reader • Lead Analysis of Soil Using Atomic Absorption Spectroscopy • MALDI-TOF Mass Spectrometry • Method of Standard Addition • Nuclear Magnetic Resonance (NMR) Spectroscopy • Raman Spectroscopy for Chemical Analysis • Tandem Mass Spectrometry • X-ray Fluorescence (XRF)
Outline Level 4	1.B.1.e.	The electronic structure of atoms with multiple electrons can be inferred from evidence provided by PES. For instance, both electrons in He are identical, and they are both roughly the same distance from the nucleus as in H, while there are two shells of electrons in Li, and the outermost electron is further from the nucleus than in H. <u>JoVE</u> • Coordination Chemistry Complexes
Outline Level 4	LO 1.5.	The student is able to explain the distribution of electrons in an atom or ion based upon data. [See SP 1.5, 6.2] <u>JoVE</u> • Nuclear Magnetic Resonance (NMR) Spectroscopy
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.B.	The atoms of each element have unique structures arising from interactions between electrons and nuclei.
Outline Level 3	EK.1.B.2.	The electronic structure of the atom can be described using an electron configuration that reflects the concept of electrons in quantized energy levels or shells; the energetics of the electrons in the atom can be understood by consideration of Coulomb’s law.
Outline Level 4	1.B.2.c.	In multielectron atoms and ions, the electrons can be thought of as being in “shells” and “subshells,” as indicated by the relatively close ionization energies associated with some groups of electrons. Inner electrons are called core electrons, and outer electrons are called valence electrons. <u>JoVE</u> • Coordination Chemistry Complexes • Nuclear Magnetic Resonance (NMR) Spectroscopy • Raman Spectroscopy for Chemical Analysis

		• Ultraviolet-Visible (UV-Vis) Spectroscopy • X-ray Fluorescence (XRF)
Outline Level 4	1.B.2.d.	Core electrons are generally closer to the nucleus than valence electrons, and they are considered to “shield” the valence electrons from the full electrostatic attraction of the nucleus. This phenomenon can be used in conjunction with Coulomb’s law to explain/rationalize/predict relative ionization energies. Differences in electron-electron repulsion are responsible for the differences in energy between electrons in different orbitals in the same shell. JoVE • Coordination Chemistry Complexes • Nuclear Magnetic Resonance (NMR) Spectroscopy • Raman Spectroscopy for Chemical Analysis • Ultraviolet-Visible (UV-Vis) Spectroscopy • X-ray Fluorescence (XRF)
Outline Level 4	LO 1.7.	The student is able to 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. [See SP 5.1, 6.2] JoVE • Coordination Chemistry Complexes • Nuclear Magnetic Resonance (NMR) Spectroscopy • Raman Spectroscopy for Chemical Analysis • Ultraviolet-Visible (UV-Vis) Spectroscopy • X-ray Fluorescence (XRF)
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.C.	Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle for understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.
Outline Level 3	EK.1.C.1.	Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Outline Level 4	1.C.1.a.	The structure of the periodic table is a consequence of the pattern of electron configurations and the presence of shells (and subshells) of electrons in atoms.

		JoVE • Coordination Chemistry Complexes
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.C.	Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle for understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.
Outline Level 3	EK.1.C.1.	Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Outline Level 4	1.C.1.d.	Periodicity is a useful tool when designing new molecules or materials, since replacing an element of one group with another of the same group may lead to a new substance with similar properties. For instance, since SiO2 can be a ceramic, SnO2 may be as well. JoVE • Coordination Chemistry Complexes
Outline Level 4	LO 1.9.	The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model. [See SP 6.4] JoVE • Coordination Chemistry Complexes
Outline Level 4	LO 1.10.	Students can justify with evidence the arrangement of the periodic table and can apply periodic properties to chemical reactivity. [See SP 6.1] JoVE • Coordination Chemistry Complexes
Outline Level 4	LO 1.11.	The student can 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. [See SP 3.1, 5.1] JoVE • Coordination Chemistry Complexes
Outline Level 1	AP.C.1.	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.

Outline Level 2	EU.1.C.	Elements display periodicity in their properties when the elements are organized according to increasing atomic number. This periodicity can be explained by the regular variations that occur in the electronic structures of atoms. Periodicity is a useful principle for understanding properties and predicting trends in properties. Its modern-day uses range from examining the composition of materials to generating ideas for designing new materials.
Outline Level 3	EK.1.C.2.	The currently accepted best model of the atom is based on the quantum mechanical model.
Outline Level 4	1.C.2.b.	Electrons are not considered to follow specific orbits. Chemists refer to the region of space in which an electron is found as an orbital. JoVE • Coordination Chemistry Complexes • Nuclear Magnetic Resonance (NMR) Spectroscopy • Raman Spectroscopy for Chemical Analysis • Ultraviolet-Visible (UV-Vis) Spectroscopy • X-ray Fluorescence (XRF)
Outline Level 4	1.C.2.c.	Electrons in atoms have an intrinsic property known as spin that can result in atoms having a magnetic moment. There can be at most two electrons in any orbital, and these electrons must have opposite spin. JoVE • Nuclear Magnetic Resonance (NMR) Spectroscopy
Outline Level 4	1.C.2.e.	The QM model can be approximately solved using computers and serves as the basis for software that calculates the structure and reactivity of molecules. JoVE • Coordination Chemistry Complexes
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.D.	Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.
Outline Level 3	EK.1.D.2.	An early model of the atom stated that all atoms of an element are identical. Mass spectrometry data demonstrate evidence that contradicts this early model.
Outline Level 4	1.D.2.b.	Data from mass spectrometry also demonstrate direct evidence of different isotopes from the same element. JoVE • Metabolic Labeling

Outline Level 4	1.D.2.c.	The average atomic mass can be estimated from mass spectra. JoVE • Freezing-Point Depression to Determine an Unknown Compound • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry
Outline Level 4	LO 1.14.	The student is able to use data from mass spectrometry to identify the elements and the masses of individual atoms of a specific element. [See SP 1.4, 1.5] JoVE • Metabolic Labeling
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.D.	Atoms are so small that they are difficult to study directly; atomic models are constructed to explain experimental data on collections of atoms.
Outline Level 3	EK.1.D.3.	The interaction of electromagnetic waves or light with matter is a powerful means to probe the structure of atoms and molecules, and to measure their concentration.
Outline Level 4	1.D.3.b.	Different types of molecular motion lead to absorption or emission of photons in different spectral regions. Infrared radiation is associated with transitions in molecular vibrations and so can be used to detect the presence of different types of bonds. Ultraviolet/visible radiation is associated with transitions in electronic energy levels and so can be used to probe electronic structure. JoVE • Coordination Chemistry Complexes • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Introduction to Fluorescence Microscopy • Introduction to the Microplate Reader • Lead Analysis of Soil Using Atomic Absorption Spectroscopy • MALDI-TOF Mass Spectrometry • Method of Standard Addition • Nuclear Magnetic Resonance (NMR) Spectroscopy • Raman Spectroscopy for Chemical Analysis • Tandem Mass Spectrometry • X-ray Fluorescence (XRF)

Outline Level 4	LO 1.15.	The student can justify the selection of a particular type of spectroscopy to measure properties associated with vibrational or electronic motions of molecules. [See SP 4.1, 6.4] JoVE • Community DNA Extraction from Bacterial Colonies • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determination Of Nox in Automobile Exhaust Using UV-VIS Spectroscopy • Determining the Empirical Formula • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • Internal Standards • Introduction to Catalysis • Introduction to Mass Spectrometry • Introduction to the Spectrophotometer • Lead Analysis of Soil Using Atomic Absorption Spectroscopy • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Method of Standard Addition • Nuclear Magnetic Resonance (NMR) Spectroscopy • Nutrients in Aquatic Ecosystems • Photometric Protein Determination • Plasmid Purification • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Solid-Liquid Extraction • Spectrophotometric Determination of an Equilibrium Constant • Tandem Mass Spectrometry • Ultraviolet-Visible (UV-Vis) Spectroscopy • X-ray Fluorescence (XRF) • Yeast Maintenance
Outline Level 4	LO 1.16.	The student can 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. [See SP 4.2, 5.1] JoVE • Coordination Chemistry Complexes • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Introduction to Fluorescence Microscopy • Introduction to the Microplate Reader • Lead Analysis of Soil Using Atomic Absorption

		Spectroscopy • MALDI-TOF Mass Spectrometry • Method of Standard Addition • Nuclear Magnetic Resonance (NMR) Spectroscopy • Raman Spectroscopy for Chemical Analysis • Tandem Mass Spectrometry • X-ray Fluorescence (XRF)
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.E.	Atoms are conserved in physical and chemical processes.
Outline Level 3	EK.1.E.1.	Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
Outline Level 4	1.E.1.a.	Various types of representations can be used to show that matter is conserved during chemical and physical processes.
Outline Level 5	1.E.1.a.1.	Symbolic representations <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.E.	Atoms are conserved in physical and chemical processes.
Outline Level 3	EK.1.E.1.	Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
Outline Level 4	1.E.1.c.	The concept of conservation of atoms plays an important role in the interpretation and analysis of many chemical processes on the macroscopic scale. Conservation of

		atoms should be related to how nonradioactive atoms are neither lost nor gained as they cycle among land, water, atmosphere, and living organisms. JoVE • Determining the Empirical Formula
Outline Level 1	AP.C.1.	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.
Outline Level 2	EU.1.E.	Atoms are conserved in physical and chemical processes.
Outline Level 3	EK.1.E.2.	Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.
Outline Level 4	1.E.2.a.	The number of atoms, molecules, or formula units in a given mass of substance can be calculated. JoVE • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry
Outline Level 4	1.E.2.b.	The subscripts in a chemical formula represent the number of atoms of each type in a molecule. JoVE • Determining the Empirical Formula
Outline Level 4	1.E.2.c.	The coefficients in a balanced chemical equation represent the relative numbers of particles that are consumed and created when the process occurs. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations

		• Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	1.E.2.d.	The concept of conservation of atoms plays an important role in the interpretation and analysis of many chemical processes on the macroscopic scale. <u>JoVE</u> • Determining the Empirical Formula
Outline Level 4	1.E.2.e.	In gravimetric analysis, a substance is added to a solution that reacts specifically with a dissolved analyte (the chemical species that is the target of the analysis) to form a solid. The mass of solid formed can be used to infer the concentration of the analyte in the initial sample. <u>JoVE</u> • Calibration Curves • Capillary Electrophoresis (CE) • Determining Rate Laws and the Order of Reaction • Determining the Density of a Solid and Liquid • Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Measuring Mass in the Laboratory • Passaging Cells • Photometric Protein Determination • Physical Properties Of Minerals II: Polymineralic Analysis • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • The ELISA Method • Understanding Concentration and Measuring Volumes
Outline Level 4	1.E.2.f.	Titrations may be used to determine the concentration of an analyte in a solution. The titrant has a known concentration of a species that reacts specifically with the analyte. The equivalence of the titration occurs when

		the analyte is totally consumed by the reacting species in the titrant. The equivalence point is often indicated by a change in a property (such as color) that occurs when the equivalence point is reached. This observable event is called the end point of the titration. JoVE • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations
Outline Level 4	LO 1.18.	The student is able to apply conservation of atoms to the rearrangement of atoms in various processes. [See SP 1.4] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 1.19.	The student can design, and/or interpret data from, an experiment that uses gravimetric analysis to determine the concentration of an analyte in a solution. [See SP 4.2, 5.1, 6.4] JoVE • Calibration Curves • Capillary Electrophoresis (CE) • Determining Rate Laws and the Order of Reaction • Determining the Density of a Solid and Liquid • Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader

		• Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Measuring Mass in the Laboratory • Photometric Protein Determination • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Understanding Concentration and Measuring Volumes
Outline Level 4	LO 1.20.	The student can design, and/or interpret data from, an experiment that uses titration to determine the concentration of an analyte in a solution. [See SP 4.2, 5.1, 6.4] JoVE • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.A.	Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.
Outline Level 3	EK.2.A.1.	The different properties of solids and liquids can be explained by differences in their structures, both at the particulate level and in their supramolecular structures.
Outline Level 4	2.A.1.a.	Solids can be crystalline, where the particles are arranged in a regular 3-D structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo any overall translation with respect to each other. Interparticle interactions and the ability to pack the particles together provide the main criteria for the structures of solids. JoVE • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Separation of Mixtures via Precipitation • Solid-Liquid Extraction

Outline Level 4	2.A.1.b.	The constituent particles in liquids are very close to each other, and they are continually moving and colliding. The particles are able to undergo translation with respect to each other and their arrangement, and movement is influenced by the nature and strength of the intermolecular forces that are present. JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Growing Crystals for X-ray Diffraction Analysis • Purifying Compounds by Recrystallization • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 4	2.A.1.c.	The solid and liquid phases for a particular substance generally have relatively small differences in molar volume because in both cases the constituent particles are very close to each other at all times. JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 4	2.A.1.d.	The differences in other properties, such as viscosity, surface tension, and volumes of mixing (for liquids), and hardness and macroscopic crystal structure (for solids), can be explained by differences in the strength of attraction between the particles and/or their overall organization. JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation

		• Solid-Liquid Extraction • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	2.A.1.e.	Heating and cooling curves for pure substances provide insight into the energetic of liquid/solid phase changes. JoVE • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.3.	The student is able to 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. [See SP 6.4, 7.1] JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling

		• Fractional Distillation • Growing Crystals for X-ray Diffraction Analysis • Ideal Gas Law • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • The Ideal Gas Law
Outline Level 1	**AP.C.2.**	**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.**
Outline Level 2	**EU.2.A.**	**Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.**
Outline Level 3	**EK.2.A.2.**	**The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.**
Outline Level 4	**2.A.2.a.**	**Ideal gases exhibit specific mathematical relationships among the number of particles present, the temperature, the pressure, and the volume.** **JoVE** • Determining Rate Laws and the Order of Reaction • Ideal Gas Law • The Ideal Gas Law
Outline Level 4	**2.A.2.c.**	**Graphical representations of the relationships between P, V, and T are useful to describe gas behavior.** **JoVE** • Determining Rate Laws and the Order of Reaction • Ideal Gas Law • The Ideal Gas Law
Outline Level 4	**2.A.2.d.**	**Kinetic molecular theory combined with a qualitative use of the Maxwell-Boltzmann distribution provides a robust model for qualitative explanations of these mathematical relationships.** **JoVE** • Determining Rate Laws and the Order of Reaction • Fractional Distillation

		• Ideal Gas Law • The Ideal Gas Law
Outline Level 4	2.A.2.e.	Some real gases exhibit ideal or near-ideal behavior under typical laboratory conditions. Laboratory data can be used to generate or investigate the relationships in 2.A.2.a and to estimate absolute zero on the Celsius scale. JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Determining Rate Laws and the Order of Reaction • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • Ideal Gas Law • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • The Ideal Gas Law
Outline Level 4	2.A.2.f.	All real gases are observed to deviate from ideal behavior, particularly under conditions that are close to those resulting in condensation. Except at extremely high pressures that are not typically seen in the laboratory, deviations from ideal behavior are the result of intermolecular attractions among gas molecules. These forces are strongly distance-dependent, so they are most significant during collisions. JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Determining Rate Laws and the Order of Reaction • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • Ideal Gas Law • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • The Ideal Gas Law
Outline Level 4	2.A.2.g.	Observed deviations from ideal gas behavior can be explained through an understanding of the structure of atoms and molecules and their intermolecular interactions. JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • Ideal Gas Law • Schlenk Lines Transfer of Solvents

		• Separation of Mixtures via Precipitation • The Ideal Gas Law
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] <u>JoVE</u> • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • Ideal Gas Law • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • The Ideal Gas Law
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.4.	The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors. [See SP 1.4, 6.4] <u>JoVE</u> • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • Ideal Gas Law • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • The Ideal Gas Law
Outline Level 4	LO 2.5.	The student is able to 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. [See SP 1.3, 6.4, 7.2]

		<u>JoVE</u> • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • Ideal Gas Law • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • The Ideal Gas Law
Outline Level 4	LO 2.6.	The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases. [See SP 2.2, 2.3] <u>JoVE</u> • Determining Rate Laws and the Order of Reaction • Ideal Gas Law • The Ideal Gas Law
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.A.	Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.
Outline Level 3	EK.2.A.3.	Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.
Outline Level 4	2.A.3.a.	In a solution (homogeneous mixture), the macroscopic properties do not vary throughout the sample. This is in contrast to a heterogeneous mixture in which the macroscopic properties depend upon the location in the mixture. The distinction between heterogeneous and homogeneous depends on the length scale of interest. As an example, colloids may be heterogeneous on the scale of micrometers, but homogeneous on the scale of centimeters. <u>JoVE</u> • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE)

		• Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant • Two-Dimensional Gel Electrophoresis • Understanding Concentration and Measuring Volumes • Using a pH Meter

Outline Level 4	2.A.3.b.	Solutions come in the form of solids, liquids, and gases. JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent

		• Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant • Two-Dimensional Gel Electrophoresis • Understanding Concentration and Measuring Volumes • Using a pH Meter
Outline Level 4	2.A.3.c.	For liquid solutions, the solute may be a gas, a liquid, or a solid. JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to the Microplate Reader • Ion-Exchange Chromatography • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization

		• Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Solid-Liquid Extraction • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Understanding Concentration and Measuring Volumes
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.A.	Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.
Outline Level 3	EK.2.A.3.	Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.
Outline Level 4	2.A.3.d.	Based on the reflections of their structure on the microscopic scale, liquid solutions exhibit several general properties:
Outline Level 5	2.A.3.d.1.	The components cannot be separated by using filter paper. <u>JoVE</u> • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts

		Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant • Two-Dimensional Gel Electrophoresis • Understanding Concentration and Measuring Volumes • Using a pH Meter
Outline Level 5	2.A.3.d.2.	There are no components large enough to scatter visible light. JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions

		• Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant

		• Two-Dimensional Gel Electrophoresis • Understanding Concentration and Measuring Volumes • Using a pH Meter
Outline Level 5	2.A.3.d.3.	The components can be separated using processes that are a result of the intermolecular interactions between and among the components. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Carbon and Nitrogen Analysis of Environmental Samples • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Ion-Exchange Chromatography • MALDI-TOF Mass Spectrometry • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Tandem Mass Spectrometry
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.A.	Matter can be described by its physical properties. The physical properties of a substance generally depend on the spacing between the particles (atoms, molecules, ions) that make up the substance and the forces of attraction among them.
Outline Level 3	EK.2.A.3.	Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.
Outline Level 4	2.A.3.e.	Chromatography (paper and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components. JoVE • Calibration Curves

		• Capillary Electrophoresis (CE) • Carbon and Nitrogen Analysis of Environmental Samples • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Ion-Exchange Chromatography • MALDI-TOF Mass Spectrometry • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Solid-Liquid Extraction • Tandem Mass Spectrometry
Outline Level 4	**2.A.3.f.**	**Distillation is used to separate chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Fractional Distillation • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 4	**2.A.3.g.**	**The formation of a solution may be an exothermic or endothermic process, depending on the relative strengths of intermolecular/interparticle interactions before and after the dissolution process.** **JoVE** • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV)

		• Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant • Two-Dimensional Gel Electrophoresis • Understanding Concentration and Measuring Volumes • Using a pH Meter
Outline Level 4	2.A.3.h.	Generally, when ionic compounds are dissolved in water, the component ions are separated and dispersed. The presence of ions in a solution can be detected by use of conductivity measurements.

		<u>JoVE</u> • Biofuels: Producing Ethanol from Cellulosic Material • Calibration Curves • Capillary Electrophoresis (CE) • Cyclic Voltammetry (CV) • DNA Gel Electrophoresis • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Electrophoretic Mobility Shift Assay (EMSA) • Gel Purification • Ion-Exchange Chromatography • Proton Exchange Membrane Fuel Cells • Separating Protein with SDS-PAGE • The Western Blot • Two-Dimensional Gel Electrophoresis
Outline Level 4	2.A.3.i.	Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory. Molarity is defined as the number of moles of solute per liter of solution. <u>JoVE</u> • Calibration Curves • Capillary Electrophoresis (CE) • Determining Rate Laws and the Order of Reaction • Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Photometric Protein Determination • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Understanding Concentration and Measuring Volumes
Outline Level 4	2.A.3.j.	Understanding how to prepare solutions of specified molarity through direct mixing of the components, through use of volumetric glassware, and by dilution of a solution of known molarity with additional solvent is important for performing laboratory work in chemistry.

		JoVE • Calibration Curves • Capillary Electrophoresis (CE) • Determining Rate Laws and the Order of Reaction • Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Photometric Protein Determination • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Understanding Concentration and Measuring Volumes
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated

		Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant • Two-Dimensional Gel Electrophoresis • Understanding Concentration and Measuring Volumes • Using a pH Meter
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography

		• Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.7.	The student is able to explain how solutes can be separated by chromatography based on intermolecular interactions. [See SP 6.2] JoVE • Calibration Curves • Capillary Electrophoresis (CE) • Carbon and Nitrogen Analysis of Environmental Samples • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Ion-Exchange Chromatography • MALDI-TOF Mass Spectrometry • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Solid-Liquid Extraction • Tandem Mass Spectrometry
Outline Level 4	LO 2.8.	The student can draw and/or interpret representations of solutions that show the interactions between the solute and solvent. [See SP 1.1, 1.2, 6.4] JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution

		• Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant • Two-Dimensional Gel Electrophoresis • Understanding Concentration and Measuring Volumes • Using a pH Meter
Outline Level 4	LO 2.9.	The student is able to create or interpret representations that link the concept of molarity with particle views of solutions. [See SP 1.1, 1.4] JoVE • Calibration Curves • Capillary Electrophoresis (CE) • Determining Rate Laws and the Order of Reaction

		• Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Photometric Protein Determination • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Understanding Concentration and Measuring Volumes
Outline Level 4	LO 2.10.	The student can 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. [See SP 4.2, 5.1, 6.4] JoVE • An Introduction to the Centrifuge • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Carbon and Nitrogen Analysis of Environmental Samples • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Column Chromatography • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrophoretic Mobility Shift Assay (EMSA) • Fractional Distillation • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Ion-Exchange Chromatography

		• MALDI-TOF Mass Spectrometry • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Rotary Evaporation to Remove Solvent • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.B.	Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.
Outline Level 3	EK.2.B.1.	London dispersion forces are attractive forces present between all atoms and molecules. London dispersion forces are often the strongest net intermolecular force between large molecules.
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.B.	Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.
Outline Level 3	EK.2.B.2.	Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force

		that exists when very electronegative atoms (N, O, and F) are involved.
Outline Level 4	**2.B.2.a.**	**Molecules with dipole moments experience Coulombic interactions that result in a net attractive interaction when they are near each other.**
Outline Level 5	**2.B.2.a.1.**	**Intermolecular dipole-dipole forces are weaker than ionic forces or covalent bonds.** **JoVE** **• Förster Resonance Energy Transfer (FRET)** **• Raman Spectroscopy for Chemical Analysis**
Outline Level 5	**2.B.2.a.2.**	**Interactions between polar molecules are typically greater than between nonpolar molecules of comparable size because these interactions act in addition to London dispersion forces.** **JoVE** **• Förster Resonance Energy Transfer (FRET)** **• Raman Spectroscopy for Chemical Analysis**
Outline Level 5	**2.B.2.a.3.**	**Dipole-dipole attractions can be represented by diagrams of attraction between the positive and negative ends of polar molecules trying to maximize attractions and minimize repulsions in the liquid or solid state.** **JoVE** **• Förster Resonance Energy Transfer (FRET)** **• Raman Spectroscopy for Chemical Analysis**
Outline Level 5	**2.B.2.a.4.**	**Dipole-induced dipole interactions are present between a polar and nonpolar molecule. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule.** **JoVE** **• An Overview of Alkenone Biomarker Analysis for Paleothermometry** **• An Overview of bGDGT Biomarker Analysis for Paleoclimatology** **• Chromatography-Based Biomolecule Purification Methods** **• Column Chromatography** **• Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry** **• Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis** **• Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction** **• Förster Resonance Energy Transfer (FRET)** **• Gas Chromatography (GC) with Flame-Ionization Detection**

		• Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 1	**AP.C.2.**	**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.**
Outline Level 2	**EU.2.B.**	**Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.**
Outline Level 3	**EK.2.B.2.**	**Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force that exists when very electronegative atoms (N, O, and F) are involved.**
Outline Level 4	**2.B.2.b.**	**Hydrogen bonding is a relatively strong type of intermolecular interaction that exists when hydrogen atoms that are covalently bonded to the highly electronegative atoms (N, O, and F) are also attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule, or a different part of the same molecule. When hydrogen bonding is present, even small molecules may have strong intermolecular attractions.** JoVE • Förster Resonance Energy Transfer (FRET) • Raman Spectroscopy for Chemical Analysis
Outline Level 4	**2.B.2.d.**	**Ionic interactions with dipoles are important in the solubility of ionic compounds in polar solvents.** JoVE • Förster Resonance Energy Transfer (FRET) • Raman Spectroscopy for Chemical Analysis

Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • Förster Resonance Energy Transfer (FRET) • Raman Spectroscopy for Chemical Analysis
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.12.	The student can qualitatively analyze data regarding real gases to identify deviations from ideal behavior and relate these to molecular interactions. [See SP 5.1, 6.5, connects to 2.A.2] JoVE • Förster Resonance Energy Transfer (FRET) • Raman Spectroscopy for Chemical Analysis
Outline Level 4	LO 2.13.	The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles. [See SP 1.4, 6.4] JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction

		• Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 1	**AP.C.2.**	**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.**
Outline Level 2	**EU.2.B.**	**Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.**
Outline Level 3	**EK.2.B.3.**	**Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.**
Outline Level 4	**2.B.3.a.**	**Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present.**
Outline Level 5	**2.B.3.a.1.**	**Boiling point** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Fractional Distillation • Growing Crystals for X-ray Diffraction Analysis • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent
Outline Level 5	**2.B.3.a.4.**	**Vapor pressure** **JoVE** • Ideal Gas Law • The Ideal Gas Law

Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.B.	Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.
Outline Level 3	EK.2.B.3.	Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Outline Level 4	2.B.3.b.	Substances with similar intermolecular interactions tend to be miscible or soluble in one another. JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to the Microplate Reader • Ion-Exchange Chromatography • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry

		• Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Solid-Liquid Extraction • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Understanding Concentration and Measuring Volumes
Outline Level 4	2.B.3.c.	The presence of intermolecular forces among gaseous particles, including noble gases, leads to deviations from ideal behavior, and it can lead to condensation at sufficiently low temperatures and/or sufficiently high pressures. JoVE • Determining Rate Laws and the Order of Reaction • Fractional Distillation • Ideal Gas Law • Rotary Evaporation to Remove Solvent • The Ideal Gas Law
Outline Level 4	2.B.3.d.	Graphs of the pressure-volume relationship for real gases can demonstrate the deviation from ideal behavior; these deviations can be interpreted in terms of the presence and strengths of intermolecular forces. JoVE • Ideal Gas Law • The Ideal Gas Law
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.B.	Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.
Outline Level 3	EK.2.B.3.	Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Outline Level 4	2.B.3.e.	The structure and function of many biological systems depend on the strength and nature of the various Coulombic forces.
Outline Level 5	2.B.3.e.1.	Substrate interactions with the active sites in enzyme catalysis JoVE • An Introduction to Cell Death • Biofuels: Producing Ethanol from Cellulosic Material • Co-Immunoprecipitation and Pull-Down Assays

		• Coordination Chemistry Complexes • DNA Ligation Reactions • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis • Live Cell Imaging of Mitosis • Molecular Cloning • PCR: The Polymerase Chain Reaction • Restriction Enzyme Digests • The ELISA Method • The TUNEL Assay
Outline Level 5	**2.B.3.e.2.**	**Hydrophilic and hydrophobic regions in proteins that determine three-dimensional structure in water solutions** **JoVE** • An Introduction to Cell Motility and Migration • An Introduction to Saccharomyces cerevisiae • An Overview of Epigenetics • An Overview of Gene Expression • Cell-surface Biotinylation Assay • Chromatin Immunoprecipitation • Co-Immunoprecipitation and Pull-Down Assays • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Drosophila Larval IHC • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Genetic Engineering of Model Organisms • Introduction to Catalysis • Introduction to Mass Spectrometry • Invasion Assay Using 3D Matrices • Ion-Exchange Chromatography • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Photometric Protein Determination • Protein Crystallization • Reconstitution of Membrane Proteins • Separating Protein with SDS-PAGE • Separation of Mixtures via Precipitation • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The ELISA Method • The Transwell Migration Assay • The Western Blot • Two-Dimensional Gel Electrophoresis • Yeast Transformation and Cloning

Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.B.	Forces of attraction between particles (including the noble gases and also different parts of some large molecules) are important in determining many macroscopic properties of a substance, including how the observable physical state changes with temperature.
Outline Level 3	EK.2.B.3.	Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • An Introduction to Caenorhabditis elegans • An Introduction to Cell Death • An Introduction to Cell Division • An Introduction to Cell Metabolism • An Introduction to Cell Motility and Migration • An Introduction to Developmental Genetics • An Introduction to Molecular Developmental Biology • An Introduction to Saccharomyces cerevisiae • An Introduction to Transfection • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of Epigenetics • An Overview of Gene Expression • An Overview of Genetic Analysis • An Overview of Genetic Engineering • An Overview of Genetics and Disease • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Annexin V and Propidium Iodide Labeling • Assembly of a Reflux System for Heated Chemical Reactions • Bacterial Transformation: Electroporation • Bacterial Transformation: The Heat Shock Method • C. elegans Maintenance • Calibration Curves • Capillary Electrophoresis (CE) • Cell Cycle Analysis • Cell-surface Biotinylation Assay • Chromatin Immunoprecipitation • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Column Chromatography • Common Lab Glassware and Uses • Community DNA Extraction from Bacterial Colonies

		• Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Cytogenetics • DNA Gel Electrophoresis • DNA Ligation Reactions • DNA Methylation Analysis • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Detecting Reactive Oxygen Species • Determining Rate Laws and the Order of Reaction • Determining the Density of a Solid and Liquid • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Development and Reproduction of the Laboratory Mouse • Development of the Chick • Dialysis: Diffusion Based Separation • Drosophila Larval IHC • Drosophila melanogaster Embryo and Larva Harvesting and Preparation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Electrophoretic Mobility Shift Assay (EMSA) • Embryonic Stem Cell Culture and Differentiation • Enzyme Assays and Kinetics • Explant Culture for Developmental Studies • Expression Profiling with Microarrays • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • FM Dyes in Vesicle Recycling • Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Gel Purification • Gene Silencing with Morpholinos • Genetic Crosses • Genetic Engineering of Model Organisms • Genetic Screens • Genome Editing • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ideal Gas Law

		• In ovo Electroporation of Chicken Embryos • Induced Pluripotency • Internal Standards • Introduction to Catalysis • Introduction to Mass Spectrometry • Introduction to Titration • Invasion Assay Using 3D Matrices • Invertebrate Lifespan Quantification • Ion-Exchange Chromatography • Isolating Nucleic Acids from Yeast • Le Châtelier's Principle • Live Cell Imaging of Mitosis • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Method of Standard Addition • Molecular Cloning • Mouse Genotyping • Nuclear Magnetic Resonance (NMR) Spectroscopy • PCR: The Polymerase Chain Reaction • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Plasmid Purification • Preparing Anhydrous Reagents and Equipment • Protein Crystallization • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Quantifying Environmental Microorganisms and Viruses Using qPCR • RNA Analysis of Environmental Samples Using RT-PCR • RNA-Seq • RNAi in C. elegans • Raman Spectroscopy for Chemical Analysis • Recombineering and Gene Targeting • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Restriction Enzyme Digests • Rotary Evaporation to Remove Solvent • SNP Genotyping • Sample Preparation for Analytical Preparation • Scanning Electron Microscopy (SEM) • Schlenk Lines Transfer of Solvents • Separating Protein with SDS-PAGE • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Spectrophotometric Determination of an Equilibrium Constant

		• Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The ATP Bioluminescence Assay • The ELISA Method • The Ideal Gas Law • The TUNEL Assay • The Transwell Migration Assay • The Western Blot • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy • Using a pH Meter • Whole-Mount In Situ Hybridization • X-ray Fluorescence (XRF) • Yeast Maintenance • Yeast Transformation and Cloning • Zebrafish Breeding and Embryo Handling • Zebrafish Microinjection Techniques • Zebrafish Reproduction and Development
Outline Level 4	**LO 2.2.**	**The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6]** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	**LO 2.15.**	**The student is able to 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. [See SP 1.4, 6.2, connects to 5.E.1]** **JoVE** • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Degassing Liquids with Freeze-Pump-Thaw Cycling • Determining the Solubility Rules of Ionic Compounds • Extraction of Biomarkers from Sediments - Accelerated

		Solvent Extraction • Growing Crystals for X-ray Diffraction Analysis • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 4	LO 2.16.	The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces. [See SP 6.2] JoVE • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Performing 1D Thin Layer Chromatography • Purifying Compounds by Recrystallization • Separation of Mixtures via Precipitation
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Outline Level 3	EK.2.C.1.	In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.
Outline Level 4	2.C.1.c.	Two or more valence electrons shared between atoms of identical electronegativity constitute a nonpolar covalent bond. JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry

		• An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Outline Level 3	EK.2.C.1.	In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.
Outline Level 4	2.C.1.d.	However, bonds between carbon and hydrogen are often considered to be nonpolar even though carbon is slightly more electronegative than hydrogen. The formation of a nonpolar covalent bond can be represented graphically as a plot of potential energy vs. distance for the interaction of two identical atoms. Hydrogen atoms are often used as an example.
Outline Level 5	2.C.1.d.1.	The relative strengths of attractive and repulsive forces as a function of distance determine the shape of the graph.

		JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	2.C.1.d.2.	The bond length is the distance between the bonded atoms’ nuclei, and is the distance of minimum potential energy where the attractive and repulsive forces are balanced. JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea

		Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	2.C.1.d.3.	The bond energy is the energy required for the dissociation of the bond. This is the net energy of stabilization of the bond compared to the two separated atoms. Typically, bond energy is given on a per mole basis. <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Outline Level 3	EK.2.C.1.	In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.
Outline Level 4	2.C.1.e.	Two or more valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond.
Outline Level 5	2.C.1.e.1.	The difference in electronegativity for the two atoms involved in a polar covalent bond is not equal to zero. <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification

		Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	2.C.1.e.2.	The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond. For diatomic molecules, the partial negative charge on the more electronegative atom is equal in magnitude to the partial positive charge on the less electronegative atom. <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis

		• High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	**2.C.1.e.3.**	**Greater differences in electronegativity lead to greater partial charges, and consequently greater bond dipoles.** JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Förster Resonance Energy Transfer (FRET) • Purification of a Total Lipid Extract with Column Chromatography • Raman Spectroscopy for Chemical Analysis • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	**2.C.1.e.4.**	**The sum of partial charges in any molecule or ion must be equal to the overall charge on the species.** JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry

		• Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	**AP.C.2.**	**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.**
Outline Level 2	**EU.2.C.**	**The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.**
Outline Level 3	**EK.2.C.1.**	**In covalent bonding, electrons are shared between the nuclei of two atoms to form a molecule or polyatomic ion. Electronegativity differences between the two atoms account for the distribution of the shared electrons and the polarity of the bond.**
Outline Level 4	**2.C.1.f.**	**All bonds have some ionic character, and the difference between ionic and covalent bonding is not distinct but rather a continuum. The difference in electronegativity is not the only factor in determining if a bond is designated ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and between two nonmetals the bonds are covalent. Examination of the properties of a compound is the best way to determine the type of bonding.** **JoVE** • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods

		• Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Determining the Solubility Rules of Ionic Compounds • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy • X-ray Fluorescence (XRF)
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure,

		interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.18.	The student is able to rank and justify the ranking of bond polarity on the basis of the locations of the bonded atoms in the periodic table. [See SP 6.1] <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment

		- Soxhlet Extraction of Lipid Biomarkers from Sediment - Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Outline Level 3	EK.2.C.2.	Ionic bonding results from the net attraction between oppositely charged ions, closely packed together in a crystal lattice.
Outline Level 4	2.C.2.a.	The cations and anions in an ionic crystal are arranged in a systematic, periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces. JoVE - Determining the Solubility Rules of Ionic Compounds - Physical Properties Of Minerals I: Crystals and Cleavage - Protein Crystallization - Raman Spectroscopy for Chemical Analysis
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Outline Level 3	EK.2.C.2.	Ionic bonding results from the net attraction between oppositely charged ions, closely packed together in a crystal lattice.
Outline Level 4	2.C.2.b.	Coulomb’s law describes the force of attraction between the cations and anions in an ionic crystal.
Outline Level 5	2.C.2.b.1.	Because the force is proportional to the charge on each ion, larger charges lead to stronger interactions. JoVE - Determining the Solubility Rules of Ionic Compounds - Physical Properties Of Minerals I: Crystals and Cleavage - Protein Crystallization - Raman Spectroscopy for Chemical Analysis
Outline Level 5	2.C.2.b.2.	Because the force is inversely proportional to the square of the distance between the centers of the ions (nuclei), smaller ions lead to stronger interactions. JoVE - Determining the Solubility Rules of Ionic Compounds - Physical Properties Of Minerals I: Crystals and Cleavage - Protein Crystallization - Raman Spectroscopy for Chemical Analysis

Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Outline Level 3	EK.2.C.2.	Ionic bonding results from the net attraction between oppositely charged ions, closely packed together in a crystal lattice.
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • Determining the Solubility Rules of Ionic Compounds
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.19.	The student can 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). [See SP 1.1, 1.4, 7.1, connects to 2.D.1, 2.D.2] JoVE • Determining the Solubility Rules of Ionic Compounds
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.

Outline Level 3	EK.2.C.3.	Metallic bonding describes an array of positively charged metal cores surrounded by a sea of mobile valence electrons.
Outline Level 4	2.C.3.a.	The valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom. JoVE • X-ray Fluorescence (XRF)
Outline Level 4	2.C.3.b.	Metallic bonding can be represented as an array of positive metal ions with valence electrons drawn among them, as if the electrons were moving (i.e., a sea of electrons). JoVE • X-ray Fluorescence (XRF)
Outline Level 4	2.C.3.c.	The electron sea model can be used to explain several properties of metals, including electrical conductivity, malleability, ductility, and low volatility. JoVE • X-ray Fluorescence (XRF)
Outline Level 4	2.C.3.d.	The number of valence electrons involved in metallic bonding, via the shell model, can be used to understand patterns in these properties, and can be related to the shell model to reinforce the connections between metallic bonding and other forms of bonding. JoVE • X-ray Fluorescence (XRF)
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • X-ray Fluorescence (XRF)
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography

		• Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.20.	The student is able to 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. [See SP 6.2, 7.1, connects to 2.D.2] JoVE • X-ray Fluorescence (XRF)
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.C.	The strong electrostatic forces of attraction holding atoms together in a unit are called chemical bonds.
Outline Level 3	EK.2.C.4.	The localized electron bonding model describes and predicts molecular geometry using Lewis diagrams and the VSEPR model.
Outline Level 4	2.C.4.g.	Organic chemists commonly use the terms “hybridization” and “hybrid orbital” to describe the arrangement of electrons around a central atom. When there is a bond angle of 180°, the central atom is said to be sp hybridized; for 120°, the central atom is sp^2 hybridized; and for 109°, the central atom is sp3 hybridized. Students should be aware of this terminology, and be able to use it. When an atom has more than four pairs of electrons surrounding the central atom, students are only responsible for the shape of the resulting molecule. JoVE • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat
Outline Level 4	2.C.4.h.	Bond formation is associated with overlap between atomic orbitals. In multiple bonds, such overlap leads to the formation of both sigma and pi bonds. The overlap is stronger in sigma than pi bonds, which is reflected in sigma bonds having larger bond energy than pi bonds. The presence of a pi bond also prevents the rotation of the bond, and leads to structural isomers. In systems, such as benzene, where atomic p-orbitals overlap strongly with more than one other p-orbital, extended pi bonding exists, which is delocalized across more than two nuclei. Such descriptions provide an alternative description to resonance in Lewis structures. A useful example of delocalized pi bonding is molecular solids that conduct electricity. The discovery of such materials at the end of the 1970s overturned a long-standing

		assumption in chemistry that molecular solids will always be insulators. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Sonication Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.21.	The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity. [See SP 1.4] <u>JoVE</u> • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	LO 2.22.	The student is able to design or evaluate a plan to collect and/or interpret data needed to deduce the type of bonding in a sample of a solid. [See SP 4.2, 6.4] <u>JoVE</u> • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization

		• Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.1.	Ionic solids have high melting points, are brittle, and conduct electricity only when molten or in solution.
Outline Level 4	2.D.1.a.	Many properties of ionic solids are related to their structure.
Outline Level 5	2.D.1.a.1.	Ionic solids generally have low vapor pressure due to the strong Coulombic interactions of positive and negative ions arranged in a regular three-dimensional array. JoVE • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 5	2.D.1.a.2.	Ionic solids tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. JoVE • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 5	2.D.1.a.3.	Ionic solids do not conduct electricity. However, when ionic solids are melted, they do conduct electricity because the ions are free to move. JoVE • Physical Properties Of Minerals I: Crystals and Cleavage • Protein Crystallization • Raman Spectroscopy for Chemical Analysis
Outline Level 5	2.D.1.a.4.	When ionic solids are dissolved in water, the separated ions are free to move; therefore, these solutions will conduct electricity. Dissolving a nonconducting solid in water, and observing the solution’s ability to conduct

		electricity, is one way to identify an ionic solid. JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Proton Exchange Membrane Fuel Cells
Outline Level 5	2.D.1.a.5.	Ionic compounds tend not to dissolve in nonpolar solvents because the attractions among the ions are much stronger than the attractions among the separated ions and the nonpolar solvent molecules. JoVE • Physical Properties Of Minerals I: Crystals and Cleavage • Protein Crystallization • Raman Spectroscopy for Chemical Analysis
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.1.	Ionic solids have high melting points, are brittle, and conduct electricity only when molten or in solution.
Outline Level 4	2.D.1.b.	The attractive force between any two ions is governed by Coulomb's law: The force is directly proportional to the charge of each ion and inversely proportional to the square of the distance between the centers of the ions.
Outline Level 5	2.D.1.b.1.	For ions of a given charge, the smaller the ions, and thus the smaller the distance between ion centers, the stronger the Coulombic force of attraction, and the higher the melting point. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Degassing Liquids with Freeze-Pump-Thaw Cycling • Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Preparing Anhydrous Reagents and Equipment • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy

Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.1.	Ionic solids have high melting points, are brittle, and conduct electricity only when molten or in solution.
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • Determining the Solubility Rules of Ionic Compounds
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.23.	The student can create a representation of an ionic solid that shows essential characteristics of the structure and interactions present in the substance. [See SP 1.1] JoVE • Degassing Liquids with Freeze-Pump-Thaw Cycling • Determining the Solubility Rules of Ionic Compounds • Fractional Distillation • Growing Crystals for X-ray Diffraction Analysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction
Outline Level 4	LO 2.24.	The student is able to explain a representation that connects properties of an ionic solid to its structural attributes and to the interactions present at the atomic

		level. [See SP 1.1, 6.2, 7.1] JoVE • Determining the Solubility Rules of Ionic Compounds
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.2.	Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny, malleable, ductile, and readily alloyed.
Outline Level 4	2.D.2.a.	A metallic solid can be represented as positive kernels (or cores) consisting of the nucleus and inner electrons of each atom surrounded by a sea of mobile valence electrons.
Outline Level 5	2.D.2.a.1.	Metals are good conductors because the electrons are delocalized and relatively free to move. JoVE • Chromatography-Based Biomolecule Purification Methods • Coordination Chemistry Complexes • Determining the Solubility Rules of Ionic Compounds • Introduction to Mass Spectrometry • X-ray Fluorescence (XRF)
Outline Level 5	2.D.2.a.2.	Metals are malleable and ductile because deforming the solid does not change the environment immediately surrounding each metal core. JoVE • Chromatography-Based Biomolecule Purification Methods • Coordination Chemistry Complexes • Determining the Solubility Rules of Ionic Compounds • Introduction to Mass Spectrometry • X-ray Fluorescence (XRF)
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.2.	Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny, malleable, ductile, and readily alloyed.
Outline Level 4	2.D.2.b.	Metallic solids are often pure substances, but may also be mixtures called alloys.

Outline Level 5	2.D.2.b.1a.	Some properties of alloys can be understood in terms of the size of the component atoms: Interstitial alloys form between atoms of different radius, where the smaller atoms fill the interstitial spaces between the larger atoms. (Steel is an example in which carbon occupies the interstices in iron.) The interstitial atoms make the lattice more rigid, decreasing malleability and ductility. JoVE • Physical Properties Of Minerals I: Crystals and Cleavage • Protein Crystallization • Raman Spectroscopy for Chemical Analysis
Outline Level 5	2.D.2.b.1b.	Some properties of alloys can be understood in terms of the size of the component atoms: Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (Brass is an example in which some copper atoms are substituted with a different element, usually zinc.) The density typically lies between those of the component metals, and the alloy remains malleable and ductile. JoVE • Physical Properties Of Minerals I: Crystals and Cleavage • Protein Crystallization • Raman Spectroscopy for Chemical Analysis
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.2.	Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny, malleable, ductile, and readily alloyed.
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • Chromatography-Based Biomolecule Purification Methods • Coordination Chemistry Complexes • Determining the Solubility Rules of Ionic Compounds • Introduction to Mass Spectrometry • X-ray Fluorescence (XRF)
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE

		• Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.27.	The student can create a representation of a metallic solid that shows essential characteristics of the structure and interactions present in the substance. [See SP 1.1] JoVE • Chromatography-Based Biomolecule Purification Methods • Coordination Chemistry Complexes • Determining the Solubility Rules of Ionic Compounds • Introduction to Mass Spectrometry • X-ray Fluorescence (XRF)
Outline Level 4	LO 2.28.	The student is able to explain a representation that connects properties of a metallic solid to its structural attributes and to the interactions present at the atomic level. See SP 1.1, 6.2, 7.1] JoVE • Chromatography-Based Biomolecule Purification Methods • Coordination Chemistry Complexes • Determining the Solubility Rules of Ionic Compounds • Introduction to Mass Spectrometry • X-ray Fluorescence (XRF)
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.3.	Covalent network solids generally have extremely high melting points, are hard, and are thermal insulators. Some conduct electricity.
Outline Level 4	2.D.3.a.	Covalent network solids consist of atoms that are covalently bonded together into a two-dimensional or three-dimensional network.
Outline Level 5	2.D.3.a.3.	Covalent network solids have high melting points because all of the atoms are covalently bonded. JoVE

		• An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Coordination Chemistry Complexes • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Fractional Distillation • Introduction to Catalysis • MALDI-TOF Mass Spectrometry • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	**2.D.3.a.4.**	**Three-dimensional covalent networks tend to be rigid and hard because the covalent bond angles are fixed.** **JoVE** • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Coordination Chemistry Complexes • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Fractional Distillation

		• Introduction to Catalysis • MALDI-TOF Mass Spectrometry • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	**2.D.3.a.5.**	**Generally, covalent network solids form in the carbon group because of their ability to form four covalent bonds.** **JoVE** • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Coordination Chemistry Complexes • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Fractional Distillation • Introduction to Catalysis • MALDI-TOF Mass Spectrometry • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy

Outline Level 1	**AP.C.2.**	**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.**
Outline Level 2	**EU.2.D.**	**The type of bonding in the solid state can be deduced from the properties of the solid state.**
Outline Level 3	**EK.2.D.3.**	**Covalent network solids generally have extremely high melting points, are hard, and are thermal insulators. Some conduct electricity.**
Outline Level 4	**LO 2.1.**	**Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1]** **JoVE** **• An Overview of Alkenone Biomarker Analysis for Paleothermometry** **• An Overview of bGDGT Biomarker Analysis for Paleoclimatology** **• Chromatography-Based Biomolecule Purification Methods** **• Column Chromatography** **• Conducting Reactions Below Room Temperature** **• Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry** **• Coordination Chemistry Complexes** **• Density Gradient Ultracentrifugation** **• Dialysis: Diffusion Based Separation** **• Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction** **• Fractional Distillation** **• Introduction to Catalysis** **• MALDI-TOF Mass Spectrometry** **• Nuclear Magnetic Resonance (NMR) Spectroscopy** **• Performing 1D Thin Layer Chromatography** **• Preparing Anhydrous Reagents and Equipment** **• Purification of a Total Lipid Extract with Column Chromatography** **• Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry** **• Sonication Extraction of Lipid Biomarkers from Sediment** **• Soxhlet Extraction of Lipid Biomarkers from Sediment** **• Tandem Mass Spectrometry** **• Two-Dimensional Gel Electrophoresis** **• Ultraviolet-Visible (UV-Vis) Spectroscopy**
Outline Level 4	**LO 2.2.**	**The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6]** **JoVE**

		• Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.29.	The student can create a representation of a covalent solid that shows essential characteristics of the structure and interactions present in the substance. [See SP 1.1] <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Coordination Chemistry Complexes • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Fractional Distillation • Introduction to Catalysis • MALDI-TOF Mass Spectrometry • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 2.30.	The student is able to explain a representation that connects properties of a covalent solid to its structural attributes and to the interactions present at the atomic level. [See SP 1.1, 6.2, 7.1]

		JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Coordination Chemistry Complexes • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Fractional Distillation • Introduction to Catalysis • MALDI-TOF Mass Spectrometry • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.4.	Molecular solids with low molecular weight usually have low melting points and are not expected to conduct electricity as solids, in solution, or when molten.
Outline Level 4	2.D.4.a.	Molecular solids consist of nonmetals, diatomic elements, or compounds formed from two or more nonmetals. JoVE • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Density Gradient Ultracentrifugation

		• Dialysis: Diffusion Based Separation • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Protein Crystallization • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis
Outline Level 1	**AP.C.2.**	**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.**
Outline Level 2	**EU.2.D.**	**The type of bonding in the solid state can be deduced from the properties of the solid state.**
Outline Level 3	**EK.2.D.4.**	**Molecular solids with low molecular weight usually have low melting points and are not expected to conduct electricity as solids, in solution, or when molten.**
Outline Level 4	**2.D.4.b.**	**Molecular solids are composed of distinct, individual units of covalently bonded molecules attracted to each other through relatively weak intermolecular forces.**
Outline Level 5	**2.D.4.b.1.**	**Molecular solids are not expected to conduct electricity because their electrons are tightly held within the covalent bonds of each constituent molecule.** **JoVE** • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Introduction to Mass Spectrometry

		• MALDI-TOF Mass Spectrometry • Metabolic Labeling • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Protein Crystallization • Purification of a Total Lipid Extract with Column Chromatography • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	2.D.4.b.2.	Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Protein Crystallization • Purification of a Total Lipid Extract with Column Chromatography • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea

		Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 5	2.D.4.b.3.	Molecular solids are sometimes composed of very large molecules, or polymers, with important commercial and biological applications. JoVE • An Introduction to Caenorhabditis elegans • An Introduction to Cell Death • An Introduction to Cell Division • An Introduction to Cell Metabolism • An Introduction to Cell Motility and Migration • An Introduction to Developmental Genetics • An Introduction to Molecular Developmental Biology • An Introduction to Saccharomyces cerevisiae • An Introduction to Transfection • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of Epigenetics • An Overview of Gene Expression • An Overview of Genetic Analysis • An Overview of Genetic Engineering • An Overview of Genetics and Disease • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Annexin V and Propidium Iodide Labeling • Bacterial Transformation: Electroporation • Bacterial Transformation: The Heat Shock Method • C. elegans Maintenance • Capillary Electrophoresis (CE) • Cell Cycle Analysis • Cell-surface Biotinylation Assay • Chromatin Immunoprecipitation • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Column Chromatography • Community DNA Extraction from Bacterial Colonies • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cytogenetics • DNA Gel Electrophoresis • DNA Ligation Reactions • DNA Methylation Analysis • Density Gradient Ultracentrifugation

		• Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Detecting Reactive Oxygen Species • Development and Reproduction of the Laboratory Mouse • Development of the Chick • Dialysis: Diffusion Based Separation • Drosophila Larval IHC • Drosophila melanogaster Embryo and Larva Harvesting and Preparation • Electrophoretic Mobility Shift Assay (EMSA) • Embryonic Stem Cell Culture and Differentiation • Enzyme Assays and Kinetics • Explant Culture for Developmental Studies • Expression Profiling with Microarrays • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Gel Purification • Gene Silencing with Morpholinos • Genetic Crosses • Genetic Engineering of Model Organisms • Genetic Screens • Genome Editing • In ovo Electroporation of Chicken Embryos • Induced Pluripotency • Introduction to Catalysis • Introduction to Mass Spectrometry • Invasion Assay Using 3D Matrices • Invertebrate Lifespan Quantification • Ion-Exchange Chromatography • Isolating Nucleic Acids from Yeast • Le Châtelier's Principle • Live Cell Imaging of Mitosis • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Molecular Cloning • Mouse Genotyping • PCR: The Polymerase Chain Reaction • Photometric Protein Determination • Plasmid Purification • Protein Crystallization • Purification of a Total Lipid Extract with Column Chromatography • Quantifying Environmental Microorganisms and Viruses Using qPCR • RNA Analysis of Environmental Samples Using RT-PCR • RNA-Seq • RNAi in C. elegans • Recombineering and Gene Targeting

		• Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Restriction Enzyme Digests • SNP Genotyping • Separating Protein with SDS-PAGE • Separation of Mixtures via Precipitation • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • Testing For Genetically Modified Foods • The ATP Bioluminescence Assay • The ELISA Method • The TUNEL Assay • The Transwell Migration Assay • The Western Blot • Two-Dimensional Gel Electrophoresis • Whole-Mount In Situ Hybridization • Yeast Maintenance • Yeast Transformation and Cloning • Zebrafish Breeding and Embryo Handling • Zebrafish Microinjection Techniques • Zebrafish Reproduction and Development
Outline Level 1	AP.C.2.	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.
Outline Level 2	EU.2.D.	The type of bonding in the solid state can be deduced from the properties of the solid state.
Outline Level 3	EK.2.D.4.	Molecular solids with low molecular weight usually have low melting points and are not expected to conduct electricity as solids, in solution, or when molten.
Outline Level 4	LO 2.1.	Students can predict properties of substances based on their chemical formulas, and provide explanations of their properties based on particle views. [See SP 6.4, 7.1] JoVE • X-ray Fluorescence (XRF)
Outline Level 4	LO 2.2.	The student is able to explain the relative strengths of acids and bases based on molecular structure, interparticle forces, and solution equilibrium. [See SP 7.2, connects to Big Idea 5, Big Idea 6] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC)

		• Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 2.31.	The student can create a representation of a molecular solid that shows essential characteristics of the structure and interactions present in the substance. [See SP 1.1] <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Protein Crystallization • Purification of a Total Lipid Extract with Column Chromatography • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 2.32.	The student is able to explain a representation that connects properties of a molecular solid to its structural attributes and to the interactions present at the atomic level. [See SP 1.1, 6.2, 7.1]

		<u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Density Gradient Ultracentrifugation • Dialysis: Diffusion Based Separation • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Introduction to Mass Spectrometry • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Protein Crystallization • Purification of a Total Lipid Extract with Column Chromatography • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	**AP.C.3.**	**Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.**
Outline Level 2	**EU.3.A.**	**Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.**
Outline Level 3	**EK.3.A.1.**	**A chemical change may be represented by a molecular, ionic, or net ionic equation.**
Outline Level 4	**3.A.1.a.**	**Chemical equations represent chemical changes, and therefore must contain equal numbers of atoms of every element on each side to be “balanced.”**

		JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	3.A.1.b.	Depending on the context in which it is used, there are different forms of the balanced chemical equations that are used by chemists. It is important not only to write a balanced molecular, ionic, or net ionic reaction equation, but also to have an understanding of the circumstances under which any of them might be the most useful form. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	3.A.1.c.	The balanced chemical equation for a reaction is capable of representing chemistry at any level, and thus it is important that it can be translated into a symbolic depiction at the particulate level, where much of the reasoning of chemistry occurs. JoVE • Assembly of a Reflux System for Heated Chemical

		Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	3.A.1.d.	Because chemistry is ultimately an experimental science, it is important that students be able to describe chemical reactions observed in a variety of laboratory contexts. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter

Outline Level 4	LO 3.1.	Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Passaging Cells • Photometric Protein Determination • Physical Properties Of Minerals II: Polymineralic Analysis • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	LO 3.2.	The student can 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. [See SP 1.5, 7.1] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis

		• Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.A.	Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.
Outline Level 3	EK.3.A.2.	Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note, so that it does not seem to be simply an exercise done only by chemists.
Outline Level 4	3.A.2.a.	Coefficients of balanced chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations that apply the mole concept; the most important place for this type of quantitative exercise is the laboratory.
Outline Level 5	3.A.2.a.1.	Calculate amount of product expected to be produced in a laboratory experiment. JoVE • Nuclear Magnetic Resonance (NMR) Spectroscopy
Outline Level 5	3.A.2.a.2.	Identify limiting and excess reactant; calculate percent and theoretical yield for a given laboratory experiment. JoVE • Cyclic Voltammetry (CV) • Nuclear Magnetic Resonance (NMR) Spectroscopy • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.A.	Chemical changes are represented by a balanced chemical equation that identifies the ratios with which reactants react and products form.
Outline Level 3	EK.3.A.2.	Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of

		stoichiometry in real-world applications is important to note, so that it does not seem to be simply an exercise done only by chemists.
Outline Level 4	3.A.2.b.	The use of stoichiometry with gases also has the potential for laboratory experimentation, particularly with respect to the experimental determination of molar mass of a gas. <u>JoVE</u> • Calibration Curves • Capillary Electrophoresis (CE) • Determining Rate Laws and the Order of Reaction • Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Photometric Protein Determination • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Understanding Concentration and Measuring Volumes
Outline Level 4	3.A.2.c.	Solution chemistry provides an additional avenue for laboratory calculations of stoichiometry, including titrations. <u>JoVE</u> • Calibration Curves • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Dissolved Oxygen in Surface Water • Introduction to Titration • Method of Standard Addition • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	LO 3.1.	Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1]

		<u>JoVE</u> **• Assembly of a Reflux System for Heated Chemical Reactions** **• Conducting Reactions Below Room Temperature** **• Coordination Chemistry Complexes** **• Cyclic Voltammetry (CV)** **• Determining Rate Laws and the Order of Reaction** **• Determining the Empirical Formula** **• Determining the Solubility Rules of Ionic Compounds** **• Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat** **• Enzyme Assays and Kinetics** **• Growing Crystals for X-ray Diffraction Analysis** **• Introduction to Catalysis** **• Introduction to Titration** **• Le Châtelier's Principle** **• Nuclear Magnetic Resonance (NMR) Spectroscopy** **• Passaging Cells** **• Photometric Protein Determination** **• Physical Properties Of Minerals II: Polymineralic Analysis** **• Preparing Anhydrous Reagents and Equipment** **• Proton Exchange Membrane Fuel Cells** **• Purifying Compounds by Recrystallization** **• Rotary Evaporation to Remove Solvent** **• Separation of Mixtures via Precipitation** **• Solutions and Concentrations** **• Spectrophotometric Determination of an Equilibrium Constant** **• The ELISA Method** **• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy** **• Using a pH Meter**
Outline Level 4	**LO 3.3.**	**The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results. [See SP 2.2, 5.1]** **<u>JoVE</u>** **• Calibration Curves** **• Determining Rate Laws and the Order of Reaction** **• Determining the Empirical Formula** **• Determining the Mass Percent Composition in an Aqueous Solution** **• Introduction to Titration** **• Method of Standard Addition** **• Solutions and Concentrations** **• Spectrophotometric Determination of an Equilibrium Constant**
Outline Level 4	**LO 3.4.**	**The student is able to 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. [See SP 2.2, 5.1, 6.4] JoVE • Calibration Curves • Capillary Electrophoresis (CE) • Cyclic Voltammetry (CV) • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Freezing-Point Depression to Determine an Unknown Compound • Gas Chromatography (GC) with Flame-Ionization Detection • High-Performance Liquid Chromatography (HPLC) • Internal Standards • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Le Châtelier's Principle • Making Solutions in the Laboratory • Method of Standard Addition • Photometric Protein Determination • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Understanding Concentration and Measuring Volumes
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.B.	Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base, and oxidation-reduction reactions.
Outline Level 3	EK.3.B.1.	Synthesis reactions are those in which atoms and/or molecules combine to form a new compound. Decomposition is the reverse of synthesis, a process whereby molecules are decomposed, often by the use of heat.
Outline Level 4	3.B.1.a.	Synthesis or decomposition reactions can be used for acquisition of basic lab techniques and observations that help students deal with the abstractions of atoms and stoichiometric calculations. JoVE

		• Calibration Curves • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Introduction to Titration • Method of Standard Addition • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	LO 3.1.	Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1] <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Passaging Cells • Photometric Protein Determination • Physical Properties Of Minerals II: Polymineralic Analysis • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	LO 3.5.	The student is able to 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. [See SP 2.1, 4.2, 6.4]

		JoVE • Determining the Empirical Formula
Outline Level 4	LO 3.6.	The student is able to use data from synthesis or decomposition of a compound to confirm the conservation of matter and the law of definite proportions. [See SP 2.2, 6.1] JoVE • Determining the Empirical Formula
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.B.	Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base, and oxidation-reduction reactions.
Outline Level 3	EK.3.B.2.	In a neutralization reaction, protons are transferred from an acid to a base.
Outline Level 4	3.B.2.a.	The amphoteric nature of water plays an important role in the chemistry of aqueous solutions, since water can both accept protons from and donate protons to dissolved species. JoVE • High-Performance Liquid Chromatography (HPLC) • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.B.	Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base, and oxidation-reduction reactions.
Outline Level 3	EK.3.B.2.	In a neutralization reaction, protons are transferred from an acid to a base.
Outline Level 4	3.B.2.b.	Acid-base reactions:
Outline Level 5	3.B.2.b.1.	Only reactions in aqueous solutions are considered. JoVE • Using a pH Meter
Outline Level 5	3.B.2.b.3.	When an acid or base ionizes in water, the conjugate acid-base pairs can be identified and their relative strengths compared.

		JoVE • Introduction to Titration • Using a pH Meter
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.B.	Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base, and oxidation-reduction reactions.
Outline Level 3	EK.3.B.2.	In a neutralization reaction, protons are transferred from an acid to a base.
Outline Level 4	LO 3.1.	Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1] JoVE • Using a pH Meter
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.B.	Chemical reactions can be classified by considering what the reactants are, what the products are, or how they change from one into the other. Classes of chemical reactions include synthesis, decomposition, acid-base, and oxidation-reduction reactions.
Outline Level 3	EK.3.B.3.	In oxidation-reduction (redox) reactions, there is a net transfer of electrons. The species that loses electrons is oxidized, and the species that gains electrons is reduced.
Outline Level 4	3.B.3.a.	In a redox reaction, electrons are transferred from the species that is oxidized to the species that is reduced. JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • Photometric Protein Determination • Proton Exchange Membrane Fuel Cells
Outline Level 4	3.B.3.c.	Balanced chemical equations for redox reactions can be constructed from tabulated half-reactions. JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration

		• Photometric Protein Determination • Proton Exchange Membrane Fuel Cells
Outline Level 4	3.B.3.d.	Recognizing that a reaction is a redox reaction is an important skill; an apt application of this type of reaction is a laboratory exercise where students perform redox titrations. <u>JoVE</u> • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • Photometric Protein Determination • Proton Exchange Membrane Fuel Cells
Outline Level 4	3.B.3.e.	There are a number of important redox reactions in energy production processes (combustion of hydrocarbons and metabolism of sugars, fats, and proteins). <u>JoVE</u> • An Introduction to Cell Metabolism • Biofuels: Producing Ethanol from Cellulosic Material • Calibration Curves • Cyclic Voltammetry (CV) • Detecting Reactive Oxygen Species • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • Photometric Protein Determination • Proton Exchange Membrane Fuel Cells • The ATP Bioluminescence Assay
Outline Level 4	LO 3.1.	Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1] <u>JoVE</u> • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • Photometric Protein Determination • Proton Exchange Membrane Fuel Cells
Outline Level 4	LO 3.8.	The student is able to identify redox reactions and justify the identification in terms of electron transfer. [See SP 6.1] <u>JoVE</u> • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat

		• Introduction to Titration • Photometric Protein Determination • Proton Exchange Membrane Fuel Cells
Outline Level 4	LO 3.9.	The student is able to design and/or interpret the results of an experiment involving a redox titration. [See SP 4.2, 5.1] JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • Photometric Protein Determination • Proton Exchange Membrane Fuel Cells
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.C.	Chemical and physical transformations may be observed in several ways and typically involve a change in energy.
Outline Level 3	EK.3.C.1.	Production of heat or light, formation of a gas, and formation of a precipitate and/or a color change are possible evidences that a chemical change has occurred.
Outline Level 4	3.C.1.a.	Laboratory observations are made at the macroscopic level, so students must be able to characterize changes in matter using visual clues and then make representations or written descriptions. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Titration • Le Châtelier's Principle • Passaging Cells • Physical Properties Of Minerals II: Polymineralic Analysis • Spectrophotometric Determination of an Equilibrium Constant • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	3.C.1.b.	Distinguishing the difference between chemical and physical changes at the macroscopic level is a challenge; therefore, the ability to investigate chemical properties is important. JoVE • An Introduction to Cell Metabolism • Cyclic Voltammetry (CV) • Detecting Reactive Oxygen Species • Enzyme Assays and Kinetics

		• Freezing-Point Depression to Determine an Unknown Compound • Introduction to Titration • Le Châtelier's Principle • Passaging Cells • Physical Properties Of Minerals II: Polymineralic Analysis • Proton Exchange Membrane Fuel Cells • Spectrophotometric Determination of an Equilibrium Constant • The ATP Bioluminescence Assay • The ELISA Method
Outline Level 4	3.C.1.c.	In order to develop the ability to distinguish experimentally between chemical and physical changes, students must make observations and collect data from a variety of reactions and physical changes within the laboratory setting. JoVE • An Introduction to Cell Metabolism • Cyclic Voltammetry (CV) • Detecting Reactive Oxygen Species • Enzyme Assays and Kinetics • Freezing-Point Depression to Determine an Unknown Compound • Introduction to Titration • Le Châtelier's Principle • Passaging Cells • Physical Properties Of Minerals II: Polymineralic Analysis • Proton Exchange Membrane Fuel Cells • Spectrophotometric Determination of an Equilibrium Constant • The ATP Bioluminescence Assay • The ELISA Method
Outline Level 4	3.C.1.d.	Classification of reactions provides important organizational clarity for chemistry; therefore, students need to identify precipitation, acid-base, and redox reactions. JoVE • Co-Immunoprecipitation and Pull-Down Assays • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Determining Rate Laws and the Order of Reaction • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis

		• Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	**LO 3.1.**	**Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1]** **<u>JoVE</u>** • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Titration • Le Châtelier's Principle • Passaging Cells • Physical Properties Of Minerals II: Polymineralic Analysis • Spectrophotometric Determination of an Equilibrium Constant • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	**LO 3.10.**	**The student is able to 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. [See SP 1.4, 6.1, connects to 5.D.2]** **<u>JoVE</u>** • An Introduction to Cell Metabolism • Cyclic Voltammetry (CV) • Detecting Reactive Oxygen Species • Enzyme Assays and Kinetics • Freezing-Point Depression to Determine an Unknown Compound • Introduction to Titration • Le Châtelier's Principle • Passaging Cells • Physical Properties Of Minerals II: Polymineralic Analysis • Proton Exchange Membrane Fuel Cells

		• Spectrophotometric Determination of an Equilibrium Constant • The ATP Bioluminescence Assay • The ELISA Method
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.C.	Chemical and physical transformations may be observed in several ways and typically involve a change in energy.
Outline Level 3	EK.3.C.2.	Net changes in energy for a chemical reaction can be endothermic or exothermic.
Outline Level 4	3.C.2.a.	Macroscopic observations of energy changes when chemicals react are made possible by measuring temperature changes. JoVE • Using a pH Meter
Outline Level 4	3.C.2.b.	These observations should be placed within the context of the language of exothermic and endothermic change. JoVE • Using a pH Meter
Outline Level 4	3.C.2.c.	The ability to translate observations made at the macroscopic level in the laboratory to a conceptual framework is aided by a graphical depiction of the process called an energy diagram, which provides a visual representation of the exothermic or endothermic nature of a reaction. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	3.C.2.d.	It is important to be able to use an understanding of energy changes in chemical reactions to identify the role of endothermic and exothermic reactions in real-world processes. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 3.1.	Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1]

		JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 3.11.	The student is able to 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. [See SP 1.5, 4.4] JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.C.	Chemical and physical transformations may be observed in several ways and typically involve a change in energy.
Outline Level 3	EK.3.C.3.	Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Outline Level 4	3.C.3.a.	Electrochemistry encompasses the study of redox reactions that occur within electrochemical cells. The reactions either generate electrical current in galvanic cells, or are driven by an externally applied electrical potential in electrolytic cells. Visual representations of galvanic and electrolytic cells are tools of analysis to identify where half-reactions occur and the direction of current flow. JoVE • Calibration Curves • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • MALDI-TOF Mass Spectrometry • Method of Standard Addition • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Raman Spectroscopy for Chemical Analysis • Tandem Mass Spectrometry • Using a pH Meter

Outline Level 4	3.C.3.b.	Oxidation occurs at the anode, and reduction occurs at the cathode for all electrochemical cells. JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • Photometric Protein Determination • Proton Exchange Membrane Fuel Cells
Outline Level 4	3.C.3.c.	The overall electrical potential of galvanic cells can be calculated by identifying the oxidation half-reaction and reduction half-reaction, and using a table of Standard Reduction Potentials. JoVE • Calibration Curves • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Proton Exchange Membrane Fuel Cells
Outline Level 4	3.C.3.d.	Many real systems do not operate at standard conditions and the electrical potential determination must account for the effect of concentrations. The qualitative effects of concentration on the cell potential can be understood by considering the cell potential as a driving force toward equilibrium, in that the farther the reaction is from equilibrium, the greater the magnitude of the cell potential. The standard cell potential, Eo, corresponds to the standard conditions of Q = 1. As the system approaches equilibrium, the magnitude (i.e., absolute value) of the cell potential decreases, reaching zero at equilibrium (when Q = K). Deviations from standard conditions that take the cell further from equilibrium than Q = 1 will increase the magnitude of the cell potential relative to E°. Deviations from standard conditions that take the cell closer to equilibrium than Q = 1 will decrease the magnitude of the cell potential relative to E°. In concentration cells, the direction of spontaneous electron flow can be determined by considering the direction needed to reach equilibrium. JoVE • Calibration Curves • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • MALDI-TOF Mass Spectrometry • Method of Standard Addition • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells

		• Raman Spectroscopy for Chemical Analysis • Tandem Mass Spectrometry • Using a pH Meter
Outline Level 4	3.C.3.e.	ΔG° (standard Gibbs free energy) is proportional to the negative of the cell potential for the redox reaction from which it is constructed. JoVE • Calibration Curves • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • MALDI-TOF Mass Spectrometry • Method of Standard Addition • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Raman Spectroscopy for Chemical Analysis • Tandem Mass Spectrometry • Using a pH Meter
Outline Level 1	AP.C.3.	Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Outline Level 2	EU.3.C.	Chemical and physical transformations may be observed in several ways and typically involve a change in energy.
Outline Level 3	EK.3.C.3.	Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Outline Level 4	3.C.3.f.	Faraday’s laws can be used to determine the stoichiometry of the redox reactions occurring in an electrochemical cell with respect to the following:
Outline Level 5	3.C.3.f.i.	Number of electrons transferred JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Proton Exchange Membrane Fuel Cells
Outline Level 5	3.C.3.f.ii.	Mass of material deposited or removed from an electrode JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Proton Exchange Membrane Fuel Cells
Outline Level 5	3.C.3.f.iii.	Current JoVE

		• Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Proton Exchange Membrane Fuel Cells
Outline Level 5	3.C.3.f.iv.	Time elapsed JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Proton Exchange Membrane Fuel Cells
Outline Level 5	3.C.3.f.v.	Charge of ionic species JoVE • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Proton Exchange Membrane Fuel Cells
Outline Level 1	**AP.C.3.**	**Big Idea 3: Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.**
Outline Level 2	EU.3.C.	**Chemical and physical transformations may be observed in several ways and typically involve a change in energy.**
Outline Level 3	EK.3.C.3.	**Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.**
Outline Level 4	LO 3.1.	Students can translate among macroscopic observations of change, chemical equations, and particle views. [See SP 1.5, 7.1] JoVE • Calibration Curves • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • MALDI-TOF Mass Spectrometry • Method of Standard Addition • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Raman Spectroscopy for Chemical Analysis • Tandem Mass Spectrometry • Using a pH Meter
Outline Level 4	LO 3.12.	The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday’s laws. [See SP 2.2, 2.3, 6.4] JoVE • Proton Exchange Membrane Fuel Cells

Outline Level 4	LO 3.13.	The student can analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions. [See SP 5.1] JoVE • An Introduction to the Micropipettor • Calibration Curves • Common Lab Glassware and Uses • Cyclic Voltammetry (CV) • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Serological Pipettes and Pipettors • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Making Solutions in the Laboratory • Measuring Mass in the Laboratory • Proton Exchange Membrane Fuel Cells • Regulating Temperature in the Lab: Applying Heat • Regulating Temperature in the Lab: Preserving Samples Using Cold • Understanding Concentration and Measuring Volumes
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.A.	Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.
Outline Level 3	EK.4.A.1.	The rate of a reaction is influenced by the concentration or pressure of reactants, the phase of the reactants and products, and environmental factors such as temperature and solvent.
Outline Level 4	4.A.1.a.	The rate of a reaction is measured by the amount of reactants converted to products per unit of time. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	4.A.1.b.	A variety of means exist to experimentally measure the loss of reactants or increase of products as a function of time. One important method involves the spectroscopic determination of concentration through Beer’s law. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts

		Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	4.A.1.c.	The rate of a reaction is influenced by reactant concentrations (except in zero-order processes), temperature, surface area, and other environmental factors. <u>JoVE</u> • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	LO 4.1.	The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction. [See SP 4.2, 5.1] <u>JoVE</u> • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.A.	Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.
Outline Level 3	EK.4.A.2.	The rate law shows how the rate depends on reactant concentrations.
Outline Level 4	4.A.2.a.	The rate law expresses the rate of a reaction as proportional to the concentration of each reactant raised to a power. The power of each reactant in the rate law is the order of the reaction with respect to that reactant. The sum of the powers of the reactant concentrations in the rate law is the overall order of the reaction. When the rate is independent of the concentration of a reactant, the reaction is zeroth order in that reactant, since raising the reactant concentration to the power zero is equivalent to the reactant concentration being absent from the rate law. <u>JoVE</u>

		• Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	4.A.2.b.	In cases in which the concentration of any other reactants remain essentially constant during the course of the reaction, the order of a reaction with respect to a reactant concentration can be inferred from plots of the concentration of reactant versus time. An appropriate laboratory experience would be for students to use spectrophotometry to determine how concentration varies with time. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	4.A.2.c.	The method of initial rates is useful for developing conceptual understanding of what a rate law represents, but simple algorithmic application should not be considered mastery of the concept. Investigation of data for initial rates enables prediction of how concentration will vary as the reaction progresses. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	LO 4.2.	The student is able to analyze concentration vs. time data to determine the rate law for a zeroth-, first-, or second-order reaction. [See SP 5.1, 6.4, connects to 4.A.3] JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 1	**AP.C.4.**	**Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.**

Outline Level 2	**EU.4.A.**	**Reaction rates that depend on temperature and other environmental factors are determined by measuring changes in concentrations of reactants or products over time.**
Outline Level 3	**EK.4.A.3.**	**The magnitude and temperature dependence of the rate of reaction is contained quantitatively in the rate constant.**
Outline Level 4	**4.A.3.a.**	**The proportionality constant in the rate law is called the rate constant.** **JoVE** • **Conducting Reactions Below Room Temperature** • **Determining Rate Laws and the Order of Reaction** • **Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat** • **Enzyme Assays and Kinetics** • **Introduction to Catalysis**
Outline Level 4	**4.A.3.b.**	**The rate constant is an important measurable quantity that characterizes a chemical reaction.** **JoVE** • **Conducting Reactions Below Room Temperature** • **Determining Rate Laws and the Order of Reaction** • **Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat** • **Enzyme Assays and Kinetics** • **Introduction to Catalysis**
Outline Level 4	**4.A.3.c.**	**Rate constants vary over many orders of magnitude because reaction rates vary widely.** **JoVE** • **Conducting Reactions Below Room Temperature** • **Determining Rate Laws and the Order of Reaction** • **Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat** • **Enzyme Assays and Kinetics** • **Introduction to Catalysis**
Outline Level 4	**4.A.3.d.**	**The temperature dependence of reaction rates is contained in the temperature dependence of the rate constant.** **JoVE** • **Conducting Reactions Below Room Temperature** • **Determining Rate Laws and the Order of Reaction** • **Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat** • **Enzyme Assays and Kinetics** • **Introduction to Catalysis**
Outline Level 4	**4.A.3.e.**	**For first-order reactions, half-life is often used as a representation for the rate constant because they are**

		inversely proportional, and the half-life is independent of concentration. For example, radioactive decay processes provide real-world context. **JoVE** • Determining Rate Laws and the Order of Reaction
Outline Level 4	LO 4.3.	The student is able to 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. [See SP 2.1, 2.2] **JoVE** • Determining Rate Laws and the Order of Reaction
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.B.	Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.
Outline Level 3	EK.4.B.1.	Elementary reactions can be unimolecular or involve collisions between two or more molecules.
Outline Level 4	4.B.1.a.	The order of an elementary reaction can be inferred from the number of molecules participating in a collision: unimolecular reactions are first order, reactions involving bimolecular collisions are second order, etc. **JoVE** • Conducting Reactions Below Room Temperature • Cyclic Voltammetry (CV) • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	4.B.1.b.	Elementary reactions involving the simultaneous collision of three particles are rare.

		<u>JoVE</u> • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Catalysis
Outline Level 4	LO 4.4.	The student is able to 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. [See SP 7.1, connects to 4.A.3, 4.B.2] <u>JoVE</u> • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.B.	Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.
Outline Level 3	EK.4.B.2.	Not all collisions are successful. To get over the activation energy barrier, the colliding species need sufficient energy. Also, the orientations of the reactant molecules during the collision must allow for the rearrangement of reactant bonds to form product bonds.
Outline Level 4	4.B.2.a.	Unimolecular reactions occur because collisions with solvent or background molecules activate the molecule in a way that can be understood in terms of a Maxwell-Boltzmann thermal distribution of particle energies. <u>JoVE</u> • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Catalysis
Outline Level 4	4.B.2.b.	Collision models provide a qualitative explanation for order of elementary reactions and the temperature dependence of the rate constant. <u>JoVE</u> • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Catalysis
Outline Level 4	4.B.2.c.	In most reactions, only a small fraction of the collisions leads to a reaction. Successful collisions have both sufficient energy to overcome activation energy barriers and orientations that allow the bonds to rearrange in the required manner.

		JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Catalysis
Outline Level 4	4.B.2.d.	The Maxwell-Boltzmann distribution describes the distribution of particle energies; this distribution can be used to gain a qualitative estimate of the fraction of collisions with sufficient energy to lead to a reaction, and also how that fraction depends on temperature. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	LO 4.5	The student is able to explain the difference between collisions that convert reactants to products and those that do not in terms of energy distributions and molecular orientation. [See SP 6.2] JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Catalysis
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.B.	Elementary reactions are mediated by collisions between molecules. Only collisions having sufficient energy and proper relative orientation of reactants lead to products.
Outline Level 3	EK.4.B.3.	A successful collision can be viewed as following a reaction path with an associated energy profile.
Outline Level 4	4.B.3.a.	Elementary reactions typically involve the breaking of some bonds and the forming of new ones. It is usually possible to view the complex set of motions involved in this rearrangement as occurring along a single reaction coordinate. JoVE • Conducting Reactions Below Room Temperature • Cyclic Voltammetry (CV) • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration

		• Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	4.B.3.b.	The energy profile gives the energy along this path, which typically proceeds from reactants, through a transition state, to products. <u>JoVE</u> • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	B.4.3.c.	The Arrhenius equation can be used to summarize experiments on the temperature dependence of the rate of an elementary reaction and to interpret this dependence in terms of the activation energy needed to reach the transition state. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 4.6.	The student is able to 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. [See SP 1.4, 6.4] <u>JoVE</u> • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction

		• Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.C.	Many reactions proceed via a series of elementary reactions.
Outline Level 3	LO 4.7.	The student is able to 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. [See SP 6.5, connects to 4.C.1, 4.C.2, 4.C.3] JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.C.	Many reactions proceed via a series of elementary reactions.
Outline Level 3	EK.4.C.1.	The mechanism of a multistep reaction consists of a series of elementary reactions that add up to the overall reaction.
Outline Level 4	4.C.1.a.	The rate law of an elementary step is related to the number of reactants, as accounted for by collision theory. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	4.C.1.b.	The elementary steps add to give the overall reaction. The balanced chemical equation for the overall reaction specifies only the stoichiometry of the reaction, not the rate. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes

		• Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	4.C.1.c.	A number of mechanisms may be postulated for most reactions, and experimentally determining the dominant pathway of such reactions is a central activity of chemistry. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Determining the Solubility Rules of Ionic Compounds • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.C.	Many reactions proceed via a series of elementary reactions.
Outline Level 3	EK.4.C.2.	In many reactions, the rate is set by the slowest elementary reaction, or rate- limiting step.
Outline Level 4	4.C.2.a.	For reactions in which each elementary step is irreversible, the rate of the reaction is set by the slowest elementary step (i.e., the rate-limiting step). JoVE • Cyclic Voltammetry (CV) • Spectrophotometric Determination of an Equilibrium Constant

Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.C.	Many reactions proceed via a series of elementary reactions.
Outline Level 3	EK.4.C.3.	Reaction intermediates, which are formed during the reaction but not present in the overall reaction, play an important role in multistep reactions.
Outline Level 4	4.C.3.a.	A reaction intermediate is produced by some elementary steps and consumed by others, such that it is present only while a reaction is occurring. JoVE • Conducting Reactions Below Room Temperature • Cyclic Voltammetry (CV) • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	4.C.3.b.	Experimental detection of a reaction intermediate is a common way to build evidence in support of one reaction mechanism over an alternative mechanism. JoVE • Conducting Reactions Below Room Temperature • Cyclic Voltammetry (CV) • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination

		• Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 1	**AP.C.4.**	**Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.**
Outline Level 2	**EU.4.D.**	**Reaction rates may be increased by the presence of a catalyst.**
Outline Level 3	**EK.4.D.1.**	**Catalysts function by lowering the activation energy of an elementary step in a reaction mechanism, and by providing a new and faster reaction mechanism.**
Outline Level 4	**4.D.1.a.**	**A catalyst can stabilize a transition state, lowering the activation energy and thus increasing the rate of a reaction.** **JoVE** • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	**4.D.1.b.**	**A catalyst can increase a reaction rate by participating in the formation of a new reaction intermediate, thereby providing a new reaction pathway or mechanism.** **JoVE** • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	**LO 4.8.**	**The student can 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. [See SP 1.5]** **JoVE** • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat

		• Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 1	AP.C.4.	Big Idea 4: Rates of chemical reactions are determined by details of the molecular collisions.
Outline Level 2	EU.4.D.	Reaction rates may be increased by the presence of a catalyst.
Outline Level 3	EK.4.D.2.	Important classes in catalysis include acid-base catalysis, surface catalysis, and enzyme catalysis.
Outline Level 4	4.D.2.a.	In acid-base catalysis, a reactant either gains or loses a proton; this changes the rate of the reaction. JoVE • Using a pH Meter
Outline Level 4	4.D.2.b.	In surface catalysis, either a new reaction intermediate is formed, or the probability of successful collisions is modified. JoVE • Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	4.D.2.c.	Some enzymes accelerate reactions by binding to the reactants in a way that lowers the activation energy. Other enzymes react with reactant species to form a new reaction intermediate. JoVE • An Introduction to Cell Death • Biofuels: Producing Ethanol from Cellulosic Material • Co-Immunoprecipitation and Pull-Down Assays • DNA Ligation Reactions • Enzyme Assays and Kinetics • Introduction to Catalysis • Live Cell Imaging of Mitosis • Molecular Cloning • PCR: The Polymerase Chain Reaction • Restriction Enzyme Digests • The ELISA Method • The TUNEL Assay
Outline Level 4	LO 4.9.	The student is able to 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. [See SP 6.2, 7.2] JoVE

		• Coordination Chemistry Complexes • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.A.	Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.
Outline Level 3	EK.5.A.1.	Temperature is a measure of the average kinetic energy of atoms and molecules.
Outline Level 4	5.A.1.a.	All of the molecules in a sample are in motion. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Catalysis
Outline Level 4	5.A.1.b.	The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample. When the average kinetic energy of the particles in the sample doubles, the Kelvin temperature is doubled. As the temperature approaches 0 K (zero Kelvin), the average kinetic energy of a system approaches a minimum near zero. JoVE • Conducting Reactions Below Room Temperature • Freezing-Point Depression to Determine an Unknown Compound • Ideal Gas Law • Regulating Temperature in the Lab: Applying Heat • Regulating Temperature in the Lab: Preserving Samples Using Cold • The Ideal Gas Law
Outline Level 4	5.A.1.c.	The Maxwell-Boltzmann distribution shows that the distribution of kinetic energies becomes greater (more disperse) as temperature increases. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Ideal Gas Law • Introduction to Catalysis

		• Regulating Temperature in the Lab: Applying Heat • Regulating Temperature in the Lab: Preserving Samples Using Cold • The Ideal Gas Law
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.2.	The student is able to 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. [See SP 1.1, 1.4, 7.1] JoVE • Fractional Distillation • Ideal Gas Law • The Ideal Gas Law
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.A.	Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.
Outline Level 3	EK.5.A.2.	The process of kinetic energy transfer at the particulate scale is referred to in this course as heat transfer, and the spontaneous direction of the transfer is always from a hot to a cold body.
Outline Level 4	5.A.2.a.	On average, molecules in the warmer body have more kinetic energy than the molecules in the cooler body. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle

		• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.A.2.b.	Collisions of molecules that are in thermal contact transfer energy. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Introduction to Catalysis • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.A.2.c.	Scientists describe this process as “energy is transferred as heat.” <u>JoVE</u> • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.A.2.d.	Eventually, thermal equilibrium is reached as the molecular collisions continue. The average kinetic energy of both substances is the same at thermal equilibrium. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.A.2.e.	Heat is not a substance, i.e., it makes no sense to say that an object contains a certain amount of heat. Rather, “heat exchange” or “transfer of energy as heat” refers to the process in which energy is transferred from a hot to a cold body in thermal contact. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.A.2.f.	The transfer of a given amount of thermal energy will not produce the same temperature change in equal masses of matter with differing specific heat capacities. <u>JoVE</u>

		• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Fractional Distillation • Ideal Gas Law • Le Châtelier's Principle • The Ideal Gas Law • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.3.	The student can 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. [See SP 7.1] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.B.	Energy is neither created nor destroyed, but only transformed from one form to another.
Outline Level 3	EK.5.B.1.	Energy is transferred between systems either through heat transfer or through one system doing work on the other system.
Outline Level 4	5.B.1.a.	Heating a cold body with a hot body is a form of energy transfer between two systems. The transfer of thermal energy is an important concept in thermodynamics. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction

		• Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Purifying Compounds by Recrystallization • Regulating Temperature in the Lab: Applying Heat • Regulating Temperature in the Lab: Preserving Samples Using Cold • Rotary Evaporation to Remove Solvent • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.B.	Energy is neither created nor destroyed, but only transformed from one form to another.
Outline Level 3	EK.5.B.2.	When two systems are in contact with each other and are otherwise isolated, the energy that comes out of one system is equal to the energy that goes into the other system. The combined energy of the two systems remains fixed. Energy transfer can occur through either heat exchange or work.
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions

		• Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	**AP.C.5.**	**Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.**
Outline Level 2	**EU.5.B.**	**Energy is neither created nor destroyed, but only transformed from one form to another.**
Outline Level 3	**EK.5.B.3.**	**Chemical systems undergo three main processes that change their energy: eating / cooling, phase transitions, and chemical reactions.**
Outline Level 4	**5.B.3.a.**	**Heating a system increases the energy of the system, while cooling a system decreases the energy. A liter of water at 50°C has more energy than a liter of water at 25°C.** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Le Châtelier's Principle • Preparing Anhydrous Reagents and Equipment • Purifying Compounds by Recrystallization • Regulating Temperature in the Lab: Applying Heat • Regulating Temperature in the Lab: Preserving Samples Using Cold • Rotary Evaporation to Remove Solvent • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	**5.B.3.b.**	**The amount of energy needed to heat one gram of a substance by 1°C is the specific heat capacity of that substance.** **JoVE** • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	**5.B.3.c.**	**Energy must be transferred to a system to cause it to melt (or boil). The energy of the system therefore increases as the system undergoes a solid-liquid (or liquid-gas) phase transition. Likewise, a system gives off energy when it freezes (or condenses). The energy of the system decreases as the system undergoes a liquid-solid (or gas-liquid) phase transition.** **JoVE**

		• Assembly of a Reflux System for Heated Chemical Reactions **• Degassing Liquids with Freeze-Pump-Thaw Cycling** **• Fractional Distillation** **• Freezing-Point Depression to Determine an Unknown Compound** **• Growing Crystals for X-ray Diffraction Analysis** **• Preparing Anhydrous Reagents and Equipment** **• Purifying Compounds by Recrystallization** **• Rotary Evaporation to Remove Solvent** **• Schlenk Lines Transfer of Solvents** **• Separation of Mixtures via Precipitation** **• Solid-Liquid Extraction** **• Solutions and Concentrations** **• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 4	**5.B.3.d.**	**The amount of energy needed to vaporize one mole of a pure substance is the molar enthalpy of vaporization, and the energy released in condensation has an equal magnitude. The molar enthalpy of fusion is the energy absorbed when one mole of a pure solid melts or changes from the solid to liquid state and the energy released when the liquid solidifies has an equal magnitude.** **JoVE** **• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 4	**5.B.3.e.**	**When a chemical reaction occurs, the energy of the system decreases (exothermic reaction), increases (endothermic reaction), or remains the same. For exothermic reactions, the energy lost by the reacting molecules (system) is gained by the surroundings. The energy is transferred to the surroundings by either heat or work. Likewise, for endothermic reactions, the system gains energy from the surroundings by heat transfer or work done on the system.** **JoVE** **• Conducting Reactions Below Room Temperature** **• Determining Rate Laws and the Order of Reaction** **• Le Châtelier's Principle** **• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 4	**5.B.3.f.**	**The enthalpy change of reaction gives the amount of energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure.** **JoVE**

		• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	**LO 5.1.**	**The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2]** **JoVE** • An Introduction to Cell Division • An Introduction to Cell Metabolism • An Introduction to Saccharomyces cerevisiae • An Introduction to Transfection • Bacterial Transformation: Electroporation • Bacterial Transformation: The Heat Shock Method • Cell Cycle Analysis • Cell-surface Biotinylation Assay • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Cyclic Voltammetry (CV) • DNA Gel Electrophoresis • DNA Ligation Reactions • Density Gradient Ultracentrifugation • Detecting Reactive Oxygen Species • Dialysis: Diffusion Based Separation • Drosophila Larval IHC • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Gel Purification • Introduction to Catalysis • Introduction to Mass Spectrometry • Ion-Exchange Chromatography • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Method of Standard Addition • Molecular Cloning • Nuclear Magnetic Resonance (NMR) Spectroscopy • PCR: The Polymerase Chain Reaction • Passaging Cells • Photometric Protein Determination • Plasmid Purification • Protein Crystallization • Reconstitution of Membrane Proteins • Restriction Enzyme Digests • Sample Preparation for Analytical Preparation • Separating Protein with SDS-PAGE

		• Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The ATP Bioluminescence Assay • The ELISA Method • The Western Blot • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 5.6.	The student is able to 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 PΔV work. [See SP 2.2, 2.3] <u>JoVE</u> • Coordination Chemistry Complexes • Ion-Exchange Chromatography • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Purification of a Total Lipid Extract with Column Chromatography • Tandem Mass Spectrometry • Ultraviolet-Visible (UV-Vis) Spectroscopy • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.B.	Energy is neither created nor destroyed, but only transformed from one form to another.
Outline Level 3	EK.5.B.4.	Calorimetry is an experimental technique that is used to determine the heat exchanged/transferred in a chemical system.
Outline Level 4	5.B.4.a.	The experimental setup for calorimetry is the following: A chemical system is put in thermal contact with a heat bath. The heat bath is a substance, such as water, whose heat capacity has been well established by previous experiments. A process is initiated in the chemical system (heating/cooling, phase transition, or chemical reaction), and the change in temperature of the heat bath is determined. <u>JoVE</u> • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.B.4.b.	Because the heat capacity of the heat bath is known, the observed change in temperature can be used to determine the amount of energy exchanged between the system and the heat bath.

		JoVE • **Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 4	**5.B.4.c.**	**The energy exchanged between the system and the heat bath is equal in magnitude to the change in energy of the system. If the heat bath increased in temperature, its energy increased, and the energy of the system decreased by this amount. If the heat bath decreased in temperature, and therefore energy, the energy of the system increased by this amount.** **JoVE** • **Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 4	**5.B.4.d.**	**Because calorimetry measures the change in energy of a system, it can be used to determine the heat associated with each of the processes listed in 5.B.3. In this manner, calorimetry may be used to determine heat capacities, enthalpies of vaporization, enthalpies of fusion, and enthalpies of reactions. Only constant pressure calorimetry is required in the course.** **JoVE** • **Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 4	**LO 5.1.**	**The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2]** **JoVE** • **Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 4	**LO 5.7.**	**The student is able to 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. [See SP 4.2, 5.1, 6.4]** **JoVE** • **Using Differential Scanning Calorimetry to Measure Changes in Enthalpy**
Outline Level 1	**AP.C.5.**	**Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.**

Outline Level 2	**EU.5.C.**	**Breaking bonds requires energy, and making bonds releases energy.**
Outline Level 3	**EK.5.C.1.**	**Potential energy is associated with a particular geometric arrangement of atoms or ions and the electrostatic interactions between them.**
Outline Level 4	**5.C.1.b.**	**A graph of energy versus the distance between atoms can be plotted and interpreted. Using this graph, it is possible to identify bond length and bond energy.** **JoVE** • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Purification of a Total Lipid Extract with Column Chromatography • Raman Spectroscopy for Chemical Analysis • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	**5.C.1.c.**	**Conceptually, bond making and bond breaking are opposing processes that have the same magnitude of energy associated with them. Thus, convention becomes important, so we define the bond energy as the energy required to break a bond.** **JoVE** • Conducting Reactions Below Room Temperature • Cyclic Voltammetry (CV) • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization

		• Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	5.C.1.e.	Stronger bonds tend to be shorter bonds. JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Purification of a Total Lipid Extract with Column Chromatography • Raman Spectroscopy for Chemical Analysis • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated

		Solvent Extraction • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.C.	Breaking bonds requires energy, and making bonds releases energy.
Outline Level 3	EK.5.C.2.	The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.
Outline Level 4	5.C.2.a.	During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the reaction system. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.C.2.b.	The average energy required to break all of the bonds in the reactant molecules can be estimated by adding up the average bond energies or bond enthalpies for all the bonds in the reactant molecules. Likewise, the average energy released in forming the bonds in the products can be estimated. If the energy released is greater than the energy required, then the reaction is exothermic. If the

		energy required is greater than the energy released, then the reaction is endothermic. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.C.2.c.	For an exothermic reaction, the products are at a lower potential energy compared with the reactants. For an endothermic reaction, the products are at a higher potential energy than the reactants. JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.C.2.e.	Because the products of a reaction are at a higher or lower temperature than their surroundings, the products of the reaction move toward thermal equilibrium with the surroundings. Thermal energy is transferred to the surroundings from the hot products in an exothermic reaction. Thermal energy is transferred from the surroundings to the cold products in an endothermic reaction. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.C.2.f.	Although the concept of “state functions” is not required for the course, students should understand these Hess’s law ideas: When a reaction is reversed, the sign of the enthalpy of the reaction is changed; when two (or more) reactions are summed to obtain an overall reaction, the enthalpies of reaction are summed to obtain the net enthalpy of reaction. JoVE • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.C.2.g.	Tables of standard enthalpies of formation can be used to calculate the standard enthalpy of reactions. Uses should go beyond algorithmic calculations and include, for

		instance, the use of such tables to compare related reactions, such as extraction of elemental metals from metal oxides. JoVE • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.8.	The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds. [See SP 2.3, 7.1, 7.2] JoVE • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.D.	Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.
Outline Level 3	EK.5.D.1.	Potential energy is associated with the interaction of molecules; as molecules draw near each other, they experience an attractive force.
Outline Level 4	5.D.1.a.	Chemists categorize intermolecular forces in terms of the nature of the charge distributions in the molecules involved. Thus, dipole-dipole, dipole-induced dipole, and induced dipole-induced dipole (dispersion) can be defined. JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Chromatography-Based Biomolecule Purification

		Methods • Column Chromatography • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ion-Exchange Chromatography • Performing 1D Thin Layer Chromatography • Preparing Anhydrous Reagents and Equipment • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 5.9.	The student is able to 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. [See SP 6.4] JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Purification of a Total Lipid Extract with Column Chromatography

		• Raman Spectroscopy for Chemical Analysis • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 1	**AP.C.5.**	**Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.**
Outline Level 2	**EU.5.D.**	**Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.**
Outline Level 3	**EK.5.D.2.**	**At the particulate scale, chemical processes can be distinguished from physical processes because chemical bonds can be distinguished from intermolecular interactions.**
Outline Level 4	**5.D.2.a.**	**The distinction between chemical and physical processes relates to the nature of the change in molecular interactions. Processes that involve the breaking and/or formation of chemical bonds are classified as chemical processes. Processes that involve only changes in weak intermolecular interactions, such as phase changes, are classified as physical processes.** JoVE • An Introduction to Cell Metabolism • Common Lab Glassware and Uses • Conducting Reactions Below Room Temperature • Cyclic Voltammetry (CV) • Detecting Reactive Oxygen Species • Determining the Density of a Solid and Liquid • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent

		• Separation of Mixtures via Precipitation • The ATP Bioluminescence Assay • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	5.3.2.b.	A gray area exists between these two extremes. For instance, the dissolution of a salt in water involves breaking of ionic bonds and the formation of interactions between ions and solvent. The magnitude of these interactions can be comparable to covalent bond strengths, and so plausible arguments can be made for classifying dissolution of a salt as either a physical or chemical process. JoVE • An Introduction to Cell Metabolism • Common Lab Glassware and Uses • Conducting Reactions Below Room Temperature • Cyclic Voltammetry (CV) • Detecting Reactive Oxygen Species • Determining the Density of a Solid and Liquid • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Introduction to Titration • Le Châtelier's Principle • Nuclear Magnetic Resonance (NMR) Spectroscopy • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Proton Exchange Membrane Fuel Cells • Purifying Compounds by Recrystallization • Rotary Evaporation to Remove Solvent • Separation of Mixtures via Precipitation • The ATP Bioluminescence Assay • The ELISA Method • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter
Outline Level 4	LO 5.10.	The student can 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. [See SP 5.1]

		JoVE • An Introduction to Cell Metabolism • Common Lab Glassware and Uses • Cyclic Voltammetry (CV) • Detecting Reactive Oxygen Species • Determining the Density of a Solid and Liquid • Determining the Mass Percent Composition in an Aqueous Solution • Enzyme Assays and Kinetics • Freezing-Point Depression to Determine an Unknown Compound • Introduction to Titration • Proton Exchange Membrane Fuel Cells • The ATP Bioluminescence Assay • The ELISA Method • Using a pH Meter
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.D.	Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.
Outline Level 3	EK.5.D.3.	Noncovalent and intermolecular interactions play important roles in many biological and polymer systems.
Outline Level 4	5.D.3.a.	In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. JoVE • An Introduction to Caenorhabditis elegans • An Introduction to Cell Death • An Introduction to Cell Division • An Introduction to Cell Metabolism • An Introduction to Cell Motility and Migration • An Introduction to Developmental Genetics • An Introduction to Molecular Developmental Biology • An Introduction to Saccharomyces cerevisiae • An Introduction to Transfection • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of Epigenetics • An Overview of Gene Expression • An Overview of Genetic Analysis • An Overview of Genetic Engineering • An Overview of Genetics and Disease • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Annexin V and Propidium Iodide Labeling • Bacterial Transformation: Electroporation

		• Bacterial Transformation: The Heat Shock Method • C. elegans Maintenance • Capillary Electrophoresis (CE) • Cell Cycle Analysis • Cell-surface Biotinylation Assay • Chromatin Immunoprecipitation • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Column Chromatography • Community DNA Extraction from Bacterial Colonies • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cytogenetics • DNA Gel Electrophoresis • DNA Ligation Reactions • DNA Methylation Analysis • Density Gradient Ultracentrifugation • Detecting Environmental Microorganisms with the Polymerase Chain Reaction and Gel Electrophoresis • Detecting Reactive Oxygen Species • Development and Reproduction of the Laboratory Mouse • Development of the Chick • Dialysis: Diffusion Based Separation • Drosophila Larval IHC • Drosophila melanogaster Embryo and Larva Harvesting and Preparation • Electrophoretic Mobility Shift Assay (EMSA) • Embryonic Stem Cell Culture and Differentiation • Enzyme Assays and Kinetics • Explant Culture for Developmental Studies • Expression Profiling with Microarrays • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Gel Purification • Gene Silencing with Morpholinos • Genetic Crosses • Genetic Engineering of Model Organisms • Genetic Screens • Genome Editing • In ovo Electroporation of Chicken Embryos • Induced Pluripotency • Introduction to Catalysis • Introduction to Mass Spectrometry • Invasion Assay Using 3D Matrices • Invertebrate Lifespan Quantification • Ion-Exchange Chromatography • Isolating Nucleic Acids from Yeast • Live Cell Imaging of Mitosis

		• MALDI-TOF Mass Spectrometry • Metabolic Labeling • Molecular Cloning • Mouse Genotyping • PCR: The Polymerase Chain Reaction • Photometric Protein Determination • Plasmid Purification • Protein Crystallization • Purification of a Total Lipid Extract with Column Chromatography • Quantifying Environmental Microorganisms and Viruses Using qPCR • RNA Analysis of Environmental Samples Using RT-PCR • RNA-Seq • RNAi in C. elegans • Recombineering and Gene Targeting • Reconstitution of Membrane Proteins • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Restriction Enzyme Digests • SNP Genotyping • Separating Protein with SDS-PAGE • Separation of Mixtures via Precipitation • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The ATP Bioluminescence Assay • The ELISA Method • The TUNEL Assay • The Transwell Migration Assay • The Western Blot • Two-Dimensional Gel Electrophoresis • Whole-Mount In Situ Hybridization • Yeast Maintenance • Yeast Transformation and Cloning • Zebrafish Breeding and Embryo Handling • Zebrafish Microinjection Techniques • Zebrafish Reproduction and Development
Outline Level 4	5.D.3.b.	The functionality and properties of molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions. For example, the function of enzymes is dictated by their structure, and properties of synthetic polymers are modified by manipulating their chemical composition and structure. JoVE • An Introduction to Cell Death • Biofuels: Producing Ethanol from Cellulosic Material • Co-Immunoprecipitation and Pull-Down Assays

		• Coordination Chemistry Complexes • DNA Ligation Reactions • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Le Châtelier's Principle • Live Cell Imaging of Mitosis • Molecular Cloning • PCR: The Polymerase Chain Reaction • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins • Restriction Enzyme Digests • The ELISA Method • The TUNEL Assay
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] <u>JoVE</u> • An Introduction to Cell Division • An Introduction to Cell Metabolism • An Introduction to Saccharomyces cerevisiae • An Introduction to Transfection • Bacterial Transformation: Electroporation • Bacterial Transformation: The Heat Shock Method • Cell Cycle Analysis • Cell-surface Biotinylation Assay • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Cyclic Voltammetry (CV) • DNA Gel Electrophoresis • DNA Ligation Reactions • Density Gradient Ultracentrifugation • Detecting Reactive Oxygen Species • Dialysis: Diffusion Based Separation • Drosophila Larval IHC • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • FM Dyes in Vesicle Recycling • Förster Resonance Energy Transfer (FRET) • Gel Purification

		• Introduction to Catalysis • Introduction to Mass Spectrometry • Ion-Exchange Chromatography • Le Châtelier's Principle • MALDI-TOF Mass Spectrometry • Metabolic Labeling • Method of Standard Addition • Molecular Cloning • Nuclear Magnetic Resonance (NMR) Spectroscopy • PCR: The Polymerase Chain Reaction • Passaging Cells • Photometric Protein Determination • Plasmid Purification • Protein Crystallization • Reconstitution of Membrane Proteins • Restriction Enzyme Digests • Sample Preparation for Analytical Preparation • Separating Protein with SDS-PAGE • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The ATP Bioluminescence Assay • The ELISA Method • The Western Blot • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy
Outline Level 4	LO 5.11.	The student is able to 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. [See SP 7.2] JoVE • Coordination Chemistry Complexes • Electrophoretic Mobility Shift Assay (EMSA) • Growing Crystals for X-ray Diffraction Analysis • Introduction to Catalysis • Physical Properties Of Minerals I: Crystals and Cleavage • Physical Properties Of Minerals II: Polymineralic Analysis • Protein Crystallization • Purifying Compounds by Recrystallization • Reconstitution of Membrane Proteins
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.E.	Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.
Outline Level 3	EK.5.E.2.	Some physical or chemical processes involve both a decrease in the internal energy of the components ($\Delta H° < 0$) under consideration and an increase in the entropy of

		those components ($\Delta S° > 0$). These processes are necessarily "thermodynamically favored" ($\Delta G° < 0$).
Outline Level 4	5.E.2.a.	For the purposes of thermodynamic analysis in this course, the enthalpy and the internal energy will not be distinguished. JoVE • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.E.2.b.	The phrase "thermodynamically favored" means that products are favored at equilibrium ($K > 1$). JoVE • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.E.2.c.	Historically, the term "spontaneous" has been used to describe processes for which $\Delta G° < 0$. The phrase "thermodynamically favored" is used here to avoid misunderstanding and confusion that can occur because of the common connotation of the term "spontaneous," which students may believe means "immediately" or "without cause." JoVE • Conducting Reactions Below Room Temperature • Enzyme Assays and Kinetics • Introduction to Catalysis
Outline Level 4	5.E.2.d.	For many processes, students will be able to determine, either quantitatively or qualitatively, the signs of both $\Delta H°$ and $\Delta S°$ for a physical or chemical process. In those cases where $\Delta H° < 0$ and $\Delta S° > 0$, there is no need to calculate $\Delta G°$ in order to determine that the process is thermodynamically favored. JoVE • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.E.2.e.	As noted below in 5.E.5, the fact that a process is thermodynamically favored does not mean that it will proceed at a measurable rate. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy

Outline Level 4	5.E.2.f.	Any process in which both ΔH° > 0 and ΔS° < 0 are not thermodynamically favored, (ΔG° > 0) and the process must favor reactants at equilibrium (K < 1). Because the signs of ΔS° and ΔH° reverse when a chemical or physical process is reversed, this must be the case. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.13.	The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both ΔH° and ΔS°, and calculation or estimation of ΔG° when needed. [See SP 2.2, 2.3, 6.4, connects to 5.E.3] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.E.	Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.
Outline Level 3	EK.5.E.4.	External sources of energy can be used to drive change in cases where the Gibbs free energy change is positive.

Outline Level 4	5.E.4.a.	Electricity may be used to cause a process to occur that is not thermodynamically favored. Useful examples are charging of a battery and the process of electrolysis. JoVE • Calibration Curves • Capillary Electrophoresis (CE) • Cyclic Voltammetry (CV) • DNA Gel Electrophoresis • Determining Rate Laws and the Order of Reaction • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Electrophoretic Mobility Shift Assay (EMSA) • Gel Purification • Ion-Exchange Chromatography • Proton Exchange Membrane Fuel Cells • Separating Protein with SDS-PAGE • The Western Blot • Two-Dimensional Gel Electrophoresis
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.E.	Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.
Outline Level 3	EK.5.E.4.	External sources of energy can be used to drive change in cases where the Gibbs free energy change is positive.
Outline Level 4	5.E.4.b.	Light may also be a source of energy for driving a process that in isolation is not thermodynamically favored. Useful examples are as follows:
Outline Level 5	5.E.4.b.1.	The photoionization of an atom, because although the separation of a negatively charged electron from the remaining positively charged ion is highly endothermic, ionization is observed to occur in conjunction with the absorption of a photon. JoVE • Capillary Electrophoresis (CE) • Chromatography-Based Biomolecule Purification Methods • Determining the Solubility Rules of Ionic Compounds • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Electrophoretic Mobility Shift Assay (EMSA) • Introduction to Mass Spectrometry • Ion-Exchange Chromatography • MALDI-TOF Mass Spectrometry • Tandem Mass Spectrometry • Two-Dimensional Gel Electrophoresis
Outline Level 5	5.E.4.b.2.	The overall conversion of carbon dioxide to glucose through photosynthesis, for which 6 $CO_2(g)$ + 6 $H_2O(l)$ →

		C6H12O6(aq) + 6 O2(g) has ΔG° = +2880 kJ/molrxn, yet is observed to occur through a multistep process that is initiated by the absorption of several photons in the range of 400–700 nm. JoVE • An Introduction to Cell Metabolism
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.E.	Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.
Outline Level 3	EK.5.E.4.	External sources of energy can be used to drive change in cases where the Gibbs free energy change is positive.
Outline Level 4	5.E.4.c.	verall reaction with a negative ΔG°. JoVE • An Introduction to Cell Metabolism • An Introduction to Cell Motility and Migration • Detecting Reactive Oxygen Species • Invasion Assay Using 3D Matrices • The ATP Bioluminescence Assay • The Transwell Migration Assay
Outline Level 4	LO 5.16.	The student can use Le Chatelier's principle to make qualitative predictions for systems in which coupled reactions that share a common intermediate drive formation of a product. [See SP 6.4, connects to 6.B.1] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	AP.C.5.	Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.
Outline Level 2	EU.5.E.	Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.
Outline Level 3	EK.5.E.5.	A thermodynamically favored process may not occur due to kinetic constraints (kinetic vs. thermodynamic control).
Outline Level 4	5.E.5.a.	Many processes that are thermodynamically favored do not occur to any measurable extent, or they occur at extremely slow rates. JoVE • Assembly of a Reflux System for Heated Chemical

		Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	5.E.5.b.	Processes that are thermodynamically favored, but do not proceed at a measurable rate, are said to be under “kinetic control.” High activation energy is a common reason for a process to be under kinetic control. The fact that a process does not proceed at a noticeable rate does not mean that the chemical system is at equilibrium. If a process is known to be thermodynamically favored (through qualitative and/or quantitative analysis of ΔH° and ΔS°), and yet it is not occurring at a measurable rate, then the conclusion is that the process is under kinetic control. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Conducting Reactions Below Room Temperature • Determining Rate Laws and the Order of Reaction • Enzyme Assays and Kinetics • Introduction to Catalysis • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.1.	The student is able to 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. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 4	LO 5.18.	The student can 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. [See SP 1.3, 7.2, connects to 6.D.1]

		JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Determining Rate Laws and the Order of Reaction • Le Châtelier's Principle • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.6.	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.
Outline Level 2	EU.6.A.	Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.
Outline Level 3	EK.6.A.1.	In many classes of reactions, it is important to consider both the forward and reverse reaction.
Outline Level 4	6.A.1.a.	Many readily observable processes are reversible. Examples include evaporating and condensing water, absorption of a gas, or dissolving and precipitating a salt. Relevant and interesting contexts include biological examples (binding of oxygen to hemoglobin and the attachment of molecules to receptor sites in the nose) and environmental examples (transfer of carbon between atmosphere and biosphere and transfer of dissolved substances between atmosphere and hydrosphere). JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Freezing-Point Depression to Determine an Unknown Compound • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant • fMRI: Functional Magnetic Resonance Imaging
Outline Level 4	6.A.1.b.	Dissolution of a solid, transfer of protons in acid-base reactions, and transfer of electrons in redox reactions are important examples of reversible reactions. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	LO 6.1.	The student is able to, 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. [See SP 6.2]

		JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Freezing-Point Depression to Determine an Unknown Compound • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	**AP.C.6.**	**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.**
Outline Level 2	**EU.6.A.**	**Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.**
Outline Level 3	**EK.6.A.2.**	**The current state of a system undergoing a reversible reaction can be characterized by the extent to which reactants have been converted to products. The relative quantities of reaction components are quantitatively described by the reaction quotient, Q.**
Outline Level 4	**6.A.2.a.**	**Given an initial set of reactant and product concentrations, only those sets of concentrations that are consistent with the reaction stoichiometry can be attained. ICE (initial, change, equilibrium) tables are useful for determining which sets of concentration values are possible.** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	**6.A.2.b.**	**The reaction quotient, Q, provides a convenient measure of the current progress of a reaction. Q does not include substances whose concentrations are independent of the amount of substance, such as for a solid in contact with a liquid solution or with a gas, or for a pure solid or liquid in contact with a gas.** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	**6.A.2.c.**	**The value of Q (and so also K) changes when a reaction is reversed. When reactions are added together through the presence of a common intermediate, Q (and so also K) of the resulting reaction is a product of the values of Q (or**

		K) for the original reactions. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	LO 6.2.	The student can, 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. [See SP 2.2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	AP.C.6.	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.
Outline Level 2	EU.6.A.	Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.
Outline Level 3	EK.6.A.3.	When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point Q = K.
Outline Level 4	6.A.3.a.	When equilibrium is reached, no observable changes occur in the system.
Outline Level 5	6.A.3.a.1.	Reactant and product molecules are present. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 5	6.A.3.a.2.	Concentration of all species remains constant. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant

Outline Level 1	AP.C.6.	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.
Outline Level 2	EU.6.A.	Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.
Outline Level 3	EK.6.A.3.	When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point Q = K.
Outline Level 4	6.A.3.c.	Comparing Q to K allows the determination of whether the reaction is at equilibrium, or will proceed toward products or reactants to reach equilibrium. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	6.A.3.e.	Given a single reaction, initial concentrations, and K, the concentrations at equilibrium may be predicted. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	6.A.3.f.	Graphs of concentration over time for simple chemical reactions can be used to understand the establishment of chemical equilibrium. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	LO 6.3.	The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions. [See SP 7.2] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation

		• Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	**AP.C.6.**	**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.**
Outline Level 2	**EU.6.A.**	**Chemical equilibrium is a dynamic, reversible state in which rates of opposing processes are equal.**
Outline Level 3	**EK.6.A.4.**	**The magnitude of the equilibrium constant, K, can be used to determine whether the equilibrium lies toward the reactant side or product side.**
Outline Level 4	**6.A.4.a.**	**For many aqueous reactions, K is either very large or very small, and this may be used to reason qualitatively about equilibrium systems.** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	**LO 6.7.**	**The student is able, for a reversible reaction that has a large or small K, to determine which chemical species will have very large versus very small concentrations at equilibrium. [See SP 2.2, 2.3]** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	**AP.C.6.**	**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.**
Outline Level 2	**EU.6.B.**	**Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.**
Outline Level 3	**EK.6.B.1.**	**Systems at equilibrium respond to disturbances by partially countering the effect of the disturbance (Le Chatelier's principle).**
Outline Level 4	**6.B.1.a.**	**Le Chatelier's principle can be used to predict the response of a system to the following stresses: addition or removal of a chemical species, change in temperature, change in volume/pressure of a gas phase system, and dilution of a reaction system with water or other solvent.**

		<u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	**6.B.1.b.**	**Le Chatelier's principle can be used to reason about the effects a stress will have on experimentally measurable properties, such as pH, temperature, and color of a solution.** <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	**LO 6.8.**	**The student is able to use Le Chatelier's principle to predict the direction of the shift resulting from various possible stresses on a system at chemical equilibrium. [See SP 1.4, 6.4]** <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	**LO 6.9.**	**The student is able to use Le Chatelier's principle to design a set of conditions that will optimize a desired outcome, such as product yield. [See SP 4.2]** <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	**AP.C.6.**	**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.**
Outline Level 2	**EU.6.B.**	**Systems at equilibrium are responsive to external perturbations, with the response leading to a change in the composition of the system.**

Outline Level 3	EK.6.B.2.	A disturbance to a system at equilibrium causes Q to differ from K, thereby taking the system out of the original equilibrium state. The system responds by bringing Q back into agreement with K, thereby establishing a new equilibrium state.
Outline Level 4	6.B.2.a.	Le Chatelier’s principle involves qualitative reasoning that is closely connected to the quantitative approach of 6.A.3. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	6.B.2.b.	Some stresses, such as changes in concentration, cause a change in Q. A change in temperature causes a change in K. In either case, the reaction shifts to bring Q and K back into equality. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	LO 6.10.	The student is able to connect Le Chatelier’s principle to the comparison of Q to K by explaining the effects of the stress on Q and K. [See SP 1.4, 7.2] <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 1	AP.C.6.	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.
Outline Level 2	EU.6.C.	Chemical equilibrium plays an important role in acid-base chemistry and in solubility.
Outline Level 3	EK.6.C.1.	Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Outline Level 4	6.C.1.a.	The concentrations of hydronium ion and hydroxide ion are often reported as pH and pOH, respectively.

		<u>JoVE</u> **• Assembly of a Reflux System for Heated Chemical Reactions** **• Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat** **• Introduction to Titration** **• Ion-Exchange Chromatography** **• Le Châtelier's Principle** **• Two-Dimensional Gel Electrophoresis** **• Using a pH Meter**
Outline Level 4	**6.C.1.b.**	**Water autoionizes with an equilibrium constant, Kw. For pure water, pH = pOH, and this condition is called “neutrality,” or a neutral solution. At 25°C, pKw = 14, and thus pH and pOH add to 14. In pure water at 25°C, pH = pOH = 7.** **<u>JoVE</u>** **• Introduction to Titration** **• Using a pH Meter**
Outline Level 4	**6.C.1.c.**	**Common strong acids include HCl, HBr, HI, HClO4, H2SO4, and HNO3. The molecules of strong acids completely ionize in solution to produce hydronium ions. In other words, 100 percent of the molecules of the strong acid are ionized in a solution (assuming that the concentration is not extremely high). As such, the concentration of H3O+ in a strong acid solution is equal to the initial concentration of the strong acid, and thus the pH of the strong acid solution is easily calculated.** **<u>JoVE</u>** **• Assembly of a Reflux System for Heated Chemical Reactions** **• Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat** **• Introduction to Titration** **• Ion-Exchange Chromatography** **• Le Châtelier's Principle** **• Two-Dimensional Gel Electrophoresis** **• Using a pH Meter**
Outline Level 4	**6.C.1.d.**	**Common strong bases include group I and II hydroxides. When dissolved in solution, strong bases completely dissociate to produce hydroxide ions. Note that some group II hydroxides are slightly soluble in water. However, 100 percent of the dissolved base is ionized.** **<u>JoVE</u>** **• Assembly of a Reflux System for Heated Chemical Reactions** **• Introduction to Titration** **• Ion-Exchange Chromatography**

		• Le Châtelier's Principle • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	6.C.1.e.	Weak acid molecules react with water to transfer a proton to the water molecule. However, weak acid molecules only partially ionize in this way. In other words, only a small percentage of the molecules of a weak acid are ionized in a solution (assuming that the initial concentration is not extremely low). Thus, the concentration of $H3O+$ does not equal the initial concentration of the molecular acid, and the vast majority of the acid molecules remain un-ionized. A solution of a weak acid thus involves equilibrium between an un-ionized acid and its conjugate base. The equilibrium constant for this reaction is Ka, often reported as pKa. The pH of a weak acid solution can be determined from the initial acid concentration and the pKa. The common weak acids include carboxylic acids. The relative magnitudes of Ka's are influenced by structural factors such as bond strength, solvation, and electronegativity of the atom bonded to the labile proton. JoVE • Introduction to Titration • Using a pH Meter
Outline Level 4	6.C.1.f.	The common weak bases include ammonia, amines and pyridines, other nitrogenous bases, and conjugate bases (defined below in g). Weak base molecules in aqueous solutions react with water molecules to produce hydroxide ions. However, only a small percentage of the molecules of a weak base in a solution ionize in this way (assuming that the initial concentration is not extremely low). Thus, the concentration of OH– in the solution does not equal the initial concentration of the molecular base, and the vast majority of the base molecules remain un-ionized. A solution of a weak base thus involves an equilibrium between an un-ionized base and its conjugate acid. The equilibrium constant for this reaction is Kb, often reported as pKb. The pH of a weak base solution can be determined from the initial base concentration and the pKb. JoVE • Introduction to Titration • Using a pH Meter
Outline Level 4	6.C.1.g.	When an acid molecule loses its proton, it becomes a base, since the resultant ion could react with water as a base. The acid and base are referred to as a conjugate acid-base pair. The ionization constants for the acid-base pair are related to Kw, and at 25°C, pKa + pKb = 14. This

		relation can be used to reason qualitatively about the relative strengths of conjugate acids and bases. For example, the conjugate base of a strong acid is a much weaker base than H_2O, and therefore does not react as a base in aqueous solutions. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	6.C.1.h.	The pH of an acid solution depends on both the strength of the acid and the concentration of the acid. If we compare solutions of a weak acid and of a strong acid at the same pH, we find that both solutions have the same concentration of H_3O^+ (aq). However, the strong acid is completely dissociated into ions in solution, whereas the weak acid is only partially dissociated into ions in solution. Thus, there are vastly more un-ionized acid molecules in the weak acid solution than in the strong acid solution at the same pH. Thus, to achieve solutions of equal pH, the weak acid solution must be a much greater concentration than the strong acid solution. If we compare solutions of a weak acid and of a strong acid of the same initial concentration, the concentration of H_3O^+ in the strong acid solution is much larger (and the pH thus lower) since the strong acid is 100 percent ionized. JoVE • Introduction to Titration • Using a pH Meter
Outline Level 1	AP.C.6.	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.
Outline Level 2	EU.6.C.	Chemical equilibrium plays an important role in acid-base chemistry and in solubility.
Outline Level 3	EK.6.C.1.	Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Outline Level 4	6.C.1.i.	Reactions of acids and bases are called neutralization reactions, and these reactions generally have $K > 1$, and thus can be considered to go to completion.

Outline Level 5	6.C.1.i.i.	For a mixture of a strong acid with a strong base, the neutralization reaction is H3O+ + OH– → H2O. The K for this reaction is 1014 at 25°C, so the reaction goes to completion. This allows the pH of mixtures of strong acids and bases to be determined from the limiting reactant, either the acid or the base. JoVE • Using a pH Meter
Outline Level 5	6.C.1.i.ii.	When a strong base is added to a solution of a weak acid, a neutralization reaction occurs: conjugate acid + OH- → conjugate base + H2O. JoVE • Using a pH Meter
Outline Level 5	6.C.1.i.iii.	When a strong acid is added to a solution of a weak base, a neutralization reaction occurs: conjugate base + H3O+ → conjugate acid + H2O. JoVE • Using a pH Meter
Outline Level 1	AP.C.6.	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.
Outline Level 2	EU.6.C.	Chemical equilibrium plays an important role in acid-base chemistry and in solubility.
Outline Level 3	EK.6.C.1.	Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Outline Level 4	6.C.1.j.	For a weak acid solution and a strong acid solution with the same pH, it takes much more base to neutralize the weak acid solution because the initial acid concentration is much larger. The weak acid solution contains a large amount of un-ionized acid molecules. Therefore, a weak acid solution resists changes in pH for a much greater amount of added base. JoVE • Using a pH Meter
Outline Level 4	6.C.1.k.	A titration technique exists for neutralization reactions. At the equivalence point, the moles of titrant and the moles of titrate are present in stoichiometric proportions. In the vicinity of the equivalence point, the pH rapidly changes. This can be used to determine the concentration of the titrant. JoVE • Dissolved Oxygen in Surface Water

		• Introduction to Titration • Solutions and Concentrations
Outline Level 4	6.C.1.l.	As base is added to either a strong acid solution or a weak acid solution, the H3O+ (aq) concentration does not change much. The change in pH is less than ~1.5 for the region where 10 to 90 percent of the base needed to reach the equivalence point has been added. <u>JoVE</u> • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations • Using a pH Meter
Outline Level 4	6.C.1.m.	The pKa of an acid can be determined from the pH at the half equivalence point of the titration if the equivalence point is known (i.e., the concentration of both the titrant and analyte are known). <u>JoVE</u> • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations
Outline Level 4	6.C.1.n.	For polyprotic acids, the use of titration curves to evaluate the number of labile protons is important, as well as knowing which species are present in large concentrations at any region along the curve. <u>JoVE</u> • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations
Outline Level 4	6.C.1.o.	Halfway to the equivalence point, the contents of a solution, formed by titrating a weak acid, is different from that formed by titrating a strong acid. For a strong acid, the main species in a solution halfway to the equivalence point are H3O+(aq), the anion from the acid (e.g., Cl–, NO3–), and the cation from the base (e.g., Na+). The total positive charge is equal to the total negative charge. For a weak acid, the main species in a solution halfway to the equivalence point are H3O+(aq), the anion from the acid (e.g., CH3COO–, F–), the cation from the base (e.g., Na+), and undissociated acid, HA. The total positive charge is equal to the total negative charge, and [HA] = [A–]. <u>JoVE</u> • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations

Outline Level 4	LO 6.11.	The student can 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. [See SP 1.1, 1.4, 2.3] JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	LO 6.12.	The student can 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. [See SP 1.4, 6.4, connects to 1.E.2] JoVE • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations
Outline Level 4	LO 6.13.	The student can 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 pKa for a weak acid, or the pKb for a weak base. [See SP 5.1, 6.4, connects to 1.E.2] JoVE • Dissolved Oxygen in Surface Water • Introduction to Titration • Solutions and Concentrations
Outline Level 4	LO 6.14.	The student can, based on the dependence of Kw on temperature, reason that neutrality requires [H+] = [OH–] as opposed to requiring pH = 7, including especially the applications to biological systems. [See SP 2.2, 6.2] JoVE • Using a pH Meter
Outline Level 4	LO 6.15.	The student can 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. [See SP 2.2, 2.3, 6.4]

		JoVE • Using a pH Meter
Outline Level 4	**LO 6.16.**	**The student can 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. [See SP 2.2, 6.4]** **JoVE** • Assembly of a Reflux System for Heated Chemical Reactions • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • High-Performance Liquid Chromatography (HPLC) • Introduction to Titration • Ion-Exchange Chromatography • Le Châtelier's Principle • Passaging Cells • Two-Dimensional Gel Electrophoresis • Using a pH Meter
Outline Level 4	**LO 6.17.**	**The student can, 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. [See SP 6.4]** **JoVE** • Using a pH Meter
Outline Level 1	**AP.C.6.**	**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.**
Outline Level 2	**EU.6.C.**	**Chemical equilibrium plays an important role in acid-base chemistry and in solubility.**
Outline Level 3	**EK.6.C.2.**	**The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pKa allows one to determine the protonation state of a molecule with a labile proton.**
Outline Level 4	**6.C.2.a.**	**A buffer solution contains a large concentration of both members in a conjugate acid-base pair. The conjugate acid reacts with added base and the conjugate base reacts with added acid. The pH of the buffer is related to the pKa and the concentration ratio of acid and base forms. The buffer capacity is related to absolute concentrations of the acid and base forms. These relationships can be used both quantitatively and qualitatively to reason about issues such as the ratio of acid to base forms in a given buffer, the impact of this on**

		the buffer capacity for added acid or base, and the choice of an appropriate conjugate acid-base pair for a desired buffer pH (including polyprotic acids). JoVE • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Le Châtelier's Principle • Using a pH Meter
Outline Level 4	6.C.2.b.	If [A–]/[HA] starts as 1, it is not until the ratio changes by a factor of 10 that a 1 pH unit change occurs; adding small amounts of either acid or base does not change the ratio much, so the pH changes are much smaller for buffers than unbuffered solutions. JoVE • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Le Châtelier's Principle • Using a pH Meter
Outline Level 4	6.C.2.c.	Weak acids and their conjugate bases make good buffers. Strong acids and bases do not. It takes much more base to change the pH of a weak acid solution because there is a large reservoir of undissociated weak acid. JoVE • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Le Châtelier's Principle • Using a pH Meter
Outline Level 4	6.C.2.d.	By comparing the pH of a solution to the pKa of any acid in the solution, the concentration ratio between the acid and base forms of that acid (the protonation state) can be determined. For example, if pH < pKa, the acid form has a higher concentration than the base form. If pH > pKa, the base form has a higher concentration than the acid form. Applications of this relationship include the use of acid-base indicators, the protonation state of protein side chains (including acids or proteins with multiple labile protons), and the pH required for acid-catalyzed reactions in organic chemistry. JoVE • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation

		• Le Châtelier's Principle • Using a pH Meter
Outline Level 4	LO 6.18.	The student can 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. [See SP 2.3, 4.2, 6.4] JoVE • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Le Châtelier's Principle • Using a pH Meter
Outline Level 4	LO 6.19.	The student can 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 pKa associated with the labile proton. [See SP 2.3, 5.1, 6.4] JoVE • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Le Châtelier's Principle • Using a pH Meter
Outline Level 4	LO 6.20.	The student can 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. [See SP 6.4] JoVE • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Le Châtelier's Principle • Using a pH Meter
Outline Level 1	AP.C.6.	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.
Outline Level 2	EU.6.C.	Chemical equilibrium plays an important role in acid-base chemistry and in solubility.
Outline Level 3	EK.6.C.3.	The solubility of a substance can be understood in terms of chemical equilibrium.
Outline Level 4	6.C.3.a.	The dissolution of a substance in a solvent is a reversible reaction, and so has an associated equilibrium constant. For dissolution of a salt, the reaction quotient, Q, is referred to as the solubility product, and the equilibrium constant for this reaction is denoted as Ksp, the

		solubility-product constant. JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to the Microplate Reader • Ion-Exchange Chromatography • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Understanding Concentration and Measuring Volumes

Outline Level 4	6.C.3.b.	The solubility of a substance can be calculated from the Ksp for the dissolution reaction. This relation can also be used to reason qualitatively about the relative solubility of different substances. JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Degassing Liquids with Freeze-Pump-Thaw Cycling • Determining the Solubility Rules of Ionic Compounds • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Growing Crystals for X-ray Diffraction Analysis • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 4	6.C.3.c.	The free energy change (ΔG°) for dissolution of a substance reflects both the breaking of the forces that hold the solid together and the interaction of the dissolved species with the solvent. In addition, entropic effects must be considered. Qualitative reasoning regarding solubility requires consideration of all of these contributions to the free energy. JoVE • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Degassing Liquids with Freeze-Pump-Thaw Cycling • Determining the Solubility Rules of Ionic Compounds • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Growing Crystals for X-ray Diffraction Analysis • Purification of a Total Lipid Extract with Column

		Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 4	6.C.3.d.	All sodium, potassium, ammonium, and nitrate salts are soluble in water. JoVE • An Introduction to the Micropipettor • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Column Chromatography • Conducting Reactions Below Room Temperature • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining the Mass Percent Composition in an Aqueous Solution • Dialysis: Diffusion Based Separation • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Freezing-Point Depression to Determine an Unknown Compound • Growing Crystals for X-ray Diffraction Analysis • Internal Standards • Introduction to Serological Pipettes and Pipettors • Introduction to the Microplate Reader • Ion-Exchange Chromatography • Making Solutions in the Laboratory • Method of Standard Addition • Performing 1D Thin Layer Chromatography • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea

		Adduction for Uk'37 Paleothermometry • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Solid-Liquid Extraction • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment • Understanding Concentration and Measuring Volumes
Outline Level 4	6.C.3.e.	A salt is less soluble in a solution that has an ion in common with the salt. This has important consequences for solubility of salts in sea water and other natural bodies of water. This phenomenon can be understood qualitatively using Le Chatelier's principle. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	6.C.3.f.	The solubility of a salt will be pH sensitive when one of the ions is an acid or base. Applications include the iron hydroxides of acid-mine drainage and the effects of acid rain on solubility of carbonates. These effects can be understood qualitatively with Le Chatelier's principle. <u>JoVE</u> • Assembly of a Reflux System for Heated Chemical Reactions • Le Châtelier's Principle • Separation of Mixtures via Precipitation • Spectrophotometric Determination of an Equilibrium Constant
Outline Level 4	LO 6.21.	The student can predict the solubility of a salt, or rank the solubility of salts, given the relevant Ksp values. [See SP 2.2, 2.3, 6.4] <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Degassing Liquids with Freeze-Pump-Thaw Cycling • Determining the Solubility Rules of Ionic Compounds • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction

		• Growing Crystals for X-ray Diffraction Analysis • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sample Preparation for Analytical Preparation • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 4	LO 6.23.	The student can interpret data regarding the relative solubility of salts in terms of factors (common ions, pH) that influence the solubility. [See SP 5.1, 6.4] <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry • Determining the Solubility Rules of Ionic Compounds • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Growing Crystals for X-ray Diffraction Analysis • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 4	LO 6.24.	The student can analyze the enthalpic and entropic changes associated with the dissolution of a salt, using particulate level interactions and representations. [See SP 1.4, 7.1, connects to 5.E] <u>JoVE</u> • An Overview of Alkenone Biomarker Analysis for Paleothermometry • An Overview of bGDGT Biomarker Analysis for Paleoclimatology • Conversion of Fatty Acid Methyl Esters by Saponification for Uk'37 Paleothermometry

		• Determining the Solubility Rules of Ionic Compounds • Extraction of Biomarkers from Sediments - Accelerated Solvent Extraction • Growing Crystals for X-ray Diffraction Analysis • Purification of a Total Lipid Extract with Column Chromatography • Purifying Compounds by Recrystallization • Removal of Branched and Cyclic Compounds by Urea Adduction for Uk'37 Paleothermometry • Sample Preparation for Analytical Preparation • Solutions and Concentrations • Sonication Extraction of Lipid Biomarkers from Sediment • Soxhlet Extraction of Lipid Biomarkers from Sediment
Outline Level 1	**AP.C.SP.**	**Science Practices for AP Chemistry**
Outline Level 2	**SP.1.**	**The student can use representations and models to communicate scientific phenomena and solve scientific problems.**
Outline Level 3	**SP.1.1.**	**The student can create representations and models of natural or man-made phenomena and systems in the domain.** <u>JoVE</u> • Calibration Curves • Capillary Electrophoresis (CE) • Chromatography-Based Biomolecule Purification Methods • Column Chromatography • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Determining Rate Laws and the Order of Reaction • Determining the Empirical Formula • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Enzyme Assays and Kinetics • Fractional Distillation • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ideal Gas Law • Internal Standards • Introduction to Catalysis • Introduction to Mass Spectrometry • Introduction to Titration • Introduction to the Microplate Reader • Ion-Exchange Chromatography • Le Châtelier's Principle • MALDI-TOF Mass Spectrometry

		• Making Solutions in the Laboratory • Metabolic Labeling • Method of Standard Addition • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Protein Crystallization • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The Ideal Gas Law • Ultraviolet-Visible (UV-Vis) Spectroscopy • Understanding Concentration and Measuring Volumes • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 3	**SP.1.2.**	**The student can describe representations and models of natural or man-made phenomena and systems in the domain.** **JoVE** • Determining the Empirical Formula • Introduction to Titration • Solutions and Concentrations • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 3	**SP.1.3.**	**The student can refine representations and models of natural or man-made phenomena and systems in the domain.** **JoVE** • Determining the Empirical Formula • Introduction to Titration • Solutions and Concentrations • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 3	**SP.1.4.**	**The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.** **JoVE** • Determining the Empirical Formula • Introduction to Titration • Solutions and Concentrations

		• Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 3	SP.1.5.	The student can re-express key elements of natural phenomena across multiple representations in the domain. JoVE • Determining the Empirical Formula • Introduction to Titration • Solutions and Concentrations • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy
Outline Level 1	AP.C.SP.	Science Practices for AP Chemistry
Outline Level 2	SP 2.	The student can use mathematics appropriately.
Outline Level 3	SP.2.1.	The student can justify the selection of a mathematical routine to solve problems. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays • Column Chromatography • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining Rate Laws and the Order of Reaction • Determining the Density of a Solid and Liquid • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC)

		• Ideal Gas Law • Internal Standards • Introduction to Catalysis • Introduction to Mass Spectrometry • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • MALDI-TOF Mass Spectrometry • Making Solutions in the Laboratory • Metabolic Labeling • Method of Standard Addition • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Protein Crystallization • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Scanning Electron Microscopy (SEM) • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation • Solid-Liquid Extraction • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The Ideal Gas Law • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy • Understanding Concentration and Measuring Volumes • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter • X-ray Fluorescence (XRF)
Outline Level 3	SP.2.2.	The student can apply mathematical routines to quantities that describe natural phenomena. JoVE • Assembly of a Reflux System for Heated Chemical Reactions • Calibration Curves • Capillary Electrophoresis (CE) • Chromatography-Based Biomolecule Purification Methods • Co-Immunoprecipitation and Pull-Down Assays

		• Column Chromatography • Conducting Reactions Below Room Temperature • Coordination Chemistry Complexes • Cyclic Voltammetry (CV) • Degassing Liquids with Freeze-Pump-Thaw Cycling • Density Gradient Ultracentrifugation • Determining Rate Laws and the Order of Reaction • Determining the Density of a Solid and Liquid • Determining the Empirical Formula • Determining the Mass Percent Composition in an Aqueous Solution • Determining the Solubility Rules of Ionic Compounds • Dialysis: Diffusion Based Separation • Electrochemical Measurements of Supported Catalysts Using a Potentiostat/Galvanostat • Electrophoretic Mobility Shift Assay (EMSA) • Enzyme Assays and Kinetics • Fractional Distillation • Freezing-Point Depression to Determine an Unknown Compound • Förster Resonance Energy Transfer (FRET) • Gas Chromatography (GC) with Flame-Ionization Detection • Growing Crystals for X-ray Diffraction Analysis • High-Performance Liquid Chromatography (HPLC) • Ideal Gas Law • Internal Standards • Introduction to Catalysis • Introduction to Mass Spectrometry • Introduction to Titration • Introduction to the Microplate Reader • Introduction to the Spectrophotometer • Ion-Exchange Chromatography • Le Châtelier's Principle • MALDI-TOF Mass Spectrometry • Making Solutions in the Laboratory • Metabolic Labeling • Method of Standard Addition • Nuclear Magnetic Resonance (NMR) Spectroscopy • Performing 1D Thin Layer Chromatography • Photometric Protein Determination • Preparing Anhydrous Reagents and Equipment • Protein Crystallization • Purifying Compounds by Recrystallization • Raman Spectroscopy for Chemical Analysis • Reconstitution of Membrane Proteins • Rotary Evaporation to Remove Solvent • Sample Preparation for Analytical Preparation • Scanning Electron Microscopy (SEM) • Schlenk Lines Transfer of Solvents • Separation of Mixtures via Precipitation

		• Solid-Liquid Extraction • Solutions and Concentrations • Spectrophotometric Determination of an Equilibrium Constant • Surface Plasmon Resonance (SPR) • Tandem Mass Spectrometry • The Ideal Gas Law • Two-Dimensional Gel Electrophoresis • Ultraviolet-Visible (UV-Vis) Spectroscopy • Understanding Concentration and Measuring Volumes • Using Differential Scanning Calorimetry to Measure Changes in Enthalpy • Using a pH Meter • X-ray Fluorescence (XRF)
Outline Level 1	AP.C.SP.	Science Practices for AP Chemistry
Outline Level 2	SP.5.	The student can perform data analysis and evaluation of evidence.
Outline Level 3	SP.5.1.	The student can analyze data to identify patterns or relationships. JoVE • Raman Spectroscopy for Chemical Analysis
Outline Level 1	AP.C.SP.	Science Practices for AP Chemistry
Outline Level 2	SP.6.	The student can work with scientific explanations and theories.
Outline Level 3	SP.6.3.	The student can articulate the reasons that scientific explanations and theories are refined or replaced. JoVE • Le Châtelier's Principle • Rotary Evaporation to Remove Solvent
Outline Level 1	AP.C.SP.	Science Practices for AP Chemistry
Outline Level 2	SP.7.	The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
Outline Level 3	SP.7.1.	The student can connect phenomena and models across spatial and temporal scales. JoVE • Determining the Empirical Formula