



# CHS Chemistry II

Wednesday, July 6, 2022, 9:41AM

Unit	Standards	Content	Skills
<a href="#">Summer Work</a>			
<a href="#">Introduction to Nomenclature</a>	<p>AP: Chemistry (2019) AP: AP ENDURING UNDERSTANDINGS SCALE, PROPORTION, AND QUANTITY SPQ-2 Chemical formulas identify substances by their unique combination of atoms. STRUCTURE AND PROPERTIES SAP-2 The periodic table shows patterns in electronic structure and trends in atomic properties. SAP-3 Atoms or ions bond due to interactions between them, forming molecules. SAP-4 Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory. UNIT 1 Atomic Structure and Properties BIG IDEA 2 Structure and Properties SAP How can the same element be used in nuclear fuel rods and fake diamonds? TOPIC 1.8 Valence Electrons and Ionic Compounds SAP-2 The periodic table shows patterns in electronic structure and trends in atomic properties. SAP-2.B.1 The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements. <a href="#">Show details</a> SAP-2.B.3 Typical charges of atoms in ionic compounds are governed by their location on the periodic table and the number of valence electrons. <a href="#">Show details</a> UNIT 2 Molecular and Ionic Compound Structure and Properties BIG IDEA 2 Structure and Properties SAP How are molecular compounds arranged? TOPIC 2.1 Types of Chemical Bonds SAP-3 Atoms or ions bond due to interactions between them, forming molecules.</p>	<p>Organic Chemistry A. Properties and Bonding in Carbon Compounds 1. Introduction to organic chemistry: hydrocarbons and functional groups (structure, nomenclature, chemical properties). Physical and chemical properties of simple organic compounds  B. Nomenclature 1. Alkyl Groups 2. IUPAC Nomenclature 3. Isomers  C. Other Organic Compounds 1. Alcohols • Primary, Secondary, and Tertiary Alcohols • Diols and Triols 2. Aldehydes 3. Ketones 4. Acids  Complex Coordinate Nomenclature  Objectives:</p>	<p>4.A Explain chemical properties or phenomena (e.g., atoms or molecules) using given chemical theories, models, and representations.  4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.  5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).</p>

	<p>SAP-3.A Explain the relationship between the type of bonding and the properties of the elements participating in the bond.  <a href="#">Show details</a></p> <p>SAP-3.A.2 Valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond. For example, bonds between carbon and hydrogen are effectively nonpolar even though carbon is slightly more electronegative than hydrogen.  <a href="#">Show details</a></p> <p>SAP-3.A.3 Valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond.  a. The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond. b. In single bonds, greater differences in electronegativity lead to greater bond dipoles. c. All polar bonds have some ionic character, and the difference between ionic and covalent bonding is not distinct but rather a continuum.  <a href="#">Show details</a></p> <p>UNIT 3 Intermolecular Forces and Properties  BIG IDEA 1 Scale, Proportion, and Quantity SPQ  How do interactions between particles influence mixtures?  © 2013 The College Board, Advanced Placement</p> <p><a href="#">AP Frameworks</a></p>	<p><b>SPQ-2.A</b> Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.</p> <p><b>SAP-2.A</b> Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.</p> <p><b>SAP-2.B</b> Explain the relationship between trends in the reactivity of elements and periodicity.</p> <p><b>SAP-3.A</b> Explain the relationship between the type of bonding and the properties of the elements participating in the bond.</p>	<p>6.A Make a scientific claim.</p>
<p><a href="#">Thermochemistry</a></p>	<p>AP: Chemistry (2019)  AP: AP SKILLS  Models and Representations 1  Describe models and representations, including across scales.</p>	<p>A. <u>General aim:</u></p> <p>To relate the fundamental aspects of the energy changes that accompany chemical reactions.</p>	<p>The student will be able to:</p> <p>1.B Describe the components of</p>

	<p>1.A Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only.</p> <p>1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.</p> <p>ENDURING UNDERSTANDINGS</p> <p>ENERGY</p> <p>ENE-1 The speed at which a reaction occurs can be influenced by a catalyst.</p> <p>ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy</p> <p>ENE-3 The energy exchanged in a chemical transformation is required to break and form bonds.</p> <p>ENE-4 Some chemical or physical processes cannot occur without intervention.</p> <p>ENE-6 Electrical energy can be generated by chemical reactions.</p> <p>UNIT 3 Intermolecular Forces and Properties</p> <p>TOPIC 3.8 Representations of Solutions</p> <p>SPQ-3 Interactions between intermolecular forces influence the solubility and separation of mixtures.</p> <p>UNIT 6 Thermodynamics</p> <p>BIG IDEA 4 Energy ENE</p> <p>Why is energy released when water becomes an ice cube? How are chemical transformations that require bonds to break and form influenced by energy?</p> <p>TOPIC 6.1 Endothermic and Exothermic Processes</p> <p>ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy</p> <p>ENE-2.A Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.</p> <p><a href="#">Show details</a></p> <p>ENE-2.A.1 Temperature changes in a system indicate energy changes.</p> <p><a href="#">Show details</a></p> <p>ENE-2.A.2 Energy changes in a system can be described as endothermic and exothermic processes such as the heating or cooling of a substance, phase changes, or chemical transformations.</p> <p><a href="#">Show details</a></p> <p>ENE-2.A.3 When a chemical reaction occurs, the energy of the system either decreases (exothermic reaction), increases (endothermic reaction), or remains the same. For</p>	<p>B. <u>Content:</u></p> <ol style="list-style-type: none"> <li>1. Concept of energy       <ol style="list-style-type: none"> <li>1. potential energy, kinetic energy</li> <li>2. first law of thermodynamics</li> <li>3. heat</li> <li>4. work</li> <li>5. state functions</li> <li>6. system and surroundings</li> <li>7. endothermic and exothermic reactions</li> <li>8. internal energy of a system</li> </ol> </li> <li>2. Calorimetry       <ol style="list-style-type: none"> <li>1. use of a calorimeter</li> <li>2. heat capacity</li> <li>3. specific heat</li> <li>4. energy released as heat</li> </ol> </li> <li>3. Enthalpy change for a chemical reaction       <ol style="list-style-type: none"> <li>1. Hess's law</li> <li>2. Enthalpies of phase changes and solution</li> <li>3. standard enthalpies of formation</li> <li>4. heat of reaction, e.g., heat of combustion</li> <li>5. bond dissociation energies</li> </ol> </li> </ol> <p>Objectives:</p>	<p>and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.</p> <p>2.D Make observations or collect data from representations of laboratory setups or results, while attending precision where appropriate.</p> <p>3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.</p> <p>4.C Explain the connection between particulate level and macroscopic properties of a substance using</p>
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	<p>exothermic reactions, the energy lost by the reacting species (system) is gained by the surroundings, as heat transfer from or work done by the system. Likewise, for endothermic reactions, the system gains energy from the surroundings by heat transfer to or work done on the system.</p> <p><a href="#">Show details</a></p> <p>ENE-2.A.4 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.</p> <p><a href="#">Show details</a></p> <p>TOPIC 6.2 Energy Diagrams</p> <p>ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy.</p> <p>ENE-2.B Represent a chemical or physical transformation with an energy diagram.</p> <p><a href="#">Show details</a></p> <p>ENE-2.B.1 A physical or chemical process can be described with an energy diagram that shows the endothermic or exothermic nature of that process.</p> <p><a href="#">Show details</a></p> <p>TOPIC 6.4 Heat Capacity and Calorimetry</p> <p>ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy.</p> <p>ENE-2.D Calculate the heat <math>q</math> absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature.</p> <p><a href="#">Show details</a></p> <p>ENE-2.D.1 The heating of a cool body by a warmer body is an important form of energy transfer between two systems. The amount of heat transferred between two bodies may be quantified by the heat transfer equation: EQN : <math>q = mc\Delta T</math> Calorimetry experiments are used to measure the transfer of heat.</p> <p><a href="#">Show details</a></p> <p>ENE-2.D.2 The first law of thermodynamics states that energy is conserved in chemical and physical processes.</p> <p><a href="#">Show details</a></p> <p>ENE-2.D.3 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.</p> <p><a href="#">Show details</a></p>	<p><b>ENE-2.A</b> Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.</p> <p><b>ENE-2.B</b> Represent a chemical or physical transformation with an energy diagram.</p> <p><b>ENE-2.C</b> Explain the relationship between the transfer of thermal energy and molecular collisions.</p> <p><b>ENE-2.D</b> Calculate the heat <math>q</math> absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature.</p> <p><b>ENE-2.E</b> Explain changes in the heat <math>q</math> absorbed or released by a system undergoing a phase transition based on the amount of the substance in moles and the molar enthalpy of the phase transition.</p> <p><b>ENE-2.F</b> Calculate the heat <math>q</math> absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the</p>	<p>models and representations.</p> <p>5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).</p> <p>5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).</p> <p>6.D Provide reasoning to justify a claim using chemical</p>
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	<p>ENE-2.D.4 Heating a system increases the energy of the system, while cooling a system decreases the energy of the system.  <a href="#">Show details</a></p> <p>ENE-2.D.5 The specific heat capacity of a substance and the molar heat capacity are both used in energy calculations.  <a href="#">Show details</a></p> <p>ENE-2.D.6 Chemical systems change their energy through three main processes: heating/cooling, phase transitions, and chemical reactions.  <a href="#">Show details</a></p> <p>TOPIC 6.5 Energy of Phase Changes</p> <p>ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy.</p> <p>ENE-2.E Explain changes in the heat <math>q</math> absorbed or released by a system undergoing a phase transition based on the amount of the substance in moles and the molar enthalpy of the phase transition.  <a href="#">Show details</a></p> <p>ENE-2.E.1 Energy must be transferred to a system to cause a substance to melt (or boil). The energy of the system therefore increases as the system undergoes a solid-to-liquid (or liquid-to-gas) phase transition. Likewise, a system releases energy when it freezes (or condenses). The energy of the system decreases as the system undergoes a liquid-to-solid (or gas-to-liquid) phase transition. The temperature of a pure substance remains constant during a phase change.  <a href="#">Show details</a></p> <p>ENE-2.E.2 The energy absorbed during a phase change is equal to the energy released during a complementary phase change in the opposite direction. For example, the molar heat of condensation of a substance is equal to the negative of its molar heat of vaporization.  <a href="#">Show details</a></p> <p>TOPIC 6.6 Introduction to Enthalpy of Reaction</p> <p>ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy.</p> <p>ENE-2.F Calculate the heat <math>q</math> absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the reacting substance in moles and the molar enthalpy of reaction.  <a href="#">Show details</a></p>	<p>reacting substance in moles and the molar enthalpy of reaction.</p> <p><b>ENE-3.A</b> Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction.</p> <p><b>ENE-3.B</b> Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.</p> <p><b>ENE-3.C</b> Represent a chemical or physical process as a sequence of steps.</p> <p><b>ENE-3.D</b> Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.</p>	<p>principles or laws, or using mathematical justification.</p> <p>6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.</p>
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ENE-2.F.1 The enthalpy change of a reaction gives the amount of heat energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure.

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TOPIC 6.7 Bond Enthalpies

ENE-3 The energy exchanged in a chemical transformation is required to break and form bonds.

ENE-3.A Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction.

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ENE-3.A.1 During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the system.

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ENE-3.A.2 The average energy required to break all of the bonds in the reactant molecules can be estimated by adding up the average bond energies of all the bonds in the reactant molecules. Likewise, the average energy released in forming the bonds in the product molecules can be estimated. If the energy released is greater than the energy required, the reaction is exothermic. If the energy required is greater than the energy released, the reaction is endothermic.

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TOPIC 6.8 Enthalpy of Formation

ENE-3 The energy exchanged in a chemical transformation is required to break and form bonds.

ENE-3.B Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.

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ENE-3.B.1 Tables of standard enthalpies of formation can be used to calculate the standard enthalpies of reactions.

$$\text{EQN} = \Delta H^\circ_{\text{reaction}} = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

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TOPIC 6.9 Hess's Law ENE

ENE-3 The energy exchanged in a chemical transformation is required to break and form bonds.

ENE-3.C Represent a chemical or physical process as a sequence of steps.

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	<p>ENE-3.C.1 Although the concept of “state function” is not required for the course, two principles of Hess’s law should be understood. First, when a reaction is reversed, the enthalpy change stays constant in magnitude but becomes reversed in mathematical sign. Second, when two (or more) reactions are added to obtain an overall reaction, the individual enthalpy changes of each reaction are added to obtain the net enthalpy of the overall reaction.  <a href="#">Show details</a></p> <p>ENE-3.D Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.  <a href="#">Show details</a></p> <p>ENE-3.D.1 When the products of a reaction are at a different temperature than their surroundings, they exchange energy with the surroundings to reach thermal equilibrium. Thermal energy is transferred to the surroundings from the products of an exothermic reaction. Thermal energy is transferred from the surroundings to the products of an endothermic reaction.  <a href="#">Show details</a></p> <p>© 2013 The College Board, Advanced Placement</p> <p><a href="#">AP Frameworks</a></p>		
<p><a href="#">Kinetics</a></p>	<p>AP: Chemistry (2019)  AP: AP  SKILLS  Representing Data and Phenomena 3  Create representations or models of chemical phenomena.  3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.  3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).  3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).  Model Analysis 4  Analyze and interpret models and representations on a single scale or across multiple scales.  4.A Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.</p>	<p><b>Chemical Kinetics</b></p> <p>A. <u>General aim:</u></p> <p>To measure, alter, and predict the rates of chemical reactions.</p> <p>B. <u>Content:</u></p> <ol style="list-style-type: none"> <li>1. Reaction rates <ol style="list-style-type: none"> <li>1. definitions and units</li> <li>2. instantaneous rates from plot of</li> </ol> </li> </ol>	<p>The student will be able to:</p> <p>1.B Describe the components of a quantitative information form models and representations that illustrate both particulate-level and macroscopic-level properties.</p>



	<p>4.B Explain whether a model is consistent with chemical theories.</p> <p>4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.</p> <p>Mathematical Routines 5</p> <p>Solve problems using mathematical relationships</p> <p>5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).</p> <p>5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.</p> <p>5.C Explain the relationship between variables within an equation when one variable changes.</p> <p>5.D Identify information presented graphically to solve a problem.</p> <p>5.E Determine a balanced chemical equation for a given chemical phenomenon.</p> <p>5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).</p> <p>ENDURING UNDERSTANDINGS</p> <p>ENERGY</p> <p>ENE-1 The speed at which a reaction occurs can be influenced by a catalyst.</p> <p>UNIT 5 Kinetics</p> <p>BIG IDEA 3 Transformations TRA</p> <p>Why are some reactions faster than other reactions?</p> <p>How long will a marble statue last?</p> <p>How can a sports drink cure a headache?</p> <p>TOPIC 5.1 Reaction Rates</p> <p>TRA-3 Some reactions happen quickly, while others happen more slowly and depend on reactant concentrations and temperature.</p> <p>TRA-3.A Explain the relationship between the rate of a chemical reaction and experimental parameters.</p> <p><a href="#">Show details</a></p> <p>TRA-3.A.1 The kinetics of a chemical reaction is defined as the rate at which an amount of reactants is converted to products per unit of time.</p> <p><a href="#">Show details</a></p>	<p>concentrations versus tie</p> <ol style="list-style-type: none"> <li>3. factors that affect rate: concentration, temperature, catalyst</li> <li>4. potential energy diagram for a reaction</li> </ol> <ol style="list-style-type: none"> <li>2. Integrated rate law       <ol style="list-style-type: none"> <li>1. equations relating concentration and time</li> <li>2. reaction order determined from the plot needed to give a straight line</li> <li>3. determination of overall order</li> </ol> </li> <li>3. Reaction mechanism       <ol style="list-style-type: none"> <li>1. molecularity</li> <li>2. rate-determining step</li> <li>3. distinguishing between catalyst and intermediates in mechanism</li> </ol> </li> <li>4. Collision model       <ol style="list-style-type: none"> <li>1. activation energy: Arrhenius equation</li> <li>2. molecular orientations</li> </ol> </li> <li>5. Catalysts: homogeneous and heterogeneous</li> <li>6. Half-life (first order for common nuclear)</li> </ol> <p>Big Idea 4: Rates of chemical reactions are determined by</p>	<p>3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).</p> <p>5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.</p> <p>5.C Explain the relationship between variables within an equations when one variable changes.</p> <p>5.E Determine a balanced chemical equation for a given chemical phenomena.</p> <p>6.E Provide reasoning to justify a claim</p>
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	<p>TRA-3.A.2 The rates of change of reactant and product concentrations are determined by the stoichiometry in the balanced chemical equation.  <a href="#">Show details</a></p> <p>TRA-3.A.3 The rate of a reaction is influenced by reactant concentrations, temperature, surface area, catalysts, and other environmental factors.  <a href="#">Show details</a></p> <p>TOPIC 5.2 Introduction to Rate Law</p> <p>TRA-3 Some reactions happen quickly, while others happen more slowly and depend on reactant concentrations and temperature.</p> <p>TRA-3.B Represent experimental data with a consistent rate law expression.  <a href="#">Show details</a></p> <p>TRA-3.B.1 Experimental methods can be used to monitor the amounts of reactants and/or products of a reaction and to determine the rate of the reaction.  <a href="#">Show details</a></p> <p>TRA-3.B.2 The rate law expresses the rate of a reaction as proportional to the concentration of each reactant raised to a power.  <a href="#">Show details</a></p> <p>TRA-3.B.3 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.  <a href="#">Show details</a></p> <p>TRA-3.B.4 The proportionality constant in the rate law is called the rate constant. The value of this constant is temperature dependent and the units reflect the overall reaction order.  <a href="#">Show details</a></p> <p>TRA-3.B.5 Comparing initial rates of a reaction is a method to determine the order with respect to each reactant.  <a href="#">Show details</a></p> <p>TOPIC 5.3 Concentration Changes Over Time</p> <p>TRA-3 Some reactions happen quickly, while others happen more slowly and depend on reactant concentrations and temperature.</p> <p>TRA-3.C Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.  <a href="#">Show details</a></p>	<p>details of the molecular collisions. [CR2]  Learning Objectives: 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9</p> <p>Kinetics</p> <ol style="list-style-type: none"> <li>1. Rates relationship to collisions</li> <li>2. Reaction Mechanisms</li> <li>3. Activation energy</li> <li>4. Nature of Reactants and Interfacial Surface Area</li> <li>5. Temperature and Pressure effects on Rates</li> <li>6. Catalyst—Homogeneous and Heterogeneous</li> <li>7. Potential Energy Diagrams—Review</li> <li>8. Activated Complex and Intermediates</li> <li>9. Arrhenius Equation</li> <li>10. Maxwell- Boltzman Diagram</li> <li>11. Average Rate</li> <li>12. Rates relationship to Stoichiometry</li> <li>13. Graphical determination of Instantaneous Rate</li> <li>14. Rate Laws</li> <li>15. Determination of Rate Laws</li> <li>16. Determination of Mechanisms</li> <li>17. Order of Reactions</li> <li>18. Calculations based on Order</li> </ol> <p>Objectives:</p> <p><b>TRA-3.A</b> Explain the relationship between the rate of a chemical</p>	<p>using connections between particulate and macroscopic scales or levels.</p>
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TRA-3.C.1 The order of a reaction can be inferred from a graph of concentration of reactant versus time.

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TRA-3.C.2 If a reaction is first order with respect to a reactant being monitored, a plot of the natural log (ln) of the reactant concentration as a function of time will be linear.

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TRA-3.C.3 If a reaction is second order with respect to a reactant being monitored, a plot of the reciprocal of the concentration of that reactant versus time will be linear.

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TRA-3.C.4 The slopes of the concentration versus time data for zeroth, first, and second order reactions can be used to determine the rate constant for the reaction.

Zeroth order: EQN :  $[A]_t - [A]_0 = -kt$

First order: EQN :  $\ln[A]_t - \ln[A]_0 = -kt$

Second order: EQN :  $1/[A]_t - 1/[A]_0 = kt$

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TRA-3.C.5 Half-life is a critical parameter for first order reactions because the half-life is constant and related to the rate constant for the reaction by the equation:

EQN :  $t_{1/2} = 0.693/k$ .

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TRA-3.C.6 Radioactive decay processes provide an important illustration of first order kinetics.

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TOPIC 5.4 Elementary Reactions

TRA-4 There is a relationship between the speed of a reaction and the collision frequency of particle collisions.

TRA-4.A Represent an elementary reaction as a rate law expression using stoichiometry.

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TRA-4.A.1 The rate law of an elementary reaction can be inferred from the stoichiometry of the molecules participating in a collision.

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TRA-4.A.2 Elementary reactions involving the simultaneous collision of three or more particles are rare.

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TOPIC 5.5 Collision Model

TRA-4 There is a relationship between the speed of a reaction and the collision frequency of particle collisions.

reaction and experimental parameters.

**TRA-3.B** Represent experimental data with a consistent rate law expression.

**TRA-3.C** Identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.

**TRA-4.A** Represent an elementary reaction rate law expression using stoichiometry.

**TRA-4.B** Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of molecular collisions.

**TRA-4.C** Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.

	<p>TRA-4.B Explain the relationship between the rate of an elementary reaction and the frequency, energy, and orientation of molecular collisions.  <a href="#">Show details</a></p> <p>TRA-4.B.1 For an elementary reaction to successfully produce products, reactants must successfully collide to initiate bond-breaking and bond-making events.  <a href="#">Show details</a></p> <p>TRA-4.B.2 In most reactions, only a small fraction of the collisions leads to a reaction. Successful collisions have both sufficient energy to overcome energy barriers and orientations that allow the bonds to rearrange in the required manner.  <a href="#">Show details</a></p> <p>TRA-4.B.3 The Maxwell-Boltzmann distribution curve 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.  <a href="#">Show details</a></p> <p>TOPIC 5.6 Reaction Energy Profile          TRA-4 There is a relationship between the speed of a reaction and the collision frequency of particle collisions.          TRA-4.C Represent the activation energy and overall energy change in an elementary reaction using a reaction energy profile.  <a href="#">Show details</a></p> <p>TRA-4.C.1 Elementary reactions typically involve the breaking of some bonds and the forming of new ones.  <a href="#">Show details</a></p> <p>TRA-4.C.2 The reaction coordinate is the axis along which the complex set of motions involved in rearranging reactants to form products can be plotted.  <a href="#">Show details</a></p> <p>TRA-4.C.3 The energy profile gives the energy along the reaction coordinate, which typically proceeds from reactants, through a transition state, to products. The energy difference between the reactants and the transition state is the activation energy for the forward reaction.  <a href="#">Show details</a></p> <p>TRA-4.C.4 The Arrhenius equation relates the temperature dependence of the rate of an elementary reaction to the activation energy needed by molecular collisions to reach the transition state.</p>	<p><b>TRA-5.A</b> Identify the components of a reaction mechanism.</p> <p><b>TRA-5.B</b> Identify the rate law for a reaction from a mechanism in which the first step is rate limiting.</p> <p><b>TRA-5.C</b> Identify the rate law for a reaction from a mechanism in which the first step is not rate limiting.</p> <p><b>TRA-5.D</b> Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile.</p> <p><b>ENE-1.A</b> Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.</p>	
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TOPIC 5.7 Introduction to Reaction Mechanisms

TRA-5 Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation.

TRA-5.A Identify the components of a reaction mechanism.

[Show details](#)

TRA-5.A.1 A reaction mechanism consists of a series of elementary reactions, or steps, that occur in sequence. The components may include reactants, intermediates, products, and catalysts.

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TRA-5.A.2 The elementary steps when combined should align with the overall balanced equation of a chemical reaction.

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TRA-5.A.3 A reaction intermediate is produced by some elementary steps and consumed by others, such that it is present only while a reaction is occurring.

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TRA-5.A.4 Experimental detection of a reaction intermediate is a common way to build evidence in support of one reaction mechanism over an alternative mechanism.

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TOPIC 5.8 Reaction Mechanism and Rate Law

TRA-5 Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation.

TRA-5.B Identify the rate law for a reaction from a mechanism in which the first step is rate limiting.

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TRA-5.B.1 For reaction mechanisms in which each elementary step is irreversible, or in which the first step is rate limiting, the rate law of the reaction is set by the molecularity of the slowest elementary step (i.e., the rate-limiting step).

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TOPIC 5.9 Steady-State Approximation

TRA-5 Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation.

TRA-5.C Identify the rate law for a reaction from a mechanism in which the first step is not rate limiting.

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TRA-5.C.1 If the first elementary reaction is not rate limiting, approximations (such as steady state) must be made to determine a rate law expression.

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TOPIC 5.10 Multistep Reaction Energy Profile

TRA-5 Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation.

TRA-5.D Represent the activation energy and overall energy change in a multistep reaction with a reaction energy profile.

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TRA-5.D.1 Knowledge of the energetics of each elementary reaction in a mechanism allows for the construction of an energy profile for a multistep reaction.

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TOPIC 5.11 Catalysis

ENE-1 The speed at which a reaction occurs can be influenced by a catalyst.

ENE-1.A Explain the relationship between the effect of a catalyst on a reaction and changes in the reaction mechanism.

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ENE-1.A.1 In order for a catalyst to increase the rate of a reaction, the addition of the catalyst must increase the number of effective collisions and/or provide a reaction path with a lower activation energy relative to the original reaction coordinate.

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ENE-1.A.2 In a reaction mechanism containing a catalyst, the net concentration of the catalyst is constant. However, the catalyst will frequently be consumed in the rate-determining step of the reaction, only to be regenerated in a subsequent step in the mechanism.

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ENE-1.A.3 Some catalysts accelerate a reaction by binding to the reactant(s). The reactants are either oriented more favorably or react with lower activation energy. There is often a new reaction intermediate in which the catalyst is bound to the reactant(s). Many enzymes function in this manner.

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ENE-1.A.4 Some catalysts involve covalent bonding between the catalyst and the reactant(s). An example is acid-base catalysis, in which a reactant or intermediate

	<p>either gains or loses a proton. This introduces a new reaction intermediate and new elementary reactions involving that intermediate.</p> <p><a href="#">Show details</a></p> <p>ENE-1.A.5 In surface catalysis, a reactant or intermediate binds to, or forms a covalent bond with, the surface. This introduces elementary reactions involving these new bound reaction intermediate(s).</p> <p><a href="#">Show details</a></p> <p>© 2013 The College Board, Advanced Placement</p> <p><a href="#">AP Frameworks</a></p>		
<p><a href="#">Equilibrium</a></p>	<p>AP: Chemistry (2019)  AP: AP  UNIT 7 Equilibrium  BIG IDEA 1 Scale, Proportion, and Quantity SPQ  Why is a waterfall considered a spontaneous reaction?  BIG IDEA 3 Transformation TRA  How can reactions occur in more than one direction?  How is caffeine removed from coffee?  Why is food stored in a refrigerator?  TOPIC 7.1 Introduction to Equilibrium  TRA-6 Some reactions can occur in both forward and reverse directions, sometimes proceeding in each direction simultaneously.  TRA-6.A Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations.  <a href="#">Show details</a>  TRA-6.A.1 Many observable processes are reversible. Examples include evaporation and condensation of water, absorption and desorption of a gas, or dissolution and precipitation of a salt. Some important reversible chemical processes include the transfer of protons in acid-base reactions and the transfer of electrons in redox reactions.  <a href="#">Show details</a>  TRA-6.A.2 When equilibrium is reached, no observable changes occur in the system. Reactants and products are simultaneously present, and the concentrations or partial pressures of all species remain constant.  TRA-6.A.3 The equilibrium state is dynamic. The forward and reverse processes continue to occur at equal rates, resulting in no net observable change.</p>	<p>Equilibrium</p> <p>Key Concepts:</p> <ol style="list-style-type: none"> <li>1. Relate the expression for K to the corresponding equation for the chemical reaction</li> <li>2. Calculate K knowing <ul style="list-style-type: none"> <li>• appropriate K values for other reactions</li> <li>• all the equilibrium partial pressures</li> <li>• all the original and one equilibrium partial pressure</li> </ul> </li> <li>3. Use LeChâtelier's principle to determine what will happen when the conditions on an equilibrium system are changed</li> <li>4. Use the value of K to determine• the direction of the</li> </ol>	<p>The student will be able to:</p> <p>3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.</p> <p>3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).</p>

	<p><a href="#">Show details</a>          TRA-6.A.4 Graphs of concentration, partial pressure, or rate of reaction versus time for simple chemical reactions can be used to understand the establishment of chemical equilibrium.</p> <p><a href="#">Show details</a>          TOPIC 7.2 Direction of Reversible Reactions          TRA-6 Some reactions can occur in both forward and reverse directions, sometimes proceeding in each direction simultaneously.</p> <p>TRA-6.B Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions.</p> <p><a href="#">Show details</a>          TRA-6.B.1 If the rate of the forward reaction is greater than the reverse reaction, then there is a net conversion of reactants to products. If the rate of the reverse reaction is greater than that of the forward reaction, then there is a net conversion of products to reactants. An equilibrium state is reached when these rates are equal.</p> <p><a href="#">Show details</a>          TOPIC 7.3 Reaction Quotient and Equilibrium Constant          TRA-7 A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K.</p> <p>TRA-7.A Represent the reaction quotient <math>Q_c</math> or <math>Q_p</math>, for a reversible reaction, and the corresponding equilibrium expressions <math>K_c = Q_c</math> or <math>K_p = Q_p</math>.</p> <p><a href="#">Show details</a>          TRA-7.A.1 The reaction quotient <math>Q_c</math> describes the relative concentrations of reaction species at any time. For gas phase reactions, the reaction quotient may instead be written in terms of pressures as <math>Q_p</math>. The reaction quotient tends toward the equilibrium constant such that at equilibrium <math>K_c = Q_c</math> and <math>K_p = Q_p</math>. As examples, for the reaction  <math>aA + bB \rightleftharpoons cC + dD</math>          the equilibrium expression for (<math>K_c, Q_c</math>) is  <math display="block">\text{EQN} : K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}</math>          and that for (<math>K_p, Q_p</math>) is  <math display="block">\text{EQN} : K_p = \frac{(P_C)^c (P_D)^d}{(P_A)^a (P_B)^b}</math></p> <p><a href="#">Show details</a></p>	<p>reaction• equilibrium partial pressures of all species          Outline:</p> <ul style="list-style-type: none"> <li>• <math>N_2O_4</math>-<math>NO_2</math> equilibrium system</li> <li>• The equilibrium constant expression</li> <li>• Determination of K</li> <li>• Applications of the equilibrium constant</li> <li>• Effect of changes in conditions on an equilibrium system</li> </ul> <p>Objectives:</p> <p><b>TRA-6.A</b> Explain the relationship between the occurrence of a reversible chemical or physical process, and the establishment of equilibrium, to experimental observations.</p> <p><b>TRA-6.B</b> Explain the relationship between the direction in which a reversible reaction proceeds and the relative rates of the forward and reverse reactions.</p> <p><b>TRA-7.A</b> Represent the reaction quotient or <math>Q_p</math>, for a reversible reaction, and the corresponding equilibrium expressions <math>K_c=Q_c</math> or <math>K_p=Q_p</math>.</p>	<p>4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.</p> <p>5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).</p> <p>5.C Explain the relationship between variables within an equation when one variable changes.</p> <p>5.F Calculate, estimate, or predict an unknown quantity from known quantities by</p>
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	<p>TRA-7.A.2 The reaction quotient does not include substances whose concentrations (or partial pressures) are independent of the amount, such as for solids and pure liquids.  <a href="#">Show details</a></p> <p>TOPIC 7.4 Calculating the Equilibrium Constant          TRA-7.A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K.          TRA-7.B Calculate <math>K_c</math> or <math>K_p</math> based on experimental observations of concentrations or pressures at equilibrium.  <a href="#">Show details</a></p> <p>TRA-7.B.1 Equilibrium constants can be determined from experimental measurements of the concentrations or partial pressures of the reactants and products at equilibrium.  <a href="#">Show details</a></p> <p>TOPIC 7.5 Magnitude of the Equilibrium Constant          TRA-7 A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K.          TRA-7.C Explain the relationship between very large or very small values of K and the relative concentrations of chemical species at equilibrium.  <a href="#">Show details</a></p> <p>TRA-7.C.1 Some equilibrium reactions have very large K values and proceed essentially to completion. Others have very small K values and barely proceed at all.  <a href="#">Show details</a></p> <p>TOPIC 7.6 Properties of the Equilibrium Constant          TRA-7 A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K.          TRA-7.D Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction.  <a href="#">Show details</a></p> <p>TRA-7.D.1 When a reaction is reversed, K is inverted.  <a href="#">Show details</a></p> <p>TRA-7.D.2 When the stoichiometric coefficients of a reaction are multiplied by a factor c, K is raised to the power c.  <a href="#">Show details</a></p>	<p><b>TRA-7.B</b> Calculate <math>K_c</math> or <math>K_p</math> based on experimental observations of concentrations or pressure at equilibrium.</p> <p><b>TRA-7.C</b> Explain the relationship between very large or very small values of K and the relative concentrations of chemical species at equilibrium.</p> <p><b>TRA-7.D</b> Represent a multistep process with an overall equilibrium expression, using the constituent K expressions for each individual reaction.</p> <p><b>TRA-7.E</b> Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and equilibrium constant.</p> <p><b>TRA-7.F</b> Represent a system undergoing a reversible reaction with a particulate model.</p> <p><b>TRA-8.A</b> Identify the response of a system at equilibrium to an</p>	<p>selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).</p> <p>6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.</p> <p>6.F Explain the connection between experimental results and chemical concepts, processes, or theories.</p>
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	<p>TRA-7.D.3 When reactions are added together, the K of the resulting overall reaction is the product of the K's for the reactions that were summed. <a href="#">Show details</a></p> <p>TRA-7.D.4 Since the expressions for K and Q have identical mathematical forms, all valid algebraic manipulations of K also apply to Q. <a href="#">Show details</a></p> <p>TOPIC 7.7 Calculating Equilibrium Concentrations TRA-7 A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K. TRA-7.E Identify the concentrations or partial pressures of chemical species at equilibrium based on the initial conditions and the equilibrium constant. <a href="#">Show details</a></p> <p>TRA-7.E.1 The concentrations or partial pressures of species at equilibrium can be predicted given the balanced reaction, initial concentrations, and the appropriate K. <a href="#">Show details</a></p> <p>TOPIC 7.8 Representations of Equilibrium TRA-7 A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and equilibrium constant K. TRA-7.F Represent a system undergoing a reversible reaction with a particulate model. <a href="#">Show details</a></p> <p>TRA-7.F.1 Particulate representations can be used to describe the relative numbers of reactant and product particles present prior to and at equilibrium, and the value of the equilibrium constant. <a href="#">Show details</a></p> <p>TOPIC 7.9 Introduction to Le Châtelier's Principle TRA-8 Systems at equilibrium respond to external stresses to offset the effect of the stress. TRA-8.A Identify the response of a system at equilibrium to an external stress, using Le Châtelier's principle. <a href="#">Show details</a></p> <p>TRA-8.A.1 Le Châtelier's principle can be used to predict the response of a system to stresses such as addition or removal of a chemical species, change in temperature, change in volume/ pressure of a gas-phase system, or dilution of a reaction system. <a href="#">Show details</a></p>	<p>external stress, using Le Châtelier's principle..</p> <p><b>TRA-8.B</b> Explain the relationship between Q, K, and the direction in which a reversible reaction will proceed to reach equilibrium.</p>	
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	<p>TRA-8.A.2 Le Châtelier's principle can be used to predict the effect that a stress will have on experimentally measurable properties such as pH, temperature, and color of a solution.  <a href="#">Show details</a></p> <p>TOPIC 7.10 Reaction Quotient and Le Châtelier's Principle          TRA-8 Systems at equilibrium respond to external stresses to offset the effect of the stress.          TRA-8.B Explain the relationships between Q, K, and the direction in which a reversible reaction will proceed to reach equilibrium.  <a href="#">Show details</a></p> <p>TRA-8.B.1 A disturbance to a system at equilibrium causes Q to differ from K, thereby taking the system out of equilibrium. The system responds by bringing Q back into agreement with K, thereby establishing a new equilibrium state.  <a href="#">Show details</a></p> <p>TRA-8.B.2 Some stresses, such as changes in concentration, cause a change in Q only. A change in temperature causes a change in K. In either case, the concentrations or partial pressures of species redistribute to bring Q and K back into equality.  <a href="#">Show details</a></p> <p>© 2013 The College Board, Advanced Placement</p> <p><a href="#">AP Frameworks</a></p>		
<p><a href="#">Acid- Base Equilibrium</a></p>	<p>AP: Chemistry (2019)          AP: AP          UNIT 4 Chemical Reactions          TOPIC 4.6 Introduction to Titration          SPQ-4 When a substance changes into a new substance, or when its properties change, no mass is lost or gained.          SPQ-4.B Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.  <a href="#">Show details</a></p> <p>SPQ-4.B.1 Titrations may be used to determine the concentration of an analyte in solution. The titrant has a known concentration of a species that reacts specifically and quantitatively with the analyte. The equivalence point of the titration occurs when the analyte is totally consumed by the reacting species in the titrant. The equivalence point</p>	<p>Lecture Outline</p> <ol style="list-style-type: none"> <li>1. Brønsted-Lowry acid-base model</li> <li>2. The ion product of water</li> <li>3. pH and pOH</li> <li>4. Weak acids and their equilibrium constants</li> <li>5. Weak bases and their equilibrium constants</li> </ol>	<p>The student will be able to:</p> <p>2.D Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.</p>

	<p>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 endpoint of the titration.</p> <p><a href="#">Show details</a></p> <p>TOPIC 4.7 Types of Chemical Reactions          TRA-2 A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.          TRA-2.A Identify a reaction as acidbase, oxidation-reduction, or precipitation.</p> <p><a href="#">Show details</a></p> <p>TRA-2.A.1 Acid-base reactions involve transfer of one or more protons between chemical species.</p> <p><a href="#">Show details</a></p> <p>TOPIC 4.8 Introduction to Acid-Base Reactions          TRA-2A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.          TRA-2.B Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.</p> <p><a href="#">Show details</a></p> <p>TRA-2.B.1 By definition, a Brønsted-Lowry acid is a proton donor and a Brønsted-Lowry base is a proton acceptor.</p> <p><a href="#">Show details</a></p> <p>TRA-2.B.2 Only in aqueous solutions, water plays an important role in many acid-base reactions, as its molecular structure allows it to accept protons from and donate protons to dissolved species.</p> <p><a href="#">Show details</a></p> <p>TRA-2.B.3 When an acid or base ionizes in water, the conjugate acid-base pairs can be identified and their relative strengths compared. Rationale: Lewis acid-base concepts are important ideas for organic chemistry. However, as the emphasis in AP Chemistry is on reactions in aqueous solution, these concepts will not be examined.</p> <p><a href="#">Show details</a></p> <p>UNIT 8 Acids and Bases          BIG IDEA 2 Structure and Properties SAP          How are reactions involving acids and bases related to pH?          How does your body maintain pH balance?          TOPIC 8.1 Introduction to Acids and Bases          SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium</p>	<p>6. Acid-base properties of salt solutions</p> <p>7. Extending the concept of acids and bases: the Lewis model</p> <p>Key Concepts</p> <ol style="list-style-type: none"> <li>1. Classify a substance as a Brønsted-Lowry acid or base and write the net ionic equation to support the classification</li> <li>2. Given <math>[H^+]</math>, <math>[OH^-]</math>, pH or pOH, calculate the three other quantities</li> <li>3. Given the pH and original concentration of a weak acid, calculate <math>K_a</math></li> <li>4. Given the <math>K_a</math> and original concentration of a weak acid, calculate <math>[H^+]</math></li> <li>5. Given the <math>K_b</math> and original concentration of a weak base, calculate <math>[OH^-]</math></li> <li>6. Given <math>K_a</math> for a weak acid, calculate <math>K_b</math> for its conjugate base (or vice-versa).             <ol style="list-style-type: none"> <li>1. 7. Predict whether a salt will be acidic, basic or neutral.</li> <li>2. 8. Understand the similarities and</li> </ol> </li> </ol>	<p>5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.</p> <p>5.C Explain the relationship between variables within an equation when one variable changes.</p> <p>5.D Identify information presented graphically to solve a problem.</p> <p>5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting an following a logical computational pathway and attending to precision (e.g., performing dimensional</p>
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	<p>concentrations being related to the strength of the acids and bases involved.</p> <p>SAP-9.A Calculate the values of pH and pOH, based on <math>K_w</math> and the concentration of all species present in a neutral solution of water.</p> <p><a href="#">Show details</a></p> <p>SAP-9.A.1 The concentrations of hydronium ion and hydroxide ion are often reported as pH and pOH, respectively</p> <p>EQN : <math>\text{pH} = -\log[\text{H}_3\text{O}^+]</math>        EQN : <math>\text{pOH} = -\log[\text{OH}^-]</math></p> <p>The terms “hydrogen ion” and “hydronium ion” and the symbols <math>\text{H}^+(\text{aq})</math> and <math>\text{H}_3\text{O}^+(\text{aq})</math> are often used interchangeably for the aqueous ion of hydrogen. Hydronium ion and <math>\text{H}_3\text{O}^+(\text{aq})</math> are preferred, but <math>\text{H}^+(\text{aq})</math> is also accepted on the AP Exam.</p> <p><a href="#">Show details</a></p> <p>SAP-9.A.2 Water autoionizes with an equilibrium constant <math>K_w</math>.</p> <p>EQN : <math>K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}</math> at <math>25^\circ\text{C}</math></p> <p><a href="#">Show details</a></p> <p>SAP-9.A.3 In pure water, <math>\text{pH} = \text{pOH}</math> is called a neutral solution. At <math>25^\circ\text{C}</math>, <math>\text{p}K_w = 14.0</math> and thus <math>\text{pH} = \text{pOH} = 7.0</math>.        EQN: <math>\text{p}K_w = 14.0 = \text{pH} + \text{pOH}</math> at <math>25^\circ\text{C}</math></p> <p><a href="#">Show details</a></p> <p>SAP-9.A.4 The value of <math>K_w</math> is temperature dependent, so the pH of pure, neutral water will deviate from 7.0 at temperatures other than <math>25^\circ\text{C}</math>.</p> <p>TOPIC 8.2 pH and pOH of Strong Acids and Bases</p> <p>SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved.</p> <p>SAP-9.B Calculate pH and pOH based on concentrations of all species in a solution of a strong acid or a strong base.</p> <p><a href="#">Show details</a></p> <p>SAP-9.B.1 Molecules of a strong acid (e.g., HCl, HBr, HI, <math>\text{HClO}_4</math>, <math>\text{H}_2\text{SO}_4</math> and <math>\text{HNO}_3</math>) will completely ionize in aqueous solution to produce hydronium ions. As such, the concentration of <math>\text{H}_3\text{O}^+</math> 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.</p> <p><a href="#">Show details</a></p>	<p>differences between Lewis and Brønsted-Lowry acids and bases</p> <p>Objectives:</p> <p><b>SPQ-4.B</b> Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.</p> <p><b>TRA-2.A</b> Identify a reaction as acid-base, oxidation-reduction, or precipitation.</p> <p><b>TRA-2.B</b> Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.</p> <p><b>SAP-9.A</b> Calculate the values of pH and pOH, based on <math>K_w</math> and the concentration of all species present in a neutral solution of water.</p> <p><b>SAP-9.B</b> Calculate pH and pOH based on concentrations of all</p>	<p>analysis and attending to significant figures).</p> <p>6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.</p>
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SAP-9.B.2 When dissolved in solution, strong bases (e.g., group I and II hydroxides) completely dissociate to produce hydroxide ions. As such, the concentration of OH<sup>-</sup> in a strong base solution is equal to the initial concentration of the strong base, and thus the pOH (and pH) of the strong base solution is easily calculated.

[Show details](#)

TOPIC 8.3 Weak Acid and Base Equilibria

SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved.

SAP-9.C Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.

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SAP-9.C.1 Weak acids react with water to produce hydronium ions. However, molecules of a weak acid will 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. Thus, the concentration of H<sub>3</sub>O<sup>+</sup> is much less than the initial concentration of the molecular acid, and the vast majority of the acid molecules remain un-ionized.

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SAP-9.C.2 A solution of a weak acid involves equilibrium between an un-ionized acid and its conjugate base. The equilibrium constant for this reaction is K<sub>a</sub>, often reported as pK<sub>a</sub>. The pH of a weak acid solution can be determined from the initial acid concentration and the pK<sub>a</sub>.

$$\text{EQN : } K_a = \frac{[\text{H}_3\text{O}^+ \text{A}^-]}{[\text{HA}]}$$

$$\text{EQN : } \text{p}K_a = -\log K_a$$

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SAP-9.C.3 Weak bases react with water to produce hydroxide ions in solution. However, ordinarily just a small percentage of the molecules of a weak base in solution will ionize in this way. Thus, the concentration of OH<sup>-</sup> in the solution does not equal the initial concentration of the base, and the vast majority of the base molecules remain un-ionized.

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SAP-9.C.4 A solution of a weak base involves equilibrium between an un-ionized base and its conjugate acid. The equilibrium constant for this reaction is K<sub>b</sub>, often reported as pK<sub>b</sub>. The pH of a weak base solution can be determined

species in a solution of a strong acid or a strong base.

**SAP-9.C** Explain the relationship among pH, pOH, and concentrations of all species in a solution of a monoprotic weak acid or weak base.

**SAP-9.D** Explain the results from the titration of a mono- or polyprotic acid or base solution, in relation to the properties of the solution and its components.

**SAP-9.F** Explain the relationship between the strength of an acid or base and the structure of the molecule or ion.

**SAP-10.A** Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pK<sub>a</sub> of the conjugate acid or the pK<sub>b</sub> of the conjugate base.

from the initial base concentration and the pK<sub>b</sub>.

$$\text{EQN : } K_b = \frac{[\text{OH}^-][\text{HB}^+]}{[\text{B}]}$$

$$\text{EQN : } \text{p}K_b = -\log K_b$$

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SAP-9.C.5 The percent ionization of a weak acid (or base) can be calculated from its pK<sub>a</sub> (pK<sub>b</sub>) and the initial concentration of the acid (base).

TOPIC 8.5 Acid-Base Titrations

SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved.

SAP-9.E Explain results from the titration of a mono- or polyprotic acid or base solution, in relation to the properties of the solution and its components.

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SAP-9.E.1 An acid-base reaction can be carried out under controlled conditions in a titration. A titration curve, plotting pH against the volume of titrant added, is useful for summarizing results from a titration.

SAP-9.E.2 At the equivalence point, the number of moles of titrant added is equal to the number of moles of analyte originally present. This relationship can be used to obtain the concentration of the analyte. This is the case for titrations of strong acids/bases and weak acids/bases.

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SAP-9.E.3 For titrations of weak acids/bases, it is useful to consider the point halfway to the equivalence point, that is, the half-equivalence point. At this point, there are equal concentrations of each species in the conjugate acid-base pair, for example, for a weak acid [HA] = [A<sup>-</sup>]. Because pH = pK<sub>a</sub> when the conjugate acid and base have equal concentrations, the pK<sub>a</sub> can be determined from the pH at the half-equivalence point in a titration.

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SAP-9.E.4 For polyprotic acids, titration curves can be used to determine the number of acidic protons. In doing so, the major species present at any point along the curve can be identified, along with the pK<sub>a</sub> associated with each proton in a weak polyprotic acid.

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TOPIC 8.6 Molecular Structure of Acids and Bases

SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium



concentrations being related to the strength of the acids and bases involved.

SAP-9.F Explain the relationship between the strength of an acid or base and the structure of the molecule or ion.

[Show details](#)

SAP-9.F.1 The protons on a molecule that will participate in acid-base reactions, and the relative strength of these protons, can be inferred from the molecular structure.

a. Strong acids (such as HCl, HBr, HI, HClO<sub>4</sub>, H<sub>2</sub>SO<sub>4</sub> and HNO<sub>3</sub>) have very weak conjugate bases that are stabilized by electronegativity, inductive effects, resonance, or some combination thereof.

b. Carboxylic acids are one common class of weak acid.

c. Strong bases (such as group I and II hydroxides) have very weak conjugate acids.

d. Common weak bases include nitrogenous bases such as ammonia as well as carboxylate ions.

e. Electronegative elements tend to stabilize the conjugate base relative to the conjugate acid, and so increase acid strength.

[Show details](#)

TOPIC 8.7 pH and pK<sub>a</sub>

SAP-10 A buffered solution resists changes to its pH when small amounts of acid or base are added.

SAP-10.A Explain the relationship between the predominant form of a weak acid or base in solution at a given pH and the pK<sub>a</sub> of the conjugate acid or the pK<sub>b</sub> of the conjugate base.

[Show details](#)

SAP-10.A.1 The protonation state of an acid or base (i.e., the relative concentrations of HA and A<sup>-</sup>) can be predicted by comparing the pH of a solution to the pK<sub>a</sub> of the acid in that solution. When solution pH < acid pK<sub>a</sub>, the acid form has a higher concentration than the base form. When solution pH > acid pK<sub>a</sub>, the base form has a higher concentration than the acid form.

[Show details](#)

SAP-10.A.2 Acid-base indicators are substances that exhibit different properties (such as color) in their protonated versus deprotonated state, making that property respond to the pH of a solution.

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[AP Frameworks](#)

[Acid base reactions and buffers](#)

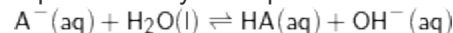
AP: Chemistry (2019)  
AP: AP  
UNIT 8 Acids and Bases  
BIG IDEA 2 Structure and Properties SAP  
How are reactions involving acids and bases related to pH?  
How does your body maintain pH balance?  
TOPIC 8.4 Acid-Base Reactions and Buffers  
SAP-9 The chemistry of acids and bases involves reversible proton-transfer reactions, with equilibrium concentrations being related to the strength of the acids and bases involved.  
SAP-9.D Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.

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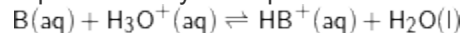
SAP-9.D.1 When a strong acid and a strong base are mixed, they react quantitatively in a reaction represented by the equation:  
$$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$$
The pH of the resulting solution may be determined from the concentration of excess reagent.

[Show details](#)

SAP-9.D.2 When a weak acid and a strong base are mixed, they react quantitatively in a reaction represented by the equation:  
$$\text{HA}(\text{aq}) + \text{OH}^-(\text{aq}) \rightleftharpoons \text{A}^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$$
If the weak acid is in excess, then a buffer solution is formed, and the pH can be determined from the Henderson-Hasselbalch (H-H) equation (see SAP-10.C.1). If the strong base is in excess, then the pH can be determined from the moles of excess hydroxide ion and the total volume of solution. If they are equimolar, then the (slightly basic) pH can be determined from the equilibrium represented by the equation:



SAP-9.D.3 When a weak base and a strong acid are mixed, they will react quantitatively in a reaction represented by the equation:



If the weak base is in excess, then a buffer solution is formed, and the pH can be determined from the H-H equation. If the strong acid is in excess, then the pH can be determined from the moles of excess hydronium ion and the total volume of solution. If they are equimolar, then the

Key concepts

1. Calculate the pH of a buffer as initially prepared.
2. Choose a buffer for a specified pH.
3. Determine whether a combination of a strong acid/base and its salt is a buffer (or not).
4. Calculate the pH of a buffer after the addition of strong acid or base.
5. Determine the color of an indicator at a specific pH, given its  $K_a$ .
6. Calculate the pH during an acid-base titration.
7. Choose the proper indicator for a titration.
8. Calculate  $K$  for an acid-base reaction.

Objectives:

**SAP-9.D** Explain the relationship among the concentrations of major species in a mixture of weak and strong acids and bases.

**SAP-10.B** Explain the relationship between the ability of a buffer to

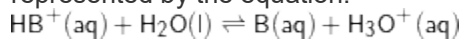
The student will be able to:

5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting an following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.

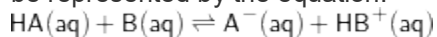
6.G Explain how potential sources of experimental error may affect the experimental results.

(slightly acidic) pH can be determined from the equilibrium represented by the equation:



[Show details](#)

SAP-9.D.4 When a weak acid and a weak base are mixed, they will react to an equilibrium state whose reaction may be represented by the equation:



[Show details](#)

TOPIC 8.8 Properties of Buffers

SAP-10 A buffered solution resists changes to its pH when small amounts of acid or base are added.

SAP-10.B Explain the relationship between the ability of a buffer to stabilize pH and the reactions that occur when an acid or a base is added to a buffered solution.

[Show details](#)

SAP-10.B.1 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. These reactions are responsible for the ability of a buffer to stabilize pH.

[Show details](#)

TOPIC 8.9 Henderson- Hasselbalch Equation

SAP-10 A buffered solution resists changes to its pH when small amounts of acid or base are added.

SAP-10.C Identify the pH of a buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.

[Show details](#)

SAP-10.C.1 The pH of the buffer is related to the pKa of the acid and the concentration ratio of the conjugate acid-base pair. This relation is a consequence of the equilibrium expression associated with the dissociation of a weak acid. Adding small amounts of acid or base to a buffered solution does not significantly change the ratio of  $[\text{A}^-]/[\text{HA}]$  and thus does not significantly change the pH. The change in pH on addition of acid or base to a buffered solution is therefore much less than it would have been in the absence of the buffer.

$$\text{EQN : } \text{pH} + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

[Show details](#)

stabilize pH and the reactions that occur when an acid or a base is added to a buffered solution.

**SAP-10.C** identify the pH of a buffer solution based on the identity and concentrations of the conjugate acid-base pair used to create the buffer.

**SAP-10.D** Explain the relationship between the buffer capacity of a solution and the relative concentrations of the conjugate acid and conjugate base components of the solution.

	<p>TOPIC 8.10 Buffer Capacity</p> <p>SAP-10 A buffered solution resists changes to its pH when small amounts of acid or base</p> <p>SAP-10.D Explain the relationship between the buffer capacity of a solution and the relative concentrations of the conjugate acid and conjugate base components of the solution.</p> <p><a href="#">Show details</a></p> <p>SAP-10.D.1 Increasing the concentration of the buffer components (while keeping the ratio of these concentrations constant) keeps the pH of the buffer the same but increases the capacity of the buffer to neutralize added acid or base.</p> <p><a href="#">Show details</a></p> <p>SAP-10.D.2 When a buffer has more conjugate acid than base, it has a greater buffer capacity for addition of added base than acid. When a buffer has more conjugate base than acid, it has a greater buffer capacity for addition of added acid than base.</p> <p><a href="#">Show details</a></p> <p>© 2013 The College Board, Advanced Placement</p> <p><a href="#">AP Frameworks</a></p>		
<p><a href="#">Common ion effect</a></p>	<p>AP: Chemistry (2019)</p> <p>AP: AP</p> <p>UNIT 4 Chemical Reactions</p> <p>BIG IDEA 3 Transformations TRA</p> <p>What are the processes related to changes in a substance?</p> <p>TOPIC 4.2 Net Ionic Equations</p> <p>TRA-1 A Substance that changes its properties, or that changes into a different substance, can be represented by chemical equations.</p> <p>TRA-1.B Represent changes in matter with a balanced chemical or net ionic equation: a. For physical changes. b. For given information about the identity of the reactants and/or product. c. For ions in a given chemical reaction.</p> <p><a href="#">Show details</a></p> <p>TOPIC 4.7 Types of Chemical Reactions</p> <p>TRA-2 A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.</p>	<p>Lecture Outline</p> <ol style="list-style-type: none"> <li>Complex ion equilibria; formation constant (<math>K_f</math>)</li> <li>Solubility; solubility product constant (<math>K_{sp}</math>)</li> <li>Precipitate formation</li> <li>Dissolving precipitates</li> </ol> <p>Key concepts:</p> <ul style="list-style-type: none"> <li>Relate <math>K_f</math> to the ratio of concentration of complex ion to metal ion</li> <li>Write the <math>K_{sp}</math> expression for any insoluble ionic solid</li> <li>Use the value of <math>K_{sp}</math> to</li> </ul>	<p>The student will be able to:</p> <p>2.D Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate</p> <p>2.F Explain how modifications to</p>

	<p>TRA-2.A Identify a reaction as acidbase, oxidation-reduction, or precipitation.  <a href="#">Show details</a></p> <p>TRA-2.A.5 Precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound. All sodium, potassium, ammonium, and nitrate salts are soluble in water.  <a href="#">Show details</a></p> <p>UNIT 7 Equilibrium          TOPIC 7.11 Introduction to Solubility Equilibria          SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.          SPQ-5.A Calculate the solubility of a <math>K_{sp}</math> salt based on the value of for the salt.  <a href="#">Show details</a></p> <p>SPQ-5.A.1 The dissolution of a salt is a reversible process whose extent can be described by <math>K_{sp}</math>, the solubility-product constant.  <a href="#">Show details</a></p> <p>SPQ-5.A.2 The solubility of a substance can be calculated from the <math>K_{sp}</math> for the dissolution process. This relationship can also be used to predict the relative solubility of different substances.  <a href="#">Show details</a></p> <p>SPQ-5.A.3 The solubility rules (see TRA-2.A.5) can be quantitatively related to <math>K_{sp}</math>, in which <math>K_{sp}</math> values <math>&gt;1</math> correspond to soluble salts.  <a href="#">Show details</a></p> <p>TOPIC 7.12 Common-Ion Effect          SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.          SPQ-5.B Identify the solubility of a salt, and/or the value of <math>K_{sp}</math> for the salt, based on the concentration of a common ion already present in solution.  <a href="#">Show details</a></p> <p>SPQ-5.B.1 The solubility of a salt is reduced when it is dissolved into a solution that already contains one of the ions present in the salt. The impact of this "common-ion effect" on solubility can be understood qualitatively using Le Châtelier's principle or calculated from the <math>K_{sp}</math> for the dissolution process.  <a href="#">Show details</a></p>	<ul style="list-style-type: none"> <li>○ Calculate the concentration of one ion, knowing the other</li> <li>● Determine whether a precipitate will form</li> <li>● Calculate the water solubility of a compound</li> <li>● Calculate the solubility of a compound in a solution of a common ion</li> <li>● Determine which ion will precipitate first</li> <li>● Calculate K for             <ul style="list-style-type: none"> <li>○ Dissolving a metal hydroxide in a strong acid</li> </ul> </li> <li>● Dissolving a precipitate in a complexing agent</li> <li>● Write balanced, net ionic equations to explain why a precipitate dissolves in             <ul style="list-style-type: none"> <li>○ Strong acid</li> </ul> </li> <li>● Ammonia or hydroxide solution</li> </ul> <p>Objectives:</p> <p><b>TRA-1.B</b> Represent changes in matter with a balanced chemical or net ionic equation:</p> <p>a) for physical changes. b) for given information about the identity of the reactants and/or products. c) For ions in a given chemical reaction. TRA-2.A Identify a reaction as acid-base, oxidation-reduction, or precipitation.</p>	<p>an experimental procedure will alter results.</p> <p>4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.</p> <p>5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.</p>
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	<p>TOPIC 7.13 pH and Solubility          SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.          SPQ-5.C Identify the qualitative effect of changes in pH on the solubility of a salt.  <a href="#">Show details</a>          SPQ-5.C.1 The solubility of a salt is pH sensitive when one of the constituent ions is a weak acid or base. These effects can be understood qualitatively using Le Châtelier's principle.  <a href="#">Show details</a>          TOPIC 7.14 Free Energy of Dissolution          SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.          SPQ-5.D Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.  <a href="#">Show details</a>          © 2013 The College Board, Advanced Placement</p> <p><a href="#">AP Frameworks</a></p>	<p><b>SPQ-5.A</b> Calculate the solubility of a salt based on the value of <math>K_{sp}</math> for the salt.</p> <p><b>SPQ-5.B</b> Identify the solubility of a salt, and/or the value of <math>K_{sp}</math> for the salt, based on the concentration of a common ion already present in solution.</p> <p><b>SPQ-5.C</b> Identify the qualitative effect of changes in pH on the solubility of a salt.</p> <p><b>SPQ-5.D</b> Explain the relationship between the solubility of a salt and changes in enthalpy and entropy that occur in the dissolution process.</p>	
<p><a href="#">Thermodynamics</a></p>	<p>AP: Chemistry (2019)          AP: AP          UNIT 7 Equilibrium          TOPIC 7.14 Free Energy of Dissolution          SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.          SPQ-5.D Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.  <a href="#">Show details</a>          SPQ-5.D.1 The free energy change (<math>\Delta G^\circ</math>) for dissolution of a substance reflects a number of factors: the breaking of the intermolecular interactions that hold the solid together, the reorganization of the solvent around the dissolved</p>	<p>Key Concepts</p> <ol style="list-style-type: none"> <li>1. Deduce the sign of <math>\Delta S^\circ</math> for a process from consideration of randomness</li> <li>2. Calculate <math>\Delta S^\circ</math> for a reaction using thermochemical data</li> <li>3. Calculate <math>\Delta G^\circ</math> at any temperature, knowing <math>\Delta H^\circ</math> and <math>\Delta S^\circ</math></li> </ol>	<p>Students will be able to:</p> <p>4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and</p>

	<p>species, and the interaction of the dissolved species with the solvent. It is possible to estimate the sign and relative magnitude of the enthalpic and entropic contributions to each of these factors. However, making predictions for the total change in free energy of dissolution can be challenging due to the cancellations among the free energies associated with the three factors cited.</p> <p><a href="#">Show details</a></p> <p>UNIT 9 Applications of Thermodynamics BIG IDEA 4 Energy ENE How does water flow uphill? How is the favorability of a chemical or physical transformation determined?</p> <p>TOPIC 9.1 Introduction to Entropy ENE-4 Some chemical or physical processes cannot occur without intervention. ENE-4.A Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.</p> <p><a href="#">Show details</a></p> <p>ENE-4.A.1 Entropy increases when matter becomes more dispersed. For example, the phase change from solid to liquid or from liquid to gas results in a dispersal of matter as the individual particles become freer to move and generally occupy a larger volume. Similarly, for a gas, the entropy increases when there is an increase in volume (at constant temperature), and the gas molecules are able to move within a larger space. For reactions involving gas-phase reactants or products, the entropy generally increases when the total number of moles of gas-phase products is greater than the total number of moles of gas-phase reactants.</p> <p><a href="#">Show details</a></p> <p>ENE-4.A.2 Entropy increases when energy is dispersed. According to kinetic molecular theory (KMT), the distribution of kinetic energy among the particles of a gas broadens as the temperature increases. As a result, the entropy of the system increases with an increase in temperature.</p> <p><a href="#">Show details</a></p> <p>TOPIC 9.2 Absolute Entropy and Entropy Change ENE-4 Some chemical or physical processes cannot occur without intervention.</p>	<p>4. Calculate <math>\Delta G^\circ</math> at 25 °C from free energies of formation</p> <p>5. Calculate the temperature at which <math>\Delta G^\circ = 0</math></p> <p>6. Calculate <math>\Delta G</math> from <math>\Delta G^\circ</math>, knowing pressures and concentrations</p> <p>7. Relate <math>\Delta G^\circ</math> to K</p> <p>8. Calculate <math>\Delta G^\circ</math> for a set of coupled reactions</p> <p>Lecture Outline</p> <ol style="list-style-type: none"> <li>1. Spontaneous processes</li> <li>2. Entropy, S</li> <li>3. Free energy, G</li> <li>4. Standard free energy change, <math>\Delta G^\circ</math></li> <li>5. Effect of temperature, pressure, and concentration on reaction spontaneity</li> <li>6. The free energy change and the equilibrium constant</li> <li>7. Additivity of free energy changes; coupled reactions</li> </ol>	<p>macroscopic properties.</p> <p>5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).</p> <p>6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.</p> <p>6.D Provide reasoning to justify a claim using chemical principles or laws,</p>
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	<p>ENE-4.B Calculate the entropy change for a chemical or physical process based on the absolute entropies of the species involved in the process.  <a href="#">Show details</a></p> <p>ENE-4.B.1 The entropy change for a process can be calculated from the absolute entropies of the species involved before and after the process occurs.  <a href="#">Show details</a></p> <p>TOPIC 9.3 Gibbs Free Energy and Thermodynamic Favorability</p> <p>ENE-4 Some chemical or physical processes cannot occur without intervention.</p> <p>ENE-4.C Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of <math>\Delta G^\circ</math>.  <a href="#">Show details</a></p> <p>ENE-4.C.1 The Gibbs free energy change for a chemical process in which all the reactants and products are present in a standard state (as pure substances, as solutions of 1.0 M concentration, or as gases at a pressure of 1.0 atm (or 1.0 bar)) is given the symbol <math>\Delta G^\circ</math>.  <a href="#">Show details</a></p> <p>ENE-4.C.2 The standard Gibbs free energy change for a chemical or physical process is a measure of thermodynamic favorability. Historically, the term “spontaneous” has been used to describe processes for which <math>\Delta G^\circ &lt; 0</math>.  <a href="#">Show details</a></p> <p>ENE-4.C.3 The standard Gibbs free energy change for a physical or chemical process may also be determined from the standard Gibbs free energy of formation of the reactants and products.  <a href="#">Show details</a></p> <p>ENE-4.C.4 In some cases, it is necessary to consider both enthalpy and entropy to determine if a process will be thermodynamically favored. The freezing of water and the dissolution of sodium nitrate are examples of such phenomena.  <a href="#">Show details</a></p> <p>ENE-4.C.5 Knowing the values of <math>\Delta H^\circ</math> and <math>\Delta S^\circ</math> for a process at a given temperature allows <math>\Delta G^\circ</math> to be calculated directly. EQN : <math>\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ</math>  <a href="#">Show details</a></p> <p>ENE-4.C.6 In general, the temperature conditions for a process to be thermodynamically favored (<math>\Delta G^\circ &lt; 0</math>) can be</p>	<p>Objectives:</p> <p><b>ENE-4.A</b> Identify the sign and relative magnitude of the entropy change associated with chemical or physical processes.</p> <p><b>ENE-4.B</b> Calculate the entropy change for a chemical or physical process based on the absolute entropies of the species involved in the process.</p> <p><b>ENE-4.C</b> Explain whether a physical or chemical process is thermodynamically favored based on an evaluation of <math>\Delta G^\circ</math>.</p> <p><b>ENE-4.D</b> Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable rate.</p> <p><b>SPQ-5.D</b> Explain the relationship between the solubility of a salt and changes in the enthalpy and entropy that occur in the dissolution process.</p>	<p>or using mathematical justification.</p> <p>6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.</p>
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predicted from the signs of  $\Delta H^\circ$  and  $\Delta S^\circ$  as shown in the table below:  
see the document for the table.  
In cases where  $\Delta H^\circ < 0$  and  $\Delta S^\circ > 0$ , no calculation of  $\Delta G^\circ$  is necessary to determine that the process is thermodynamically favored ( $\Delta G^\circ < 0$ ). In cases where  $\Delta H^\circ > 0$  and  $\Delta S^\circ < 0$ , no calculation of  $\Delta G^\circ$  is necessary to determine that the process is thermodynamically unfavored ( $\Delta G^\circ > 0$ ).

[Show details](#)

TOPIC 9.4 Thermodynamic and Kinetic Control

ENE-4 Some chemical or physical processes cannot occur without intervention.

ENE-4.D Explain, in terms of kinetics, why a thermodynamically favored reaction might not occur at a measurable rate.

[Show details](#)

ENE-4.D.1 Many processes that are thermodynamically favored do not occur to any measurable extent, or they occur at extremely slow rates.

[Show details](#)

ENE-4.D.2 Processes that are thermodynamically favored, but do not proceed at a measurable rate, are 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, and yet does not occur at a measurable rate, it is reasonable to conclude that the process is under kinetic control.

[Show details](#)

TOPIC 9.5 Free Energy and Equilibrium

ENE-5 The relationship between  $\Delta G^\circ$  and K can be used to determine favorability of a chemical or physical transformation.

ENE-5.A Explain whether a process is thermodynamically favored using the relationships between K,  $\Delta G^\circ$ , and T.

[Show details](#)

ENE-5.A.1 The phrase "thermodynamically favored" ( $\Delta G^\circ < 0$ ) means that the products are favored at equilibrium ( $K > 1$ ).

[Show details](#)

ENE-5.A.2 The equilibrium constant is related to free energy by the equations

**ENE-5.A** Explain whether a process is thermodynamically favored using the relationships between K,  $\Delta G^\circ$ , and T.

**ENE-5.B** Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.

	<p>EQN : <math>K = e^{-\Delta G^\circ/RT}</math> and  EQN : <math>\Delta G^\circ = RT \ln K</math>  <a href="#">Show details</a>  ENE-5.A.3 Connections between <math>K</math> and <math>\Delta G^\circ</math> can be made qualitatively through estimation. When <math>\Delta G^\circ</math> is near zero, the equilibrium constant will be close to 1. When <math>\Delta G^\circ</math> is much larger or much smaller than <math>RT</math>, the value of <math>K</math> deviates strongly from 1.  <a href="#">Show details</a>  ENE-5.A.4 Processes with <math>\Delta G^\circ &lt; 0</math> favor products (i.e., <math>K &gt; 1</math>) and those with <math>\Delta G^\circ &gt; 0</math> favor reactants (i.e., <math>K &lt; 1</math>).  <a href="#">Show details</a>  TOPIC 9.6 Coupled Reactions  ENE-5 The relationship between <math>\Delta G^\circ</math> and <math>K</math> can be used to determine favorability of a chemical or physical transformation.  ENE-5.B Explain the relationship between external sources of energy or coupled reactions and their ability to drive thermodynamically unfavorable processes.  <a href="#">Show details</a>  ENE-5.B.1 An external source of energy can be used to make a thermodynamically unfavorable process occur. Examples include: a. Electrical energy to drive an electrolytic cell or charge a battery. b. Light to drive the overall conversion of carbon dioxide to glucose in photosynthesis.  <a href="#">Show details</a>  ENE-5.B.2 A desired product can be formed by coupling a thermodynamically unfavorable reaction that produces that product to a favorable reaction (e.g., the conversion of ATP to ADP in biological systems). In the coupled system, the individual reactions share one or more common intermediates. The sum of the individual reactions produces an overall reaction that achieves the desired outcome and has <math>\Delta G^\circ &lt; 0</math>.  <a href="#">Show details</a>  © 2013 The College Board, Advanced Placement   <a href="#">AP Frameworks</a></p>		
<a href="#">Redox and electrochemistry</a>	AP: Chemistry (2019) AP: AP SKILLS	Lecture Outline	The students will be able to:

	<p>Models and Representations 1 Describe models and representations, including across scales.</p> <p>1.A Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only.</p> <p>1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.</p> <p>Question and Method 2 Determine scientific questions and methods.</p> <p>2.A Identify a testable scientific question based on an observation, data, or a model.</p> <p>2.B Formulate a hypothesis or predict the results of an experiment.</p> <p>2.C Identify experimental procedures that are aligned to a scientific question (which may include a sketch of a lab setup).</p> <p>2.D Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.</p> <p>2.E Identify or describe potential sources of experimental error.</p> <p>Representing Data and Phenomena 3 Create representations or models of chemical phenomena.</p> <p>3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.</p> <p>3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).</p> <p>3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).</p> <p>Model Analysis 4 Analyze and interpret models and representations on a single scale or across multiple scales.</p> <p>4.A Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.</p> <p>4.B Explain whether a model is consistent with chemical theories.</p> <p>4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.</p>	<p>1. Oxidation States</p> <p>2. Balancing Oxidation-Reduction Equations</p> <p>3. Voltaic cells</p> <p>4. Standard voltages</p> <p>5. Relations between <math>E^\circ</math>, <math>\Delta G^\circ</math> and <math>K</math></p> <p>6. Electrolytic cells</p> <p>7. Commercial cells</p> <p><b>Key Concepts:</b></p> <p>1. Determine oxidation numbers.</p> <p>2. Balance half-equations and redox equations.</p> <p>3. Draw a diagram for a voltaic cell, labeling the electrodes and diagramming current flow</p> <p>4. Use standard potentials to:</p> <p>Compare relative strengths of oxidizing and reducing agents</p> <p>Calculate <math>E</math> and/or reaction spontaneity</p>	<p>2.F Explain how modifications to an experimental procedure will alter results.</p> <p>5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.</p> <p>5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).</p> <p>6.D Provide reasoning to justify a claim</p>
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	<p>4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties. Mathematical Routines 5 Solve problems using mathematical relationships</p> <p>5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).</p> <p>5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.</p> <p>5.C Explain the relationship between variables within an equation when one variable changes.</p> <p>5.D Identify information presented graphically to solve a problem.</p> <p>5.E Determine a balanced chemical equation for a given chemical phenomenon.</p> <p>5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).</p> <p>Argumentation 6 Develop an explanation or scientific argument.</p> <p>6.A Make a scientific claim.</p> <p>6.B Support a claim with evidence from experimental data.</p> <p>6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.</p> <p>6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.</p> <p>6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.</p> <p>6.F Explain the connection between experimental results and chemical concepts, processes, or theories.</p> <p>6.G Explain how potential sources of experimental error may affect the experimental results.</p> <p>ENDURING UNDERSTANDINGS SCALE, PROPORTION, AND QUANTITY SPQ-1 The mole allows different units to be compared. SPQ-2 Chemical formulas identify substances by their unique combination of atoms. SPQ-3 Interactions between intermolecular forces influence the solubility and separation of mixtures. SPQ-4 When a substance changes into a new substance, or when its properties change, no mass is lost or gained.</p>	<p>5. Relate <math>E^\circ</math> to <math>\Delta G^\circ</math> and <math>K</math></p> <p>6. Use the Nernst equation to relate voltage to concentration</p> <p>7. Relate mass of product to charge, energy or current in electrolysis reactions</p> <p>Objectives:</p> <p><b>TRA-2.A</b> Identify a reaction as acid-base, oxidation-reduction, or precipitation.</p> <p><b>TRA-2.C</b> Represent a balanced redox reaction equation using half- reactions.</p> <p><b>ENE-6.A</b> Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.</p> <p><b>ENE-6.B</b> Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half-reactions within the cell.</p> <p><b>ENE-6.C</b> Explain the relationship between deviations from standard</p>	<p>using chemical principles or laws, or using mathematical justification.</p>
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	<p>SPQ-5 The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.</p> <p><b>STRUCTURE AND PROPERTIES</b></p> <p>SAP-1 Atoms and molecules can be identified by their electron distribution and energy.</p> <p>SAP-2 The periodic table shows patterns in electronic structure and trends in atomic properties.</p> <p>SAP-3 Atoms or ions bond due to interactions between them, forming molecules.</p> <p><b>TRANSFORMATIONS</b></p> <p>TRA-1 A substance that changes its properties, or that changes into a different substance, can be represented by chemical equations.</p> <p>TRA-5 Many chemical reactions occur through a series of elementary reactions. These elementary reactions when combined form a chemical equation.</p> <p>TRA-6 Some reactions can occur in both forward and reverse directions, sometimes proceeding in each direction simultaneously.</p> <p><b>ENERGY</b></p> <p>ENE-2 Changes in a substance's properties or change into a different substance requires an exchange of energy</p> <p>ENE-3 The energy exchanged in a chemical transformation is required to break and form bonds.</p> <p>ENE-5 The relationship between <math>\Delta G^\circ</math> and K can be used to determine favorability of a chemical or physical transformation.</p> <p>ENE-6 Electrical energy can be generated by chemical reactions.</p> <p><b>UNIT 4 Chemical Reactions</b></p> <p><b>TOPIC 4.7 Types of Chemical Reactions</b></p> <p>TRA-2 A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.</p> <p>TRA-2.A Identify a reaction as acidbase, oxidation-reduction, or precipitation.</p> <p><a href="#">Show details</a></p> <p>TRA-2.A.2 Oxidation-reduction reactions involve transfer of one or more electrons between chemical species, as indicated by changes in oxidation numbers of the involved species. Combustion is an important subclass of oxidation-reduction reactions, in which a species reacts with oxygen gas. In the case of hydrocarbons, carbon dioxide and water are products of complete combustion.</p>	<p>cell conditions and changes in the cell potential.</p> <p><b>ENE-6.D</b> Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.</p>	
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TRA-2.A.3 In a redox reaction, electrons are transferred from the species that is oxidized to the species that is reduced.

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TRA-2.A.4 Oxidation numbers may be assigned to each of the atoms in the reactants and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction.

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TOPIC 4.9 Oxidation-Reduction(Redox) Reactions

TRA-2 A substance can change into another substance through different processes, and the change itself can be classified by the sort of processes that produced it.

TRA-2.C Represent a balanced redox reaction equation using half-reactions.

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TRA-2.C.1 Balanced chemical equations for redox reactions can be constructed from half-reactions.

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UNIT 9 Applications of Thermodynamics

BIG IDEA 4 Energy ENE

How is electrical energy generated using chemical reactions?

TOPIC 9.7 Galvanic (Voltaic) and Electrolytic Cells

ENE-6 Electrical energy can be generated by chemical reactions.

ENE-6.A Explain the relationship between the physical components of an electrochemical cell and the overall operational principles of the cell.

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ENE-6.A.1 Each component of an electrochemical cell (electrodes, solutions in the half-cells, salt bridge, voltage/current measuring device) plays a specific role in the overall functioning of the cell. The operational characteristics of the cell (galvanic vs. electrolytic, direction of electron flow, reactions occurring in each half-cell, change in electrode mass, evolution of a gas at an electrode, ion flow through the salt bridge) can be described at both the macroscopic and particulate levels.

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ENE-6.A.2 Galvanic, sometimes called voltaic, cells involve a thermodynamically favored reaction, whereas electrolytic cells involve a thermodynamically unfavored reaction.

Visual representations of galvanic and electrolytic cells are



tools of analysis to identify where half-reactions occur and in what direction current flows.

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ENE-6.A.3 For all electrochemical cells, oxidation occurs at the anode and reduction occurs at the cathode. LABELING AN ELECTRODE AS POSITIVE OR NEGATIVE WILL NOT BE ASSESSED ON THE AP EXAM. Rationale: Sign conventions vary depending on the type of electrochemical cell, even though oxidation always occurs at the anode.

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TOPIC 9.8 Cell Potential and Free Energy

ENE-6 Electrical energy can be generated by chemical reactions.

ENE-6.B Explain whether an electrochemical cell is thermodynamically favored, based on its standard cell potential and the constituent half-reactions within the cell.

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ENE-6.B.1 Electrochemistry encompasses the study of redox reactions that occur within electrochemical cells. The reactions are either thermodynamically favored (resulting in a positive voltage) or thermodynamically unfavored (resulting in a negative voltage and requiring an externally applied potential for the reaction to proceed).

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ENE-6.B.2 The standard cell potential of electrochemical cells can be calculated by identifying the oxidation and reduction half-reactions and their respective standard reduction potentials.

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ENE-6.B.3  $\Delta G^\circ$  (standard Gibbs free energy change) is proportional to the negative of the cell potential for the redox reaction from which it is constructed. Thus, a cell with a positive  $E^\circ$  involves a thermodynamically favored reaction, and a cell with a negative  $E^\circ$  involves a thermodynamically unfavored reaction. EQN :  $\Delta G^\circ = -nFE^\circ$

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TOPIC 9.9 Cell Potential Under Nonstandard Conditions

ENE-6 Electrical energy can be generated by chemical reactions.

ENE-6.C Explain the relationship between deviations from standard cell conditions and changes in the cell potential.

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ENE-6.C.1 In a real system under nonstandard conditions, the cell potential will vary depending on the concentrations of the active species. The cell potential is a driving force

toward equilibrium; the farther the reaction is from equilibrium, the greater the magnitude of the cell potential. ENE-6.C.2 Equilibrium arguments such as Le Châtelier's principle do not apply to electrochemical systems, because the systems are not in equilibrium.

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ENE-6.C.3 The standard cell potential  $E^\circ$  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  $E^\circ$ . Deviations from standard conditions that take the cell closer to equilibrium than  $Q = 1$  will decrease the magnitude of the cell potential relative to  $E^\circ$ . In concentration cells, the direction of spontaneous electron flow can be determined by considering the direction needed to reach equilibrium.

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ENE-6.C.4 Algorithmic calculations using the Nernst equation are insufficient to demonstrate an understanding of electrochemical cells under nonstandard conditions. However, students should qualitatively understand the effects of concentration on cell potential and use conceptual reasoning, including the qualitative use of the Nernst equation:  $E = E^\circ - (RT/nF) \ln Q$  to solve problems.

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TOPIC 9.10 Electrolysis and Faraday's Law

ENE-6 Electrical energy can be generated by chemical reactions.

ENE-6.D Calculate the amount of charge flow based on changes in the amounts of reactants and products in an electrochemical cell.

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ENE-6.D.1 Faraday's laws can be used to determine the stoichiometry of the redox reaction occurring in an electrochemical cell with respect to the following:

- Number of electrons transferred
- Mass of material deposited on or removed from an electrode
- Current
- Time elapsed
- Charge of ionic species

EQN:  $I = q/t$

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