AP CHEMISTRY

UNIT 1

Atomic Structure and Properties

7–9%
AP EXAM WEIGHTING

~9–10
CLASS PERIODS

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Atomic Structure and Properties

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?

Developing Understanding

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 period 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.

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**

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.

EQN: $n = m/M$

TOPIC 1.2
Mass Spectra of Elements

Required Course Content

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
1.2.A Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.	**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	ESSENTIAL KNOWLEDGE
1.4.A Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.	**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.

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

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.*

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
1.5.A Represent the ground-state electron configuration of an atom of an element or its ions using the Aufbau principle.	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	ESSENTIAL KNOWLEDGE
1.6.A Explain the relationship between the photoelectron spectrum of an atom or ion and: i. The ground-state electron configuration of the species. ii. The interactions between the electrons and the nucleus.	**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.

AVAILABLE RESOURCES

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

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:

i. Ionization energy
ii. Atomic and ionic radii
iii. Electron affinity
iv. 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.

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.