Covalent Bonding

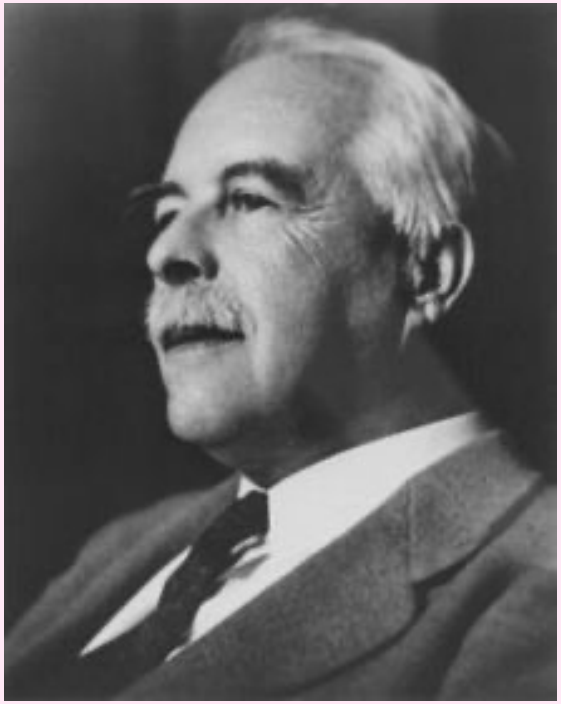
Drawing Lewis Structures

Sharing of Electrons

What Bonds With What?

- Metals + nonmetals
  - IONIC
  - transfer of electrons
- Metals + metals
  - METALLIC BONDING (Alloys if a mixture.)
  - sea of loose valence electrons
- Nonmetals + nonmetals
  - MOLECULAR
  - covalent bonding

Gilbert Newton Lewis

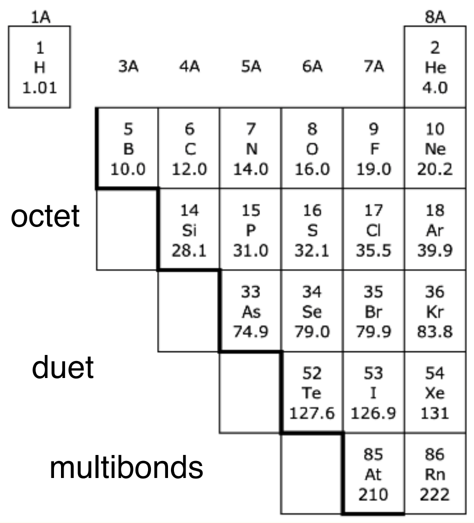


- October 25, 1875 – March 23, 1946
- Was an American physical chemist known for the discovery of the covalent bond and the concept of sharing electron pairs
- His Lewis dot structures and other contributions to valence bond theory have shaped modern theories of chemical bonding
- Born right here in Weymouth, Massachusetts
- Probably the most famous chemist who never won a Nobel Prize. He was nominated for a Nobel Prize 41 times, but never won one

Drawing Lewis Structures

1. Sum the valence electrons for each atom
   - ✓ add an extra electron for polyatomic ions with negative charge. (−1 means 1 extra e^-, −2 means 2 extra e^-)
   - ✓ subtract and electron for each positive charge
2. Connect all atoms with single bonds
3. Complete the octet for all atoms
   - ✓ only a duet for the very small hydrogen atom
4. If there are not enough electrons to go around, use multiple bonds to get "double duty" out of electrons
   - ✓ add only 1 multi-bond at a time as needed

Lewis Structures



1. F_2

2. H_2

3. O_2

4. N_2

Lewis Structures

1A	3A	4A	5A	6A	7A	8A
1 H 1.01						2 He 4.0
	5 B 10.0	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
		14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
			33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
				52 Te 127.6	53 I 126.9	54 Xe 131
					85 At 210	86 Rn 222

octet

duet

multibonds

1. F_2

   7x2 = 14e

2. H_2

   1x2 = 2e

3. O_2

   6x2 = 12e

4. N_2

   5x2 = 10e

Comparative Bond Lengths

Single Double Triple

Bonds – Length & Strength

- Single
  - Sharing of one pair of electrons is generally longer but weaker
- Double
  - Sharing of two pair of electrons is generally shorter but stronger
- Triple
  - Overlap of three pair of electrons is generally shortest and strongest
  - *more on why triple is the shortest later in the unit.*

Bond	Length (A) / strength (kJ/mol)	
C—C	1.54	
C=C	1.34	614
C≡C	1.20	839
C—N	1.43	305
C=N	1.38	615
C≡N	1.16	891
C—O	1.43	358
C=O	1.23	745
C≡O	1.13	1070

A = Angstrom
10^{-10} m

H–H 0.74 A

Bond	Length (A) / strength (kJ/mol)	
N—N	1.47	160
N=N	1.24	418
N≡N	1.10	945
N—O	1.36	201
N=O	1.22	607
O—O	1.48	204
O=O	1.21	498

Lewis Structures

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C inside

H, F terminal

1. CH_2F_2

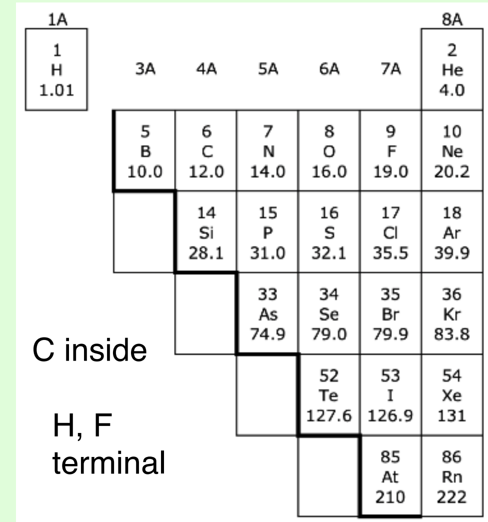
2. H_2O

3. CN^-

4. NO_2^-

valence electrons for ions

Lewis Structures



1. CH_2F_2

   $4 + 1x2 + 7x2 = 20e$

2. H_2O

   $1x2 + 6 = 8e$

3. CN^-

   $4 + 5 + 1 = 10e$

4. NO_2^-

   $5 + 6x2 + 1 = 18e$

valence electrons for ions

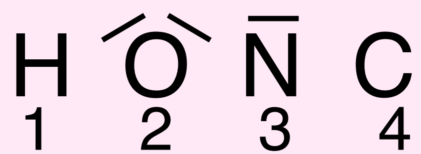
Rules to guide you when deciding what connects to what.

- Sometimes the order listed may help
  - ✓ Central atom is often written first

H_2O should really be written OH_2 !

- H's and F's are terminal (on outside of molecules)
- O's do not bond together
  - ✓ Except in O_2 and in peroxide molecules (H_2O_2)
- C's will bond together and are usually inside, not terminal to avoid unshared pairs on C's

✓



Lewis Structures

More often then not AP will give the atom arrangement

H, F terminal

C inside

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1. HNO_2 H O N O

2. C_2H_5OH

H H

H C C O H

H H

H O N C

1 2 3 4

3. O_3

Lewis Structures

More often then not AP will give the atom arrangement

H, F terminal

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	5 B 10.0	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
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C inside

1. HNO_2

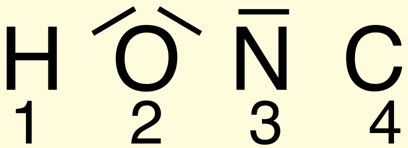
H O N O

1 + 5 + 6x2 = 18e

2. C_2H_5OH

H H
H C C O H
H H

4x2 + 1x5 + 6 + 1 = 20e



3. O_3

6x3 = 18e

Resonance

Same arrangement of atoms

Different arrangement of electrons

Formal Charge

A concept used to decide among equivalent resonance structures

Resonance

- Two or more Lewis Structures in which;
  - ✓ The connection and placement of the atoms is the *same*
  - ✓ But the arrangement of the electrons is *different*
  - ✓ Yet still obeying the octet rule.
- Contrast this with an *isomer* which is a different arrangement of atoms

Ozone and Bond Length O_3

$6 \times 3 = 18e$

- Draw a Lewis structure for ozone.
- Re-sketch the ozone molecule and shift the electrons around.

✓ This is called a resonance structure.

✓ You may be asked explicitly;

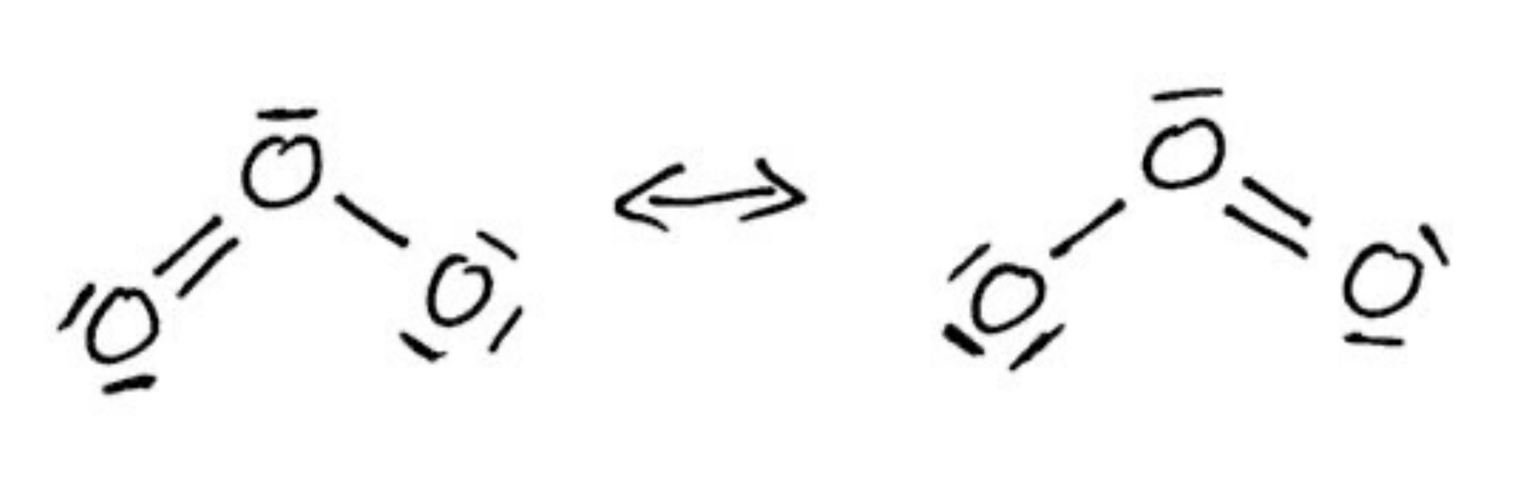
- *Draw the two resonance structures for ozone*

✓ You may be asked implicitly

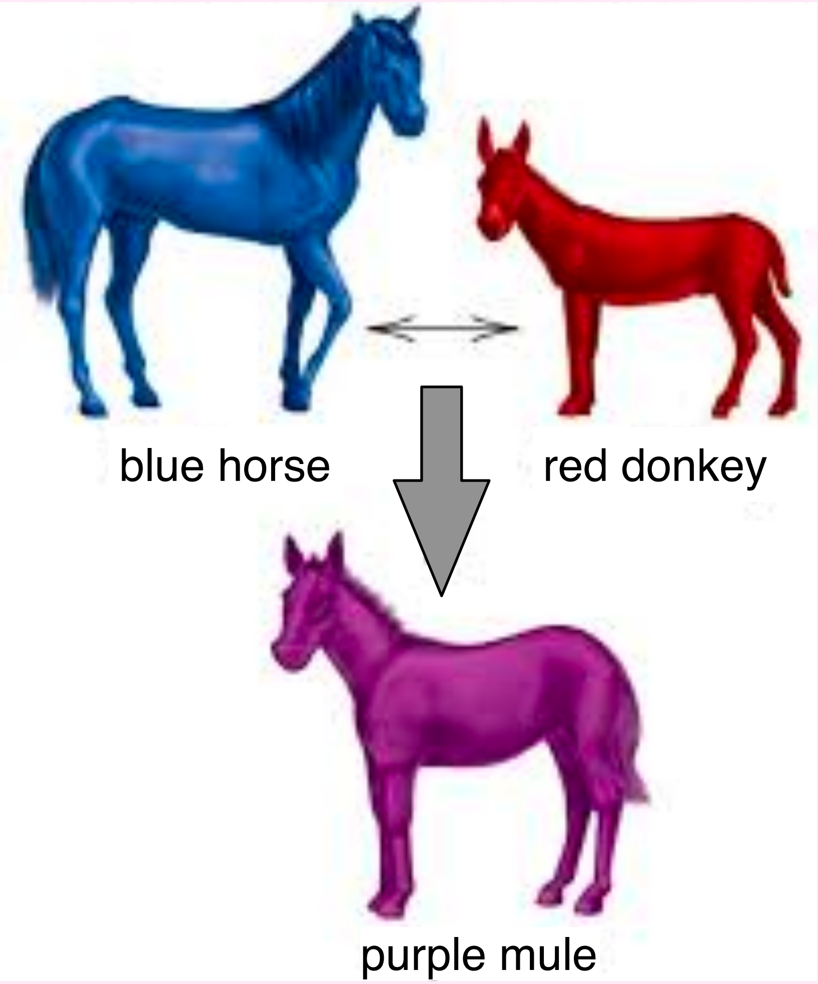
- *Explain why bond length studies have demonstrated that the ozone molecule does not have a short O=O and a long O−O bond.*
- *Rather the bond lengths are equal and intermediate in between a double O=O and single O−O.*

Resonance in Ozone: O_3

- The two bonds in ozone are the SAME length and both bonds are shorter than a single bond and longer than a double bond.
- The molecule does not actually flip between the two structures, but is an average of the two.

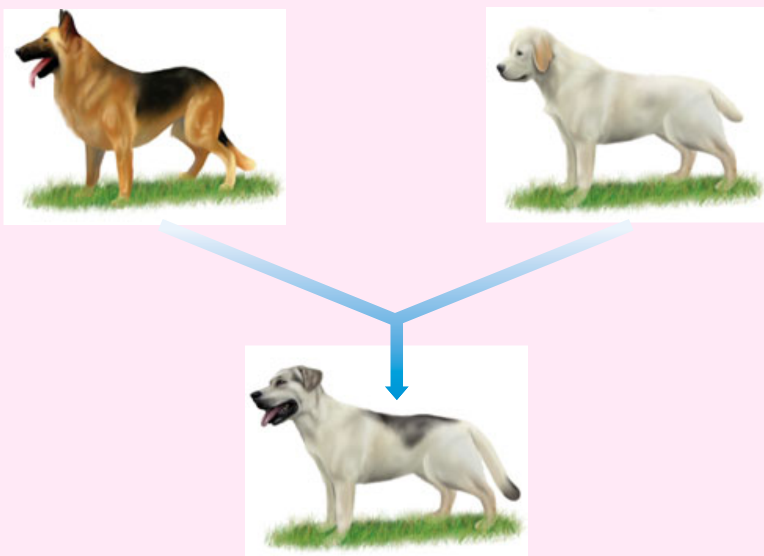


Resonance – two (or more) separate Lewis structures, but actually, the molecule is a **blend** of the various structures we can draw.



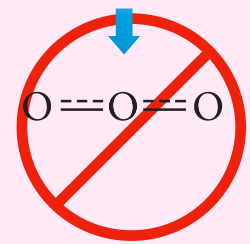
A Purple Mule, Not a Blue Horse and a Red Donkey A mule is a genetic mix, a hybrid, of a horse and a donkey; it is not a horse one instant and a donkey the next. Similarly, the color purple is a mix of red and blue, not red one instant and blue the next. In the same sense, a resonance hybrid is one molecular species, not one resonance form this instant and another resonance form the next. The problem is that we cannot depict the actual species, the hybrid, accurately with a single Lewis structure.

Resonance – two (or more) separate Lewis structures, but actually, the molecule is a **blend** of the various structures we can draw.



Hybrid

Some books will use this notation.



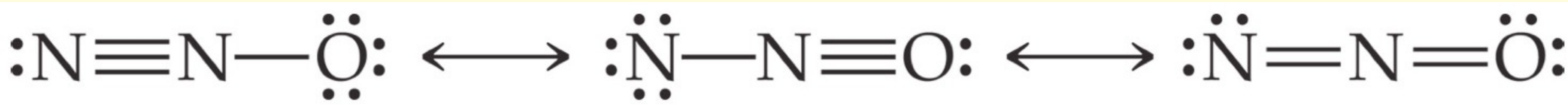
Do NOT draw this on your AP Exam

- It's not as if your dog is shepherd on Tues and Lab on Wed, the dog is a mix everyday.
- Just the same, the molecule is a mix or a blend.

Resonance in N_2O

- Draw a Lewis structure for N_2O
  - ✓ Put one of the N’s in the middle.
  - ✓ draw as many resonance structures as you can

Resonance in N_2O

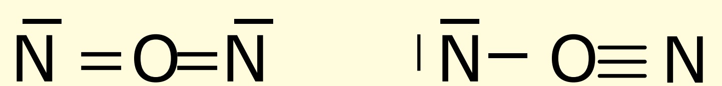


- Is one resonance structure better than the other?
  - ✓ Yes !
- Introducing FORMAL CHARGE
  - ✓ Not a real charge, but a bookkeeping system
  - ✓ used to assess resonance structures

- calculate FC = (# valence e^-) − (nonbonding e^-) − (bonds)

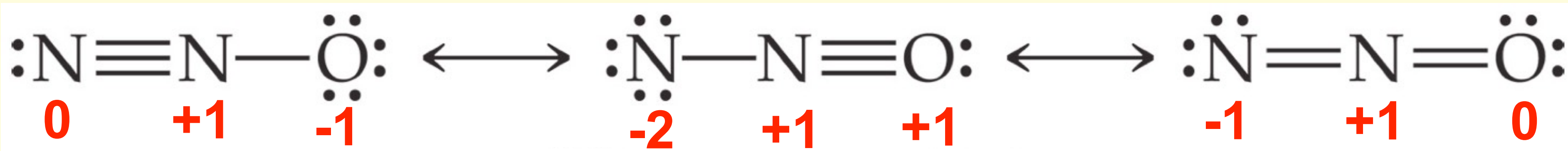
- Never apply formal charge unless AP **asks explicitly**.

What about these isomers?



Using Formal Charge to Assess Resonance

- (# valence e^-) − (nonbonding e^-) − (bonds)

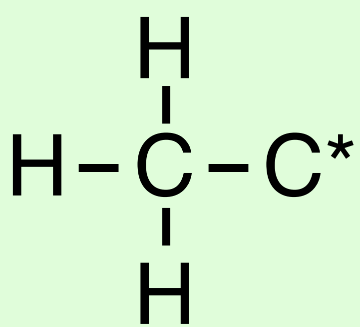


- All FC of zero would be best,
- or the least amount of FC,
- If equal amounts of formal charge, the negative formal charge should reside on the more electronegative atom.

Two resonance structures that are isomers of the above structures do not occur. As you can see, very poor FC.

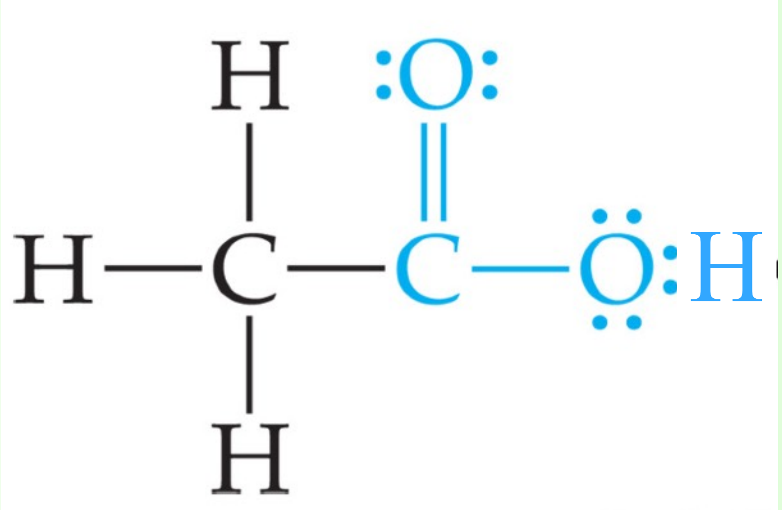
Carboxylic (Organic) Acids -COOH group

- Complete the Lewis structure for acetic acid (aka ethanoic acid): $HC_2H_3O_2$
- Arrange the remaining atoms as appropriate around the C* and fill in all of the electron pairs including nonbonded pairs of electrons.
- Sometimes written in expanded format: CH_3COOH



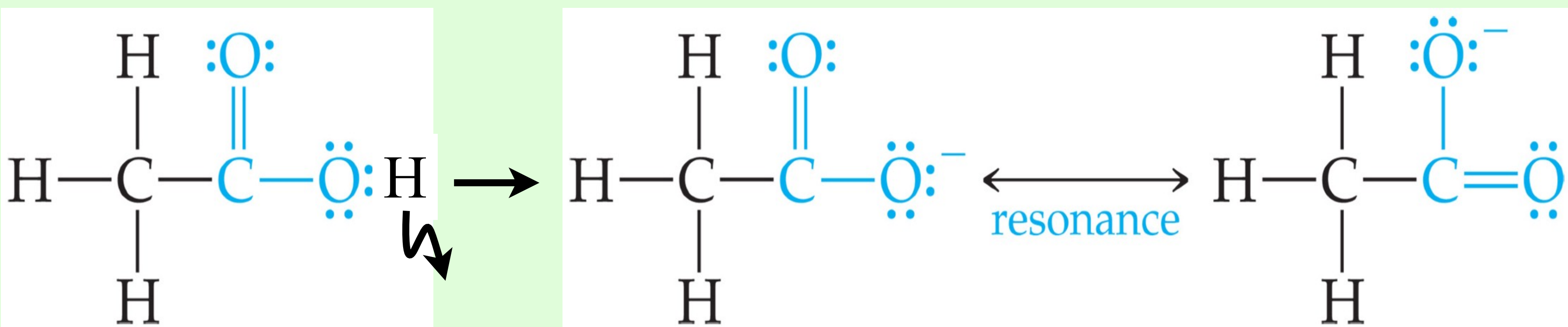
Acetic Acid -COOH functional group

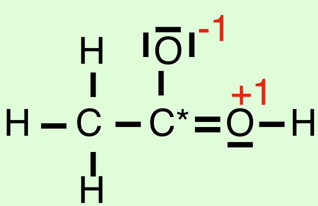
- Which H do you suppose is the acidic proton?
- Bond length studies indicate that the lengths of the carbon oxygen bonds in acetic acid are different lengths, yet in the conjugate base, the carbon oxygen bonds are the same length. Why?



Acetic Acid, stable conjugate base

- After the H^+ ionizes, the C=O and C−O bonds can exhibit resonance
  - ✓ Resonance is the relocation electrons in an available nearby location resulting in an “averaging” of the structures.
- Resonance allows the electrons to “spread out,” distributing the charge and stabilizing the conjugate base.





This resonance structure for the acid molecule would not be equivalent because of formal charge.
The structure above left has NO formal charge.

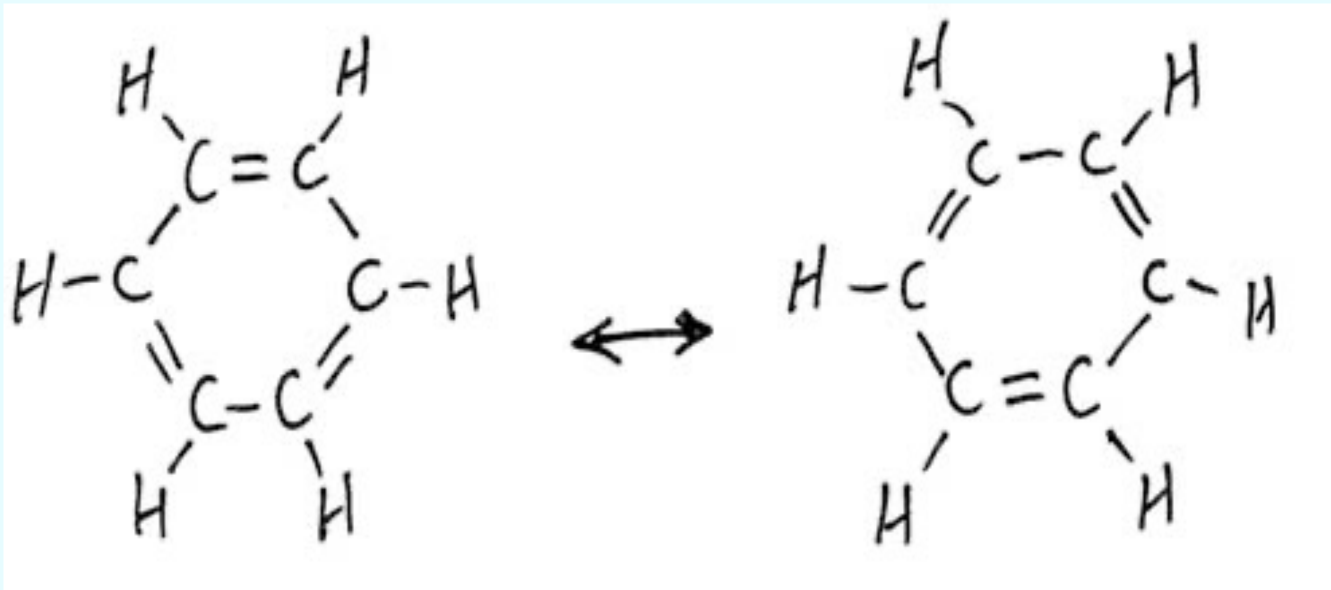
Draw a Lewis structure for benzene, a 6 carbon *ring* structure C_6H_6

4x6 + 1x6 = 30e

...now build one with your partner

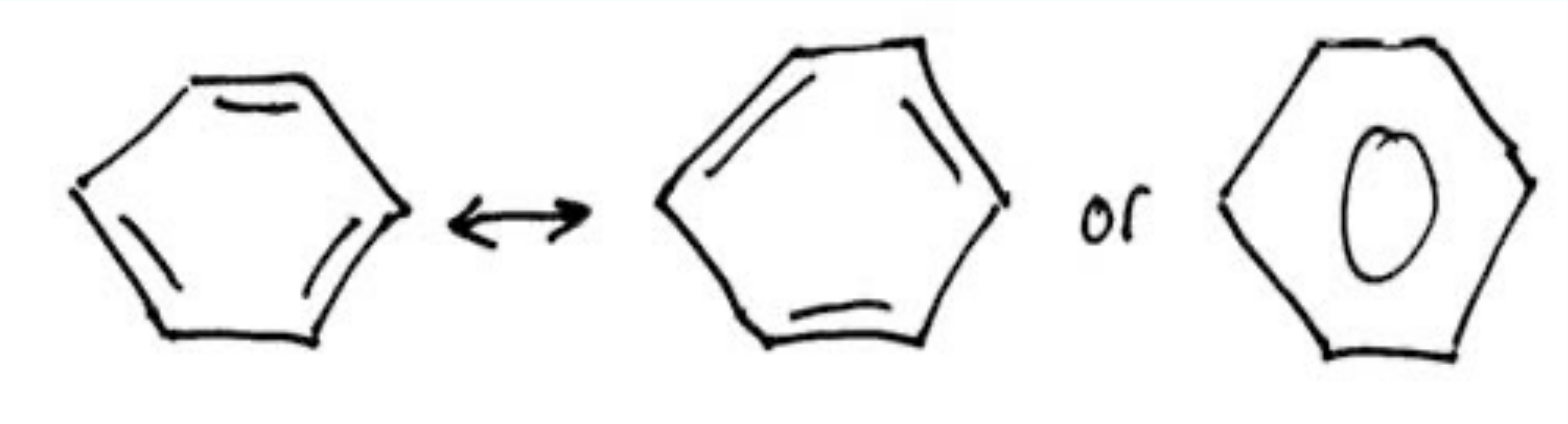
What do you notice about the 3-D shape of this molecule?

Resonance in Benzene: C_6H_6



- C_6H_6 with 30 valence electrons - make a ring structure - double bonds will be necessary.
- The molecule does not flip between the two structures, but is an average of the two.
- The electrons are delocalized (smeared)
- What would you expect about the carbon-carbon bond lengths?

Representing Benzene: C_6H_6



- The carbon-carbon bonds are all the same length
- This is an alternative way of representing carbon structures.
- At each corner the appropriate number of hydrogens are attached.
- The circle structure on the right emphasizes the delocalization (smearing) of the electrons.

More Lewis Structures

1A						8A
1 H 1.01	3A	4A	5A	6A	7A	2 He 4.0
	5 B 10.0	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
		14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
			33 As 74.9	34 Se 79.0	35 Br 79.9	36 Kr 83.8
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					85 At 210	86 Rn 222

1. NH_3

2. NH_4^+

3. CO_2

no need to draw resonance structures unless asked in some (explicitly or implicitly) and formal charge only when asked explicitly

Lewis Structures

1A	3A	4A	5A	6A	7A	8A
1 H 1.01						2 He 4.0
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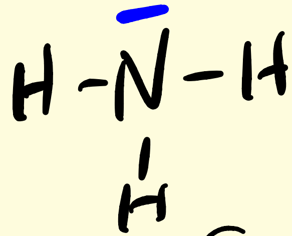
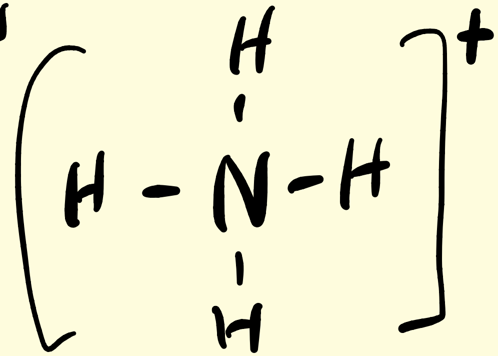
1. NH_3

5 + 1x3 = 8e



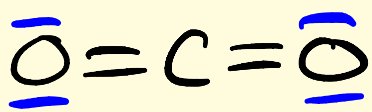


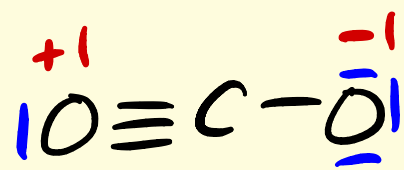
2. NH_4^+

5 + 1x4 – 1 = 8e

3. CO_2

4 + 6x2 = 16e





not an equivalent resonance structure because of formal charge

no need to draw resonance structures unless asked in some (explicitly or implicitly) and formal charge only when asked explicitly

Lewis Structures

multibond?
less than octet

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		14 Si 28.1	15 P 31.0	16 S 32.1	17 Cl 35.5	18 Ar 39.9
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1. BF_3

2. PF_5

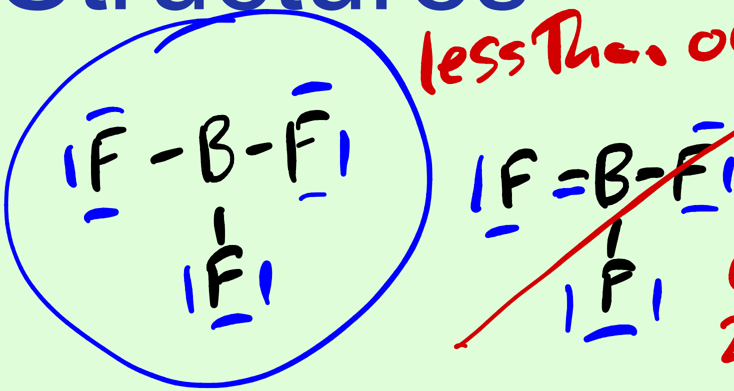
expanded
octed

3. SF_6

Lewis Structures

1. BF_3

3 + 7x3 = 24e



less than octet

multibond?
less than octet

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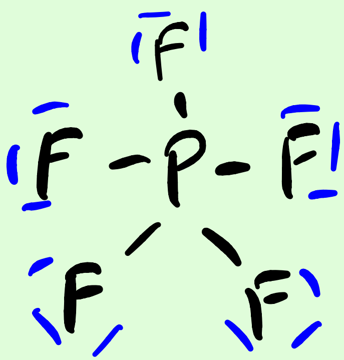
elements in 2nd period can NOT have an expanded octet.

2. PF_5

5 + 7x5 = 40e

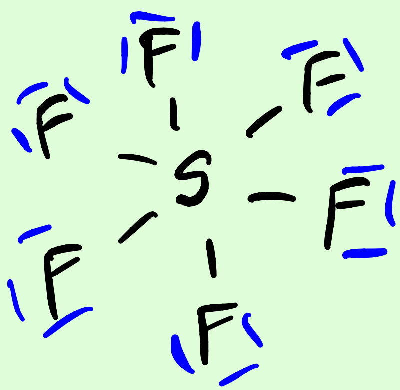


Expanded octet

expanded
octed

3. SF_6

6 + 7x5 = 48e



Lewis Structures

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1. SO_2

resonance
formal
charge

2. CO_2

resonance
bond lengths

3. CO_3^{2-}

4. NO

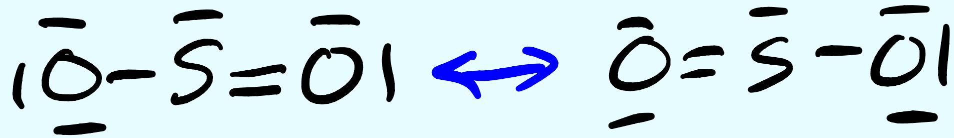
free
radicals

Lewis Structures

resonance only if asked

1. SO_2

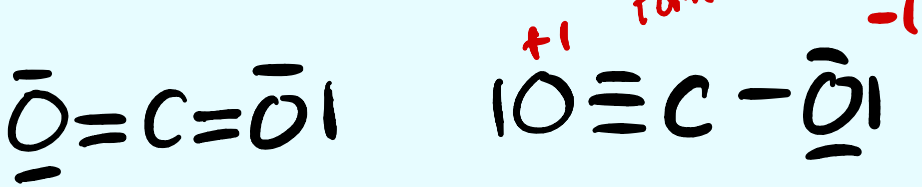
$6 + 6x2 = 18e$



2. CO_2

$4 + 6x2 = 16e$

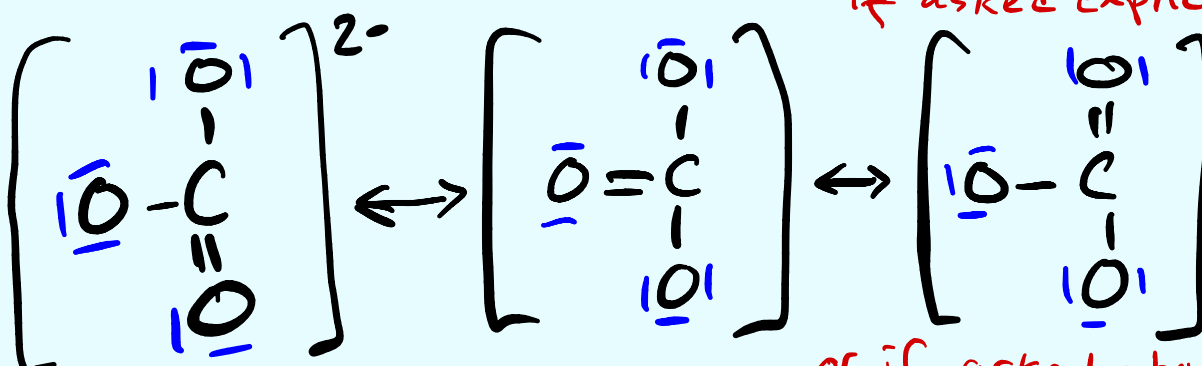
Formal charge



Resonance structures only need to be drawn if asked explicitly

3. CO_3^{2-}

$4 + 6x3 + 2 = 24e$



resonance
bond lengths

or if asked about bond length

4. NO

$5 + 6 = 11e$!
oh oh an odd #

see the next slides

free
radicals

1A							8A
1 H 1.01		3A	4A	5A	6A	7A	2 He 4.0
		5 B 10.0	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
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resonance
formal
charge

Free Radicals

Odd Number of Electrons

Odd Number of Electrons

Exception to the Octet Rule

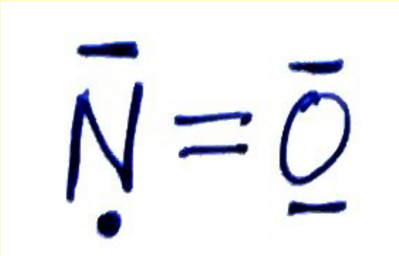
- Put fewer electrons on an atom NOT more.
  - ✓ *(there would not be an orbital available to hold more than 8)*
- Sketch a Lewis Structure for
  - ✓ NO and NO_2

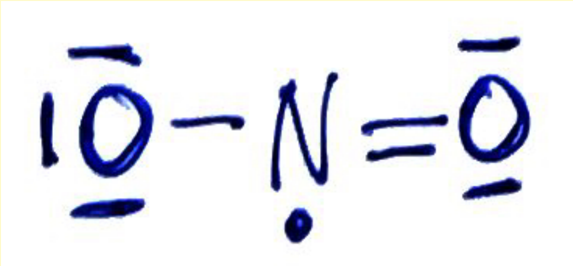
5 + 6 = 11e   5 + 6x2 = 17e

Odd Number of Electrons

Exceptions to the Octet Rule

- Put fewer electrons on an atom NOT more.
  - ✓ *(there would not be an orbital available to hold more than 8)*
- The less electronegative atom, nitrogen ends up with less electrons



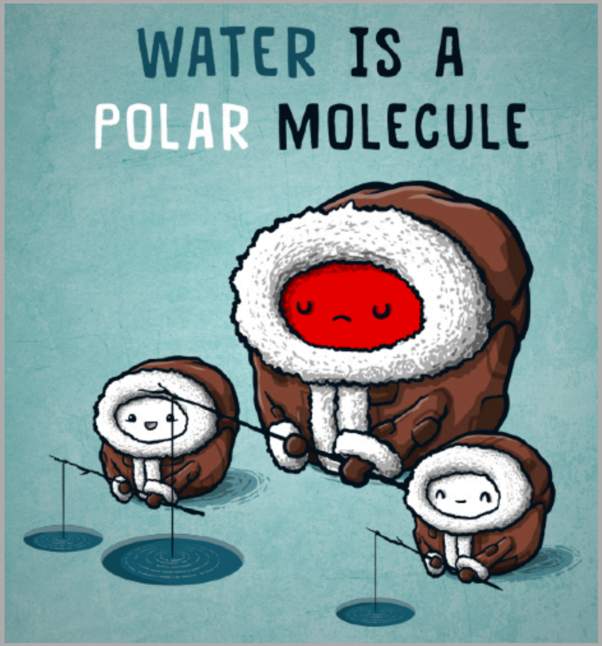


Odd Number of Electrons
Free Radicals

- Free radicals are very unstable and react quickly with other compounds, trying to capture the needed electron to gain stability.
- Generally, free radicals attack the nearest stable molecule, "stealing" an electron or stealing an atom with an electron.
- When the "attacked" molecule loses an electron, or an atom with an electron, that molecule becomes a free radical itself, beginning a chain reaction.
- Once the process is started, it can cascade, often resulting in the disruption of important molecules.

Polarity

Unequal Sharing of Electrons



Electronegativity

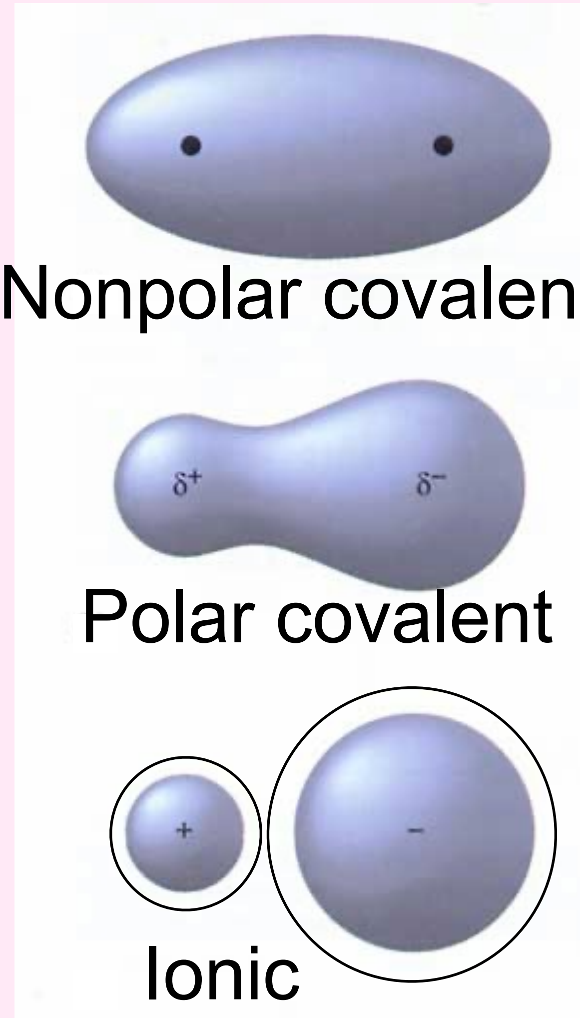
- The ability of an atom to attract electrons to itself in a chemical bond.
  - ✓ This number is not measured, it is determined by committee after analyzing measurements & properties of atoms.
  - ✓ A scale of 0 - 4 is used.
- Increases up and to the right on the periodic chart.

1A	3A	4A	5A	6A	7A	8A
1 H 2.1						2 He --
	5 B 2.0	6 C 2.5	7 N 3.0	8 O 3.5	9 F 4.0	10 Ne --
		14 Si 1.8	15 P 2.2	16 S 2.5	17 Cl 3.0	18 Ar
			33 As 2.0	34 Se 2.4	35 Br 2.8	36 Kr 3.0
				52 Te 2.1	53 I 2.5	54 Xe 2.6
					85 At 2.2	86 Rn --

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

The result of uneven sharing of electrons.

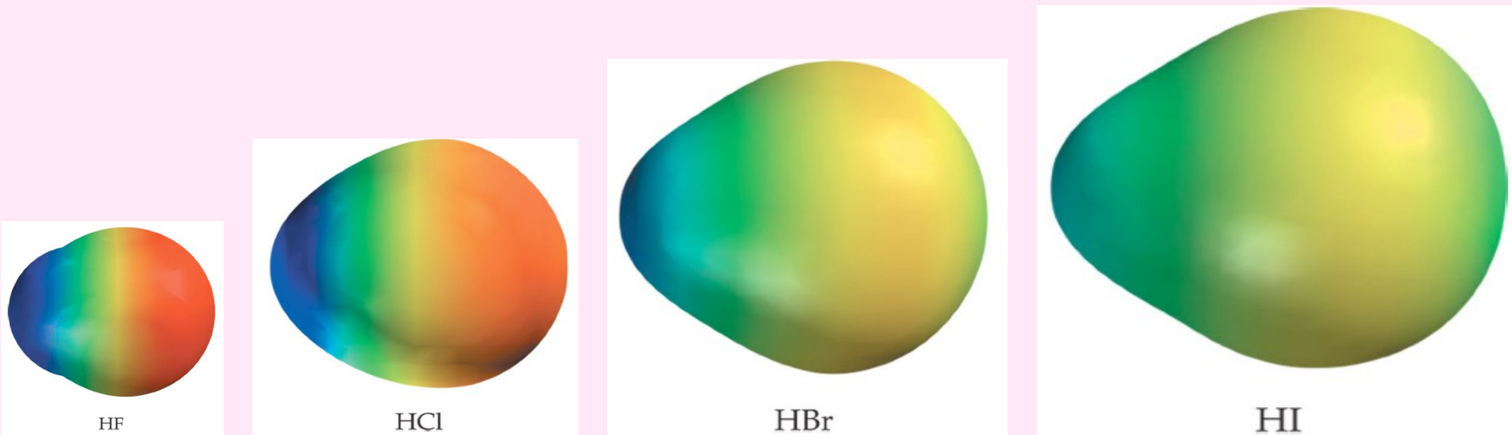


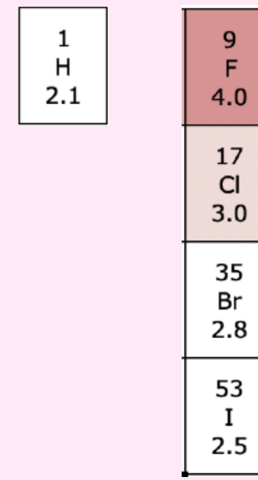
How should you symbolize bond polarity?

$\overset{\delta+}{H}—\overset{\delta-}{F}$ or $\overset{\longmapsto}{H—F}$

Hydrogen-Halogen Series

- Larger halogen atoms have smaller electronegativity.
- Difference in electronegativity decreases between H−halogen.
- Therefore polarity decreases and the measured dipole moment is smaller, measured in debyes.





Compound	Bond Length (Å)	Electronegativity Difference	Dipole Moment (D)
HF	0.92	1.9	1.82
HCl	1.27	0.9	1.08
HBr	1.41	0.7	0.82
HI	1.61	0.4	0.44

Polarity

Draw a Lewis Structure
Decide on the polarity of the bonds
Build/Sketch the molecule
Determine and explain the polarity of the molecule

You will only be asked about the polarity of molecules NOT polyatomic ions

1. CO_2

2. SO_2

3. OH_2

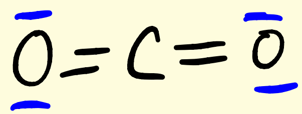
Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

The two dipoles are symmetrically opposed in the linear geometry and will cancel out, resulting in a NONpolar molecule

1. CO_2

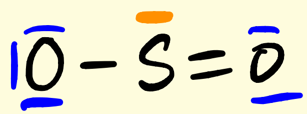
4 + 6x2 = 16e

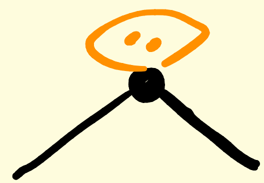


The 3 e⁻ domains on the central S are arranged in an trigonal planar, but the 1 unshared e⁻ pair causes a bent molecular geometry in which the S–O dipoles are NOT symmetrically opposed and will NOT cancel out, resulting in a POLAR molecule.

2. SO_2

6 + 6x2 = 18e

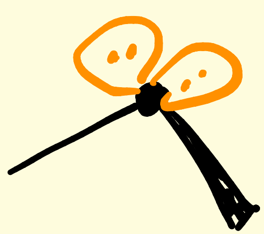




3. OH_2

6 + 1x2 = 8e

H_2O



The 4 e⁻ domains on the central O are arranged in an tetrahedron, but the 2 unshared e⁻ pairs cause a bent molecular geometry in which the O–H dipoles are NOT symmetrically opposed and will NOT cancel out, resulting in a POLAR molecule.

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

Draw a Lewis Structure
Decide on the polarity of the bonds
Build/Sketch the molecule
Determine and explain the polarity of the molecule

You will only be asked about the polarity of molecules NOT polyatomic ions

1. NH_3

2. CH_2O

3. CF_4

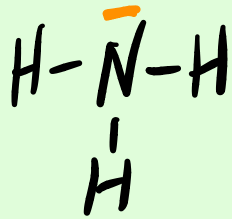
Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

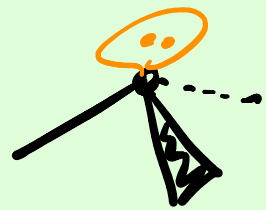
Polarity

The 4 e⁻ domains on the central N are arranged in an tetrahedron, but the 1 unshared e⁻ pair causes a trigonal pyramid molecular geometry in which the N–H dipoles are NOT symmetrically opposed and will NOT cancel out, resulting in a POLAR molecule.

1. NH_3

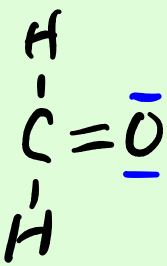
$5 + 1x3 = 8e$

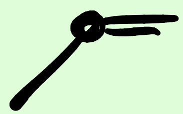




2. CH_2O

$4 + 1x2 + 6 = 12e$

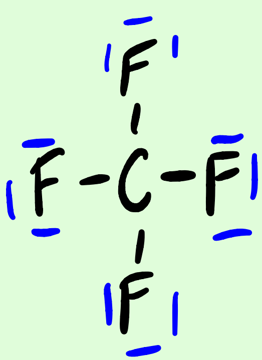


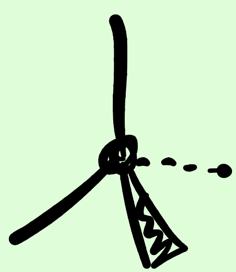


The C=O polar bond is NOT symmetrically opposed by an equivalent polar bond in the trigonal planar geometry and will cancel NOT out, resulting in a POLAR molecule

3. CF_4

$4 + 7x4 = 32e$





The four dipoles are symmetrically opposed in the tetrahedral geometry and will cancel out, resulting in a NONpolar molecule

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

Draw a Lewis Structure
Decide on the polarity of the bonds
Build/Sketch the molecule
Determine and explain the polarity of the molecule

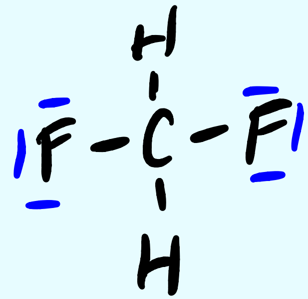
You will only be asked about the polarity of molecules NOT polyatomic ions

1. CH_2F_2

2. CH_3F

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

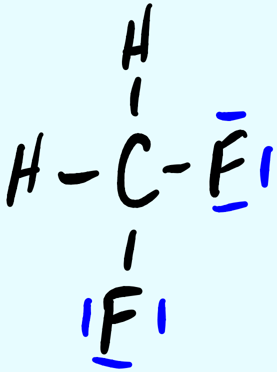
Polarity

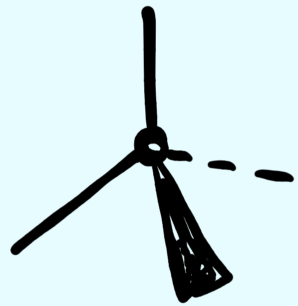


← F's on opposite sides could lead to an incorrect conclusion.

1. CH_2F_2

4 + 1x2 + 7x2 = 20e

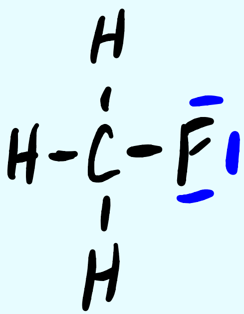


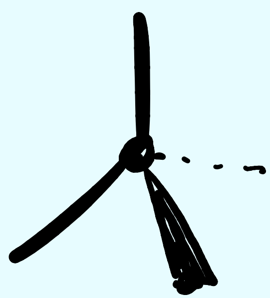


In a tetrahedron the two C–F dipoles can NOT be symmetrically opposed and will NOT cancel out, resulting in a POLAR molecule

2. CH_3F

4 + 1x3 + 7 = 14e





In the tetrahedron the single C–F dipole is NOT symmetrically opposed by the nonpolar C– H bonds and will NOT cancel out, resulting in a POLAR molecule

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

Draw a Lewis Structure
Decide on the polarity of the bonds
Build/Sketch the molecule
Determine and explain the polarity of the molecule

You will only be asked about the polarity of molecules NOT polyatomic ions

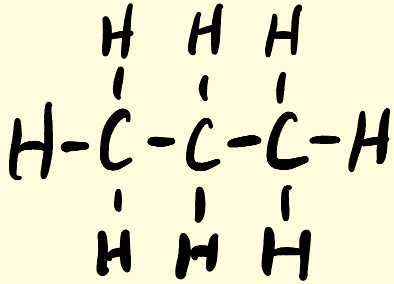
1. C_3H_8

2. C_3H_7OH

3. CH_3OCH_3

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

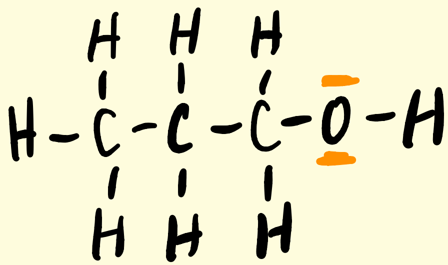
Polarity

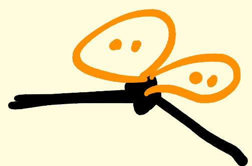


C–H bonds are all geometrically opposed and are considered nonpolar resulting in a nonpolar molecule.

1. C_3H_8

$4x3 + 1x8 = 28e$

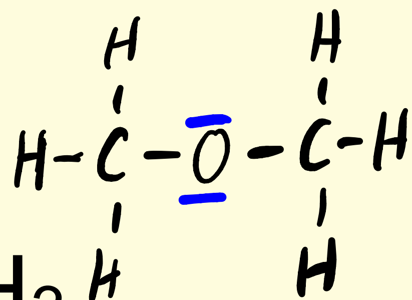




The two unshared e⁻ pairs on the oxygen atom result in a bent geometry, making the O–H and C–O bonds NOT symmetrically opposed, and will NOT cancel out, resulting in a POLAR molecule.

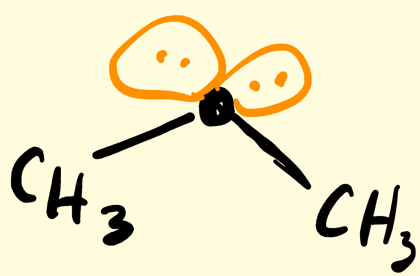
2. C_3H_7OH

$4x3 + 1x8 + 6 = 26e$



3. CH_3OCH_3

$4x2 + 1x6 + 6 = 20e$



The two unshared e⁻ pairs on the oxygen atom result in a bent geometry, making the C–O bonds NOT symmetrically opposed, and will NOT cancel out, resulting in a POLAR molecule.

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

Draw a Lewis Structure
Decide on the polarity of the bonds
Build/Sketch the molecule
Determine and explain the polarity of the molecule

You will only be asked about the polarity of molecules NOT polyatomic ions

1. SF_6

2. SF_4

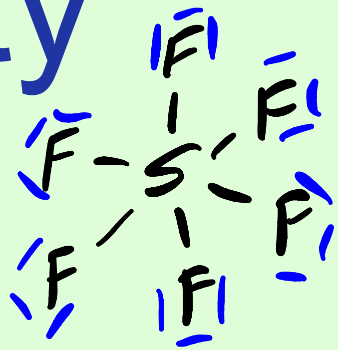
3. ClF_3

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

1. SF_6

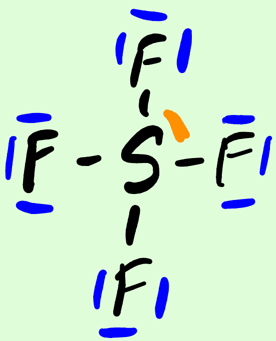
$6 + 7x6 = 48e$

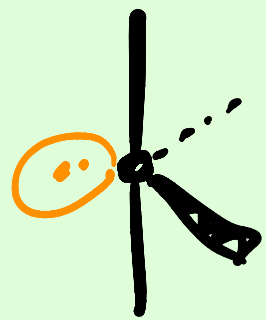


The six dipoles arranged in an octahedron are symmetrically opposed and will cancel out, resulting in a NONpolar molecule

2. SF_4

$6 + 7x6 = 34e$

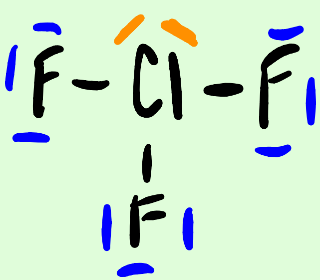


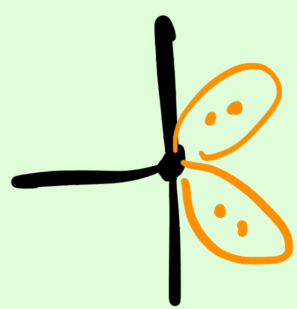


The 5 e domains on the central S are arranged in an trigonal bipyramid, but the 1 unshared e^- pair causes a see-saw molecular geometry in which the S–F dipoles are NOT symmetrically opposed and will NOT cancel out, resulting in a POLAR molecule.

3. ClF_3

$7 + 7x3 = 28e$





The 5 e domains on the central Cl are arranged in a trigonal bipyramid, but the 2 unshared e^- pairs cause a T-shape molecular geometry in which the Cl–F dipoles are NOT symmetrically opposed and will NOT cancel out, resulting in a POLAR molecule.

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

Draw a Lewis Structure
Decide on the polarity of the bonds
Build/Sketch the molecule
Determine and explain the polarity of the molecule

You will only be asked about the polarity of molecules NOT polyatomic ions

1. PCl_5

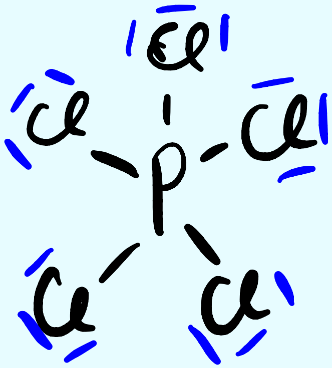
2. BrF_5

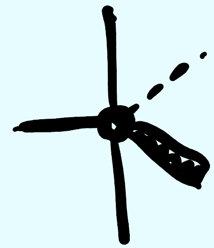
Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

1. PCl_5

5 + 7x5 = 40e

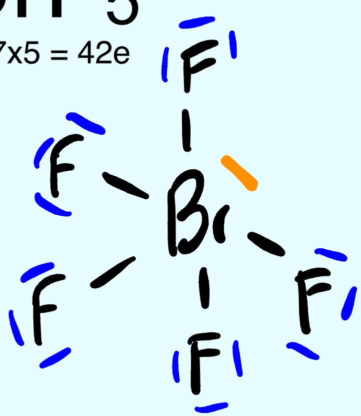




The five P–Cl dipoles arranged in a trigonal bipyramid are symmetrically opposed and will cancel out, resulting in a NONpolar molecule

2. BrF_5

7 + 7x5 = 42e



The 6 e domains on the central Br are arranged in an octahedron, but the 1 unshared e pair causes a square pyramid molecular geometry in which the Br–F dipoles are NOT symmetrically opposed and will NOT cancel out, resulting in a POLAR molecule.

Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity

Draw a Lewis Structure
Decide on the polarity of the bonds
Build/Sketch the molecule
Determine and explain the polarity of the molecule

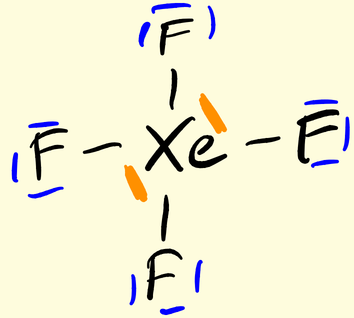
You will only be asked about the polarity of molecules NOT polyatomic ions

1. XeF_4

2. KrF_2

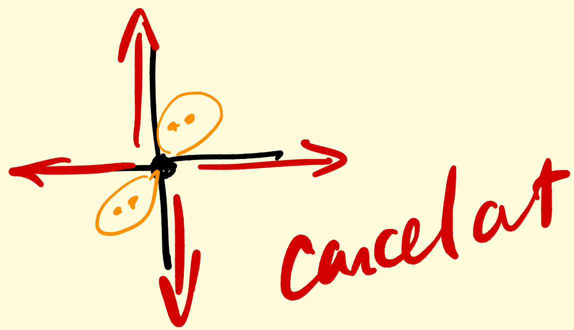
Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

Polarity



1. XeF_4

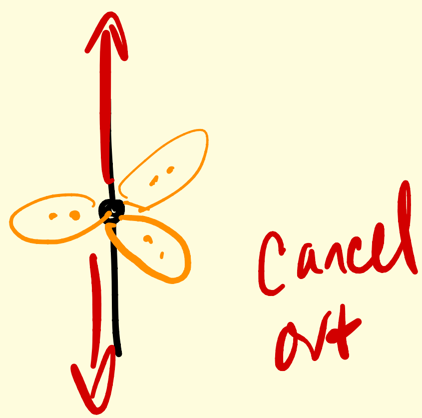
8 + 7x4 = 36e



The 6 e domains on the central Xe are arranged in an octahedron, but the 2 unshared e pairs cause a square planar molecular geometry in which the Xe–F dipoles are symmetrically opposed and will cancel out, resulting in a NONpolar molecule.

2. KrF_2

8 + 7x2 = 22e

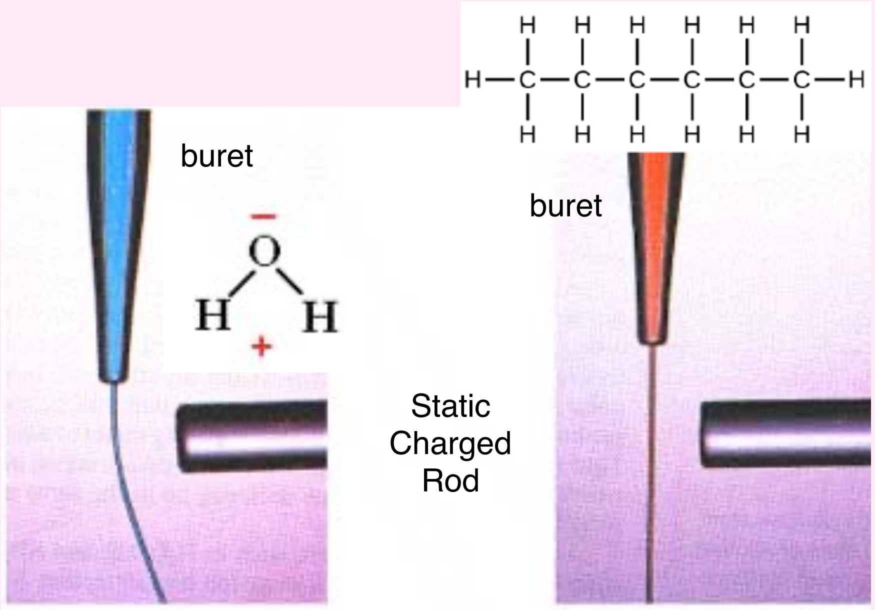


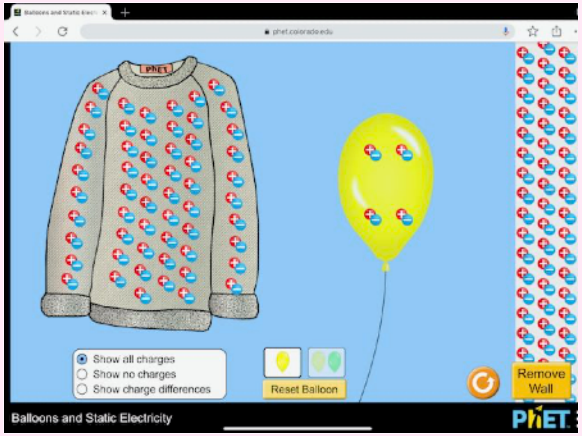
The 5 e domains on the central Kr are arranged in an trigonal bipyramid, but the 3 unshared e^- pairs causes a linear molecular geometry in which the Kr–F dipoles are symmetrically opposed and will cancel out, resulting in a NONpolar molecule.

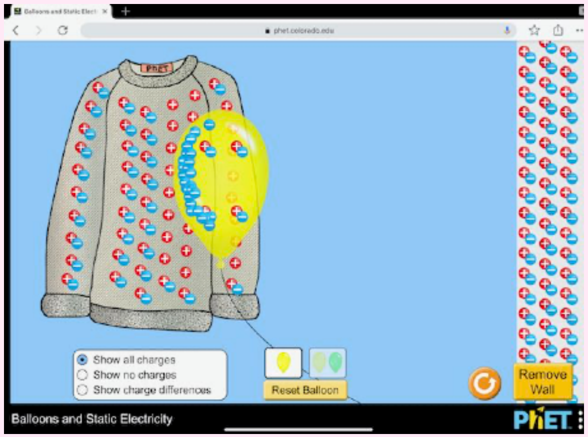
Since you will not have access to electronegativity table on the AP exam, assume bonds made with the two different atoms are polar *except* C–H bonds which will be considered nonpolar or unless you are given some other information that leads you to believe the bond is nonpolar.

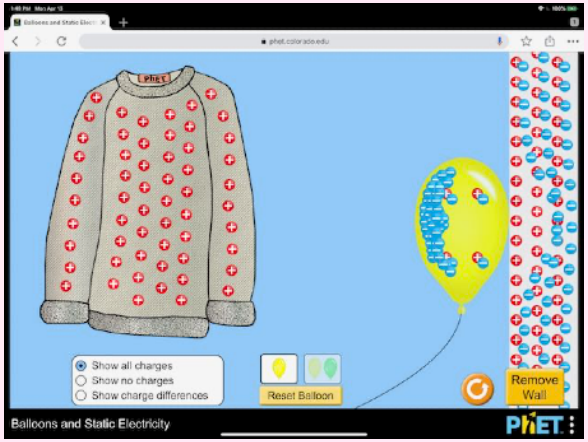
The effect of a charged surface on polar molecules

- The stream of polar water coming from a buret is bent by the charged rod.
- Nonpolar hexane, C_6H_{14} does not bend.
- Google PhET balloon & static electricity simulation







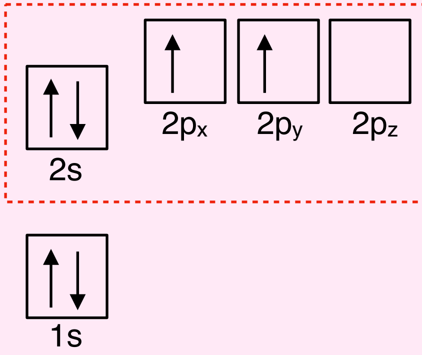


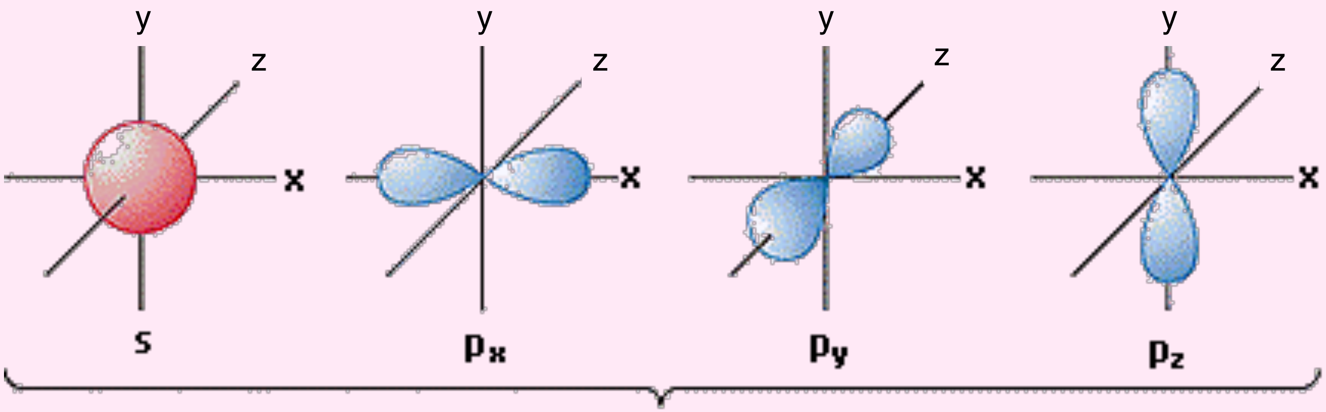
Hybridization

A blend of atomic orbitals to produce bonding orbitals

4 electron domains, sp^3 hybrid

Atomic carbon has 4 valence orbitals that blend to make hybrid orbitals when carbon combines to make CH_4 → C: $1s^2\ 2s^2\ 2p^4$





4 domains always means sp^2 hydridized

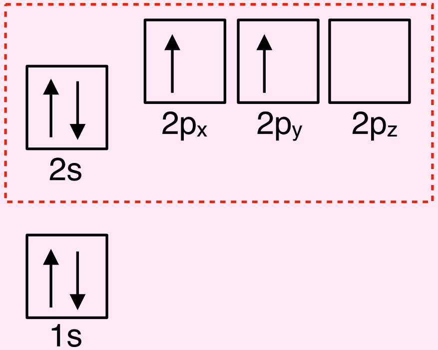
4 atomic orbital blend to produce
4 equivalent hybrid orbitals

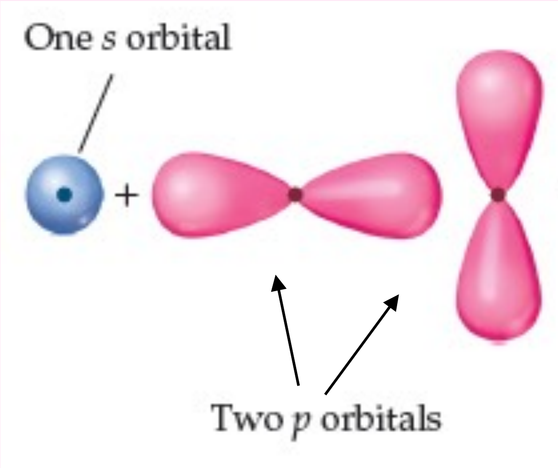
4 equivalent sp^3 hybrid orbitals

CH_4
Tetrahedral

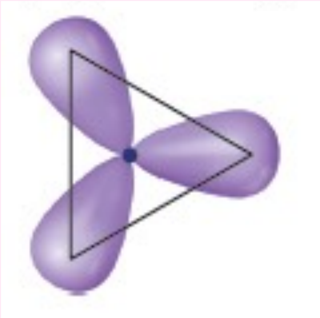
3 electron domains, sp^2 hybrid

Atomic carbon has 4 valence orbitals
but only 3 blend to make 3 hybrid orbitals
when carbon combines to make CH_2O



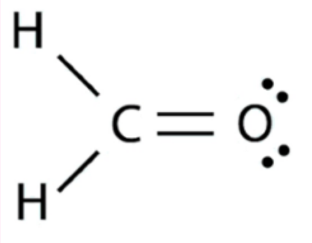


hybridize →



to produce 3 **equivalent**
sp^2 hybrid orbitals

3 domains always
means sp^2 hydridized



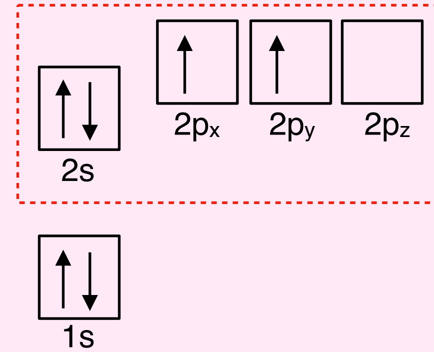
Trigonal Planar CH_2O

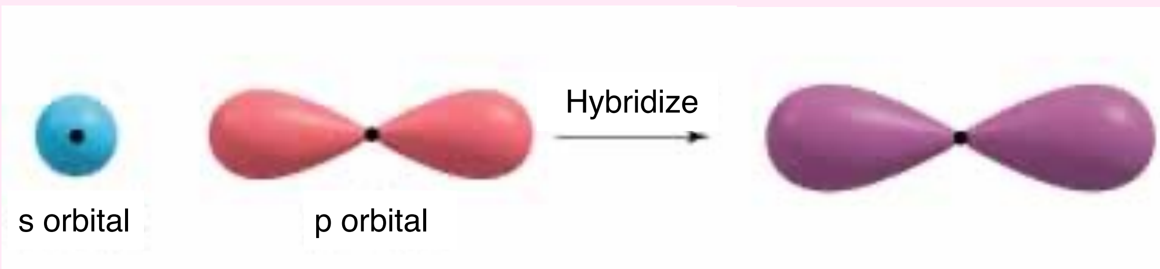
What valence orbital is left over NOT hybridized?

next....

2 electron domains, sp hybrid

Atomic carbon has 4 valence orbitals but only 2 blend to make 2 hybrid orbitals when carbon combines to make C_2H_2





2 domains always means sp hydridized

Linear, C_2H_2

What valence orbitals are left over NOT hybridized?

Summary of Hybrid Orbitals

# domains	Atomic orbitals that morph together	to make equivalent hybrid orbitals	The resulting e⁻ domain shape of the hybrid orbitals
4	s + p + p + p	Four equivalent sp^3 orbitals (containing either sigma (σ) bonds or unshared pairs)	Tetrahedral
3	s + p + p (1 p orbital left unhybridized)	Three equivalent sp^2 orbitals (containing either sigma (σ) bonds or unshared pairs)	Trigonal planar
2	s + p (2 p orbitals left unhybridized)	Two equivalent sp orbitals (containing either sigma (σ) bonds or unshared pairs)	Linear

sigma (σ)

pi (π)

naming bond types

Double and Triple Bonds

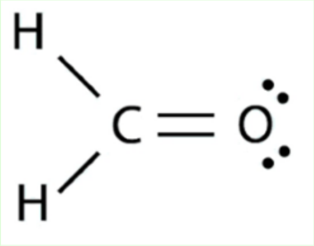
- The overlap region that occurs directly between two nuclei on the *internuclear* axis is called a sigma bond (σ)
  - ✓ All single bonds are called sigma bonds (σ)

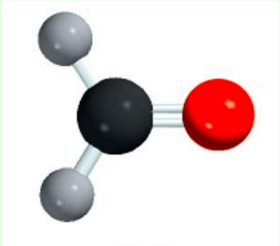
- The electrons above and below the sigma (σ) bond made from un-hybridized p orbital(s) is(are) called a pi (π) bond(s)
  - ✓ All double bonds are made of one sigma bond and one pi bond
  - ✓ All triple bonds are made of one sigma bond and two pi bonds

Formaldehyde CH_2O

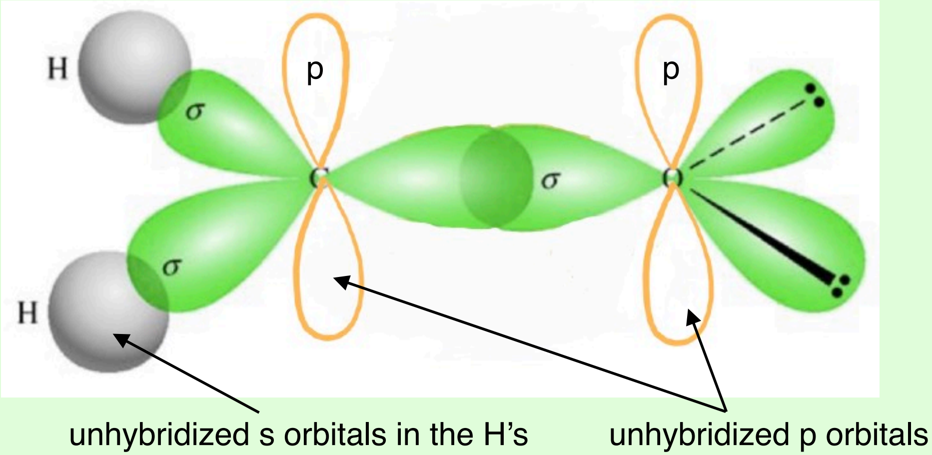
- Let's take a closer look at what's going on around the carbon in CH_2O.
  - ✓ Sketch the Lewis structure
  - ✓ How many domains around the carbon? How many domains around the oxygen?
  - ✓ What is the shape of the electron domains around the carbon and around the oxygen?
  - ✓ What is the molecular geometry around the carbon?
  - ✓ What is the name of the hybrid orbitals?
  - ✓ How many σ bonds? How many π bonds?

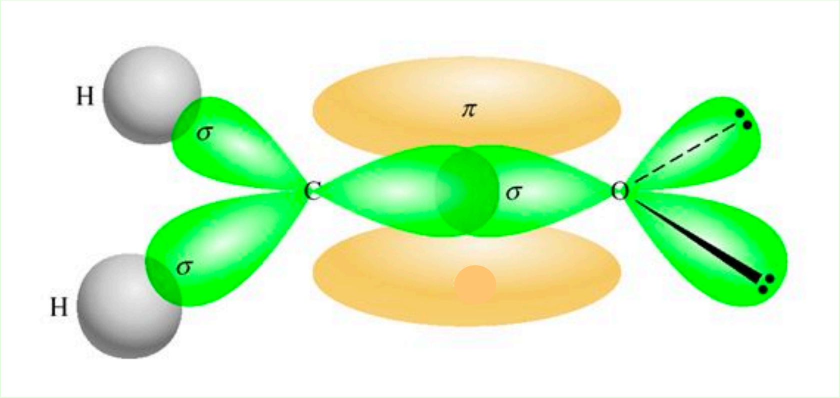
Formaldehyde CH_2O





- Both the oxygen and carbon form their own 3 equivalent sp^2 hybrid orbitals.
- One of the sp^2 hybrids makes part of the double bond, the sigma (σ) part.
- The carbon uses the other 2 sp^2 to make sigma (σ) bonds with the H's.
- The oxygen uses its other 2 sp^2 to hold the two unshared pairs.
- The unhybridized p orbital from the C and the O overlap to form the other half of the double bond, the pi (**π**) part.
- The "hot dog bun" bond !





Draw a Lewis structure for N_2

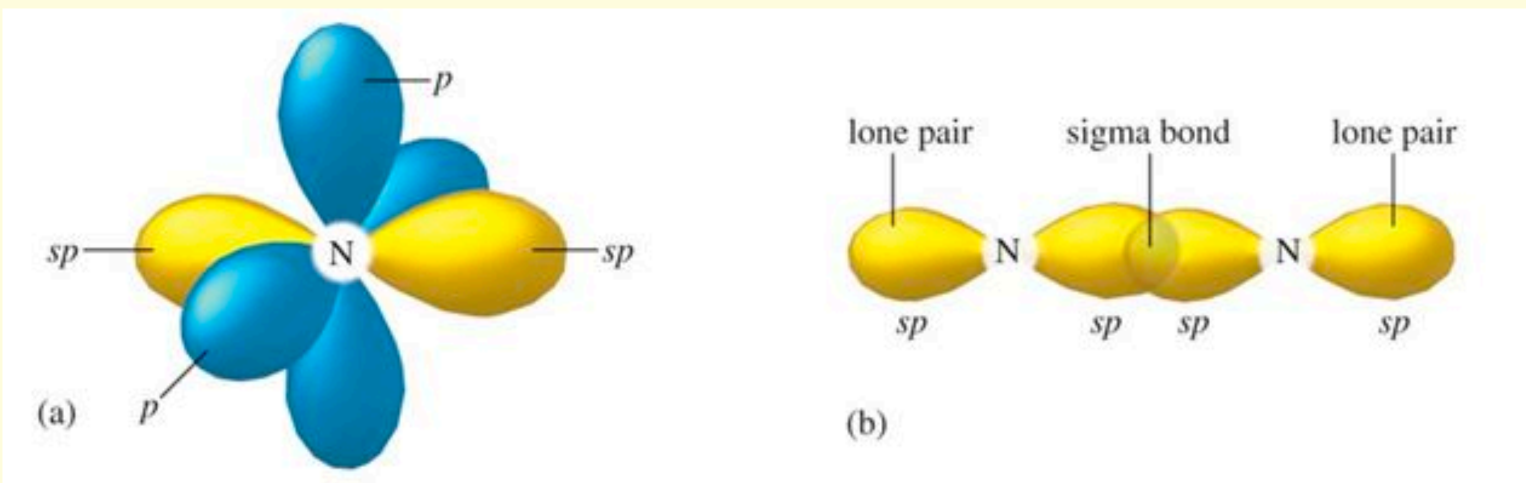
- Let's take a closer look at what's going on around the nitrogens.
  - ✓ Sketch the Lewis structure
  - ✓ How many domains around each nitrogen?
  - ✓ What is the shape of the electron domains around the nitrogens?
  - ✓ What is the molecular geometry around the carbon?
  - ✓ What is the name of the hybrid orbitals?
  - ✓ How many σ bonds? How many π bonds?

Draw a Lewis structure for N_2

- What is the hybridization of each N?

IN≡NI

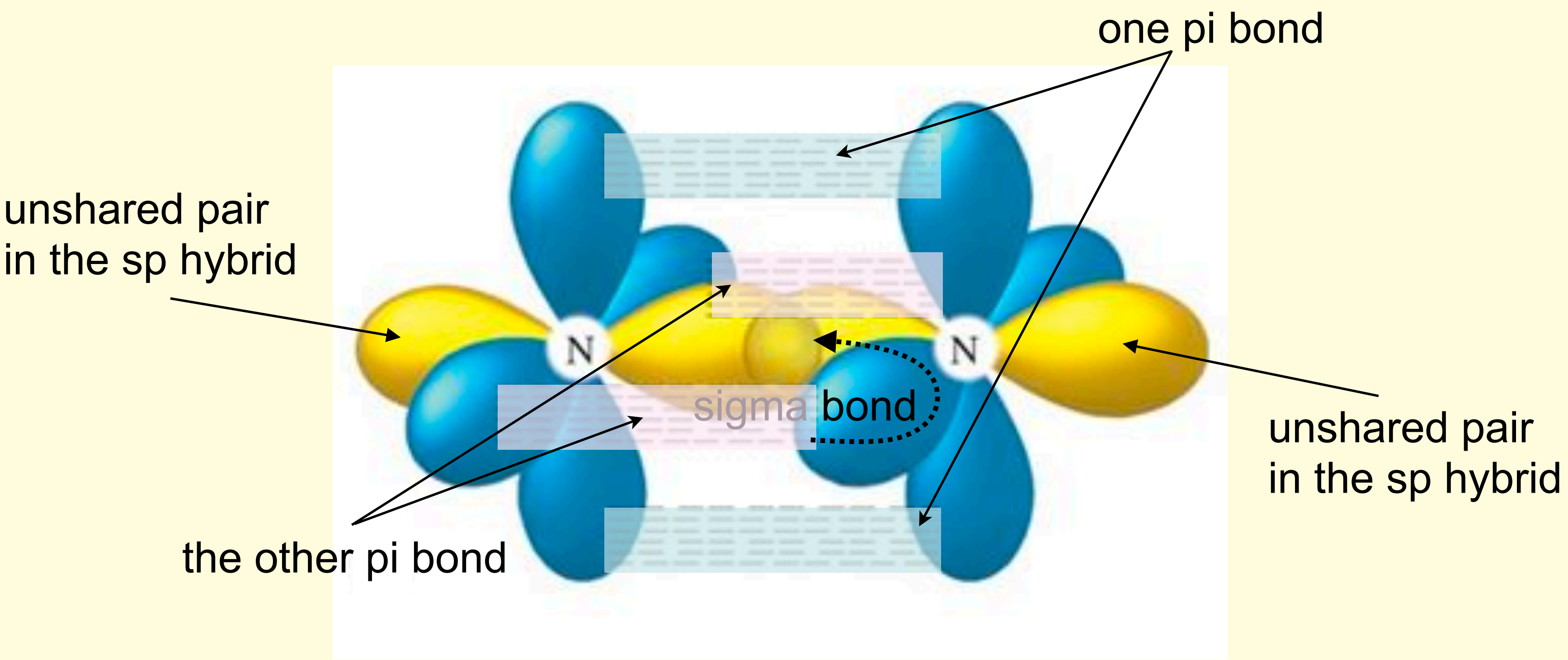
  - ✓2 e⁻ domains always indicates sp hybridization
  - ✓ The diagram on left shows the two yellow sp hybrid orbitals and the two (not 4) unhybridized p orbitals
  - ✓ The diagram on the right shows the sigma (σ) overlap of the sp hybrid orbitals to make up one third of the triple bond.



Now let’s put both nitrogens together....

Bonding in N_2

- pi orbitals overlap above and below the internuclear axis.
- Two "hot dog bun" bonds !

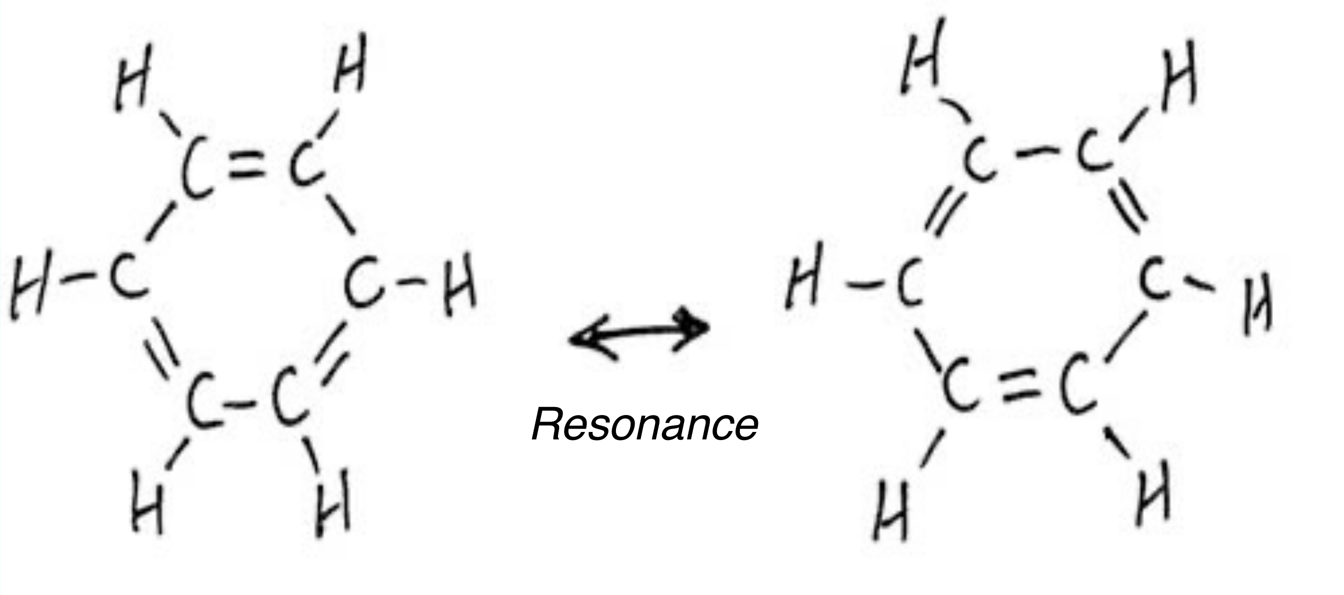


Lewis structure for benzene C_6H_6 ?

- Let's take a closer look at what's going on around the carbons.
  - ✓ Sketch the Lewis structure.
  - ✓ How many electron domains around each carbon?
  - ✓ What is the shape of the electron domains around the C's?
  - ✓ What is the molecular geometry around the carbons?
  - ✓ What is the name of the hybrid orbitals around the C's?
  - ✓ How many σ bonds? How many π bonds?

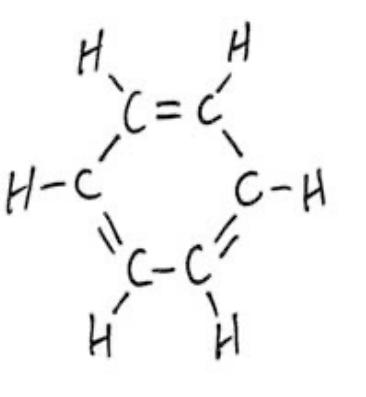
Remember benzene C_6H_6 ?

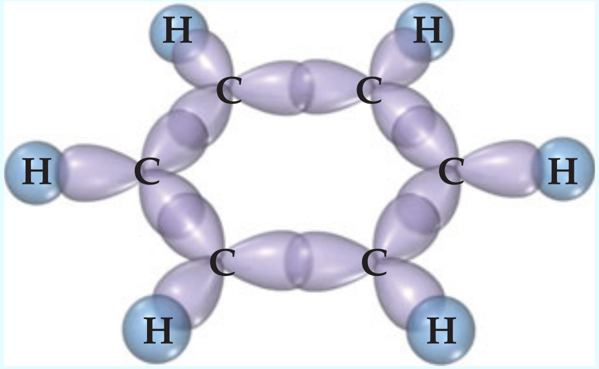
The ringed structure

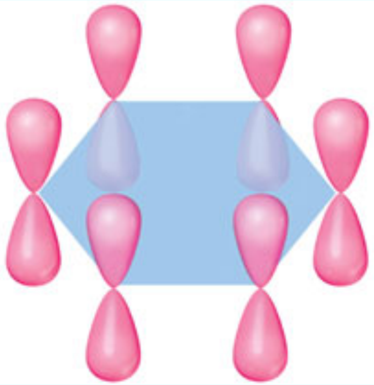


Hybridization and Resonance, C_6H_6

- 3 electron domains around each carbon
- Trigonal planar electron domains around each C
- No unshared pairs so trigonal planar around each C
- Trigonal planar domains are always sp^2 hybrid.
- 12 σ bonds. 3 π bonds

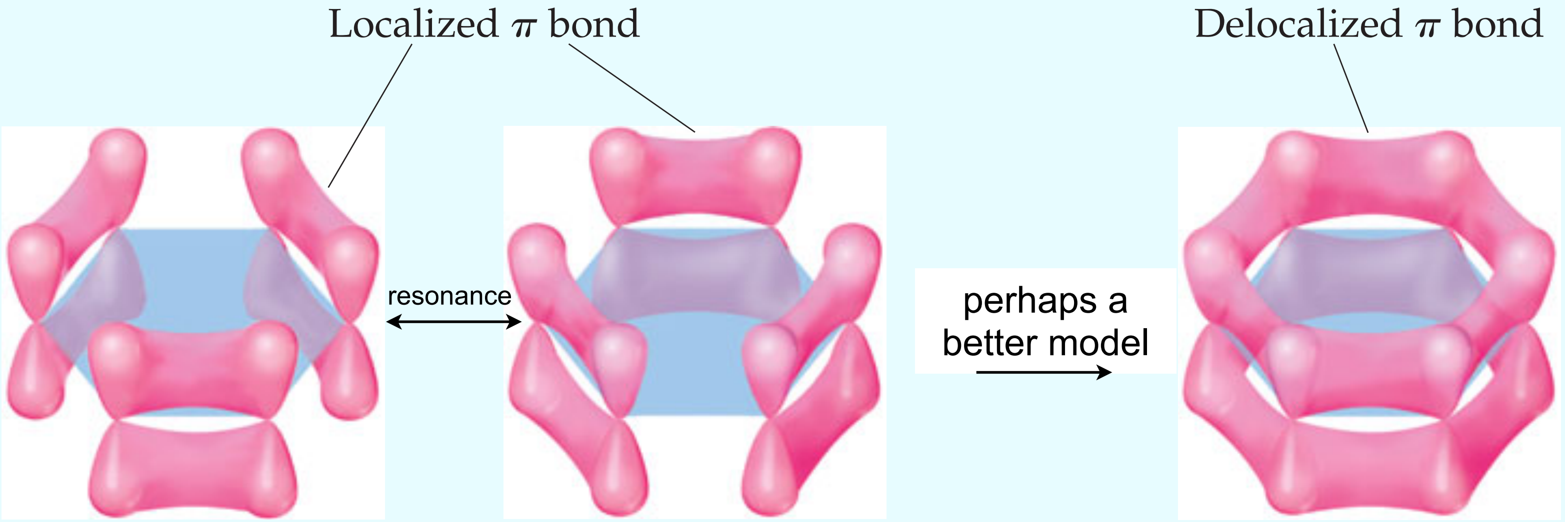






Delocalization of electrons, C_6H_6

- Because of the alternating double bonds you can write resonance structures
- These electrons are said to be "delocalized."
- Delocalization leads to more stable molecules.



Large Molecules

Geometry around specific atoms

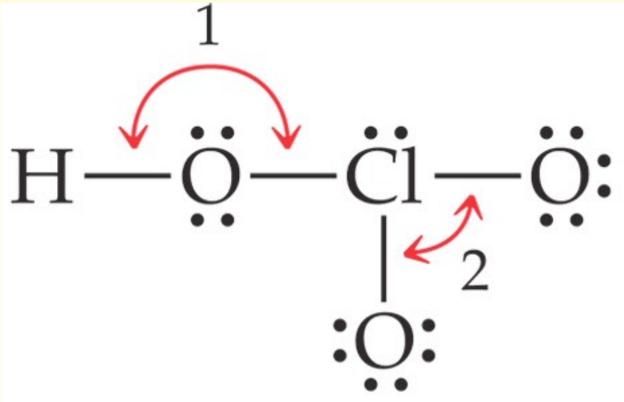
Geometry, Hybridization & σ, π bonds

Around the left O

- Name the electron domain geometry.
  - ✓ tetrahedral
- Name the molecular geometry (shape).
  - ✓ bent
- Give the bond angle
  - ✓ <<109.5º
- Name the hybridization orbitals.
  - ✓ sp^3
- List the number of σ and π bonds.
  - ✓ 2 σ bonds, no π bonds

Around the Cl

- Name the electron domain geometry.
  - ✓ tetrahedral
- Name the molecular geometry (shape).
  - ✓ Trigonal pyramid
- Give the bond angle
  - ✓ <109.5º
- Name the hybridization orbitals.
  - ✓ sp^3
- List the number of σ and π bonds.
  - ✓ 3 σ bonds, no π bonds



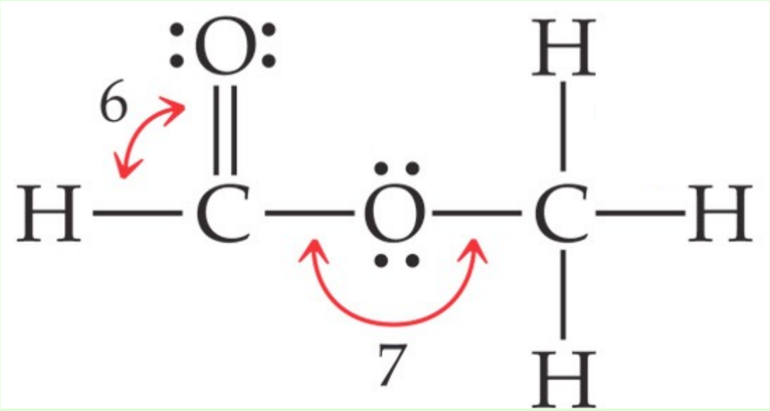
Geometry, Hybridization & σ π bonds

Around the left C

- Name the electron domain geometry.
  - ✓ Trigonal planar
- Name the molecular geometry (shape).
  - ✓ trigonal planar
- Give the bond angle (6)
  - ✓ >120º
- Name the hybridization orbitals.
  - ✓ sp^2
- List the number of σ and π bonds.
  - ✓ 3 σ bonds, 1 π bonds

Around the right O

- Name the electron domain geometry.
  - ✓ tetrahedral
- Name the molecular geometry (shape).
  - ✓ bent
- Give the bond angle (7)
  - ✓ <<109.5º
- Name the hybridization orbitals.
  - ✓ sp^3
- List the number of σ and π bonds.
  - ✓ 2 σ bonds, no π bonds



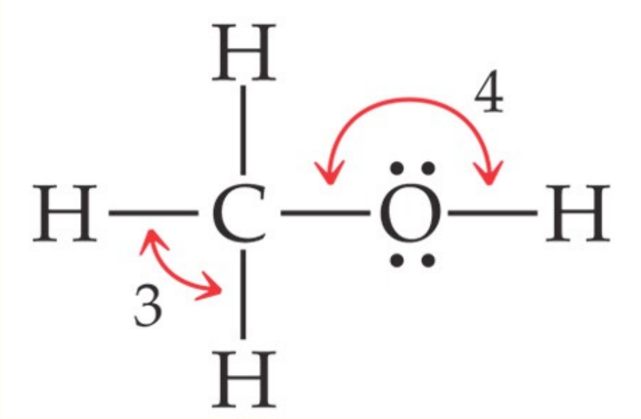
Geometry, Hybridization & σ π bonds

Around the C

- Name the electron domain geometry.
  - ✓ tetrahedral
- Name the molecular geometry (shape).
  - ✓ tetrahedral
- Give the bond angle
  - ✓ 109.5º
- Name the hybridization orbitals.
  - ✓ sp^3
- List the number of σ and π bonds.
  - ✓ 4 σ bonds, no π bonds

Around the O

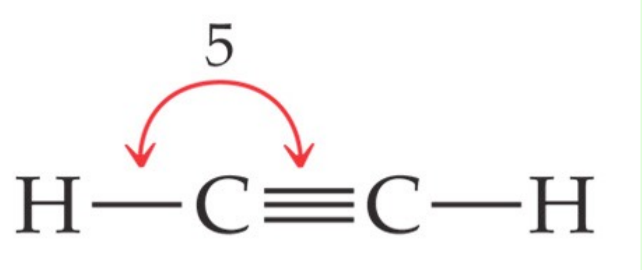
- Name the electron domain geometry.
  - ✓ tetrahedral
- Name the molecular geometry (shape).
  - ✓ bent
- Give the bond angle
  - ✓ <<109.5º
- Name the hybridization orbitals.
  - ✓ sp^3
- List the number of σ and π bonds.
  - ✓ 2 σ bonds, no π bonds



Geometry, Hybridization & σ π bonds

Around the left C

- Name the electron domain geometry.
  - ✓ linear
- Name the molecular geometry (shape).
  - ✓ linear
- Give the bond angle
  - ✓ 180º
- Name the hybridization orbitals.
  - ✓ sp
- List the number of σ and π bonds.
  - ✓ 2 σ bonds, 2 π bonds



Isomers

Same Chemical Formula

Different Arrangement of atoms

Isomers

- Sketch and build the molecule C_2H_6O
- Often presented in two different ways
  - ✓ C_2H_6O
  - ✓ C_2H_5OH
- Draw two different isomers for this molecule.

Isomers

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- Often presented in two different ways
  - ✓ C_2H_6O
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Isomers

- Sketch and build the molecule C_4H_{10}
- Saturated hydrocarbon
  - only C's & H's
  - maximum # of H's = no double bonds
- Draw as many isomers as you can for this molecule.
  - Hint: there are only 2

Isomers of C_4H_{10}

Draw the Lewis structure $C_2H_4F_2$

Build the molecule with your kit.

Select the number of different isomers that can exist for $C_2H_4F_2$

1. 1 structure
2. 2 structures
3. 3 structures
4. 4 structures
5. 5 structures

Select the number of different isomers that can exist for $C_2H_4F_2$

1. 1 structure
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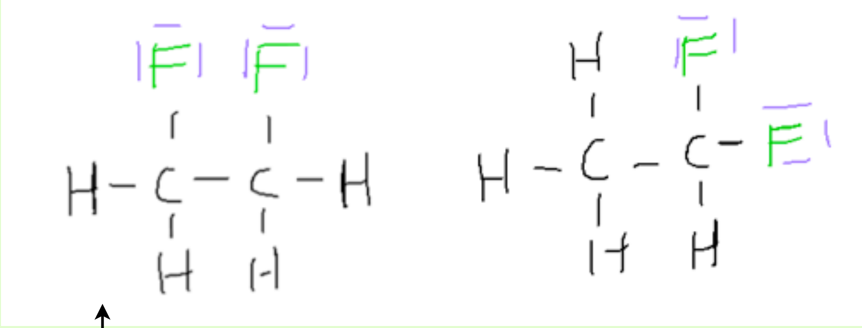
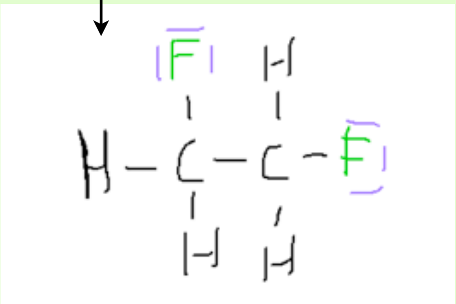


same



This structure is the same as the one above it because of free rotation around the single bond.

Polar molecule? or Nonpolar molecule?

Draw a Lewis structure for $C_2H_2F_2$

Isomer: Two molecules with the same chemical formula, but different structural formula, a different arrangement of atoms.

Can you sketch more than one isomer for $C_2H_2F_2$?

Build them with your model kit.

Of the 3 isomers that exist for $C_2H_2F_2$ how many are polar?

1. 1 structure
2. 2 structures
3. all 3 structures
4. none are polar

Of the 3 isomers that exist for $C_2H_2F_2$ how many are polar?

1. 1 structure
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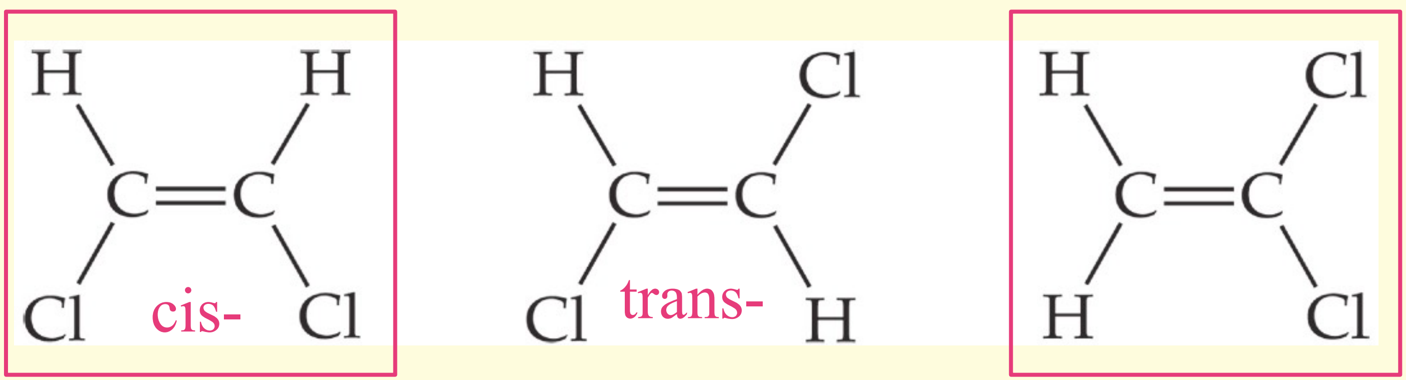
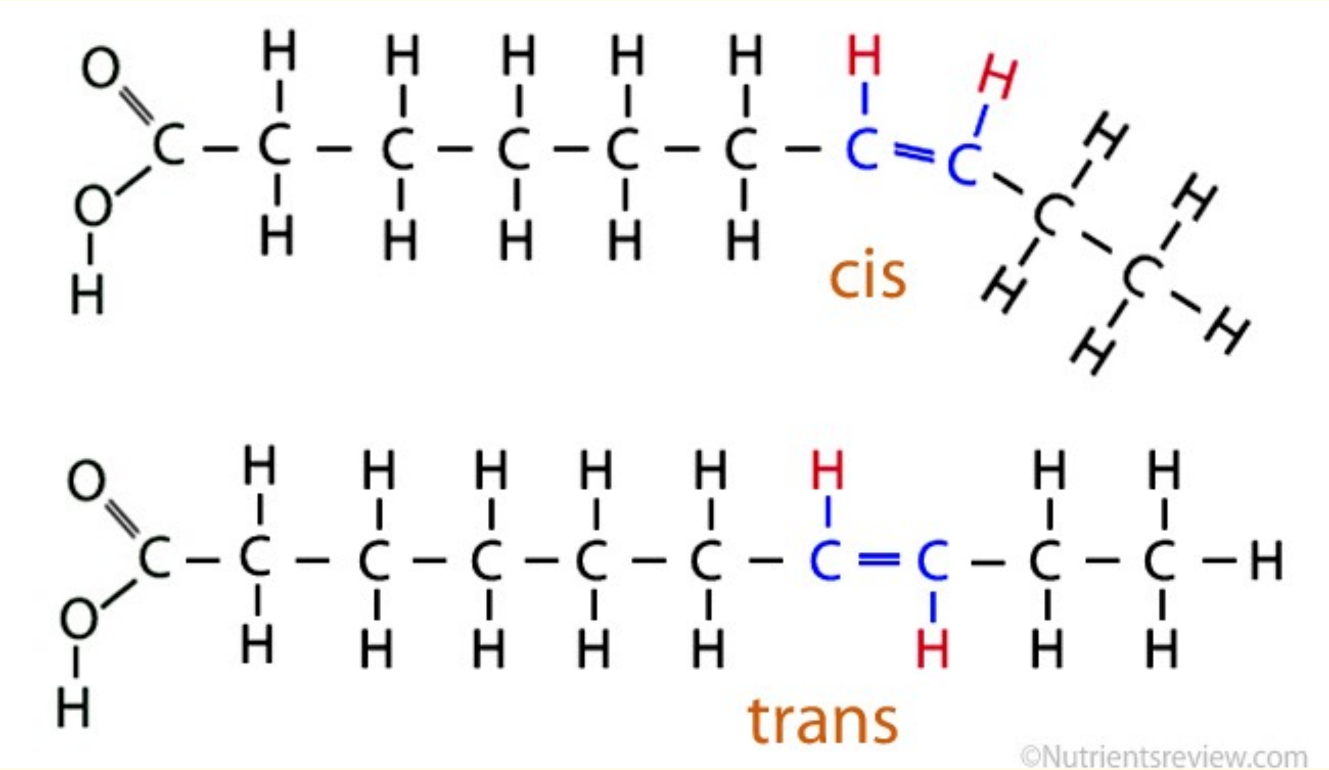


cis-dichloroethene trans dichloroethene 1,1 dichloroethene

Where have you have heard cis- and trans- in reference to molecules before?

cis means same side
trans means opposite side

cis-
and
trans-
fatty acids



This slight change has metabolic implications.

Now, convert your benzene to $C_6H_4F_2$ with your model kit.

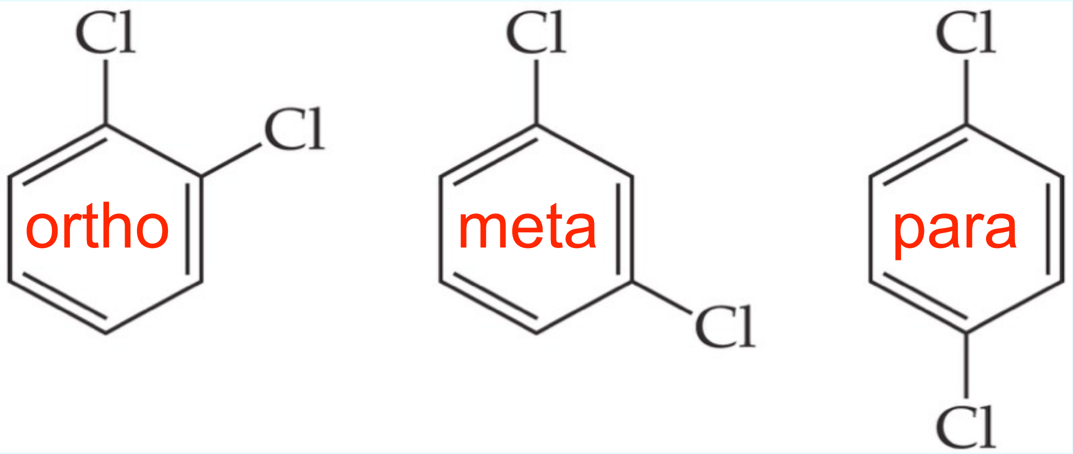
Notice, there are some isomers.

Think about the polarity of these isomers.

How many different isomers???

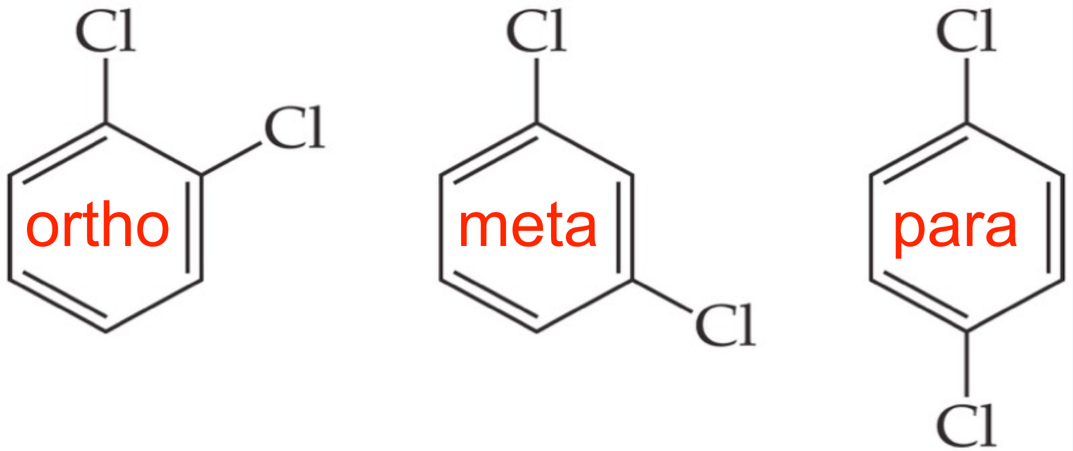
Which of these structures would be most polar?

mothballs



1. Ortho
2. Meta
3. Para
4. Ortho and meta are equally polar
5. All three structures are equally polar
6. None of the structures are polar

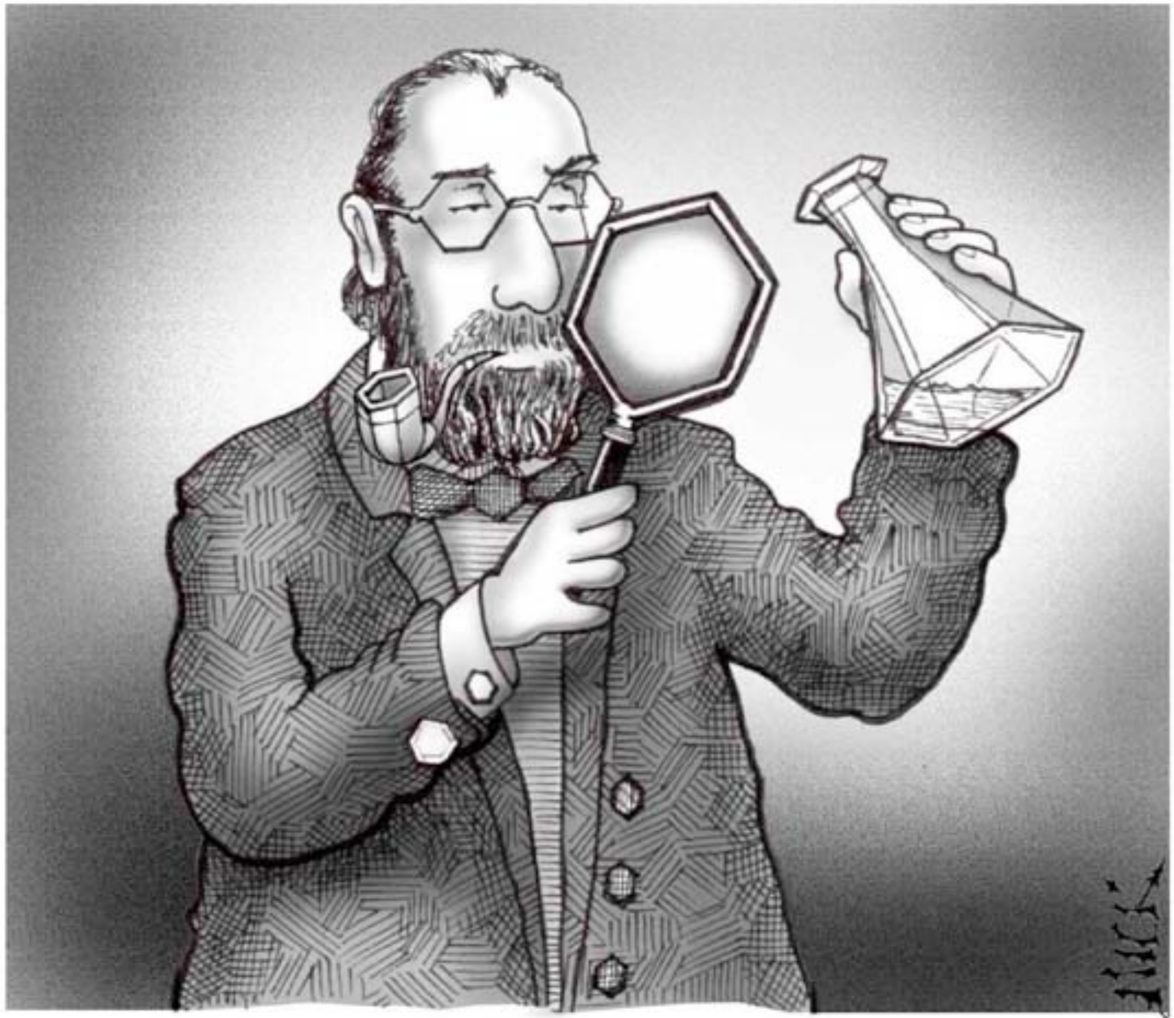
Which of these structures would be most polar?



1. Ortho
2. Meta
3. Para
4. Ortho and meta are equally polar
5. All three structures are equally polar
6. None of the structures are polar

- This is a planar molecule, and the molecule will be most polar when the polar C-Cl bond is oriented in the same direction.

Great events in Chemistry...



1865: Kekulé, moments before his brilliant insight into the structure of benzene.