

AP CHEMISTRY

UNIT 2

**Molecular
and Ionic
Compound
Structure and
Properties**



7–9%

AP EXAM WEIGHTING



~12–13

CLASS PERIODS

The icon consists of a light blue circle containing a white square with the letters 'AP' in blue. Below the square is a small black horizontal bar with two short vertical lines extending downwards, resembling a computer monitor or a stylized 'I'.

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 2

Multiple-choice: ~15 questions

Free-response: 1 question

- Long-answer

Molecular and Ionic Compound Structure and Properties



Developing Understanding

BIG IDEA 2 Structure and Properties **SAP**

- How has the discovery of DNA changed the world?
- How are molecular compounds arranged?

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 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

Enduring Understanding	Topic	Suggested Skill	Class Periods
			~12–13 CLASS PERIODS
SAP-3	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.	
SAP-4	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 Bond 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 Personal 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. 197 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

ENDURING UNDERSTANDING

SAP-3

Atoms or ions bond due to interactions between them, forming molecules.

LEARNING OBJECTIVE

SAP-3.A

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

ESSENTIAL KNOWLEDGE

SAP-3.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.

SAP-3.A.2

Valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond. For example, bonds between carbon and hydrogen are effectively nonpolar even though carbon is slightly more electronegative than hydrogen.

SAP-3.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.

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LEARNING OBJECTIVE

SAP-3.A

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

ESSENTIAL KNOWLEDGE

SAP-3.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.

SAP-3.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 Resources > [Ending Misconceptions About the Energy of Chemical Bonds](#)

TOPIC 2.2

Intramolecular Force and Potential Energy

Required Course Content

ENDURING UNDERSTANDING

SAP-3

Atoms or ions bond due to interactions between them, forming molecules.

LEARNING OBJECTIVE

SAP-3.B

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

ESSENTIAL KNOWLEDGE

SAP-3.B.1

A graph of potential energy versus the distance between atoms 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).

SAP-3.B.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.

SAP-3.B.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

ENDURING UNDERSTANDING

SAP-3

Atoms or ions bond due to interactions between them, forming molecules.

LEARNING OBJECTIVE

SAP-3.C

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

ESSENTIAL KNOWLEDGE

SAP-3.C.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.

✖ KNOWLEDGE OF SPECIFIC TYPES OF CRYSTAL STRUCTURES WILL NOT BE ASSESSED ON THE AP EXAM.

Rationale: Study of specific crystal structures is not essential to an understanding of the big ideas.

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

ENDURING UNDERSTANDING

SAP-3

Atoms or ions bond due to interactions between them, forming molecules.

LEARNING OBJECTIVE

SAP-3.D

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

SAP-3.D.1

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

SAP-3.D.2

Interstitial alloys form between atoms of 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).

SAP-3.D.3

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

TOPIC 2.5

Lewis Diagrams

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](#)

Required Course Content

ENDURING UNDERSTANDING

SAP-4

Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory.

LEARNING OBJECTIVE

SAP-4.A

Represent a molecule with a Lewis diagram.

ESSENTIAL KNOWLEDGE

SAP-4.A.1

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

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

ENDURING UNDERSTANDING

SAP-4

Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory.

LEARNING OBJECTIVE

SAP-4.B

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

SAP-4.B.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.

SAP-4.B.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.

SAP-4.B.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 Bond 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

ENDURING UNDERSTANDING

SAP-4

Molecular compounds are arranged based on Lewis diagrams and Valence Shell Electron Pair Repulsion (VSEPR) theory.

LEARNING OBJECTIVE

SAP-4.C

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

SAP-4.C.1

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

SAP-4.C.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
- 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 of the molecule

SAP-4.C.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° .

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LEARNING OBJECTIVE

SAP-4.C

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

AN UNDERSTANDING OF THE DERIVATION AND DEPICTION OF HYBRID ORBITALS WILL NOT BE ASSESSED ON THE AP EXAM.

Rationale: 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. Additional aspects related to hybridization are both controversial and do not substantially enhance understanding of molecular structure.

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.

Rationale: Current evidence suggests that main-group hybridization involving d orbitals does not exist, and there is controversy about the need to teach any hybridization. Until agreement is reached in the chemistry community, we will continue to include only sp , sp^2 , and sp^3 hybridization on the AP Exam.

SAP-4.C.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 structural isomers.

MOLECULAR ORBITAL THEORY IS RECOMMENDED AS A WAY TO PROVIDE DEEPER INSIGHT INTO BONDING. HOWEVER, THE AP EXAM WILL NEITHER EXPLICITLY ASSESS MOLECULAR ORBITAL DIAGRAM, FILLING OF MOLECULAR ORBITALS, NOR THE DISTINCTION BETWEEN BONDING, NONBONDING, AND ANTBONDING ORBITALS.

Rationale: As currently covered in general chemistry college textbooks, molecular orbital theory is limited to homonuclear molecules in the second period.