AP CHEMISTRY

# UNIT 1

# Atomic Structure and Properties

**7–9%**
AP EXAM WEIGHTING

**~9–10**
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and skills.

## Personal Progress Check 1

**Multiple-choice: ~20 questions**
**Free-response: 2 questions**

- Short-answer
- Short-answer

UNIT 1

**7–9%** AP EXAM WEIGHTING | **~9–10** CLASS PERIODS

# Atomic Structure and Properties

**BIG IDEA 1**
***Scale, Proportion, and Quantity*** SPQ
- Why are eggs sold as a dozen?

**BIG IDEA 2**
***Structure and Properties*** SAP
- How can the same element be used in nuclear fuel rods and fake diamonds?

## 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 that they require moles as a unit of comparison. The periodic table provides information about each element's predictable periodicity as a function of the 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 and 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.

# UNIT AT A GLANCE

| Enduring Understanding | Topic | Suggested Skill | Class Periods ~9–10 CLASS PERIODS |
|---|---|---|---|
| SPQ-1 | **1.1 Moles and Molar Mass** | 5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem. | |
| | **1.2 Mass Spectroscopy of Elements** | 5.D Identify information presented graphically to solve a problem. | |
| SPQ-2 | **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). | |
| SAP-1 | **1.5 Atomic Structure 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. | |
| SAP-2 | **1.7 Periodic Trends** | 4.A 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 **Personal 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. 197 for more examples of activities and strategies.

| Activity | Topic | Sample Activity |
|---|---|---|
| 1 | 1.1 | **Think-Pair-Share**<br>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: $3.0 \times 10^{23}$ molecules of water). Then have them compare and defend their choices with a partner. |
| 2 | 1.2 | **Simulations**<br>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**<br>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<br>1.5 | **Explore Representations**<br>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)**<br>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**

- Classroom Resource > **Quantitative Skills in the AP Sciences**
- 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

### ENDURING UNDERSTANDING

**SPQ-1**

The mole allows different units to be compared.

### LEARNING OBJECTIVE

**SPQ-1.A**

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

### ESSENTIAL KNOWLEDGE

**SPQ-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.

**SPQ-1.A.2**

Avogadro's number ($N_A = 6.022 \times 10^{23}$ 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.

**SPQ-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 Spectroscopy of Elements

## Required Course Content

### ENDURING UNDERSTANDING

SPQ-1

The mole allows different units to be compared.

### LEARNING OBJECTIVE

SPQ-1.B

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

### ESSENTIAL KNOWLEDGE

SPQ-1.B.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.

SPQ-1.B.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.

**INTERPRETING MASS SPECTRA**

*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?**

## TOPIC 1.3

# Elemental Composition of Pure Substances

## Required Course Content

### ENDURING UNDERSTANDING

**SPQ-2**

Chemical formulas identify substances by their unique combination of atoms.

### LEARNING OBJECTIVE

**SPQ-2.A**

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

### ESSENTIAL KNOWLEDGE

**SPQ-2.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.

**SPQ-2.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.

**SPQ-2.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

## Required Course Content

### ENDURING UNDERSTANDING

**SPQ-2**

Chemical formulas identify substances by their unique combination of atoms.

### LEARNING OBJECTIVE

**SPQ-2.B**

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

### ESSENTIAL KNOWLEDGE

**SPQ-2.B.1**

While pure substances contain molecules or formula units of a single type, mixtures contain molecules or formula units of two or more types, whose relative proportions can vary.

**SPQ-2.B.2**

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

**SUGGESTED SKILL**

*Mathematical Routines*

**5.A**

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

**AVAILABLE RESOURCES**

- Classroom Resource > **Quantitative Skills in the AP Sciences**

**SUGGESTED SKILL**

*Models and Representations*

**1.A**

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

**AVAILABLE RESOURCES**

- Classroom Resource > **Alternative Approaches to Teaching Traditional Topics**

# TOPIC 1.5
# Atomic Structure and Electron Configuration

## Required Course Content

### ENDURING UNDERSTANDING

**SAP-1**

Atoms and molecules can be identified by their electron distribution and energy.

### LEARNING OBJECTIVE

**SAP-1.A**

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

### ESSENTIAL KNOWLEDGE

**SAP-1.A.1**

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

**SAP-1.A.2**

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

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

**SAP-1.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 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.

**X THE ASSIGNMENT OF QUANTUM NUMBERS TO ELECTRONS IN SUBSHELLS OF AN ATOM WILL NOT BE ASSESSED ON THE AP EXAM.**

***Rationale:*** *Assignment of quantum numbers to electrons in specific subshells does not increase students' understanding of the structure of the atom.*

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## LEARNING OBJECTIVE

SAP-1.A

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

## ESSENTIAL KNOWLEDGE

**SAP-1.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**

# TOPIC 1.6
# Photoelectron Spectroscopy

## Required Course Content

### ENDURING UNDERSTANDING

**SAP-1**

Atoms and molecules can be identified by their electron distribution and energy.

### LEARNING OBJECTIVE

**SAP-1.B**

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

a. The electron configuration of the species.

b. The interactions between the electrons and the nucleus.

### ESSENTIAL KNOWLEDGE

**SAP-1.B.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 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**

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

**AVAILABLE RESOURCES**

- Classroom Resource > **Alternative Approaches to Teaching Traditional Topics**

## Required Course Content

### ENDURING UNDERSTANDING

**SAP-2**

The periodic table shows patterns in electronic structure and trends in atomic properties.

### LEARNING OBJECTIVE

**SAP-2.A**

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

### ESSENTIAL KNOWLEDGE

**SAP-2.A.1**

The organization of the periodic table is based on the recurring properties of the elements and explained by the pattern of electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms.

**X WRITING THE ELECTRON CONFIGURATION OF ELEMENTS THAT ARE EXCEPTIONS TO THE AUFBAU PRINCIPLE WILL NOT BE ASSESSED ON THE AP EXAM.**

***Rationale:*** *The mere rote recall of the exceptions does not match the goals of the curriculum revision.*

**SAP-2.A.2**

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

a. Ionization energy
b. Atomic and ionic radii
c. Electron affinity
d. Electronegativity.

**SAP-2.A.3**

The periodicity (in SAP-2.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

### ENDURING UNDERSTANDING

**SAP-2**

The periodic table shows patterns in electronic structure and trends in atomic properties.

### LEARNING OBJECTIVE

**SAP-2.B**

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

### ESSENTIAL KNOWLEDGE

**SAP-2.B.1**

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

**SAP-2.B.2**

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

**SAP-2.B.3**

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