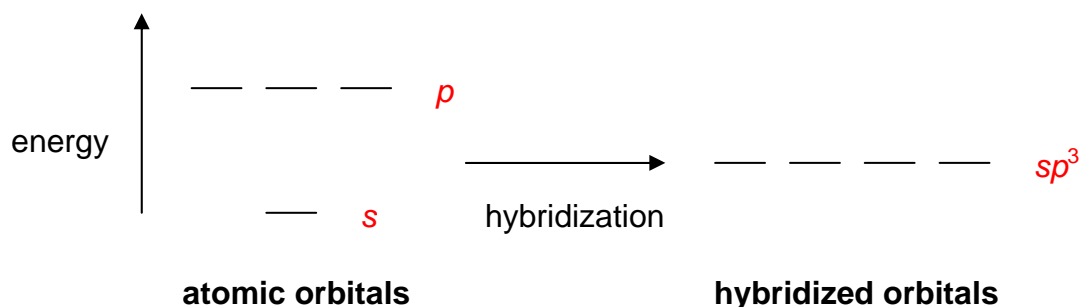


## Worksheet 16 - Hybridization

When atoms bond to form molecules, they use **molecular orbitals**. These are formed through the **hybridization** of the **atomic orbitals** that we have already discussed, **s**, **p**, and **d** orbitals.

The **hybridized molecular orbitals** have different shapes and energy levels than the **atomic orbitals**. The number of molecular orbitals created by hybridization depends on the number of atomic orbitals that are mixed to form them.

In forming  **$sp^3$**  hybridized orbitals, **four** atomic orbitals are mixed, one **s** and three **p**. The energy diagram for this process is shown below. The hybridized orbitals are higher in energy than the **s** orbital, but lower in energy than the **p** orbitals, following Hund's rule.



Carbon has 4 valence electrons. Add these electrons to the atomic and molecular orbitals. This hybridization gives **tetrahedral geometry**.

With this hybridization, C will form **four equivalent  $\sigma$  bonds**.

Draw a similar energy diagram for  **$sp^3$**  hybridized **oxygen**.

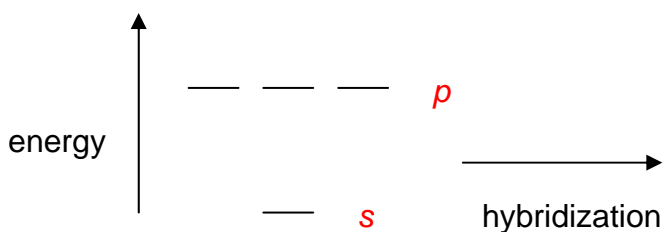
How many  $\sigma$  bonds will be formed?

How are the other  $sp^3$  orbitals used?

Do the same for  **$sp^3$**  hybridized **nitrogen**.

In some Lewis structures, there are only **three** equivalent bonds formed. To create three equivalent hybridized orbitals, mix **three** atomic orbitals.

Draw and name the orbitals formed in this hybridization, then add the electrons for **sulfur**. Since the hybridized orbitals are close in energy, every orbital is filled with one electron before electrons are paired.



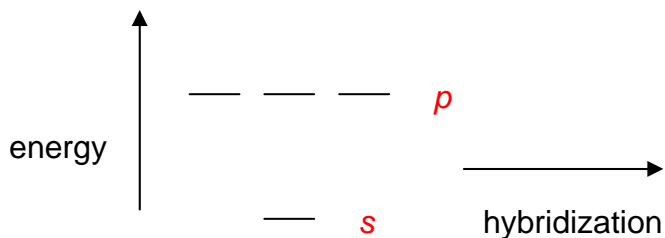
The hybridized orbitals will form \_\_\_\_\_  $\sigma$  bond(s).

The unhybridized orbital will form \_\_\_\_\_  $\pi$  bond(s).

There will be \_\_\_\_\_ lone pair(s).

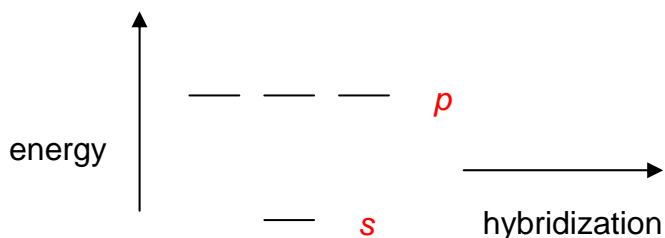
This hybridization gives **trigonal planar** geometry.

In **linear** molecules, like  $\text{CO}_2$ , the central atom has only **two** equivalent bonding orbitals. Draw the energy levels and name the orbitals formed in this hybridization.



Fill in the electrons for carbon and determine the number and typed of bonds formed.

In  $\text{CO}_2$ , determine the hybridization of the **oxygen** atoms. Complete the energy diagram for the oxygens. Draw the structure of  $\text{CO}_2$ .



In atoms with  $n=3$  or larger, the  $d$  orbitals can also be hybridized. In molecules with **five** molecular orbitals, **five** atomic orbitals are mixed:



This will give **trigonal bipyramidal** geometry and is called  **$dsp^3$**  hybridization.

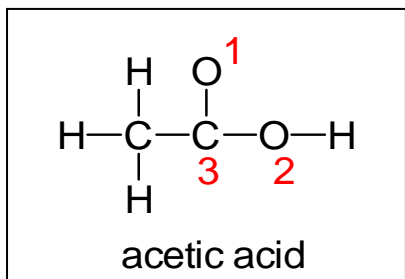
Finally, molecules with **octahedral** geometry, will have \_\_\_ molecular orbitals. This hybridization is called \_\_\_\_\_ .

Shown below is a portion of the chart from **Worksheet 14**. Fill in the **hybridization** for each of the compounds.

compound	bonds	lone pairs	geometry	shape	hybridization
SF <sub>6</sub>	6	0	octahedral	octahedral	
NH <sub>3</sub>	3	1	tetrahedral	trigonal pyramidal	
ICl <sub>4</sub> <sup>-</sup>	4	2	octahedral	square planar	
CF <sub>4</sub>	4	0	tetrahedral	tetrahedral	
SO <sub>3</sub>	3	0	trigonal planar	trigonal planar	
SF <sub>4</sub>	4	1	trigonal bipyramidal	seesaw	
CO <sub>2</sub>	2	0	linear	linear	
H <sub>2</sub> O	2	2	tetrahedral	V-shaped	
NO <sub>2</sub> <sup>-</sup>	2	1	trigonal planar	V-shaped	

Fill in the chart below and then complete the Lewis structures for the molecules shown below and fill in those charts.

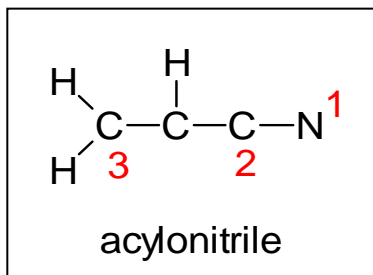
element	Lewis symbol	# bonds	# lone pairs
C			
N			
H			
O			
Halogen			



$\sigma$  bonds \_\_\_\_\_

$\pi$  bonds \_\_\_\_\_

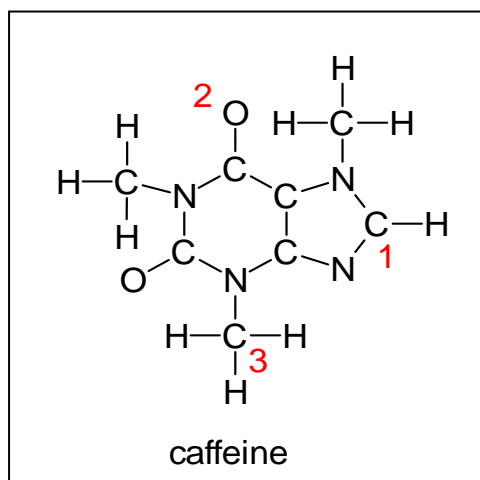
atom #	bond angle	hybridization
1		
2		
3		



$\sigma$  bonds \_\_\_\_\_

$\pi$  bonds \_\_\_\_\_

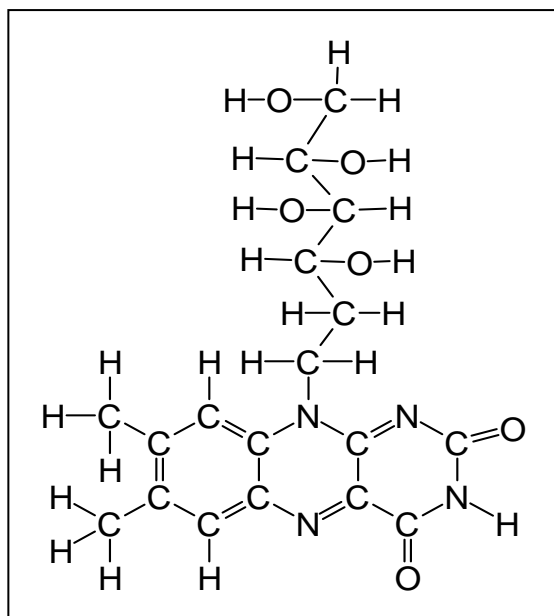
atom #	bond angle	hybridization
1		
2		
3		



$\sigma$  bonds \_\_\_\_\_

$\pi$  bonds \_\_\_\_\_

atom #	bond angle	hybridization
1		
2		
3		



The molecule shown to the left is riboflavin (vitamin B2). Answer the following questions about its structure.

- a) how many carbons are  $sp^3$  hybridized?  
 $sp^2$  hybridized?  
 $sp$  hybridized?
- b) How many nitrogens are  $sp^3$  hybridized?  
 $sp^2$  hybridized?  
 $sp$  hybridized?
- c) How many oxygens are  $sp^3$  hybridized?  
 $sp^2$  hybridized?  
 $sp$  hybridized?
- d) How many  $\sigma$  bonds are there in total?
- e) How many  $\pi$  bonds are there in total?
- f) Which of the three rings are **planar**?

The acetate ion,  $C_2H_3O_2^-$ , has both oxygens bonded to the same carbon.

- a) Draw the Lewis structure and all resonance forms.
- b) Label the hybridization around each carbon.
- c) Pick one resonance structure and label the hybridization of each oxygen.
- d) How many  $\sigma$  and  $\pi$  bonds are present?
- e) Which atom carries the formal negative charge?