


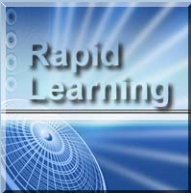
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 **Chemical Bonding Theories**

AP Chemistry Rapid Learning Series

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2/51



Learning Objectives

By completing this tutorial you will learn...



- 4 types of bonding and the properties associated with those bond types
- Valence Bond Theory
- Hybridization of orbitals
- Sigma and Pi bonds

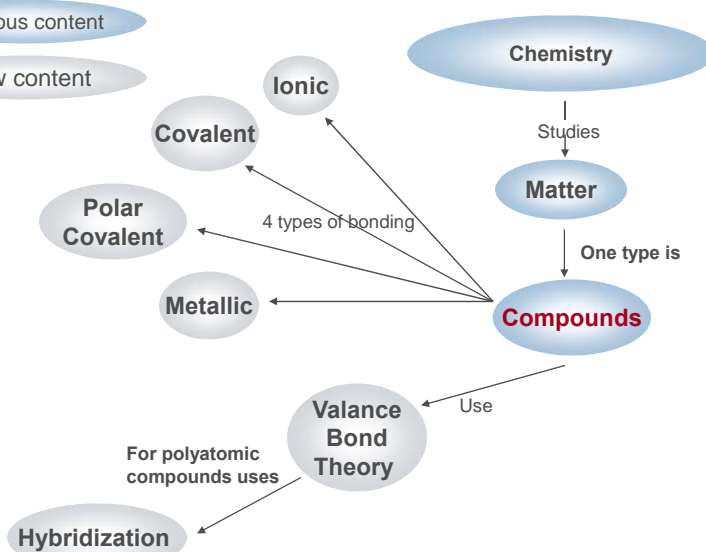
3/51



Concept Map


Previous content

New content





4/51






Types of Chemical Bonds

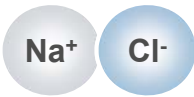




5/51 



Definition: Ionic Bond

Ionic Bond – Formed from the electrostatic attraction between positive and negatively charged ions due to transfer of electrons - contains both metals and non-metals.

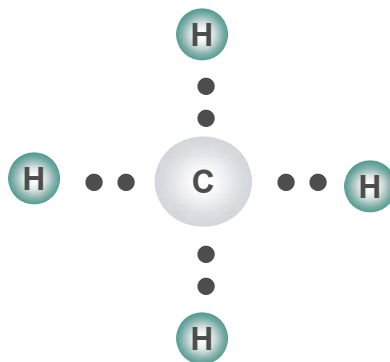


6/51 



Definition: Covalent Bond

Covalent bond – Two non-metals share electrons.



7/51



Definition: Polar Covalent Bond

Polar Covalent Bond – Two non-metals share electrons unevenly - electrons are closer to one atom than the other.



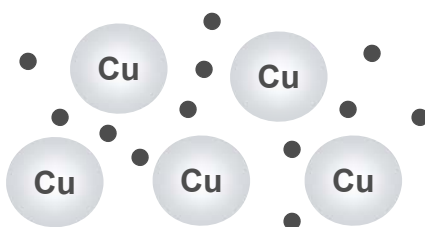
8/51





Definition: Metallic Bond

Metallic Bond – Metal atoms join together and pool their electrons in a large network.



9/51




4 Types of Bonds

The different bond types have different properties.

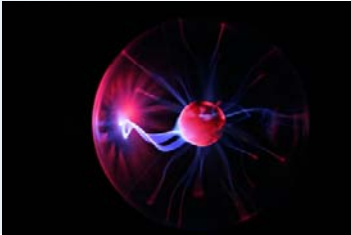
	Happens between	Electrons are	Characteristics
Ionic	Metals & Non-metals	Transferred from one atom to another to create ions	High melting points, brittle, often dissolve in water, conduct electricity when aqueous
Covalent	Non-metals	Shared between 2 atoms	Low melting points, do not often dissolve in water, do not conduct when aqueous
Polar Covalent	Non-Metals	Shared unevenly between 2 atoms	Medium melting points, sometimes dissolve in water, do not conduct electricity when aqueous
Metallic	Metals	Shared in a large pool with all the atoms	Soft, Conductors of heat and electricity, do not dissolve in water


10/51





Ionic Electrostatic Attractions



11/51 



Definition - Lattice Energy

Lattice Energy – Energy needed to turn 1 mole of a solid ionic compound into gaseous ions.



12/51 



Lattice Energy

The strength of the lattice depends on the size of the charges and the ions.

$$E = k \frac{Q_1 Q_2}{d}$$

Where **E** = energy

k = a constant ($8.99 \times 10^9 \text{ J m/C}^2$)

Q₁ & **Q₂** = the charges on the particles

d = distance between the centers of the particles

As charge increases, the strength of their attraction increases.

As radii (and distance from center to center) increases, the strength of their attraction decreases!

13/51



Covalent Bonds: Bond Polarity



14/51





Common Element Electronegativities

Here are 8 common elements & their electronegativities.

Element	Electronegativity
H	2.1
C	2.5
N	3.0
O	3.5
F	4.0
S	2.5
Cl	3.0
Br	2.8

17/51



Determining a Polar Bond

1 Look up the electronegativities for the two atoms.

2 Determine the (absolute value) difference in electronegativity.

Differences of:

0 → 0.4 = Non-polar covalent bond

0.5 → 1.4 = polar covalent bond

> 1.4 = ionic bond

3 If there is a polar bond, indicate it with an arrow being drawn toward the more electronegative element with a cross on the tail.

Example: Determine if each is a polar bond.

C - H C = 2.5
 H = 2.1
 Difference = 0.4
 Non-polar

C - N C = 2.5
 N = 3.0
 Difference = 0.5
 Polar

↔

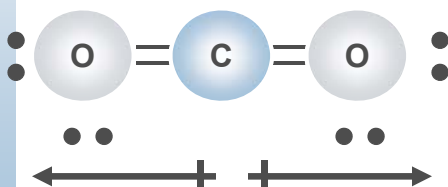
18/51



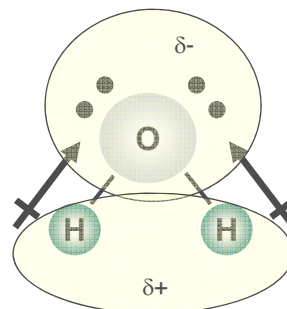


Definition: Polar Molecules

Polar Molecule – Polar bonds do not cancel out and the molecule overall has partially positive and partially negative areas.



Polar bonds, but non-polar molecule



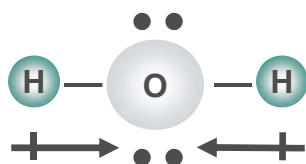
Polar bonds, polar molecule

19/51

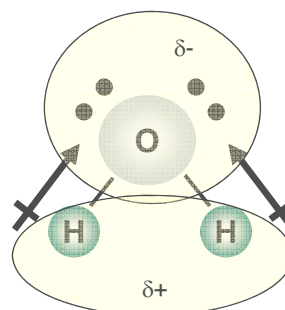


Polar Molecules and Bond Geometry

The manner in which we draw a molecule could affect our determination of polarity.



Drawing water in this way makes it appear to be a non-polar molecule.




However, water actually is shaped like this, and it is a polar molecule.


It is important to know the actual 3D arrangement to determine polarity of a molecule. This will be covered in the next tutorial.


20/51

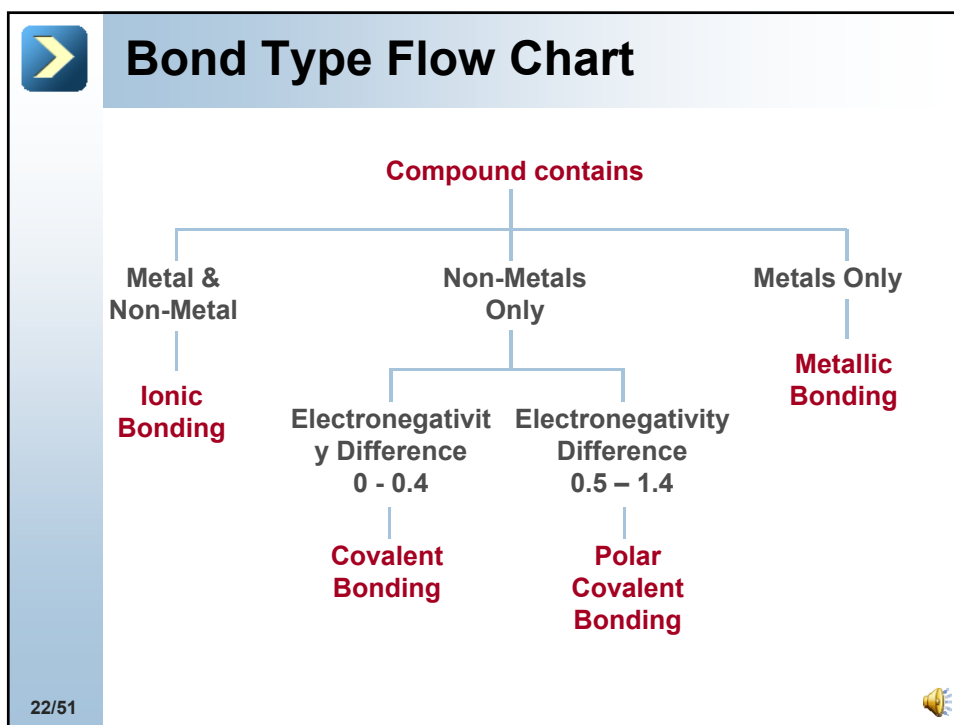




Determining Bond Types



21/51 



Determining Bond Type Example

Example: Determine the bond type of each:

K – O Metal & non-metal
Ionic Bonding

C – O Non-metals
 $\begin{array}{c} \text{+} \\ \text{---} \\ \text{+} \end{array} \rightarrow$
 C = 2.5
 O = 3.5
 Difference = 1.0
Polar Covalent

C – S Non-metals
 C = 2.5
 S = 2.5
 Difference = 0
Covalent

23/51



Covalent Bonds: Isomers and Resonance



24/51





Definition: Isomers

Isomers – Two molecules with the same chemical formula and a different bond structure.

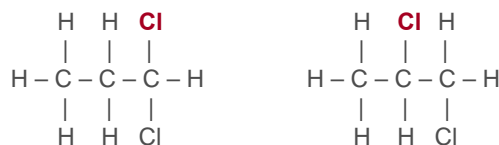


25/51

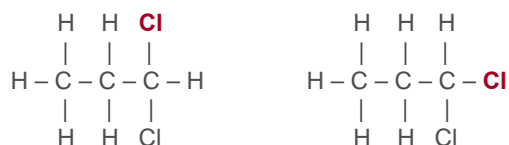


Examples of Isomers

Isomers have the same formula, with different structures.



The following aren't isomers...



The chlorine is still bonded to the same carbon in each structure. They are IDENTICAL molecules.

26/51





Definition: Resonance

Resonance – Average of two or more Lewis Structures which differ only in the position of the electrons between atoms.

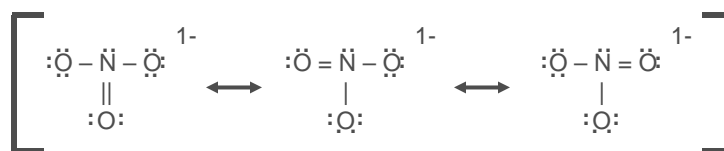


27/51



Examples of Resonance

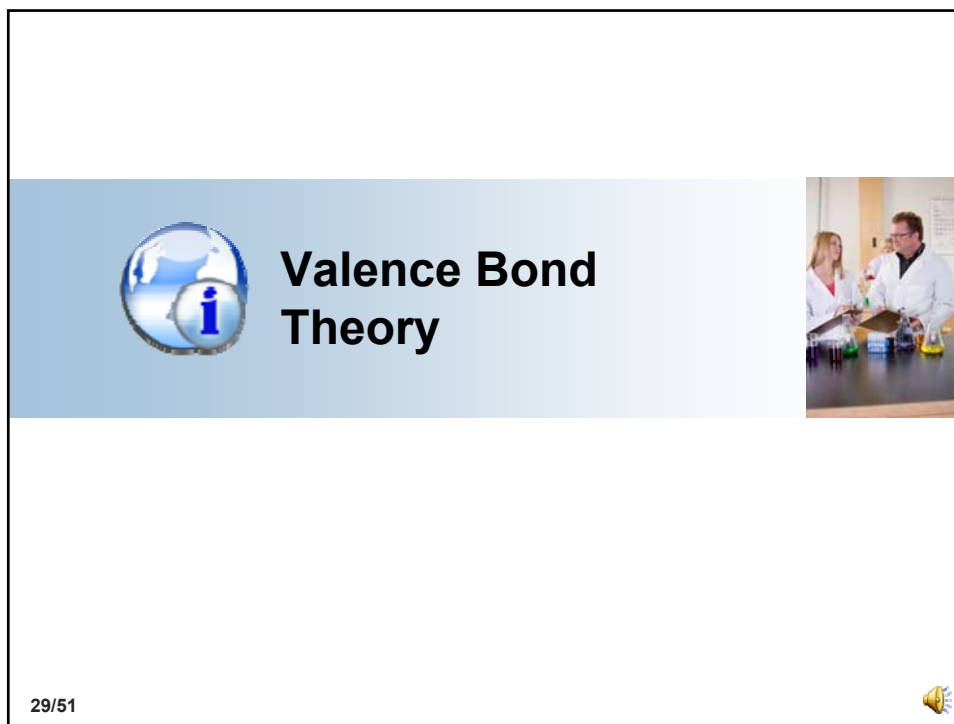
Here are two resonance structures.





The actual compound is a mix of the three—it doesn't flip back and forth between them, it's all at the same time.


28/51

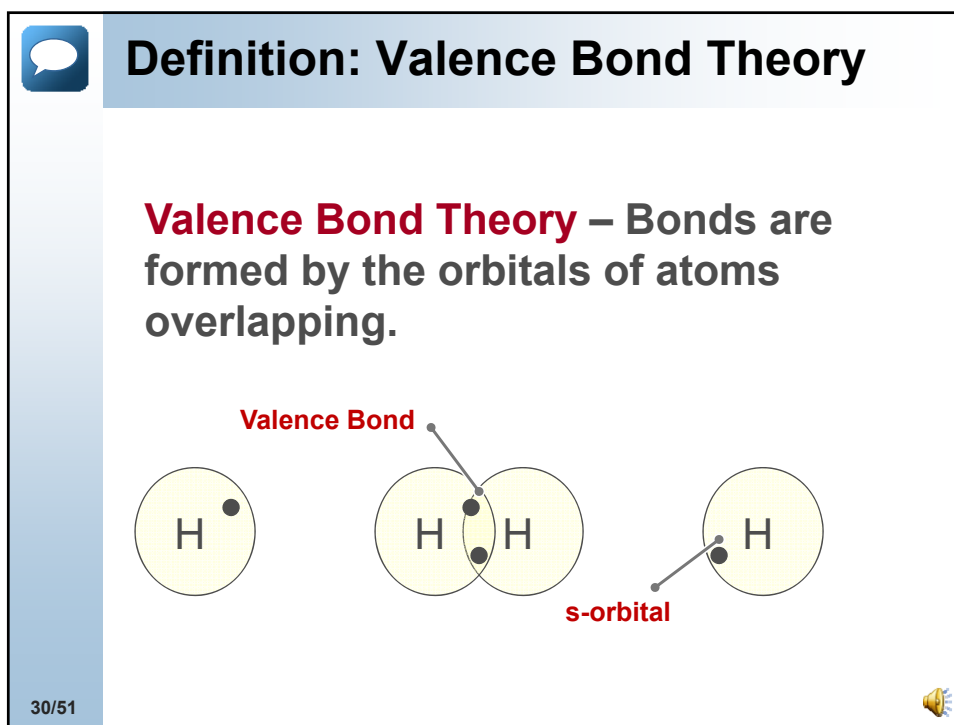





 **Valence Bond Theory**

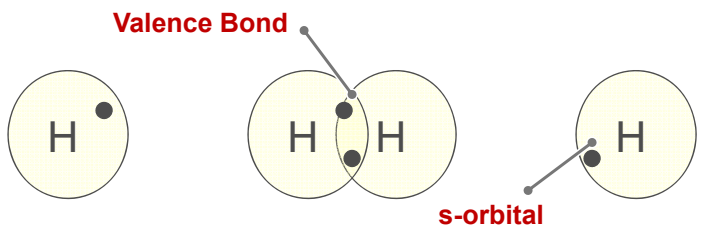


29/51 





 **Definition: Valence Bond Theory**


Valence Bond Theory – Bonds are formed by the orbitals of atoms overlapping.





The diagram illustrates the formation of a valence bond through the overlap of s-orbitals. It shows three hydrogen atoms, each represented by a yellow circle with a black dot (nucleus) and labeled 'H'. The first atom is on the left. The second and third atoms are in the center, with their orbitals overlapping. A red arrow points from the text 'Valence Bond' to the overlapping region. A red arrow points from the text 's-orbital' to one of the overlapping orbitals.

30/51 




 **Sigma and Pi Bonds**


31/51 

 **Definition: Sigma Bond - 1**

Sigma Bond (σ bond) – A bond in which one pair of electrons is shared. Formed from the overlap of 2 s-orbitals.



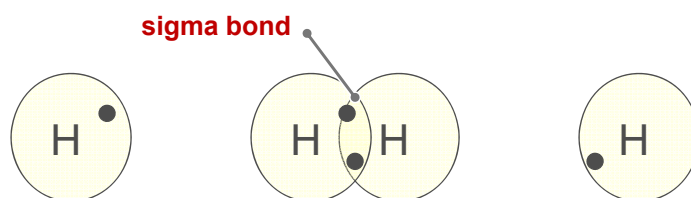
2 hydrogen atoms—each have 1 electron in an s-orbital

32/51 



Definition: Sigma Bond - 2

Sigma Bond (σ bond) – A bond in which one pair of electrons is shared. Formed from the overlap of 2 s-orbitals.



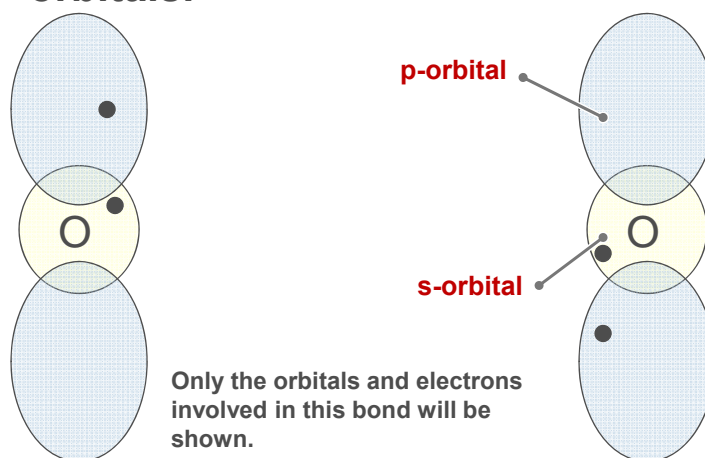
2 hydrogen atoms - each have 1 electron in an s-orbital.
As the atoms move together, their s-orbitals overlap and form a sigma bond.

33/51



Definition: Pi Bond - 1

π Bond – 2nd or 3rd bond between two atoms. Formed from parallel p-orbitals.



Only the orbitals and electrons involved in this bond will be shown.

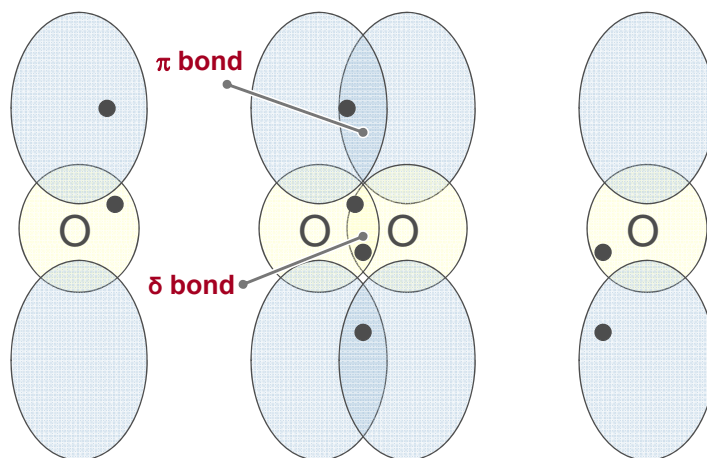
34/51





Definition: Pi Bond - 2

π Bond – 2nd or 3rd bond between two atoms. Formed from parallel p-orbitals.



35/51

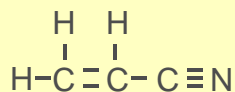


Determining Types of Bonds

How many sigma and pi bonds are in a molecule?

- σ Each first bond between 2 atoms is a sigma bond.
- π All 2nd and 3rd bonds between 2 atoms are pi bonds.

Example: Count the sigma and pi bonds in the following molecule:



σ 4

π 2

36/51





Diatomic and Polyatomic Compounds

The Valence Bond Theory works well for diatomic compounds (H_2 , O_2 , etc.).

But what about polyatomic compounds, such as CH_4 ?

The next section will show why this theory is not adequate for more complex compounds and an introduce an alternative theory.

37/51



Hybridization



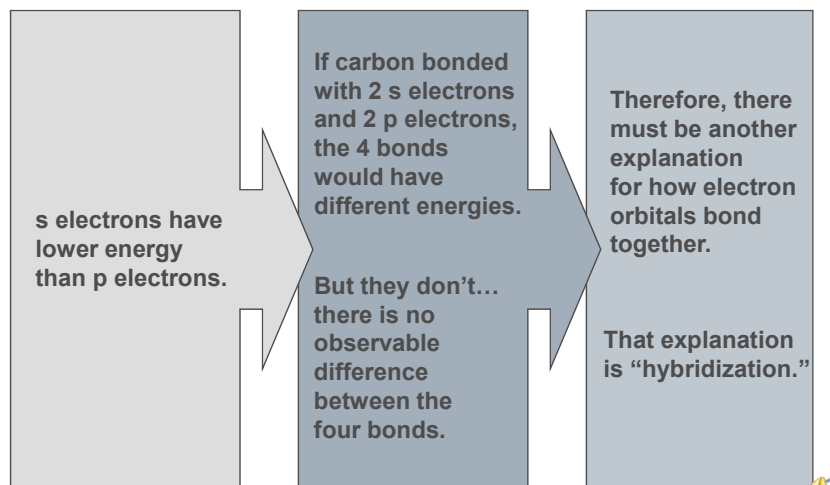
38/51





Why do We Need Another Theory?

A carbon atom has 2 electrons in an s-orbital, and 2 electrons in 2 p-orbitals ($C = 1s^2 2s^2 2p^2$).



39/51



Definition: Hybrid Orbitals

Hybrid Orbitals – All of the orbitals in an atom involved in sigma bonds hybridize into equal energy orbitals to form the bonds. Formed from mixing of orbitals.



Pi bonds are still between p-orbitals, not hybrid orbitals.

The sigma bond (first bond) between two atoms is formed with hybrid orbitals.

The second or third bond (pi bond) is formed from p orbitals.

40/51




sp Hybridization

How do 1 s and 1 p orbital hybridize?

The diagram illustrates the process of sp hybridization. It starts with an s orbital (a single orange sphere) and one p orbital (a blue dumbbell shape). An arrow labeled "hybridize" points to two hybrid orbitals (pink dumbbell shapes). A downward arrow labeled "Put together" points to two sp hybrid orbitals (pink dumbbell shapes). A leftward arrow labeled "plus" points to two unhybridized p orbitals (blue dumbbell shapes).

s orbital p orbital 2 hybrid orbitals formed

2 p orbitals that didn't hybridize 2 sp hybrid orbitals

41/51 


sp² Hybridization

How do 1 s and 2 p orbitals hybridize?

The diagram illustrates the process of sp² hybridization. It starts with an s orbital (a single orange sphere) and two p orbitals (blue dumbbell shapes). An arrow labeled "hybridize" points to three hybrid orbitals (pink dumbbell shapes). A downward arrow labeled "Put together" points to three sp² hybrid orbitals (pink dumbbell shapes). A leftward arrow labeled "plus" points to one unhybridized p orbital (blue dumbbell shape).

s orbital 2 p orbitals 3 hybrid orbitals formed

1 p orbital that didn't hybridize 3 sp² hybrid orbitals

42/51 

sp³ Hybridization


How do 1 s and 3 p orbitals hybridize?

s orbital 3 p orbitals

hybridize

4 sp³ hybrid orbitals 4 hybrid orbitals formed

Put together


43/51 


Which Hybrids Form & When?


How do you know which hybrid will form?


hybrid	# of sigma bonds	Which orbitals are involved?
sp	2	1 s and 1 p
sp ²	3	1 s and 2 p's
sp ³	4	1 s and 3 p's


Elements that contain d orbitals can have hybrids including d's (e.g. sp³d, sp³d², etc.).

44/51 



 **Bonding Theory & The AP Exam**


45/51 

 **Bonding Theory in the Exam**

Common bonding theory problems:

- Hybridization of an atom in a molecule.
- List molecules in order of bond angle, length or strength.
- Draw isomers or resonance structures.
- Explain properties based on bonding theory.

Bonding Theory is often combined with Lewis Structures and VSEPR theory.

46/51 



Multiple Choice Questions

Multiple choice bonding questions often give a list of compounds and ask several questions about that list.

Example: Given the following compounds:

- a. CO_2 **$\text{O}=\text{C}=\text{O}$ has 2 double bonds**
- b. H_2O **$\text{H}-\text{O}-\text{H}$ with the O having two lone pairs**
- c. HNO **$\text{H}-\text{N}=\text{O}$ with the N having one lone pair**
- d. HCN **$\text{H}-\text{C}\equiv\text{N}$ has 1 single & 1 double bond**
- e. NaCl **$\text{Na}^+ \text{Cl}^-$ a metal & a nonmetal are ionic**

1. Which has the greatest ionic character?

e. NaCl

2. Which has the shortest bond length?

Triples are shorter than doubles are shorter than singles. d. HCN

3. Which has sp^2 hybridization?

Which one has AX_3 or AX_2E ? c. HNO

47/51



Free Response Questions

Free Response questions often use bonding theory to explain behavior.

Example: Magnesium solid conducts electricity while sulfur solid does not. Explain this observation.

Magnesium is metal. The atoms are bonded together with a pool of electrons which are free to move throughout. The free moving electrons can conduct electricity. Sulfur is a non-metal. The atoms are covalently bonded together—the electrons are not free to move, therefore they cannot conduct electricity.


48/51

Learning Summary

The **type of bond** can be determined from the atoms involved, and each type has common properties.

The **Valence Bond Theory** uses the overlap of atomic orbitals for diatomic compounds, and hybridization for polyatomic compounds.

The first bond between two atoms is a **sigma bond**, each additional bond is a **pi bond**.


49/51 

Congratulations

You have successfully completed the tutorial

Chemical Bonding Theories

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