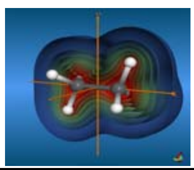
Chapter 9

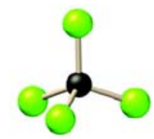
Bonding II:

Molecular Geometry and Bonding Theories



Preview

- The **VSEPR** model
  - Molecular geometry (going from two-dimensional "Lewis structure" to three-dimensional "VSEPR model" shapes)
  - Polarity
- Valence bond theory
- Hybridization of atomic orbitals
- Molecular orbital (MO) theory
  - MO energy diagram
  - Delocalization of orbitals



Molecular Geometry

- ***V***alence ***S***hell ***E***lectron-***P***air ***R***epulsion (**VSEPR**) model helps to determine the molecular structure and geometry in 3-D in the space.
- Even though it is not as precise as other models, the VSERP model is a simple, extremely useful model.
- The **VSEPR** model deals with molecules of the general type:

$$AB_x$$

where the central atom **A** is surrounded by x of **B** atoms, and x can take values from 2 to 6.

Molecular Geometry

- The **VSEPR** model is based on the assumption that:

Bonding and nonbonding electron pairs in the valence shell are positioned around the central atom such that *electron-pair repulsions* are *minimized*.

- A central atom can be surrounded by:
  - Bonding pairs (**B**)
    - can be single, double or triple bonds
  - Lone pairs (**E**)

} Electron domains

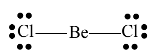
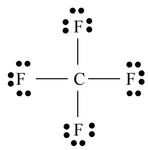
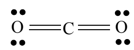
$$AB_xE_y$$

where the number of electron domains = $x + y$

Counting Electron Domains

- A central atom can be surrounded by:
  - Bonding pairs (**B**)
    - can be single, double or triple bonds
  - Lone pairs (**E**)

Electron domains

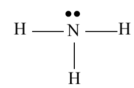
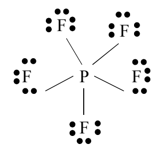
Total # of electron domains

2 4 2

Counting Electron Domains

- A central atom can be surrounded by:
  - Bonding pairs (**B**)
    - Can be single, double or triple bonds
  - Lone pairs (**E**)

Electron domains

Total # of electron domains

4 5

Arrangement of Electron Domains around the Central Atom

Number of Electron Domains		Electron-Domain Geometry
2		Linear
3		Trigonal planar
4		Tetrahedral

The repulsion of electron pairs is *minimized*

Arrangement of Electron Domains around the Central Atom

Number of Electron Domains		Electron-Domain Geometry
5		Trigonal bipyramidal
6		Octahedral

The repulsion of electron pairs is *minimized*

Steps of Determining Molecular Geometry

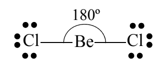
1. Draw the molecule's ***Lewis structure***.
2. Count the ***number of electron domains*** on the central atom.
3. Determine the ***electron-domain geometry***.
4. Determine the ***molecular geometry***.

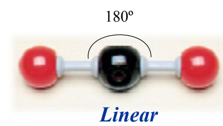
Lewis structure → Electron-domain geometry → Molecular geometry

Lewis structure → Electron-domain geometry → Molecular geometry

Molecular Geometry

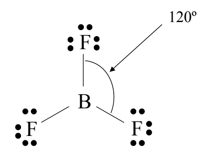
AB_2

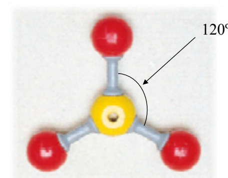




Linear

AB_3



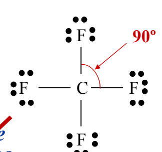


Trigonal planar

Lewis structure → Electron-domain geometry → Molecular geometry

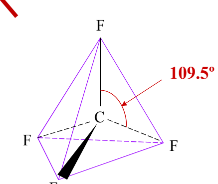
Molecular Geometry

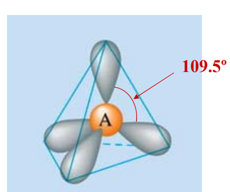
AB_4



~~*Square planar??*~~

Is there another possible orientation that can further minimize the repulsion between the four electron domains around the C atom??

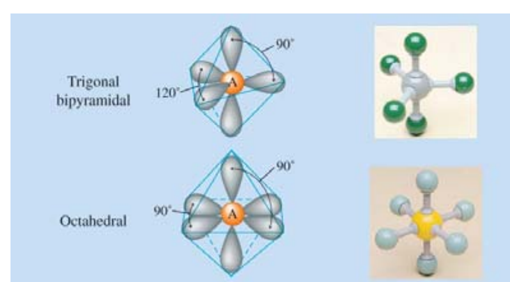




Tetrahedral

Lewis structure → Electron-domain geometry → Molecular geometry

Molecular Geometry



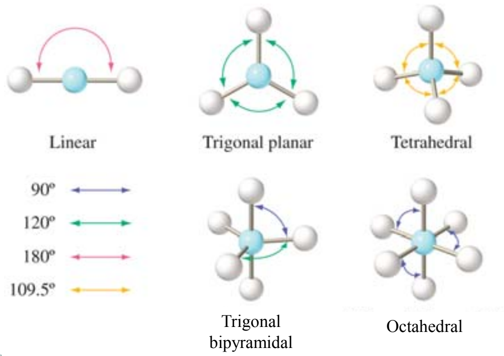
PCl_5

AB_5

SF_6

AB_6

Molecular Geometry for AB_x Molecules



Molecular Geometry for AB_x Molecules

Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_2	2	0	linear	linear
AB_3	3	0	trigonal planar	trigonal planar
AB_4	4	0	tetrahedral	tetrahedral
AB_5	5	0	trigonal bipyramidal	trigonal bipyramidal
AB_6	6	0	Octahedral	Octahedral

Other Subclasses of Molecules

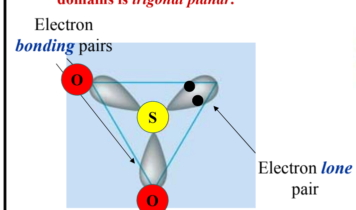
Main Class	Other subclasses	# lone pairs on central atom	# bonding pairs on central atom	Total # of electron domains
AB_2	None	-	-	-
AB_3	AB_2E	1	2	3
AB_4	AB_3E	1	3	4
	AB_2E_2	2	2	4
AB_5	AB_4E	1	4	5
	AB_3E_2	2	3	5
	AB_2E_3	3	2	5
AB_6	AB_5E	1	5	6
	AB_4E_2	2	4	6

Lewis structure → Electron-domain geometry → Molecular geometry

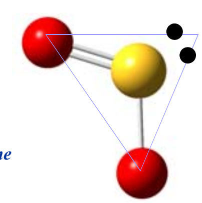
AB_2E Class Molecules

- SO_2

• **Arrangement of the electron domains is *trigonal planar*.**



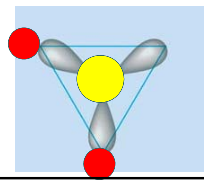
Molecular geometry is ***V-shaped or bent***



Chapter 9 Section 1

The Geometry of AB_3 Class Molecules

Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_3	3	0	Trigonal planar	Trigonal planar
AB_2E	2	1	Trigonal planar	V-shaped / bent

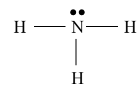


Dr. A. Al-Saadi 17

Chapter 9 Section 1

AB_3E Class Molecules

- NH_3



• **Arrangement of the electron domains is *tetrahedral*.**

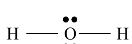
Molecular geometry is ***Trigonal Pyramid***

Dr. A. Al-Saadi 18

Chapter 9 Section 1

AB_2E_2 Class Molecules

- H_2O



• **Arrangement of the electron domains is again *tetrahedral*.**

Molecular geometry is ***V-shaped or bent***

Dr. A. Al-Saadi 19

Chapter 9 Section 1

Geometry AB_3 and AB_4 Class Molecules

Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_3	3	0	Trigonal planar	Trigonal planar
AB_2E	2	1	Trigonal planar	V-shaped / bent
AB_4	4	0	tetrahedral	tetrahedral
AB_3E	3	1	tetrahedral	trigonal pyramidal
AB_2E_2	2	2	tetrahedral	V-shaped / bent

Dr. A. Al-Saadi 20

Geometry of Subclasses of AB_5 Molecules

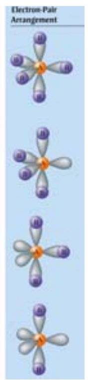
Class

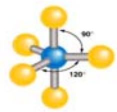
AB_5

AB_4E

AB_3E_2

AB_2E_3

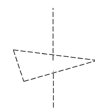


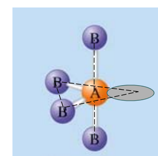


PCl_5

Geometry of Subclasses of AB_5 Molecules

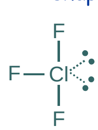
Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_5	5	0	Trigonal bipyramidal	Trigonal bipyramidal
AB_4E	4	1	Trigonal bipyramidal	See-saw





Geometry of Subclasses of AB_5 Molecules

Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_5	5	0	Trigonal bipyramidal	Trigonal bipyramidal
AB_4E	4	1	Trigonal bipyramidal	See-saw
AB_3E_2	3	2	Trigonal bipyramidal	T-shaped

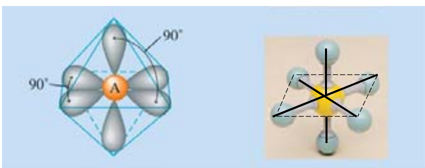


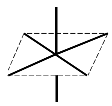
Geometry of Subclasses of AB_5 Molecules

Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_5	5	0	Trigonal bipyramidal	Trigonal bipyramidal
AB_4E	4	1	Trigonal bipyramidal	See-saw
AB_3E_2	3	2	Trigonal bipyramidal	T-shaped
AB_2E_3	2	3	Trigonal bipyramida	

Geometry of Subclasses of AB_6 Molecules

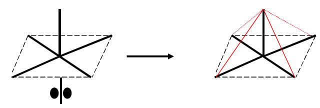
Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_6	6	0	Octahedral	Octahedral





Geometry of Subclasses of AB_6 Molecules

Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_6	6	0	Octahedral	Octahedral
AB_5E	5	1	Octahedral	Square pyramidal



Geometry of Subclasses of AB_6 Molecules

Class	# of atoms bonded to central atom	# lone pairs on central atom	Electron-domain geometry	Molecular geometry
AB_6	6	0	Octahedral	Octahedral
AB_5E	5	1	Octahedral	Square pyramidal
AB_4E_2	4	2	Octahedral	Square planar

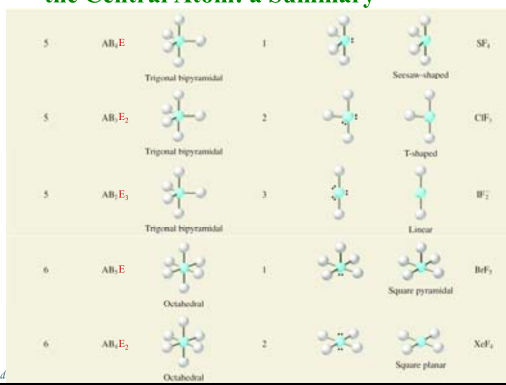
✓

Geometry of Molecules with Lone Pairs on the Central Atom: a Summary

Total Number of Electron Domains	Type of Molecule	Electron-Domain Geometry	Number of Lone Pairs	Placement of Lone Pairs	Molecular Geometry	Example
3	AB_2E	Trigonal planar	1		Bent	SO_2
4	AB_3E	Tetrahedral	1		Trigonal pyramidal	NH_3
4	AB_2E_2	Tetrahedral	2		Bent	H_2O

Chapter 9 Section 1

Geometry of Molecules with Lone Pairs on the Central Atom: a Summary



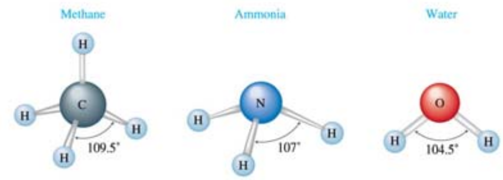
Dr. A. Al-Saad

29

Chapter 9 Section 1

Deviation from Ideal Bond Angles

- Bond angles in methane, ammonia, and water molecules.



- ***Lone pairs*** require more space than bonding pairs and tend to slightly ***squeeze*** the angles between the bonding pairs.

Dr. A. Al-Saadi

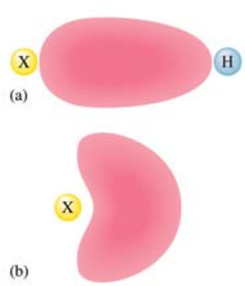
30

Chapter 9 Section 1

Deviation from Ideal Bond Angles

(a) For a bonding pair in a molecules, the electrons are attracted towards two nuclei.

(b) For a lone pair, it is localized on only one nucleus and occupies more space around the nucleus.

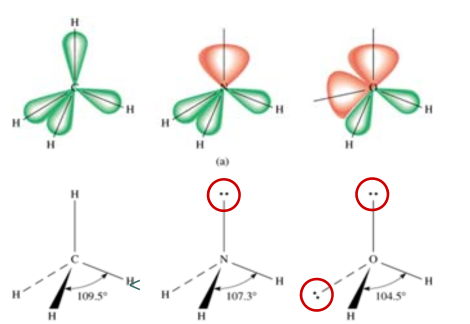


Dr. A. Al-Saadi

31

Chapter 9 Section 1

Deviation from Ideal Bond Angles



Bonding-pair nonbonding-pair repulsion increases

Dr. A. Al-Saadi

32

Chapter 9 Section 1

Deviation from Ideal Bond Angles

- ***Multiple bonds*** (double and triple) repel more strongly than single bonds because they have more electron density.
- The order of deviation from ideal angles is:

single bond < double bond < triple bond < lone pair

Repulsion increases →

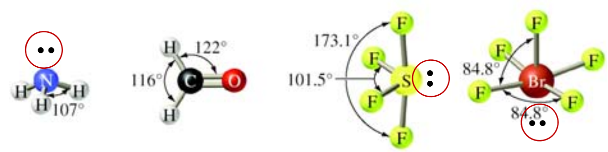
Dr. A. Al-Saadi 33

Chapter 9 Section 1

Deviation from Ideal Bond Angles

single bond < double bond < triple bond < lone pair

Repulsion increases →



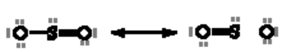
NH_3 CH_2O SF_4 BrF_5

Dr. A. Al-Saadi 34

Chapter 9 Section 1

Lewis structure → Electron-domain geometry → Molecular geometry

Examples: SO_2



A double bond should be counted as one electron domain.

Electron-domain geometry: trigonal planar.

Class : AB_2E

Molecular geometry: Bent or V-shaped.

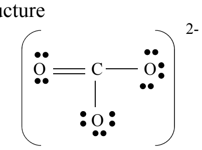
Dr. A. Al-Saadi 35

Chapter 9 Section 1

Lewis structure → Electron-domain geometry → Molecular geometry

Examples: CO_3^{2-}

Lewis structure



There are 3 electron domains on the central atom.

Electron-domain geometry: trigonal planar

Class: AB_3

Molecular geometry: trigonal planar

Dr. A. Al-Saadi 36

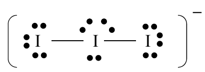
Chapter 9 Section 1

Lewis structure → Electron-domain geometry → Molecular geometry

Examples: I_3^-

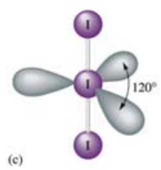
- Extra valence electrons, if any, must go to the central atom.

(I_3^-) $(21+1)e^- - 4e^- = 18e^-$



Electron-domain geometry: trigonal bipyramidal.

Class: AB_2E_3

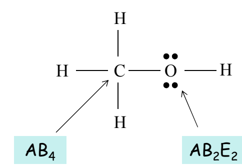


Linear

Chapter 9 Section 1

Molecules with More Than One Central Atom

- CH_3OH



Chapter 9 Section 2

Predicting Polarity from Molecular Geometry

- When the correct geometry is obtained for a given molecule, the polarity of that molecule can be predicted.

HF

$\overset{\delta+}{H} - \overset{\delta-}{F}$

$\overset{+\!\!\longrightarrow}{H - F}$

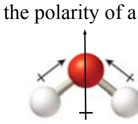
- Bond dipoles are ***vectors*** and therefore are ***additive***.

Chapter 9 Section 2

Predicting Polarity from Molecular Geometry

- Bond dipoles are ***vectors*** and therefore are ***additive***.
- Only the ***bonding pairs*** of electrons play a role in determining the polarity of a molecule.

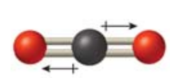
H_2O



dipole moment > 0

H_2O molecule is ***polar***

CO_2



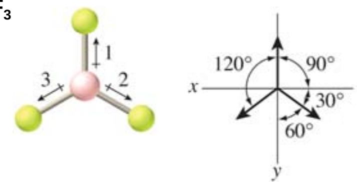
dipole moment = 0

CO_2 molecule is ***not polar***, although it has polar bonds

Chapter 9 Section 2

Predicting Polarity from Molecular Geometry

BF_3



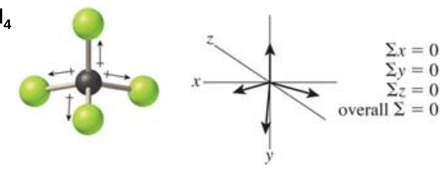
BF_3 molecule is ***not polar***

Dr. A. Al-Saadi 41

Chapter 9 Section 2

Predicting Polarity from Molecular Geometry

CCl_4



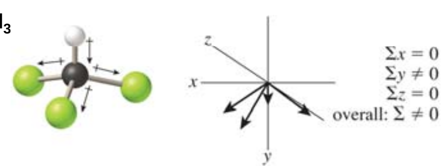
CCl_4 molecule is also ***not polar***

Dr. A. Al-Saadi 42

Chapter 9 Section 2

Predicting Polarity from Molecular Geometry

$CHCl_3$



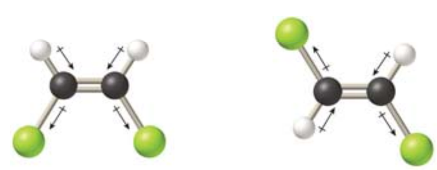
$CHCl_3$ molecule is ***polar***

Dr. A. Al-Saadi 43

Chapter 9 Section 2

Predicting Polarity from Molecular Geometry

- Which one of the following two $C_2H_2Cl_2$ geometries is polar?



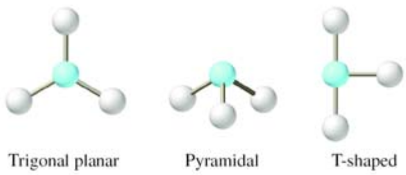
polar not polar

Dr. A. Al-Saadi 44

Chapter 9 Section 2

Predicting Polarity from Molecular Geometry

- Which one of the following geometries are polar?

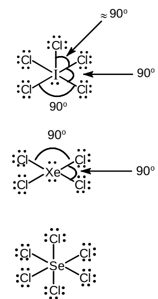


not polar polar polar

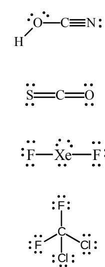
Chapter 9 Section 1 and 2

Exercises

94. Predict the molecular structure (including bond angles) for each of the following. (See Exercises 89 and 90.)
 a. ICl_5
 b. $XeCl_4$
 c. $SeCl_6$



100. Write Lewis structures and predict whether each of the following is polar or nonpolar.
 a. HOCN (exists as HO—CN)
 b. COS
 c. XeF_2
 d. CF_2Cl_2



Chapter 9 Section 3

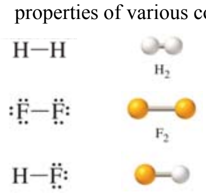
Valence Bond Theory

- Do you still remember the shapes of atomic orbitals?
  - 1*s* and 2*s* orbitals.
  - 2*p* and 3*p* orbitals.

Chapter 9 Section 3

Valence Bond Theory

- ***Valence bond theory*** explains the differences in the properties of various covalent bonds.



- Although Lewis model is useful, but it can't account for different bond lengths and bond strengths of different molecules.

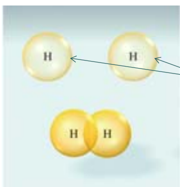
TABLE 9.3 Bond Lengths and Bond Enthalpies of H_2, F_2, and HF

	Bond Length (Å)	Bond Enthalpy (kJ/mol)
H_2	0.74	436.4
F_2	1.42	150.6
HF	0.92	568.2

Chapter 9 Section 3

Valence Bond Theory

- According to ***valence bond theory*** , atoms form a covalent bond when *an atomic orbital* on one atom ***overlaps*** with *an atomic orbital* of another atom.



Each atomic orbital must have: a single unpaired electron. (shown as transparent orbitals)

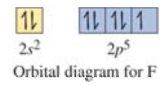
Furthermore, the two electrons in the two atomic orbitals must have opposite spins.

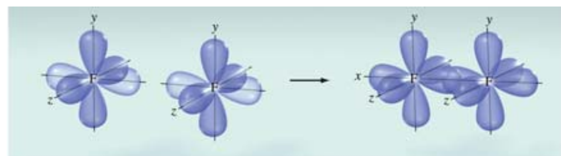
$H(1s^1) + H(1s^1) \rightarrow H\text{–}H$

Chapter 9 Section 3

Valence Bond Theory

- According to ***valence bond theory*** , atoms form a covalent bond when *an atomic orbital* on one atom ***overlaps*** with *an atomic orbital* of another atom.



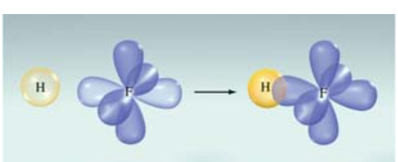


$F(1s^2 2s^2 2p^5) + F(1s^2 2s^2 2p^5) \rightarrow F\text{–}F$

Chapter 9 Section 3

Valence Bond Theory

- According to ***valence bond theory*** , atoms form a covalent bond when *an atomic orbital* on one atom ***overlaps*** with *an atomic orbital* of another atom.

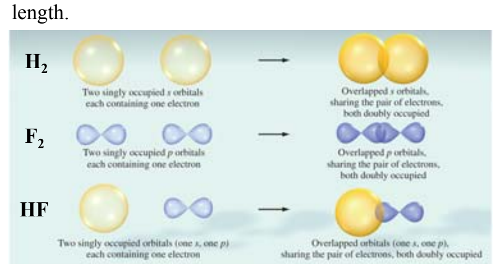


$H(1s^1) + F(1s^2 2s^2 2p^5) \rightarrow H\text{–}F$

Chapter 9 Section 3

Valence Bond Theory

- According to quantum mechanics (Chapter 6), the size, shape and energy of 1*s* and 2*p* orbitals are different. Therefore, the bonds in H_2, F_2 and HF vary in strength and length.



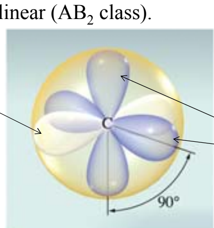
Chapter 9 Section 4

Hybridization of Atomic Orbitals

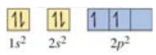
- *Can you apply **valence bond theory** to the CO_2 molecule?*

  From VSEPR model, CO_2 is linear (AB_2 class).

Actual bond angle is 180°



Bond angle should be 90°.



From the C atom electron configuration, there are two singly occupied *p* orbitals.

Valence bond theory doesn't work in this case!

Dr. A. Al-Saadi 53

Chapter 9 Section 4

Hybridization of Atomic Orbitals

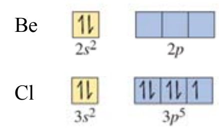
- *Can you apply **valence bond theory** to the $BeCl_2$ molecule?*

  From VSEPR model, $BeCl_2$ is again linear (AB_2 class). Moreover, experimental observations show that both Be-Cl bonds are identical.

- ***Hybridization*** "mixing of atomic orbitals" helps much in understanding many experimental observations that couldn't be explained with valence bond theory.

:Cl—Be—Cl:

There are ***two electron domains*** on the central atom



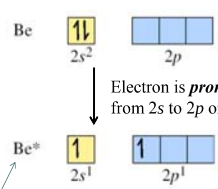
The Be atom doesn't have singly occupied atomic orbitals, so the valence bond theory can't be applied in this case!

Dr. A. Al-Saadi 54

Chapter 9 Section 4

Hybridization of Atomic Orbitals

:Cl—Be—Cl:



- No unpaired electrons
- Now Be has two singly occupied atomic orbitals and can form two bonds

Excited Be atom

But one problem is still there!

Dr. A. Al-Saadi 55

Chapter 9 Section 4

Hybridization of Atomic Orbitals

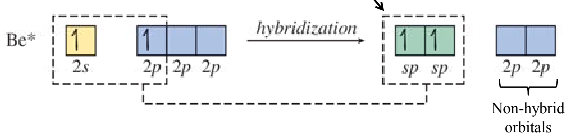
:Cl—Be—Cl:

- Although the Be atom can now form two bonds, but from the above diagram those two bonds are different.
- Experiment, however, shows that the two Be-Cl bonds are *identical*! Thus, some extra treatments should be done!

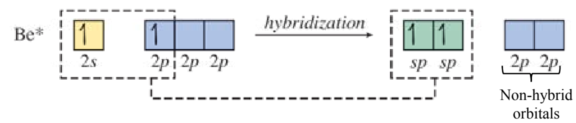
Dr. A. Al-Saadi 56

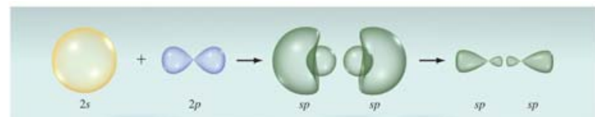
sp Hybridization

- Recall that :
  - Orbital shapes (boundary surfaces) are pictorial representations of wave functions.
  - Wave functions are mathematical functions.
  - Mathematical functions can be *combined*.
- Thus, the atomic orbitals on an atom mix themselves in order to form new ***hybrid orbitals*** that are identical in shape, energy, and size.



sp Hybridization



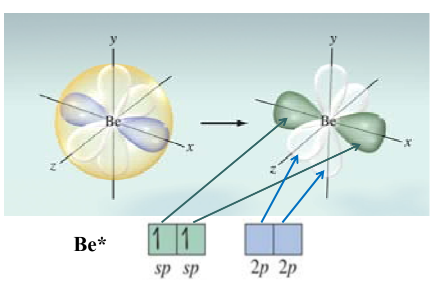


Before hybridization

After hybridization

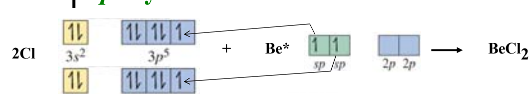
- The new two *sp* orbitals are identical in shape, size and energy.

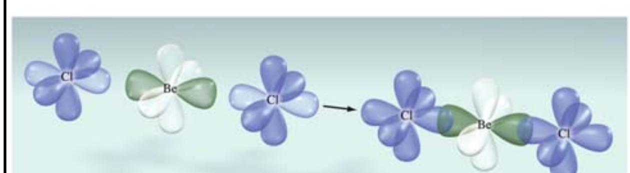
sp Hybridization



- The two *sp* orbitals, each with one electron, point in opposite directions inline with one another. This results in an angle of 180°.

sp Hybridization



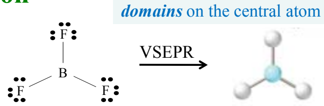


- Each hybrid *sp* orbital overlaps with a 3*p* singly occupied atomic orbital and the angle formed is 180°. ***Hybridization*** accounts very well for the linear geometry of $BeCl_2$.

sp^2 Hybridization

There are ***three electron domains*** on the central atom

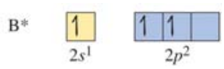
- Let's try the same approach with BF_3.



- trigonal planar
- all bonds equivalent

- only 1 unpaired electron available, while 3 bonds are there!

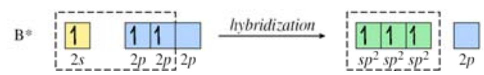
Electrons promotion



- two types of overlap with 2*s* and 2*p*. So hybridization is required.

sp^2 Hybridization

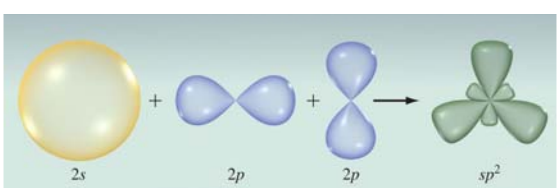
- The next step is ***hybridizing*** "mixing" the 2*s* orbital and 2*p* orbitals.



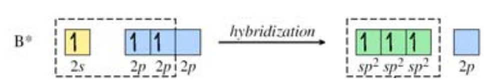
- The new three hybrid sp^2 orbitals are identical in shape, size and energy.

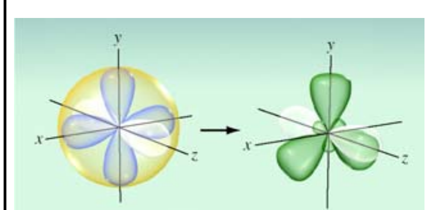
sp^2 Hybridization

- The new three hybrid sp^2 orbitals are identical in shape, size and energy and are 120° apart from each other.



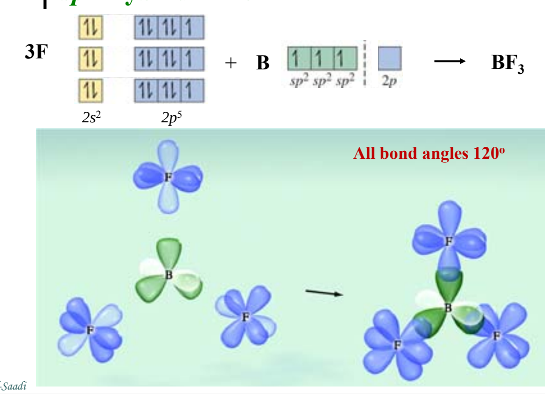
sp^2 Hybridization



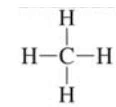


- The three hybrid sp^2 orbitals facilitate the trigonal planar geometry.
- There are still one *p* unhybrid orbital not involved in the bonding process.

sp^2 Hybridization

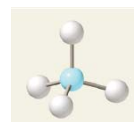


sp^3 Hybridization



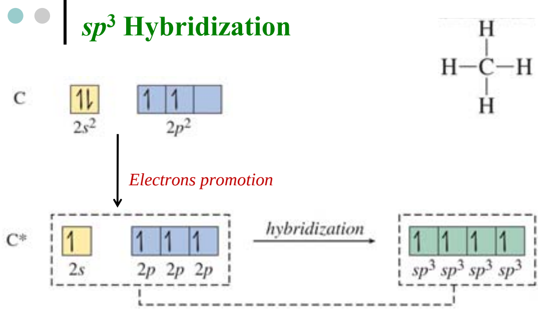
There are ***four electron domains*** on the central atom

- Same kind of analysis can be applied for C atom in the methane molecule (CH_4).
- How many hybrid orbitals do you need for the C atom in CH_4?



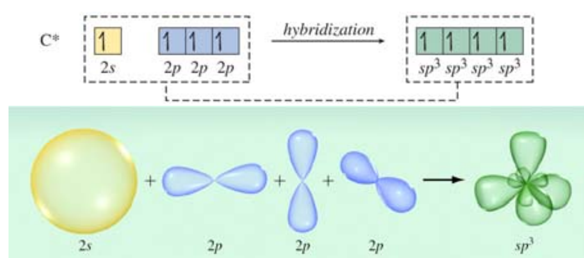
CH_4 has a tetrahedral shape and all bonds are equivalent.

sp^3 Hybridization



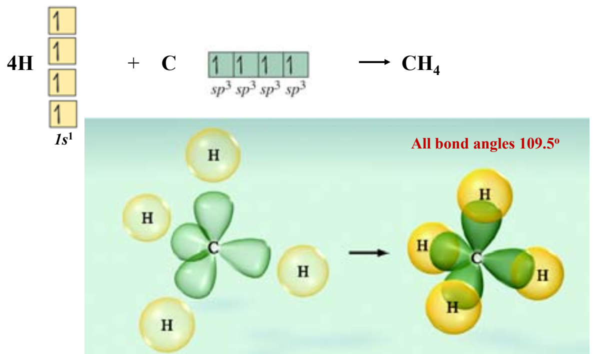
- The new **hybrid sp^3 orbitals** are identical in their shape, size and energy. They adopt tetrahedral geometry and make 109° angle with respect to each other.

sp^3 Hybridization



- The new **hybrid sp^3 orbitals** are identical in their shape, size and energy. They adopt tetrahedral geometry and make 109° angle with respect to each other.

sp^3 Hybridization

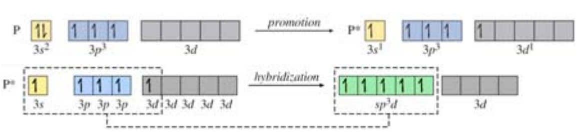


sp , sp^2 and sp^3 Hybridizations

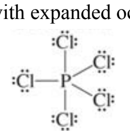
TABLE 9.4 Number of Electron Domains and Hybrid Orbitals on Central Atom

Number of Electron Domains on Central Atom	Hybrid Orbitals	Geometry
2	sp	Linear
3	sp^2	Trigonal planar
4	sp^3	Tetrahedral

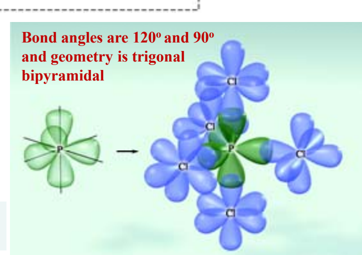
sp^3d Hybridization



- sp^3d hybrid orbitals are used by atoms with expanded octet.

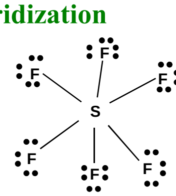


There are ***five electron domains*** on the central atom

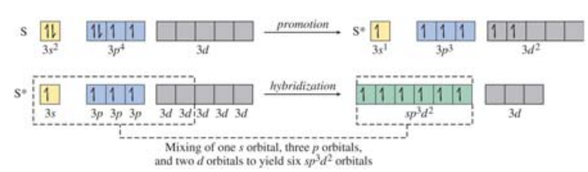


sp^3d^2 Hybridization

- sp^3d^2 hybrid orbitals are also used by atoms with expanded octet.

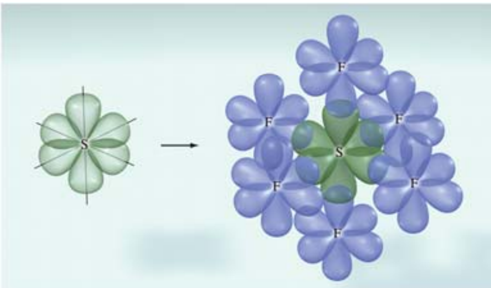


There are ***six electron domains*** on the central atom



sp^3d^2 Hybridization

- The sp^3d^2 hybrid orbitals on the S atom adopt 90° angles and a geometry that is octahedral.



sp , sp^2 , sp^3, sp^3d and sp^3d^2 Hybridizations

❑ In order to predict the correct hybridization for a given atom :

1) Draw correct ***Lewis structure***.
2) Determine the ***number of electron domains*** on the central atom.
3) Use the table to predict the appropriate hybridization and geometry

TABLE 9.4 Number of Electron Domains and Hybrid Orbitals on Central Atom

Number of Electron Domains on Central Atom	Hybrid Orbitals	Geometry
2	sp	Linear
3	sp^2	Trigonal planar
4	sp^3	Tetrahedral
5	sp^3d	Trigonal bipyramidal
6	sp^3d^2	Octahedral

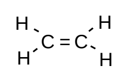
Exercises

- Predict the hybridization of the central atom in the following molecules:
  - Ammonia (NH_3)
  - KrF_4
  - $BrCl_3$

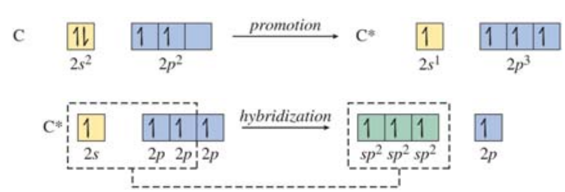
Hybridization in Molecules Containing Multiple Bonds

\# electron domains = 3

Required hybridization is sp^2

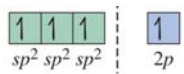


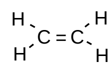
Ethylene



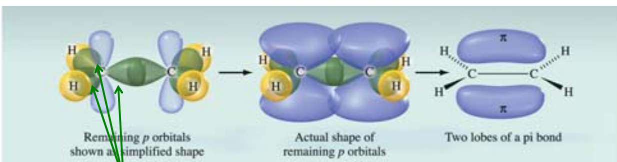
Hybridization in Molecules Containing Multiple Bonds

Hybrid orbitals of C atom in ethylene





Ethylene

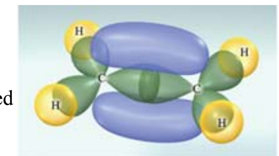


3 sigma "σ" bonds
Head-to-head bonding

1 pi "π" bond
Sideways bonding

Hybridization in Molecules Containing Multiple Bonds

- A ***pi (π) bond*** forms from the sideway overlap of non-hybrid *p* orbitals resulting in regions of electron density that are concentrated above and below the plane of the molecule. "sideways" overlap.



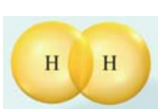
Double bond = 1 σ bond + 1 π bond

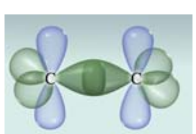
Triple bond = 1 σ bond + 2 π bonds

- ***pi (π) bonds*** are not as strong as ***sigma (σ) bonds.***

Hybridization in Molecules Containing Multiple Bonds

- A ***sigma (σ) bond*** is a bond in which the shared electron density is concentrated directly along the internuclear axis between the two nuclei involved in bonding. "head-to-head" overlap.





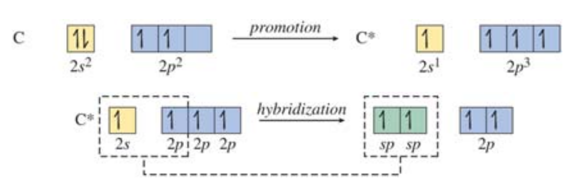
Hybridization in Molecules Containing Multiple Bonds

electron domains = 2

Required hybridization is *sp*

H – C ≡ C – H

Acetylene



Chapter 9 Section 5

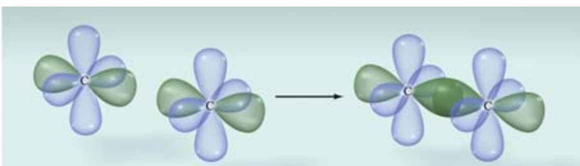
Hybridization in Molecules Containing Multiple Bonds

Hybrid orbitals of C atom in acetylene

↿ ↿ (sp sp) | ↿ ↿ (2p)

H – C ≡ C – H

Acetylene



Formation of a C-C single bond

Dr. A. Al-Saadi 81

Chapter 9 Section 5

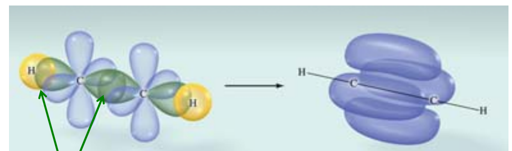
Hybridization in Molecules Containing Multiple Bonds

Hybrid orbitals of C atom in acetylene

↿ ↿ (sp sp) | ↿ ↿ (2p)

H – C ≡ C – H

Acetylene



2 sigma "σ" bonds
Head-to-head bonding

2 pi "π" bonds
Sideways bonding

Dr. A. Al-Saadi 82

Chapter 9 Section 5

Hybridization in Molecules Containing Multiple Bonds

C # electron domains = 3
Required hybridization is *sp*^{2}

O # electron domains = 3
Required hybridization is *sp*^{2}

:O:
||
H – C – H

Formaldehyde

C ↿ (2s) ↿ ↿ ↿ (2p 2p 2p) —*hybridization*→ ↿ ↿ ↿ (sp^2 sp^2 sp^2) ↿ (2p)

O ⥮ (2s) ⥮ ↿ ↿ (2p 2p 2p) —*hybridization*→ ⥮ ⥮ ↿ (sp^2 sp^2 sp^2) ↿ (2p)

Dr. A. Al-Saadi 83

Chapter 9 Section 5

Hybridization in Molecules Containing Multiple Bonds

⥮ ⥮ ↿ (sp^2 sp^2 sp^2) | ↿ (2p)

O

↿ ↿ ↿ (sp^2 sp^2 sp^2) | ↿ (2p)

C

:O:
||
H – C – H

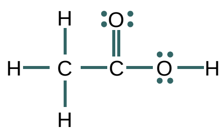
Formaldehyde

Dr. A. Al-Saadi 84

Chapter 9 Section 5

Exercises

- How many sigma (σ) and pi (π) bonds are in acetic acid?

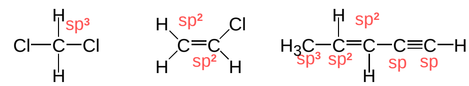


7 σ-bonds and 1 π-bond.

Chapter 9 Section 5

Exercises

- How many pi bonds and sigma bonds are in each of the following molecules? Describe the hybridization of each C atom?



(a) (b) (c)

(a) 4 sigma bonds
(b) 5 sigma bonds, 1 pi bond
(c) 10 sigma bonds, 3 pi bonds