



INCLUDES

- ✓ Course framework
- ✓ Instructional section
- ✓ Sample exam questions

AP[®] Chemistry

COURSE AND EXAM DESCRIPTION--1

Effective
Fall 2024

PERIODIC TABLE OF THE ELEMENTS																														
1	2		3										4	5	6	7	8	9	10	11	12	13			14	15	16	17	18	
1 H 1.008																							5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18		
3 Li 6.94	4 Be 9.01																					13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95			
11 Na 22.99	12 Mg 24.30																													
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.97	35 Br 79.90	36 Kr 83.80													
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29													
55 Cs 132.91	56 Ba 137.33	57-71 *	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po	85 At	86 Rn													
87 Fr	88 Ra	89-103 †	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og													

AP® CHEMISTRY EQUATIONS AND CONSTANTS, EFFECTIVE 2025

UNIT SYMBOLS	
gram,	g
mole,	mol
liter,	L
meter,	m
second,	s
hertz,	Hz
atmosphere,	atm
millimeter of mercury,	mm Hg
degree Celsius,	°C
Kelvin,	K
joule,	J
volt,	V
coulomb,	C
ampere,	A

UNIT CONVERSIONS
1 hertz = 1 s ⁻¹
1 atm = 760 mm Hg = 760 torr
K = °C + 273.15
1 volt = $\frac{1 \text{ joule}}{1 \text{ coulomb}}$
1 ampere = $\frac{1 \text{ coulomb}}{1 \text{ second}}$

METRIC PREFIXES		
Factor	Prefix	Symbol
10 ⁹	giga	G
10 ⁶	mega	M
10 ³	kilo	k
10 ⁻²	centi	c
10 ⁻³	milli	m
10 ⁻⁶	micro	μ
10 ⁻⁹	nano	n
10 ⁻¹²	pico	p

ATOMIC STRUCTURE

$$E = h\nu$$

$$c = \lambda\nu$$

$$F_{\text{coulombic}} \propto \frac{q_1 q_2}{r^2}$$

E = energy

ν = frequency

λ = wavelength

F = force

q = charge

r = separation

Planck's constant, $h = 6.626 \times 10^{-34}$ J s

Speed of light, $c = 2.998 \times 10^8$ m s⁻¹

Avogadro's number = 6.022×10^{23} mol⁻¹

GASES, LIQUIDS, AND SOLUTIONS

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$PV = nRT$$

$$P_A = P_{\text{total}} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{\text{total}} = P_A + P_B + P_C + \dots$$

$$n = \frac{m}{M}$$

$$D = \frac{m}{V}$$

$$KE = \frac{1}{2}mv^2$$

$$M = \frac{n_{\text{solute}}}{L_{\text{solution}}}$$

$$A = \epsilon bc$$

P = pressure

V = volume

T = temperature

n = number of moles

X = mole fraction

m = mass

M = molar mass

D = density

KE = kinetic energy

v = velocity

M = molarity

A = absorbance

ϵ = molar absorptivity

b = path length

c = concentration

Gas constant, $R = 8.314$ J mol⁻¹ K⁻¹

= 0.08206 L atm K⁻¹ mol⁻¹

STP = 273.15 K and 1.0 atm

Ideal gas at STP = 22.4 L mol⁻¹

KINETICS

$$[A]_t - [A]_0 = -kt$$

$$\ln[A]_t - \ln[A]_0 = -kt$$

$$\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$$

$$t_{1/2} = \frac{0.693}{k}$$

k = rate constant
 t = time
 $t_{1/2}$ = half-life

EQUILIBRIUM

$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b}, \text{ where } a A + b B \rightleftharpoons c C + d D$$

$$K_p = \frac{(P_C)^c (P_D)^d}{(P_A)^a (P_B)^b}$$

$$K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ\text{C}$$

$$pK_w = 14 = \text{pH} + \text{pOH at } 25^\circ\text{C}$$

$$\text{pH} = -\log[H_3O^+], \quad \text{pOH} = -\log[OH^-]$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}, \quad K_b = \frac{[OH^-][HB^+]}{[B]}$$

$$pK_a = -\log K_a, \quad pK_b = -\log K_b$$

$$K_w = K_a \times K_b, \quad pK_w = pK_a + pK_b$$

$$\text{pH} = pK_a + \log \frac{[A^-]}{[HA]}$$

Equilibrium Constants

K_c (molar concentrations)
 K_p (gas pressures)
 K_w (water)
 K_a (acid)
 K_b (base)

THERMODYNAMICS/ELECTROCHEMISTRY

$$q = mc\Delta T$$

$$\Delta H^\circ_{\text{reaction}} = \sum \Delta H^\circ_{f \text{ products}} - \sum \Delta H^\circ_{f \text{ reactants}}$$

$$\Delta S^\circ_{\text{reaction}} = \sum S^\circ_{\text{products}} - \sum S^\circ_{\text{reactants}}$$

$$\Delta G^\circ_{\text{reaction}} = \sum \Delta G^\circ_{f \text{ products}} - \sum \Delta G^\circ_{f \text{ reactants}}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= -RT \ln K$$

$$= -nFE^\circ$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{nF} \ln Q$$

q = heat
 m = mass
 c = specific heat capacity
 T = temperature
 S° = standard entropy
 H° = standard enthalpy
 G° = standard Gibbs free energy
 R = gas constant
 K = equilibrium constant
 n = number of moles of electrons
 E° = standard potential
 I = current (amperes)
 q = charge (coulombs)
 t = time (seconds)
 Q = reaction quotient

Faraday's constant, $F = 96,485 \text{ coulombs / 1 mol } e^-$

Course Content

Metaphor

Example

Connection

Question

Visualization

The AP Chemistry course framework provides a clear and detailed description of the course requirements necessary for student success. The framework specifies what students must know, be able to do, and understand with a focus on core principles, theories, and processes of chemistry that prepare them for advanced chemistry coursework.

UNITS

The course content is organized into commonly taught units. The units have been arranged in a logical sequence frequently found in many college courses and textbooks.

The nine units in AP Chemistry, and their weighting on the multiple-choice section of the AP Exam, are listed on the following page.

Pacing recommendations at the unit level and on the Course at a Glance provide suggestions for how to teach the required course content and administer the Progress Checks. The suggested class periods are based on a schedule in which the class meets five days a week for 45 minutes each day. While these recommendations have been made to aid planning, teachers should adjust the pacing based on the needs of their students, alternate schedules (e.g., block scheduling), or their school's academic calendar.

Units of Instruction	Exam Weighting
Unit 1: <i>Atomic Structure and Properties</i>	7–9%
Unit 2: <i>Compound Structure and Properties</i>	7–9%
Unit 3: <i>Properties of Substances and Mixtures</i>	18–22%
Unit 4: <i>Chemical Reactions</i>	7–9%
Unit 5: <i>Kinetics</i>	7–9%
Unit 6: <i>Thermochemistry</i>	7–9%
Unit 7: <i>Equilibrium</i>	7–9%
Unit 8: <i>Acids and Bases</i>	11–15%
Unit 9: <i>Thermodynamics and Electrochemistry</i>	7–9%

TOPICS

Each unit is broken down into teachable segments called topics. The topic pages (starting on p. 30) contain the required content for each topic.

Learning Objectives and Science Practices

In AP Chemistry, every exam question will be aligned to a learning objective and a skill. The learning objectives represent the content domain, while the skill articulates the science practice required to successfully complete the task. The six categories of science practices are described as discrete practices; they are, in fact, interrelated and should be applied throughout the course. For a given learning objective, teachers are encouraged to ask the following questions about a phenomenon to help students apply the science practices:

- How could the concepts be described verbally?
- What experiment could a student design, or what data would students analyze?

- How could students create or interpret graphs and other visual representations?
- How could students explain the phenomenon using theories or models?
- What quantitative problems could students solve?
- How could the course content be used as evidence to justify or support a claim about the behavior of a system, chemical phenomena, or outcome of an experiment?

Equations

Relevant equations are included in the Topic pages within this course framework and are labeled as “EQN:”. All of the equations in this course framework appear on the equation sheet provided to students while taking the AP Chemistry Exam. Additionally, variables used within this course framework follow the definitions given on the equation sheet. For a complete list of the equations available to students on the AP Chemistry Exam, please see the AP Chemistry Equations and Constants in Appendix 2.

Course at a Glance

Plan

The Course at a Glance provides a useful visual organization of the AP Chemistry curricular components, including:

- Sequence of units, along with approximate weighting and suggested pacing. Please note, pacing is based on 45-minute class periods, meeting five days each week for a full academic year.
- Progression of topics within each unit.
- Spiraling of the science practices across units.

Teach

SCIENCE PRACTICES

Science practices spiral throughout the course.

- | | |
|--|--------------------------------|
| 1 Models and Representations | 4 Model Analysis |
| 2 Question and Method | 5 Mathematical Routines |
| 3 Representing Data and Phenomena | 6 Argumentation |

Required Course Content

Each topic contains required Learning Objective and Essential Knowledge Statements that form the basis of the assessment on the AP Exam.

Assess

Assign the Progress Checks—either as homework or in class—for each unit. Each Progress Check contains formative multiple-choice and free-response questions. The feedback from the Progress Checks shows students the areas where they need to focus.

UNIT 1

Atomic Structure and Properties

~9–10

Class Periods

7–9%

AP Exam Weighting

5

1.1 Moles and Molar Mass

5

1.2 Mass Spectra of Elements

2

1.3 Elemental Composition of Pure Substances

5

1.4 Composition of Mixtures

1

1.5 Atomic Structure and Electron Configuration

4

1.6 Photoelectron Spectroscopy

4

1.7 Periodic Trends

4

1.8 Valence Electrons and Ionic Compounds

UNIT 2

Compound Structure and Properties

~12–13

Class Periods

7–9%

AP Exam Weighting

6

2.1 Types of Chemical Bonds

3

2.2 Intramolecular Force and Potential Energy

4

2.3 Structure of Ionic Solids

4

2.4 Structure of Metals and Alloys

3

2.5 Lewis Diagrams

6

2.6 Resonance and Formal Charge

6

2.7 VSEPR and Hybridization

Progress Check 1

Multiple-choice: ~20 questions

Free-response: 2 questions

- Short
- Short

Progress Check 2

Multiple-choice: ~15 questions

Free-response: 1 question

- Long

continued on next page

UNIT 3

Properties of Substances and Mixtures

~14–15

Class Periods

18–22%

AP Exam Weighting

4	3.1	Intermolecular and Interparticle Forces
4	3.2	Properties of Solids
3	3.3	Solids, Liquids, and Gases
5	3.4	Ideal Gas Law
4	3.5	Kinetic Molecular Theory
6	3.6	Deviation from Ideal Gas Law
5	3.7	Solutions and Mixtures
3	3.8	Representations of Solutions
2	3.9	Separation of Solutions and Mixtures
4	3.10	Solubility
4	3.11	Spectroscopy and the Electromagnetic Spectrum
5	3.12	Properties of Photons
2	3.13	Beer-Lambert Law

Progress Check 3

Multiple-choice: ~30 questions

Free-response: 2 questions

- Short
- Short

UNIT 4

Chemical Reactions

~14–15

Class Periods

7–9%

AP Exam Weighting

2	4.1	Introduction for Reactions
5	4.2	Net Ionic Equations
3	4.3	Representations of Reactions
6	4.4	Physical and Chemical Changes
5	4.5	Stoichiometry
3	4.6	Introduction to Titration
1	4.7	Types of Chemical Reactions
1	4.8	Introduction to Acid-Base Reactions
5	4.9	Oxidation-Reduction (Redox) Reactions

Progress Check 4

Multiple-choice: ~20 questions

Free-response: 1 question

- Long

UNIT 5

Kinetics

~13–14

Class Periods

7–9%

AP Exam Weighting

6	5.1	Reaction Rates
5	5.2	Introduction to Rate Law
5	5.3	Concentration Changes Over Time
5	5.4	Elementary Reactions
6	5.5	Collision Model
3	5.6	Reaction Energy Profile
1	5.7	Introduction to Reaction Mechanisms
5	5.8	Reaction Mechanism and Rate Law
5	5.9	Pre-Equilibrium Approximation
3	5.10	Multistep Reaction Energy Profile
6	5.11	Catalysis

Progress Check 5

Multiple-choice: ~25 questions

Free-response: 2 questions

- Short
- Long

continued on next page

UNIT 6

Thermochemistry

~10–11

Class Periods

7–9%

AP Exam Weighting

6	6.1 Endothermic and Exothermic Processes
3	6.2 Energy Diagrams
6	6.3 Heat Transfer and Thermal Equilibrium
2	6.4 Heat Capacity and Calorimetry
1	6.5 Energy of Phase Changes
4	6.6 Introduction to Enthalpy of Reaction
5	6.7 Bond Enthalpies
5	6.8 Enthalpy of Formation
5	6.9 Hess's Law

Progress Check 6

Multiple-choice: ~20 questions

Free-response: 2 questions

- Short
- Short

UNIT 7

Equilibrium

~13–15

Class Periods

7–9%

AP Exam Weighting

6	7.1 Introduction to Equilibrium
4	7.2 Direction of Reversible Reactions
3	7.3 Reaction Quotient and Equilibrium Constant
5	7.4 Calculating the Equilibrium Constant
6	7.5 Magnitude of the Equilibrium Constant
5	7.6 Properties of the Equilibrium Constant
3	7.7 Calculating Equilibrium Concentrations
3	7.8 Representations of Equilibrium
6	7.9 Introduction to Le Châtelier's Principle
5	7.10 Reaction Quotient and Le Châtelier's Principle
5	7.11 Introduction to Solubility Equilibria
2	7.12 Common-Ion Effect

Progress Check 7

Multiple-choice: ~30 questions

Free-response: 2 questions

- Short
- Long

UNIT 8

Acids and Bases

~14–16

Class Periods

11–15%

AP Exam Weighting

5	8.1 Introduction to Acids and Bases
5	8.2 pH and pOH of Strong Acids and Bases
5	8.3 Weak Acid and Base Equilibria
5	8.4 Acid-Base Reactions and Buffers
5	8.5 Acid-Base Titrations
6	8.6 Molecular Structure of Acids and Bases
2	8.7 pH and pK_a
6	8.8 Properties of Buffers
5	8.9 Henderson-Hasselbalch Equation
6	8.10 Buffer Capacity
2	8.11 pH and Solubility

Progress Check 8

Multiple-choice: ~30 questions

Free-response: 1 question

- Long

continued on next page

UNIT 9

Thermodynamics and Electrochemistry

~10–13

Class
Periods

7–9%

AP Exam
Weighting

6	9.1 Introduction to Entropy
5	9.2 Absolute Entropy and Entropy Change
6	9.3 Gibbs Free Energy and Thermodynamic Favorability
6	9.4 Thermodynamic and Kinetic Control
6	9.5 Free Energy and Equilibrium
4	9.6 Free Energy of Dissolution
4	9.7 Coupled Reactions
2	9.8 Galvanic (Voltaic) and Electrolytic Cells
5	9.9 Cell Potential and Free Energy
6	9.10 Cell Potential Under Nonstandard Conditions
5	9.11 Electrolysis and Faraday's Law

Progress Check 9

Multiple-choice: ~30 questions

Free-response: 2 questions

- Short
- Long

AP CHEMISTRY

Unit Guides

Introduction

Designed with input from the community of AP Chemistry educators, the Unit Guides offer teachers helpful guidance in building students' skills and content knowledge. The suggested sequence was identified through a thorough analysis of the syllabi of highly effective AP teachers and the organization of typical college textbooks.

This unit structure respects new AP teachers' time by providing one possible sequence they can adopt or modify rather than having to build from scratch. An additional benefit is that these units enable the AP Program to provide interested teachers with formative assessments—the Progress Checks—that they can assign their students at the end of each unit to gauge progress toward success on the AP Exam. However, experienced AP teachers who are satisfied with their current course organization and exam results should feel no pressure to adopt these units, which comprise an optional sequence for this course.

AP CHEMISTRY

UNIT 1

Atomic Structure and Properties



7–9%

AP EXAM WEIGHTING



~9–10

CLASS PERIODS

Atomic Structure and Properties



Developing Understanding

ESSENTIAL QUESTIONS

- How can the same element be used in nuclear fuel rods and fake diamonds?
- How can large quantities of objects be counted by weighing?
- If atoms are too small to be observed directly, how do we know how they're structured?
- Why does the periodic table have the shape that it does?

This first unit sets the foundation for the course by examining the atomic theory of matter, the fundamental premise of chemistry. Although atoms represent the foundational level of chemistry, observations of chemical properties are made on collections of atoms. Macroscopic systems involve such large numbers of particles that they require the units of moles to translate between this and the particulate scale. The organization of the periodic table reflects the periodicity of element properties as a function of atomic number. The electronic structure of an atom can be described by an electron configuration that provides a method for describing the distribution of electrons in an atom or ion. In subsequent units, students will apply their understanding of atomic structure to models and representations of chemical phenomena to explain changes and interactions of chemical substances.

Building the Science Practices

1.A 2.A 4.A 4.B 4.C 5.A 5.B 5.D

In Unit 1, students will practice identifying components of commonly used models and representations to illustrate chemical phenomena. They will construct models and representations and explain whether they are consistent with chemical theories. Students will also practice translating between data and various representations (e.g., photoelectron spectroscopy data and electron configurations). Students should then be able to use representations (e.g., PES graphs, electron configurations, periodic table, drawings) to explain atomic structure, which is the foundation for all subsequent units.

Many of the most useful concepts in chemistry relate to patterns in the behavior of chemical systems, such as periodic trends in atomic and molecular properties. In this unit and all subsequent units, students should learn to analyze data presented graphically to identify patterns and relationships. Once a pattern is identified,

students should be able to examine evidence to determine if it supports the pattern or hypothesis pertaining to a testable question.

Preparing for the AP Exam

On the AP Exam, students must be able to justify claims with evidence. This starts when students can identify the evidence needed to solve a problem or support a claim and then connect that evidence to known chemical theories. However, many students consistently demonstrate difficulty with this skill. For example, while students can memorize periodic trends, they struggle to explain the electrostatic interactions within an atom that produces periodic trends as well as exceptions to these trends. Further, students often have difficulty connecting periodic trends to the shell model, Coulomb's law, and elements of quantum theory. To combat these challenges, teachers can ensure that students have a strong foundation in identifying mathematical relationships or patterns from graphical or tabular information and that they can explain how those patterns are consistent with chemical theories and models.

UNIT AT A GLANCE

Topic	Suggested Skill
1.1 Moles and Molar Mass	5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem.
1.2 Mass Spectra of Elements	5.D Identify information presented graphically to solve a problem.
1.3 Elemental Composition of Pure Substances	2.A Identify a testable scientific question based on an observation, data, or a model.
1.4 Composition of Mixtures	5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).
1.5 Atomic Spectra and Electron Configuration	1.A Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only.
1.6 Photoelectron Spectroscopy	4.B Explain whether a model is consistent with chemical theories.
1.7 Periodic Trends	4.A Predict and/or explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.
1.8 Valence Electrons and Ionic Compounds	4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.



Go to [AP Classroom](#) to assign the **Progress Check** for Unit 1.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches into the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 187 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	1.1	Think-Pair-Share Ask students to individually rank three samples in order of increasing number of particles, increasing mass, and increasing mole amounts (Sample A: 1.0 mole of carbon, Sample B: 18 grams of carbon monoxide, Sample C: 3.0×10^{23} molecules of water). Then have them compare and defend their choices with a partner.
2	1.2	Simulations Conduct a simulation of a mass spectrometer, using a strong magnet and steel ball bearings of various masses, to show students how mass can be used to separate particles based on their ability to be manipulated in an electromagnetic field. Present samples of mass spectra for students to analyze and have them calculate the average atomic mass of an element. Discuss how mass spectrometry could be used to identify the presence of an element within a mixture and the isotopic abundance within an element. Forensic science applications and other modern uses of the technology can be discussed to give relevant context to the concepts.
3	1.3	Think-Pair-Share Have students design an experiment to determine the percent composition of a mixture of sodium carbonate (inert) and sodium bicarbonate. After carrying out the experiment, provide them with a mock student report to analyze and critique. Then have them get into pairs and reflect on their particular approach and come up with additional approaches to this problem.
4	1.4 1.5	Explore Representations Translate PES data into an electron configuration and/or predict a PES spectrum based on an element's electron configuration or location in the periodic table. Have students compare their predictions to the actual electron configuration and discuss discrepancies.
5	1.6	Process Oriented Guided Inquiry Learning (POGIL) Given ionization energy data from various elements, guide students through a series of questions to help them rationalize the relationship of the charge of the ion to its position on the periodic table, its electronic structure, and reactivity.

SUGGESTED SKILL

 *Mathematical Routines*

5.B

Identify an appropriate theory, definition, or mathematical relationship to solve a problem.



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 3: What Makes Hard Water Hard?](#)
- Classroom Resource > [Guided Inquiry Activities for the Classroom: Lesson 1](#)

highlight key term

Use Chinese to explain if needed

TOPIC 1.1

Moles and Molar Mass

Required Course Content

LEARNING OBJECTIVE

1.1.A

Calculate quantities of a substance or its relative number of particles using **dimensional analysis** and the mole concept.

ESSENTIAL KNOWLEDGE

1.1.A.1

One cannot count particles directly while performing laboratory work. Thus, there must be a connection between the masses of substances reacting and the actual number of particles undergoing chemical changes.

1.1.A.2

Avogadro's number ($N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$) provides the connection between the number of moles in a pure sample of a substance and the number of constituent particles (or formula units) of that substance.

1.1.A.3

Expressing the mass of an individual atom or molecule in **atomic mass units (amu)** is useful because the average mass in amu of one particle (atom or molecule) or formula unit of a substance will always be numerically equal to the **molar mass** of that substance in grams. Thus, there is a quantitative connection between the mass of a substance and the number of particles that the substance contains.

$$\text{EQN: } n = m/M$$

Date

How do you feel about this topic.

mind map/ duo coding / examples / questions (use 2 strategies)



TOPIC 1.2

Mass Spectra of Elements

Required Course Content

LEARNING OBJECTIVE

1.2.A

Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.

ESSENTIAL KNOWLEDGE

1.2.A.1

The mass spectrum of a sample containing a single element can be used to determine the identity of the isotopes of that element and the relative abundance of each isotope in nature.

1.2.A.2

The average atomic mass of an element can be estimated from the weighted average of the isotopic masses using the mass of each isotope and its relative abundance.

Exclusion Statement: Interpreting mass spectra of samples containing multiple elements or peaks arising from species other than singly charged monatomic ions will not be assessed on the AP Exam.

SUGGESTED SKILL

Mathematical Routines

5.D

Identify information presented graphically to solve a problem.

**AVAILABLE RESOURCES**

- Classroom Resource > [Exploring Atomic Structure Using Photoelectron Spectroscopy \(PES\) Data](#)

SUGGESTED SKILL

 Question and Method

2.A

Identify a testable scientific question based on an observation, data, or a model.



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 3: What Makes Hard Water Hard?](#)
- The Exam > [2023 Chief Reader Report](#)

TOPIC 1.3

Elemental Composition of Pure Substances

Required Course Content

LEARNING OBJECTIVE

1.3.A

Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.

ESSENTIAL KNOWLEDGE

1.3.A.1

Some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit.

1.3.A.2

According to the law of definite proportions, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.

1.3.A.3

The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula.

TOPIC 1.4

Composition of Mixtures

SUGGESTED SKILL

*Mathematical Routines*

5.A

Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).

Required Course Content

LEARNING OBJECTIVE**1.4.A**

Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.

ESSENTIAL KNOWLEDGE**1.4.A.1**

Pure substances contain atoms, molecules, or formula units of a single type. Mixtures contain atoms, molecules, or formula units of two or more types, whose relative proportions can vary.

1.4.A.2

Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity.

SUGGESTED SKILL

 Models and Representations

1.A

Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only.

TOPIC 1.5

Atomic Structure and Electron Configuration

Required Course Content

LEARNING OBJECTIVE

1.5.A

Represent the ground-state electron configuration of an atom of an element or its ions using the Aufbau principle.

ESSENTIAL KNOWLEDGE

1.5.A.1

The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons.

1.5.A.2

Coulomb's law is used to calculate the force between two charged particles.

$$\text{EQN: } F_{\text{coulombic}} \propto \frac{q_1 q_2}{r^2}$$

1.5.A.3

In atoms and ions, the electrons can be thought of as being in "shells (energy levels)" and "subshells (sublevels)," as described by the ground-state electron configuration. Inner electrons are called core electrons, and outer electrons are called valence electrons. The electron configuration is explained by quantum mechanics, as delineated in the Aufbau principle and exemplified in the periodic table of the elements.

Exclusion Statement: The assignment of quantum numbers to electrons in subshells of an atom will not be assessed on the AP Exam.

continued on next page

LEARNING OBJECTIVE

1.5.A

Represent the electron configuration of an element or ions of an element using the Aufbau principle.

ESSENTIAL KNOWLEDGE

1.5.A.4

The relative energy required to remove an electron from different subshells of an atom or ion or from the same subshell in different atoms or ions (ionization energy) can be estimated through a qualitative application of Coulomb's law. This energy is related to the distance from the nucleus and the effective (shield) charge of the nucleus.

SUGGESTED SKILL

 Model Analysis

4.B

Explain whether a model is consistent with chemical theories.



AVAILABLE RESOURCES

- Classroom Resource > [Exploring Atomic Structure Using Photoelectron Spectroscopy \(PES\) Data](#)
- The Exam > [2021 Chief Reader Report](#)

TOPIC 1.6

Photoelectron Spectroscopy

Required Course Content

LEARNING OBJECTIVE

1.6.A

Explain the relationship between the photoelectron spectrum of an atom or ion and:

- The ground-state electron configuration of the species.
- The interactions between the electrons and the nucleus.

ESSENTIAL KNOWLEDGE

1.6.A.1

The energies of the electrons in a given shell can be measured experimentally with photoelectron spectroscopy (PES). The position of each peak in the PES spectrum is related to the energy required to remove an electron from the corresponding subshell, and the relative height of each peak is (ideally) proportional to the number of electrons in that subshell.

TOPIC 1.7

Periodic Trends

SUGGESTED SKILL

Model Analysis

4.A

Predict and/or explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.



Required Course Content

LEARNING OBJECTIVE**1.7.A**

Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.

ESSENTIAL KNOWLEDGE**1.7.A.1**

The organization of the periodic table is based on patterns of recurring properties of the elements, which are explained by patterns of ground-state electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms.

Exclusion Statement: Writing the electron configuration of elements that are exceptions to the aufbau principle will not be assessed on the AP Exam.

1.7.A.2

Trends in atomic properties within the periodic table (periodicity) can be predicted by the position of the element on the periodic table and qualitatively understood using Coulomb's law, the shell model, and the concepts of shielding and effective nuclear charge. These properties include:

- Ionization energy
- Atomic and ionic radii
- Electron affinity
- Electronegativity.

1.7.A.3

The periodicity (in 1.7.A.2) is useful to predict/estimate values of properties in the absence of data.

AVAILABLE RESOURCES

- The Exam > 2021 Chief Reader Report

SUGGESTED SKILL

 Model Analysis

4.C

Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.



AVAILABLE RESOURCES

- Classroom Resource > [Alternative Approaches to Teaching Traditional Topics](#)

TOPIC 1.8

Valence Electrons and Ionic Compounds

Required Course Content

LEARNING OBJECTIVE

1.8.A

Explain the relationship between trends in the reactivity of elements and periodicity.

ESSENTIAL KNOWLEDGE

1.8.A.1

The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.

1.8.A.2

Elements in the same column of the periodic table tend to form analogous compounds.

1.8.A.3

Typical charges of atoms in ionic compounds are governed by the number of valence electrons and predicted by their location on the periodic table.

AP CHEMISTRY

UNIT 2

Compound Structure and Properties



7–9%

AP EXAM WEIGHTING



~12–13

CLASS PERIODS

Compound Structure and Properties



Developing Understanding

ESSENTIAL QUESTIONS

- How are molecular compounds arranged?
- Why are some bonds easier to break than others?
- In what ways does a diagram drawn on paper accurately reflect the structure of a molecule? In what ways does it not accurately reflect the structure?

In Unit 2, students apply their knowledge of atomic structure at the particulate level and connect it to the macroscopic properties of a substance. Both the chemical and physical properties of materials can be explained by the structure and arrangement of atoms, ions, or molecules and the forces between them. These forces, called chemical bonds, are distinct from typical intermolecular interactions. Electronegativity can be used to make predictions about the type of bonding present between two atoms. In subsequent units, students will use the periodic table and the atomic properties to predict the type of bonding present between two atoms based on position.

Building the Science Practices

3.A 3.B 4.C 6.A 6.C

In this unit, students will learn how to interpret simple graphical representations of changes in potential energy as two atoms approach each other to explain optimal bond length as well as why bonds may or may not occur. Students should also practice constructing representations and models for chemical phenomena (e.g., ionic and metallic solids) and using representations to make claims or predictions. For example, students can use VSEPR theory to draw Lewis structures of molecules and predict their three-dimensional geometry and polarity.

Instead of simply connecting chemical theories to phenomena occurring at the atomic level, it is important to provide explanations across scales. For example, teachers can ask students to explain the connection between electronegativity and ionization energy with the type of bond formed and the macroscopic properties of a particular substance. Students should also work with several chemical concepts (Coulomb's law, formal charge, and resonance) to evaluate the accuracy of a model in

representing both the particulate-level structure and macroscopic observations. In future units, students will use the practice of constructing and understanding molecular representations to make predictions and claims about interparticle interactions, intermolecular forces, and their connections to macroscopic observations.

Preparing for the AP Exam

On the AP Exam, students must be able to construct Lewis structures and make predictions or claims based on them. However, students often struggle to predict the correct molecular shape or bond angle based on VSEPR and the use of formal charge. Mistakes include: using the incorrect number of valence electrons, violating the octet rule, or confusing molecular geometry with bond angles. Teachers can provide students with multiple opportunities to practice drawing Lewis electron-dot diagrams, including resonance structures. Students should also practice predicting and describing molecular shapes, bond angles, and polarities from Lewis structures, and calculating and connecting formal charges in Lewis structures to the predicted structure of a molecule.

UNIT AT A GLANCE

Topic	Suggested Skill
2.1 Types of Chemical Bonds	6.A Make a scientific claim.
2.2 Intramolecular Force and Potential Energy	3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.
2.3 Structure of Ionic Solids	4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.
2.4 Structure of Metals and Alloys	4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.
2.5 Lewis Diagrams	3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).
2.6 Resonance and Formal Charge	6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.
2.7 VSEPR and Hybridization	6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.

 Go to [AP Classroom](#) to assign the **Progress Check** for Unit 2.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches into the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 187 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	2.2	Think-Pair-Share After a review of the graph of potential energy versus internuclear distance in a hydrogen molecule, have students pair up and describe what they believe the graph would look like for various other molecules.
2	2.3	Explore Representations Demonstrate a model of ionic bonding. Put opaque adhesive tape on top of disk magnets to make "+" and "-" signs. Be sure to affix the tape on opposite sides for the differing charges (so that opposite ions have opposite magnetic polarity when arranged on a flat surface). Arrange the ions in an alternating array on the overhead projector to show the structure of an ionic crystal. Engage students in a discussion about malleability/brittleness, and ask why distorting an ionic crystal causes shattering. This also introduces Coulombic forces in a visual and memorable way. Then have students predict and identify the bonding in binary compounds using periodic trends.
3	2.4	Manipulatives Have students use various sized/colored paper plates to illustrate a particular type of alloy (interstitial and/or substitutional). Then have them engage in a gallery walk around the room to listen to others explain the connection between the structure of the different alloys and the properties of each.
4	2.5 2.6 2.7	Simulations Construct various VSEPR shapes using balloons to show the three-dimensional arrangement of atoms in various bonding arrangements. Then use a PhET simulation to help students see the effects of lone pairs and bonding pairs on molecular shape. Students can work on this individually after being shown how to use the interface, or it can be projected and examined as a class. Have students work with the simulation to add/remove bonds and add/remove lone pairs to determine the most likely three-dimensional shape and bond angles in a molecule.

SUGGESTED SKILL

 Argumentation

6.A

Make a scientific claim.



AVAILABLE RESOURCES

- Classroom Resource >
[Guided Inquiry Activities for the Classroom: Lesson 3](#)
- AP Chemistry Lab Manual >
[Investigation 6: What's in That Bottle?](#)

TOPIC 2.1

Types of Chemical Bonds

Required Course Content

LEARNING OBJECTIVE

2.1.A

Explain the relationship between the type of bonding and the properties of the elements participating in the bond.

ESSENTIAL KNOWLEDGE

2.1.A.1

Electronegativity values for the representative elements increase going from left to right across a period and decrease going down a group. These trends can be understood qualitatively through the electronic structure of the atoms, the shell model, and Coulomb's law.

2.1.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.

2.1.A.3

Valence electrons shared between atoms of unequal electronegativity constitute a polar covalent bond.

- The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond.
- In single bonds, greater differences in electronegativity lead to greater bond dipoles.
- All polar bonds have some ionic character, and the difference between ionic and covalent bonding is not distinct but rather a continuum.

continued on next page

LEARNING OBJECTIVE

2.1.A

Explain the relationship between the type of bonding and the properties of the elements participating in the bond.

ESSENTIAL KNOWLEDGE

2.1.A.4

The difference in electronegativity is not the only factor in determining if a bond should be designated as ionic or covalent. Generally, bonds between a metal and nonmetal are ionic, and bonds between two nonmetals are covalent. Examination of the properties of a compound is the best way to characterize the type of bonding.

2.1.A.5

In a metallic solid, the valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.

SUGGESTED SKILL

 *Representing Data and Phenomena*

3.A

Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 5: Sticky Question: How Do You Separate Molecules That Are Attracted to One Another?](#)
- Classroom Resource > [Ending Misconceptions About the Energy of Chemical Bonds](#)
- The Exam > [2023 Chief Reader Report](#)

TOPIC 2.2

Intramolecular Force and Potential Energy

Required Course Content

LEARNING OBJECTIVE

2.2.A

Represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.

ESSENTIAL KNOWLEDGE

2.2.A.1

A graph of potential energy versus the distance between atoms (internuclear distance) is a useful representation for describing the interactions between atoms. Such graphs illustrate both the equilibrium bond length (the separation between atoms at which the potential energy is lowest) and the bond energy (the energy required to separate the atoms).

2.2.A.2

In a covalent bond, the bond length is influenced by both the size of the atom's core and the bond order (i.e., single, double, triple). Bonds with a higher order are shorter and have larger bond energies.

2.2.A.3

Coulomb's law can be used to understand the strength of interactions between cations and anions.

- Because the interaction strength is proportional to the charge on each ion, larger charges lead to stronger interactions.
- Because the interaction strength increases as the distance between the centers of the ions (nuclei) decreases, smaller ions lead to stronger interactions.

TOPIC 2.3

Structure of Ionic Solids

Required Course Content

LEARNING OBJECTIVE

2.3.A

Represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions.

ESSENTIAL KNOWLEDGE

2.3.A.1

The cations and anions in an ionic crystal are arranged in a systematic, periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces.

Exclusion Statement: Knowledge of specific crystal structures is not essential to an understanding of the learning objective and will not be assessed on the AP Exam.

SUGGESTED SKILL



Model Analysis

4.C

Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.



AVAILABLE RESOURCES

- The Exam > 2017 Chief Reader Report

SUGGESTED SKILL

 Model Analysis

4.C

Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.



AVAILABLE RESOURCES

- The Exam > [2017 Chief Reader Report](#)

TOPIC 2.4

Structure of Metals and Alloys

Required Course Content

LEARNING OBJECTIVE

2.4.A

Represent a metallic solid and/or alloy using a model to show essential characteristics of the structure and interactions present in the substance.

ESSENTIAL KNOWLEDGE

2.4.A.1

Metallic bonding can be represented as an array of positive metal ions surrounded by delocalized valence electrons (i.e., a “sea of electrons”).

2.4.A.2

Interstitial alloys form between atoms of significantly different radii, where the smaller atoms fill the interstitial spaces between the larger atoms (e.g., with steel in which carbon occupies the interstices in iron).

2.4.A.3

Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (e.g., in certain brass alloys, other elements, usually zinc, substitute for copper.)

TOPIC 2.5

Lewis Diagrams

Required Course Content

LEARNING OBJECTIVE

2.5.A

Represent a molecule with a Lewis diagram.

ESSENTIAL KNOWLEDGE

2.5.A.1

Lewis diagrams can be constructed according to an established set of principles.

SUGGESTED SKILL



Representing Data and Phenomena

3.B

Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).



AVAILABLE RESOURCES

- Classroom Resource > [Guided Inquiry Activities for the Classroom: Lesson 3](#)
- The Exam > [2018 Chief Reader Report](#)

SUGGESTED SKILL

 Argumentation

6.C

Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.



AVAILABLE RESOURCES

- Classroom Resource > [Guided Inquiry Activities for the Classroom: Lesson 3](#)

TOPIC 2.6

Resonance and Formal Charge

Required Course Content

LEARNING OBJECTIVE

2.6.A

Represent a molecule with a Lewis diagram that accounts for resonance between equivalent structures or that uses formal charge to select between nonequivalent structures.

ESSENTIAL KNOWLEDGE

2.6.A.1

In cases where more than one equivalent Lewis structure can be constructed, resonance must be included as a refinement to the Lewis structure. In many such cases, this refinement is needed to provide qualitatively accurate predictions of molecular structure and properties.

2.6.A.2

The octet rule and formal charge can be used as criteria for determining which of several possible valid Lewis diagrams provides the best model for predicting molecular structure and properties.

2.6.A.3

As with any model, there are limitations to the use of the Lewis structure model, particularly in cases with an odd number of valence electrons.

TOPIC 2.7

VSEPR and Hybridization

SUGGESTED SKILL



Argumentation

6.C

Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.



AVAILABLE RESOURCES

- Classroom Resource > [Guided Inquiry Activities for the Classroom: Lesson 3](#)

Required Course Content

LEARNING OBJECTIVE

2.7.A

Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities:

- Explain structural properties of molecules.
- Explain electron properties of molecules.

ESSENTIAL KNOWLEDGE

2.7.A.1

VSEPR theory uses the Coulombic repulsion between electrons as a basis for predicting the arrangement of electron pairs around a central atom.

2.7.A.2

Both Lewis diagrams and VSEPR theory must be used for predicting electronic and structural properties of many covalently bonded molecules and polyatomic ions, including the following:

- Molecular geometry (linear, trigonal planar, tetrahedral, trigonal pyramidal, bent, trigonal bipyramidal, seesaw, T-shaped, octahedral, square pyramidal, square planar)
- Bond angles
- Relative bond energies based on bond order
- Relative bond lengths (multiple bonds, effects of atomic radius)
- Presence of a dipole moment
- Hybridization of valence orbitals for atoms within a molecule or polyatomic ion

2.7.A.3

The terms “hybridization” and “hybrid atomic orbital” are used to describe the arrangement of electrons around a central atom. When the central atom is sp hybridized, its ideal bond angles are 180° ; for sp^2 hybridized atoms the bond angles are 120° ; and for sp^3 hybridized atoms the bond angles are 109.5° .

continued on next page

LEARNING OBJECTIVE

2.7.A

Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities:

- Explain structural properties of molecules.
- Explain electron properties of molecules.

ESSENTIAL KNOWLEDGE

Exclusion Statement: An understanding of the derivation and depiction of hybrid orbitals will not be assessed on the AP Exam. The course includes the distinction between sigma and pi bonding, the use of VSEPR to explain the shapes of molecules, and the sp , sp^2 , and sp^3 nomenclature.

Exclusion Statement: Hybridization involving d orbitals will not be assessed on the AP Exam. When an atom has more than four pairs of electrons surrounding the central atom, students are only responsible for the shape of the resulting molecule.

2.7.A.4

Bond formation is associated with overlap between atomic orbitals. In multiple bonds, such overlap leads to the formation of both sigma and pi bonds. The overlap is stronger in sigma than pi bonds, which is reflected in sigma bonds having greater bond energy than pi bonds. The presence of a pi bond also prevents the rotation of the bond and leads to geometric isomers.

Exclusion Statement: Molecular orbital theory is recommended as a way to provide deeper insight into bonding. However, the AP Exam will neither explicitly assess molecular orbital diagrams, filling of molecular orbitals, nor the distinction between bonding, nonbonding, and antibonding orbitals.

AP CHEMISTRY

UNIT 3

Properties of Substances and Mixtures



18–22%
AP EXAM WEIGHTING



~14–15
CLASS PERIODS

Properties of Substances and Mixtures



Developing Understanding

ESSENTIAL QUESTIONS

- How do interactions between particles influence the properties of pure substances and mixtures?
- Why does the smell of perfume only last for a short time?
- Why can you swim in water, but you can't walk through a wall?
- How does the spacing and motion of particles relate to a substance's state of matter and the properties of gases?
- How can you determine the structure and concentration of a chemical species in a mixture?

Transformations of matter can be observed in ways that are generally categorized as either a chemical or physical change. The shapes of the particles involved and the space between them are key factors in determining the nature of physical changes. The properties of solids, liquids, and gases reflect the relative orderliness of the arrangement of particles in those states, their relative freedom of motion, and the nature and strength of the interactions between them. There is a relationship between the macroscopic properties of solids, liquids, and gases, as well as the structure of the constituent particles of those materials on the molecular and atomic scale. In subsequent units, students will explore chemical transformations of matter.

Building the Science Practices

2.C 2.D 2.E 3.C 4.C 4.D 5.C 5.F

This unit requires students to draw upon claims made in Unit 2 about molecular geometry and polarity to support claims about intermolecular forces between molecules. Further, students will practice illustrating such claims by constructing particle representations of pure solids, liquids, gases, and solutions.

This unit also requires students to build proficiency with mathematical reasoning skills, essential for success in the remainder of the course. Students should be able to explain relationships between variables in an equation (e.g., the ideal gas law) and then estimate the approximate value of one variable within an equation when the value of another variable changes. Students will practice these skills when choosing and implementing experimental procedures, making observations, and/or collecting data to address a question. Students can then determine the accuracy and precision of the data as well as manipulate it with known mathematical equations to support their claims (e.g., concentration of a substance, properties of substances in a mixture).

Preparing for the AP Exam

On the AP Exam (in both the multiple-choice and the free-response section), students are required to compare the physical properties of substances and relate them to the attractive forces between particles. Students often struggle with questions that require them to determine the forces of attraction that are present between molecules. Moreover, it can be challenging for them to determine which forces are most important in explaining the differences in physical properties, such as melting points, boiling points, and vapor pressures of molecules in the solid and/or liquid state.

Students also confuse the terms intramolecular and intermolecular forces. Another common mistake students make is to simplify their explanations about governing intermolecular forces in a substance by using terms such as "strong" and "weak." Teachers can ensure that students can identify an actual intermolecular force and explain its strength in relation to other forces at play.

UNIT AT A GLANCE

Topic	Suggested Skill
3.1 Intermolecular and Interparticle Forces	4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.
3.2 Properties of Solids	4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.
3.3 Solids, Liquids, and Gases	3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).
3.4 Ideal Gas Law	5.C Explain the relationship between variables within an equation when one variable changes.
3.5 Kinetic Molecular Theory	4.A Predict and/or explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.
3.6 Deviation from Ideal Gas Law	6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.
3.7 Solutions and Mixtures	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).
3.8 Representations of Solutions	3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).
3.9 Separation of Solutions and Mixtures	2.C Identify experimental procedures that are aligned to the question (which may include a sketch of a lab setup).
3.10 Solubility	4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.
3.11 Spectroscopy and the Electromagnetic Spectrum	4.A Predict and/or explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.
3.12 Properties of Photons	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).
3.13 Beer-Lambert Law	2.E Identify or describe potential sources of experimental error.



Go to [AP Classroom](#) to assign the **Progress Check** for Unit 3.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches into the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 187 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	3.1	Demo with Q&A Fill a long glass tube halfway with water and then layer ethanol over the top and fill the tube, leaving one inch at the top. Have a student mark the liquid level with a permanent marker and invert the tube (with thumb pressed firmly over the top) several times. A noticeable volume decrease occurs, and students should hypothesize why. Introduce a model showing the interparticle spacing between ethanol molecules and water molecules. The model takes into account the spacing between molecules and why volume is not a conserved quantity (unlike mass). Review hydrogen bonding as a relevant interparticle force for this demonstration.
2	3.3	Explore Representations Have students create particle representations for samples of solid, liquid, and gaseous H ₂ O. Each diagram should contain 10 molecules, and students should show how the placement and motion of the particles varies in each phase.
4	3.7 3.8	Explore Representations Begin by telling students that hexane does not mix with water, but ethanol does. Then have them create a particulate representation of each of the mixtures (which illustrate the interactions between the molecules that allow/disallow the solubility).
5	3.9	Post-Lab Discussion After investigating three different dyes using chromatography, have students determine which of the three dyes is the most polar based on macroscopic observations and an understanding of the interactions between the dyes and the solvent, or between the dyes and the paper. Then have them discuss their answers (based on evidence) and evaluate the strengths of each other's claims using both the evidence and understanding of intermolecular forces.
7	3.13	Predict and Confirm Have students use a Sep-Pak C18 Cartridge (Flinn Scientific AP8917) to separate Grape Kool-Aid into its component red and blue dyes. Then have them compare the separated dyes to reference solutions of common food dyes using a spectrophotometer and measure the percent transmittance at 25 nm intervals across the range of 400 nm–750 nm.

SUGGESTED SKILL

 Model Analysis

4.D

Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.



AVAILABLE RESOURCES

- Classroom Resource > [Guided Inquiry Activities for the Classroom: Lesson 3](#)
- The Exam > [2017 Chief Reader Report](#)

TOPIC 3.1

Intermolecular and Interparticle Forces

Required Course Content

LEARNING OBJECTIVE

3.1.A

Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when:

- The molecules are of the same chemical species.
- The molecules are of two different chemical species.

ESSENTIAL KNOWLEDGE

3.1.A.1

London dispersion forces are a result of the Coulombic interactions between temporary, fluctuating dipoles. London dispersion forces are often the strongest net intermolecular force between large molecules.

- Dispersion forces increase with increasing contact area between molecules and with increasing polarizability of the molecules.
- The polarizability of a molecule increases with an increasing number of electrons in the molecule and the size of the electron cloud. It is enhanced by the presence of pi bonding.
- The term “London dispersion forces” should not be used synonymously with the term “van der Waals forces.”

3.1.A.2

The dipole moment of a polar molecule leads to additional interactions with other chemical species.

- Dipole-induced dipole interactions are present between a polar and nonpolar molecule. These forces are always attractive. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule.

continued on next page

LEARNING OBJECTIVE

3.1.A

Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when:

- The molecules are of the same chemical species.
- The molecules are of two different chemical species.

ESSENTIAL KNOWLEDGE

- Dipole-dipole interactions are present between polar molecules. The interaction strength depends on the magnitudes of the dipoles and their relative orientation. Interactions between polar molecules are typically greater than those between nonpolar molecules of comparable size because these interactions act in addition to London dispersion forces.
- Ion-dipole forces of attraction are present between ions and polar molecules. These tend to be stronger than dipole-dipole forces.

3.1.A.3

The relative strength and orientation dependence of dipole-dipole and ion-dipole forces can be understood qualitatively by considering the sign of the partial charges responsible for the molecular dipole moment, and how these partial charges interact with an ion or with an adjacent dipole.

3.1.A.4

Hydrogen bonding is a strong type of intermolecular interaction that exists when hydrogen atoms covalently bonded to the highly electronegative atoms (N, O, and F) are attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule, or a different part of the same molecule.

3.1.A.5

In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule.

SUGGESTED SKILL

 Model Analysis

4.C

Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 6: What's in That Bottle?](#)

TOPIC 3.2

Properties of Solids

Required Course Content

LEARNING OBJECTIVE

3.2.A

Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.

ESSENTIAL KNOWLEDGE

3.2.A.1

Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. Because intermolecular interactions are overcome completely when a substance vaporizes, the vapor pressure and boiling point are directly related to the strength of those interactions. Melting points also tend to correlate with interaction strength, but because the interactions are only rearranged, in melting, the relations can be more subtle.

3.2.A.2

Particulate-level representations, showing multiple interacting chemical species, are a useful means to communicate or understand how intermolecular interactions help to establish macroscopic properties.

3.2.A.3

Due to strong interactions between ions, ionic solids tend to have low vapor pressures, high melting points, and high boiling points. They tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. They conduct electricity only when the ions are mobile, as when the ionic solid is melted (i.e., in a molten state) or dissolved in water or another solvent.

continued on next page

LEARNING OBJECTIVE

3.2.A

Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.

ESSENTIAL KNOWLEDGE

3.2.A.4

In covalent network solids, the atoms are covalently bonded together into a three-dimensional network (e.g., diamond) or layers of two-dimensional networks (e.g., graphite). These are only formed from nonmetals and metalloids: elemental (e.g., diamond, graphite) or binary compounds (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting points. Three-dimensional network solids are also rigid and hard, because the covalent bond angles are fixed. However, graphite is soft because adjacent layers can slide past each other relatively easily.

3.2.A.5

Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers.

3.2.A.6

Metallic solids are good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting.

3.2.A.7

In large biomolecules or polymers, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions.

SUGGESTED SKILL

 *Representing Data and Phenomena*

3.C

Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).



AVAILABLE RESOURCES

- The Exam > 2017 Chief Reader Report

TOPIC 3.3

Solids, Liquids, and Gases

Required Course Content

LEARNING OBJECTIVE

3.3.A

Represent the differences between solid, liquid, and gas phases using a particulate-level model.

ESSENTIAL KNOWLEDGE

3.3.A.1

Solids can be crystalline, where the particles are arranged in a regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo overall translation with respect to each other. The structure of the solid is influenced by interparticle interactions and the ability of the particles to pack together.

3.3.A.2

The constituent particles in liquids are in close contact with each other, and they are continually moving and colliding. The arrangement and movement of particles are influenced by the nature and strength of the forces (e.g., polarity, hydrogen bonding, and temperature) between the particles.

3.3.A.3

The solid and liquid phases for a particular substance typically have similar molar volume because, in both phases, the constituent particles are in close contact at all times.

3.3.A.4

In the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion, and minimal effects of forces between particles, a gas has neither a definite volume nor a definite shape.

Exclusion Statement: Understanding/interpreting phase diagrams will not be assessed on the AP Exam.

TOPIC 3.4

Ideal Gas Law

SUGGESTED SKILL

 *Mathematical Routines*

5.C

Explain the relationship between variables within an equation when one variable changes.



AVAILABLE RESOURCES

- The Exam > 2017 Chief Reader Report

Required Course Content

LEARNING OBJECTIVE

3.4.A

Explain the relationship between the macroscopic properties of a sample of gas or mixture of gases using the ideal gas law.

ESSENTIAL KNOWLEDGE

3.4.A.1

The macroscopic properties of ideal gases are related through the ideal gas law:

$$\text{EQN: } PV = nRT.$$

3.4.A.2

In a sample containing a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the partial pressure of a gas within the mixture is proportional to its mole fraction (X), and the total pressure of the sample is the sum of the partial pressures.

$$\text{EQN: } P_A = P_{\text{total}} \times X_A,$$

where X_A = moles A/total moles;

$$\text{EQN: } P_{\text{total}} = P_A + P_B + P_C + \dots$$

3.4.A.3

Graphical representations of the relationships between P , V , T , and n are useful to describe gas behavior.

SUGGESTED SKILL

 Model Analysis

4.A

Predict and/or explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.

TOPIC 3.5

Kinetic Molecular Theory

Required Course Content

LEARNING OBJECTIVE

3.5.A

Explain the relationship between the motion of particles and the macroscopic properties of gases with:

- The kinetic molecular theory (KMT).
- A particulate model.
- A graphical representation.

ESSENTIAL KNOWLEDGE

3.5.A.1

The kinetic molecular theory (KMT) relates the macroscopic properties of gases to motions of the particles in the gas. The Maxwell-Boltzmann distribution describes the distribution of the kinetic energies of particles at a given temperature.

3.5.A.2

All the particles in a sample of matter are in continuous, random motion. The average kinetic energy of a particle is related to its average velocity by the equation:

$$\text{EQN: } KE = \frac{1}{2} mv^2.$$

3.5.A.3

The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample.

3.5.A.4

The Maxwell-Boltzmann distribution provides a graphical representation of the energies/velocities of particles at a given temperature.

TOPIC 3.6

Deviation from Ideal Gas Law

Required Course Content

LEARNING OBJECTIVE**3.6.A**

Explain the relationship among non-ideal behaviors of gases, interparticle forces, and/or volumes.

ESSENTIAL KNOWLEDGE**3.6.A.1**

The ideal gas law does not explain the actual behavior of real gases. Deviations from the ideal gas law may result from interparticle attractions among gas molecules, particularly at conditions that are close to those resulting in condensation. Deviations may also arise from particle volumes, particularly at extremely high pressures.

SUGGESTED SKILL*Argumentation***6.E**

Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.

**AVAILABLE RESOURCES**

- The Exam > [2019 Chief Reader Report](#)

SUGGESTED SKILL

 *Mathematical Routines*

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).



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 7: Using the Principle That Each Substance Has Unique Properties to Purify a Mixture: An Experiment in Applying Green Chemistry in Purification](#)

TOPIC 3.7

Solutions and Mixtures

Required Course Content

LEARNING OBJECTIVE

3.7.A

Calculate the number of solute particles, volume, or molarity of solutions.

ESSENTIAL KNOWLEDGE

3.7.A.1

Solutions, also sometimes called homogeneous mixtures, can be solids, liquids, or gases. In a solution, the macroscopic properties do not vary throughout the sample. In a heterogeneous mixture, the macroscopic properties depend on location in the mixture.

3.7.A.2

Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory.

$$\text{EQN: } M = n_{\text{solute}} / L_{\text{solution}}$$

TOPIC 3.8

Representations of Solutions

Required Course Content

LEARNING OBJECTIVE**3.8.A**

Using particulate models for mixtures:

- Represent interactions between components.
- Represent concentrations of components.

ESSENTIAL KNOWLEDGE**3.8.A.1**

Particulate representations of solutions communicate the structure and properties of solutions, by illustration of the relative concentrations of the components in the solution and/or drawings that show interactions among the components.

Exclusion Statement: Colligative properties will not be assessed on the AP Exam.

Exclusion Statement: Calculations of molality, percent by mass, and percent by volume for solutions will not be assessed on the AP Exam.

SUGGESTED SKILL

 **Representing Data and Phenomena**

3.C

Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).

**AVAILABLE RESOURCES**

- The Exam > **2021 Chief Reader Report**

SUGGESTED SKILL

 Question and Method

2.C

Identify experimental procedures that are aligned to the question (which may include a sketch of a lab setup).



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > Investigation 5: Sticky Question: How Do You Separate Molecules That Are Attracted to One Another?

TOPIC 3.9

Separation of Solutions and Mixtures

Required Course Content

LEARNING OBJECTIVE

3.9.A

Explain the results of a separation experiment based on intermolecular interactions.

ESSENTIAL KNOWLEDGE

3.9.A.1

The components of a liquid solution cannot be separated by filtration. They can, however, be separated using processes that take advantage of differences in the intermolecular interactions of the components.

- Chromatography (paper, thin-layer, and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components of the solution (the mobile phase) and with the surface components of the stationary phase. The resulting chromatogram can be used to infer the relative polarities of components in a mixture.
- Distillation separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.

TOPIC 3.10

Solubility

SUGGESTED SKILL*Model Analysis***4.D**

Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.

Required Course Content

LEARNING OBJECTIVE**3.10.A**

Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.

ESSENTIAL KNOWLEDGE**3.10.A.1**

Substances with similar intermolecular interactions tend to be miscible or soluble in one another.

SUGGESTED SKILL

 Model Analysis

4.A

Predict and/or explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 1: What is the Relationship Between the Concentration of a Solution and the Amount of Transmitted Light Through the Solution?](#)

TOPIC 3.11

Spectroscopy and the Electromagnetic Spectrum

Required Course Content

LEARNING OBJECTIVE**3.11.A**

Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.

ESSENTIAL KNOWLEDGE**3.11.A.1**

Differences in absorption or emission of photons in different spectral regions are related to the different types of molecular motion or electronic transition:

- Microwave radiation is associated with transitions in molecular rotational levels.
- Infrared radiation is associated with transitions in molecular vibrational levels.
- Ultraviolet/visible radiation is associated with transitions in electronic energy levels.

TOPIC 3.12

Properties of Photons

SUGGESTED SKILL

Mathematical
Routines

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).

Required Course Content

LEARNING OBJECTIVE

3.12.A

Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.

ESSENTIAL KNOWLEDGE

3.12.A.1

When a photon is absorbed (or emitted) by an atom or molecule, the energy of the species is increased (or decreased) by an amount equal to the energy of the photon.

3.12.A.2

The wavelength of the electromagnetic wave is related to its frequency and the speed of light by the equation:

$$\text{EQN: } c = \lambda\nu.$$

The energy of a photon is related to the frequency of the electromagnetic wave through Planck's equation:

$$\text{EQN: } E = h\nu.$$

SUGGESTED SKILL

 Question and Method

2.E

Identify or describe potential sources of experimental error.



AVAILABLE RESOURCES

- The Exam > [2021 Chief Reader Report](#)

TOPIC 3.13

Beer-Lambert Law

Required Course Content

LEARNING OBJECTIVE

3.13.A

Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.

ESSENTIAL KNOWLEDGE

3.13.A.1

The Beer-Lambert law relates the absorption of light by a solution to three variables according to the equation:

$$\text{EQN: } A = \epsilon bc.$$

The molar absorptivity, ϵ , describes how intensely a chemical species absorbs light of a specific wavelength. The path length, b , and concentration, c , are proportional to the number of light-absorbing particles in the light path.

3.13.A.2

In most experiments the path length and wavelength of light are held constant. In such cases, the absorbance is proportional only to the concentration of absorbing molecules or ions. The spectrophotometer is typically set to the wavelength of maximum absorbance (optimum wavelength) for the species being analyzed to ensure the maximum sensitivity of measurement.

AP CHEMISTRY

UNIT 4

Chemical Reactions



7–9%

AP EXAM WEIGHTING



~14–15

CLASS PERIODS

Chemical Reactions



Developing Understanding

ESSENTIAL QUESTIONS

- What makes fireworks explode?
- In what ways can a chemical change be described and documented?
- How can you predict that a chemical reaction will generate enough product?

This unit explores chemical transformations of matter by building on the physical transformations studied in Unit 3. Chemical changes involve the making and breaking of chemical bonds. Many properties of a chemical system can be understood using the concepts of varying strengths of chemical bonds and weaker intermolecular interactions. When chemical changes occur, the new substances formed have properties that are distinguishable from the initial substance or substances. Chemical reactions are the primary means by which transformations in matter occur. Chemical equations are a representation of the rearrangement of atoms that occur during a chemical reaction. In subsequent units, students will explore rates at which chemical changes occur.

Building the Science Practices

1.B 2.B 5.C 5.E 6.B

In Unit 3, students constructed particulate-level representations of compounds and molecules and explained the forces that come into play when particles interact. In Unit 4, students will describe and construct equations of chemical systems and learn to balance those equations. Students should be able to identify and effectively represent types of reactions (e.g., acid-base, redox, precipitation) and then use that knowledge to make hypotheses or predictions about the outcome of a reaction. Additionally, students should be able to support their claims about the identity and amount of product yield through evidence gained with both experimentation and the principles of stoichiometry. Further, students should be able to determine the output of a reaction when the number of moles of reactants change or are in limited/excess supply. This practice of effectively representing balanced chemical equations and using stoichiometry to calculate outcomes of such reactions is critical to student success in the remainder of the course.

Preparing for the AP Exam

On the AP Exam, students must be able to demonstrate proficiency in writing and balancing chemical equations (molecular, complete, net ionic) and calculating quantities in multiple contexts using more than just 1:1 stoichiometric ratios. Students often struggle with questions that require them to justify their identification of a particular type of reaction using an equation. They also encounter difficulty with determining the limiting reactant using stoichiometry. For example, with stoichiometric calculations, students often make the mistake of comparing mass to mass instead of mole to mole when determining the limiting reactant. Teacher can ensure that students practice writing balanced equations (for net ionic and molecular) and that they develop a strong understanding of the mole concept and gain proficiency with dimensional analysis. This will help them correctly calculate required quantities using stoichiometric ratios.

UNIT AT A GLANCE

Topic	Suggested Skill
4.1 Introduction for Reactions	2.B Formulate a hypothesis or predict the results of an experiment.
4.2 Net Ionic Equations	5.E Determine a balanced chemical equation for a given chemical phenomena.
4.3 Representations of Reactions	3.B Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).
4.4 Physical and Chemical Changes	6.B Support a claim with evidence from experimental data.
4.5 Stoichiometry	5.C Explain the relationship between variables within an equation when one variable changes.
4.6 Introduction to Titration	3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.
4.7 Types of Chemical Reactions	1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.
4.8 Introduction to Acid-Base Reactions	1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.
4.9 Oxidation-Reduction (Redox) Reactions	5.E Determine a balanced chemical equation for a given chemical phenomena.
 Go to AP Classroom to assign the Progress Check for Unit 4. Review the results in class to identify and address any student misunderstandings.	

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches into the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 187 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	4.2 4.3	Explore Representations Have students work through an online simulation of particulate-level representations of various single-displacement reactions. Then have them translate these particle-level views into net ionic equations.
2	4.5	Simulations Have students view a simulated reaction pertaining to a limiting reagent problem. Each iteration of the simulation provides students with different unknown concentrations of the reactants from which students calculate the amount of product that is dissolved. Then have them check their answers upon completion of the simulation.
3	4.6	Think-Pair-Share Ask students to connect four different particulate representations with a strong acid-strong base titration curve between $\text{HCl} + \text{NaOH}$. The representations depict the acid before base has been added, the half equivalence point of the titration, the equivalence point of the titration, and some point beyond the equivalence point (excess base). Have students defend their choices with a partner.
4	4.7	Critique Reasoning After a review of different types of chemical reactions (acid-base, redox, precipitation), give students a series of 10 reactions (both the equation and a short demo of the reaction taking place). Have them identify what type of reaction is taking place and justify that claim with evidence. Then have them pair up and evaluate the strength of each other's claims.
5	4.9	Simulations After viewing a simulation on metal/metal ion reactions, provide students with several 1 molar solutions and a piece of aluminum and ask them to select a solution that would react to coat the Al. Students who select incorrect solutions should go back and revisit the simulation.

SUGGESTED SKILL

 Question and Method

2.B

Formulate a hypothesis or predict the results of an experiment.



AVAILABLE RESOURCES

- Classroom Resource >
[Guided Inquiry Activities for the Classroom: Lesson 1](#)

TOPIC 4.1

Introduction for Reactions

Required Course Content

LEARNING OBJECTIVE**4.1.A**

Identify evidence of chemical and physical changes in matter.

ESSENTIAL KNOWLEDGE**4.1.A.1**

A physical change occurs when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/separation of mixtures of substances are common physical changes.

4.1.A.2

A chemical change occurs when substances are transformed into new substances, typically with different compositions. Production of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.

TOPIC 4.2

Net Ionic Equations

Required Course Content

LEARNING OBJECTIVE

4.2.A

Represent changes in matter with a balanced chemical or net ionic equation:

- For physical changes.
- For given information about the identity of the reactants and/or product.
- For ions in a given chemical reaction.

ESSENTIAL KNOWLEDGE

4.2.A.1

All physical and chemical processes can be represented symbolically by balanced equations.

4.2.A.2

Chemical equations represent chemical changes. These changes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass and charge are conserved in chemical reactions.

4.2.A.3

Balanced molecular, complete ionic, and net ionic equations are differing symbolic forms used to represent a chemical reaction. The form used to represent the reaction depends on the context in which it is to be used.

SUGGESTED SKILL

 *Mathematical Routines*

5.E

Determine a balanced chemical equation for a given chemical phenomena.

**AVAILABLE RESOURCES**

- AP Chemistry Lab Manual > [Investigation 8: How Can We Determine the Actual Percentage of H₂O₂ in a Drugstore Bottle of Hydrogen Peroxide?](#)
- The Exam > [2023 Chief Reader Report](#)

SUGGESTED SKILL

 *Representing Data and Phenomena*

3.B

Represent chemical substances or phenomena with appropriate diagrams or models (e.g., electron configuration).



AVAILABLE RESOURCES

- Classroom Resource > [Guided Inquiry Activities for the Classroom: Lesson 1](#)
- The Exam > [2022 Chief Reader Report](#)

TOPIC 4.3

Representations of Reactions

Required Course Content

LEARNING OBJECTIVE

4.3.A

Represent a given chemical reaction or physical process with a consistent particulate model.

ESSENTIAL KNOWLEDGE

4.3.A.1

Balanced chemical equations in their various forms can be translated into symbolic particulate representations.

TOPIC 4.4

Physical and Chemical Changes

Required Course Content

LEARNING OBJECTIVE

4.4.A

Explain the relationship between macroscopic characteristics and bond interactions for:

- Chemical processes.
- Physical processes.

ESSENTIAL KNOWLEDGE

4.4.A.1

Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.

4.4.A.2

Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.

SUGGESTED SKILL*Argumentation***6.B**

Support a claim with evidence from experimental data.

**AVAILABLE RESOURCES**

- AP Chemistry Lab Manual > [Investigation 9: Can the Individual Components of Quick Ache Relief Be Used to Resolve Consumer Complaint?](#)

SUGGESTED SKILL

 *Mathematical Routines*

5.C

Explain the relationship between variables within an equation when one variable changes.



AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 7: Using the Principle That Each Substance Has Unique Properties to Purify a Mixture: An Experiment in Applying Green Chemistry to Purification](#)

TOPIC 4.5

Stoichiometry

Required Course Content

LEARNING OBJECTIVE

4.5.A

Explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.

ESSENTIAL KNOWLEDGE

4.5.A.1

Because atoms must be conserved during a chemical process, it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known product amounts.

4.5.A.2

Coefficients of balanced chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations involving the mole concept.

4.5.A.3

Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gases and solutions.

TOPIC 4.6

Introduction to Titration

SUGGESTED SKILL

*Representing Data
and Phenomena*

3.A

Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.



Required Course Content

LEARNING OBJECTIVE

4.6.A

Identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.

ESSENTIAL KNOWLEDGE

4.6.A.1

Titration may be used to determine the amount 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 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.

AVAILABLE RESOURCES

- AP Chemistry Lab Manual > [Investigation 4: How Much Acid Is in Fruit Juice and Soft Drinks?](#)
- The Exam > [2018 Chief Reader Report](#)

SUGGESTED SKILL

 Models and Representations

1.B

Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.

TOPIC 4.7

Types of Chemical Reactions

Required Course Content

LEARNING OBJECTIVE

4.7.A

Identify a reaction as acid-base, oxidation-reduction, or precipitation.

ESSENTIAL KNOWLEDGE

4.7.A.1

Acid-base reactions involve transfer of one or more protons (H^+ ions) between chemical species.

4.7.A.2

Oxidation-reduction (redox) 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.

4.7.A.3

In a redox reaction, electrons are transferred from the species that is oxidized to the species that is reduced.

Exclusion Statement: The meaning of the terms “reducing agent” and “oxidizing agent” will not be assessed on the AP Exam.

4.7.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.

continued on next page

LEARNING OBJECTIVE

4.7.A

Identify a reaction as acid-base, oxidation-reduction, or precipitation.

ESSENTIAL KNOWLEDGE

4.7.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.

Exclusion Statement: Rote memorization of “solubility rules” other than those implied in 4.7.A.5 will not be assessed on the AP Exam.

SUGGESTED SKILL

 Models and Representations

1.B

Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.



AVAILABLE RESOURCES

- Classroom Resource > [Guided Inquiry Activities for the Classroom: Lesson 2](#)

TOPIC 4.8

Introduction to Acid-Base Reactions

Required Course Content

LEARNING OBJECTIVE

4.8.A

Identify species as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species.

ESSENTIAL KNOWLEDGE

4.8.A.1

By definition, a Brønsted-Lowry acid is a proton donor and a Brønsted-Lowry base is a proton acceptor.

4.8.A.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.

4.8.A.3

When an acid or base ionizes in water, the conjugate acid-base pairs can be identified and their relative strengths compared.

Exclusion Statement: *Lewis acid-base concepts will not be assessed on the AP Exam. The emphasis in AP Chemistry is on reactions in aqueous solution.*

TOPIC 4.9

Oxidation-Reduction (Redox) Reactions

SUGGESTED SKILL

 *Mathematical
Routines*

5.E

Determine a balanced chemical equation for a given chemical phenomena.

Required Course Content

LEARNING OBJECTIVE

4.9.A

Represent a balanced redox reaction equation using half-reactions.

ESSENTIAL KNOWLEDGE

4.9.A.1

Balanced chemical equations for redox reactions can be constructed from half-reactions.

