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1) Select the molecule that possesses a dipole.

○ CCl_4

○ SeF_6

○ CO_2

● NH_3

2) The temperature of an ideal gas increases 5-fold, while the volume decreases 2-fold. How does the pressure change?

● Increases 10-fold

○ Increases 2.5-fold

○ Decreases 10-fold

○ Decreases 2.5-fold

3) What is the H-C-H bond-angle of ethylene (below).

$$H_2C{=}CH_2$$

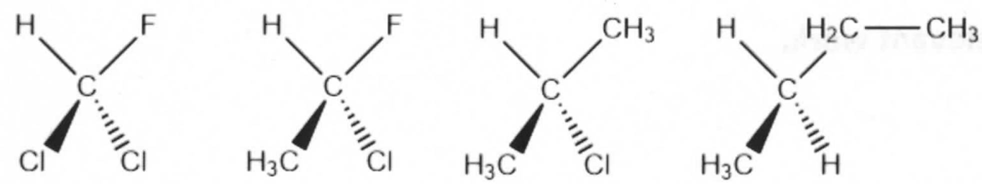
○ 180 degrees

● 120 degrees

○ 109.5 degrees

○ 107 degrees

4) Identify the chiral molecule.



○ ● ○ ○

5) Choose the diatomic molecule with the greatest bond order.

● N_2

○ H_2

○ O_2

○ F_2

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6. Consider the reaction

$$N_2O_4(g) \rightarrow 2\,NO_2(g)$$

in which dinitrogen tetroxide (N_2O_4) dissociates to form nitrogen dioxide (NO_2) in the gas phase, at very low pressure p. Note that each molecule of N_2O_4 produces two molecules of NO_2, so that the number of molecules is different before and after the reaction.

a) If the dissociation reaction proceeds to completion at fixed volume V and temperature T, by how much does the pressure p change? Write an equation relating the initial pressure p_{initial} to the final pressure p_{final}. Show all work or explain your reasoning.

$PV = nRT$

$n_i = 1\,\text{mol}$

$n_f = 2\,\text{mol}$

$\frac{P_i}{n_i} = \frac{RT}{V}$

$\frac{P_f}{n_f} = \frac{RT}{V}$

$\frac{P_i}{n_i} = \frac{P_f}{n_f} \Rightarrow \frac{P_i}{1\,\text{mol}} = \frac{P_f}{2\,\text{mol}} \Rightarrow \boxed{P_f = 2P_i}$

b) Which has the greater kinetic energy: an N_2O_4 molecule at the beginning of the reaction, or an NO_2 molecule at the end of the reaction (at the same temperature)? Or are they the same? Explain your reasoning in 1-2 sentences.

○ N_2O_4

○ NO_2

● same

Explain: kinetic energy depends on temperature:

$KE = \frac{3}{2} k_B T$

B/c temp T is the same, the KE is the same.

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c) Which has the greater average speed: an N_2O_4 molecule at the beginning of the reaction, or an NO_2 molecule at the end of the reaction (at the same temperature)? Or are they the same? Explain your reasoning in 1-2 sentences.

○ N_2O_4 ● NO_2 ○ same	Explain: NO_2 has the greater average speed b/c: $\langle K \rangle = \frac{3}{2} k_B T = \frac{1}{2} m \langle v^2 \rangle \Rightarrow \sqrt{\langle v^2 \rangle} = \sqrt{\frac{3 k_B T}{m}} \Rightarrow \sqrt{\langle v^2 \rangle} \propto \sqrt{\frac{T}{m}}$ $\langle K \rangle$ same for both molecules. NO_2 has smaller m ∴ NO_2 must have a greater speed.

d) During a short time Δt, the number of gas molecules colliding with a wall of the container is

$$N_{\text{coll}} = \frac{1}{2} N \frac{v\,\Delta t}{L}$$

where N is the number of molecules, v is their speed, and L is the length of the container.

For N_2O_4 dissociation at fixed V and T, are collisions with the wall more frequent before the reaction, or after? Or are they the same? Explain your reasoning in 1-2 sentences.

○ before reaction ● after reaction ○ same	Explain: After the rxn, there are more molecules moving at a greater speed. N increases, v increases, so N_{coll} also increases after the reaction.

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e) If the gas container is wrapped in thermal insulation, then its temperature can change as a result of the reaction. Consider a reactant gas with 1 mole of N_2O_4 at pressure $p_{\text{initial}} = 0.2$ bar and initial temperature $T_{\text{initial}} = 1600$ K. After reaction, the product gas with 2 moles of NO_2 has pressure $p_{\text{final}} = 0.1$ bar and a final temperature T_{final}. Assuming that the volume is fixed ($V_{\text{initial}} = V_{\text{final}}$), calculate the value of T_{final}. Show your work.

$PV = nRT$

Given: $P_i = 2P_f$

$n_i = \frac{1}{2} n_f$

$\frac{T_i n_i}{P_i} = \frac{V}{R}$

$\frac{T_f n_f}{P_f} = \frac{V}{R}$

$\frac{T_i n_i}{P_i} = \frac{T_f n_f}{P_f} \Rightarrow \frac{T_i \cdot \frac{1}{2} n_f}{2P_f} = \frac{T_f n_f}{P_f}$

$\frac{1}{4} T_i = T_f$

$\frac{1}{4}(1600\ K) = T_f$

$T_f = 400\ K$

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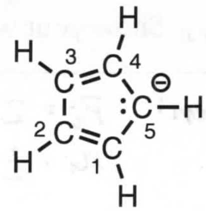
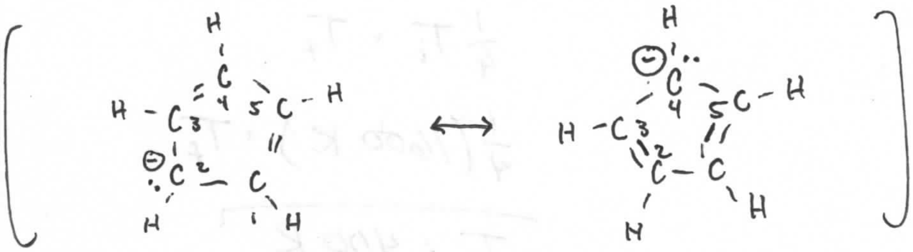
7. Consider the planer molecule cyclopentadienyl anion ($C_5H_5^-$), with the carbon atoms numbered from 1-5, as sketched in the diagram below. Complete the following questions. Please reason your answers and show your work:



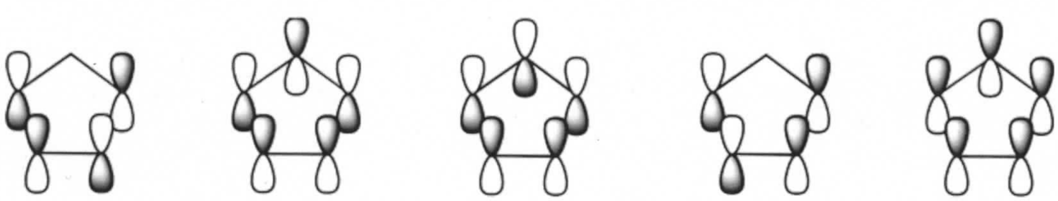
a. $C_5H_5^-$ has 5 *equivalent* Lewis dot structures. Draw 2 other Lewis dot structures of $C_5H_5^-$. Please number your carbons.



b. What is the hybridization of the carbon atoms? Hint: All carbon atoms are identical and the geometry of $C_5H_5^-$ is planer.

- ○ sp
- ● sp^2
- ○ sp^3

c. Consider the pi molecular orbitals hybridized from the $2p_z$ on each carbon atom, as shown in the diagram below. The $2p_z$ orbitals are perpendicular to the plane of the molecule. Which is/are the lowest energy molecular orbital(s)? Which is/are the highest energy molecular orbital(s). You may select more than one (fill in multiple choice on next page).



(i) (ii) (iii) (iv) (v)

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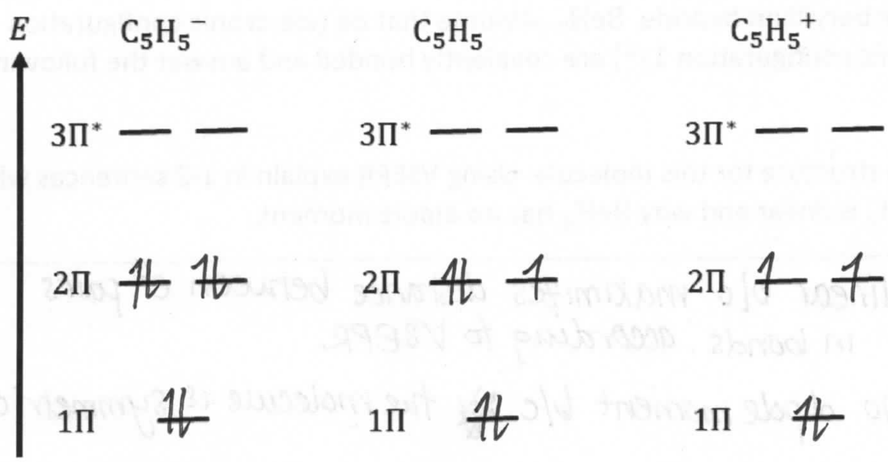
Lowest energy	Highest energy
○ i	● i
○ ii	● ii
○ iii	○ iii
○ iv	○ iv
● v	○ v

d. The energy level diagrams below show the positioning of the orbitals for cyclopentadienyl. Complete the electronic configuration ***for the pi bond system*** using Aufbau, Pauli, and Hund rules for the cyclopentadienyl anion ($C_5H_5^-$), neutral (C_5H_5), and cation ($C_5H_5^+$). Do not account for electrons in sigma bonds.

6 e⁻ in the π system (2 double bonds & 1 lone pair in Lewis structure)



e. Which molecule(s) is/are magnetic?

○ $C_5H_5^-$

● C_5H_5

● $C_5H_5^+$

molecules w/ at least 1 unpaired electron

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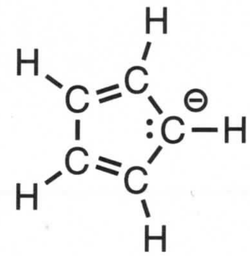
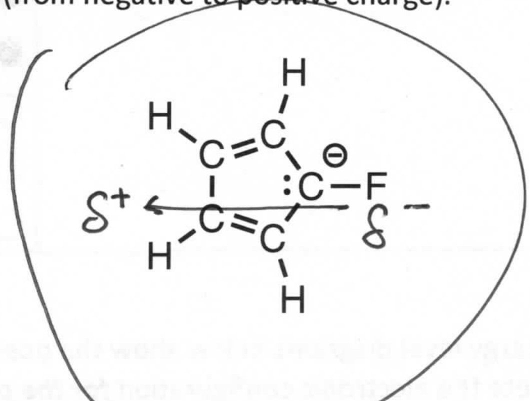
f. The molecule 1-floro-2,4-cyclopentadienide anion ($C_5H_4F^-$) is identical to cyclopentadienyl anion ($C_5H_5^-$) with one of the hydrogens replaced with florin atom (see the figure below). Circle the molecule that has a dipole moment and draw an arrow pointing in the direction of the dipole (from negative to positive charge).





8. Consider the molecule beryllium hydride, BeH_2. Assume that Be (electronic configuration $1s^2\ 2s^2$) and H (electronic configuration $1s^1$) are covalently bonded and answer the following questions:

a. Write the best Lewis structure for this molecule. Using VSEPR explain in 1-2 sentences why the geometry of BeH_2 is linear and why BeH_2 has no dipole moment.

H – Be – H
180°

linear b/c maximizes distance between e⁻ pairs in bonds, according to VSEPR

no dipole moment b/c the molecule is symmetric

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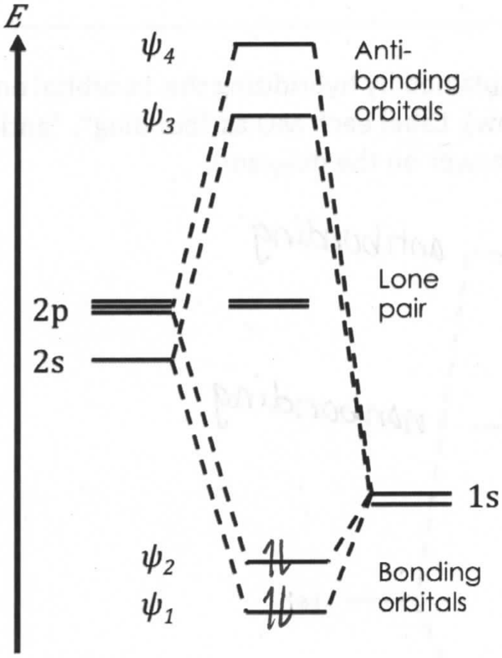
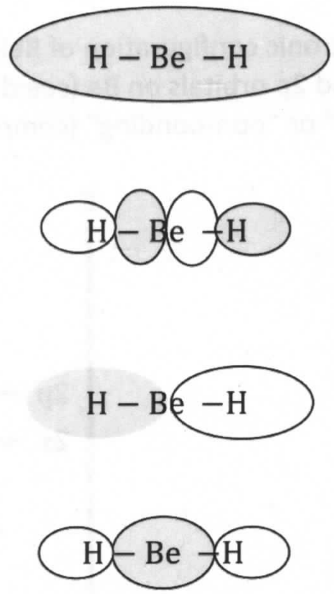
b. The energy level diagram below describes the molecular orbital energies of BeH_2. The two lowest molecular orbitals are bonding, and the two highest molecular orbitals are anti-bonding. The molecular orbitals shown on the right diagram were formed by hybridizing the 1s orbital of each hydrogen atom with the 2s and the $2p_z$ orbitals of Be (color code: dark is positive; bright is negative). The $2p_x$ and $2p_y$ orbitals of Be are load pair (often called "non-bonding") and do not participate in bond formation. Assign the molecular orbital (i)-(iv) to the corresponding orbital energies ($\psi_1 - \psi_4$).





(iv) ψ_1

(iii) ψ_4

(ii) ψ_2

(i) ψ_3

more nodes → higher energy

c. Use the diagram above (in b.) to complete the electronic configuration of BeH_2. What is the bond order for each Be-H bond?

bond order: 1	$BO_{total} : 2$ $BO_{Be\text{-}H} = \frac{BO_{total}}{2} = 1$

d. Would Be-H bond in BeH_2 be shorter or longer than the O-H bond in water? Use periodic trends and reason your answer in 1-2 sentences.

○ BeH_2 bonds would be shorter ● BeH_2 bonds would be longer	Explain: O is more electronegative than Be ∴ it pulls e⁻s closer. This causes the O–H bond to ~~[illegible]~~ be shorter than the Be–H bond.

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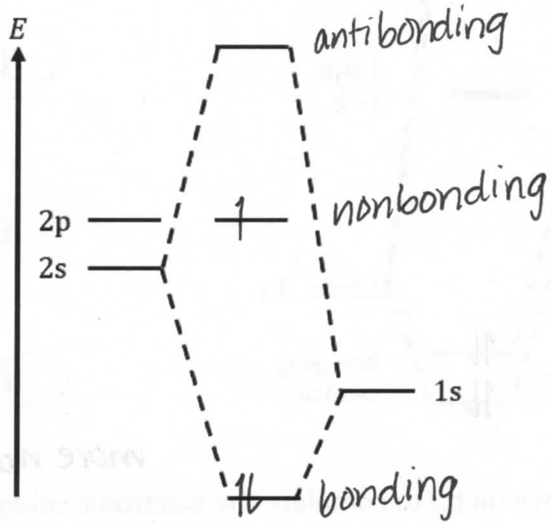
e. Consider the reaction $BeH_2 \rightarrow H\cdot + \cdot BeH$ (the "·" symbol for a radical). Write the Lewis dot structure of BeH· radical (remember: radicals have odd number of electrons and thus, are an exception to the complete shell rule).

• Be – H

f. The electronic configuration of BeH· can be explained by hybridizing the 1s orbital on H with the 2s and 2p orbitals on Be (see diagram below). Label each MO as "bonding", "anti-bonding," or "non-bonding" (complete your answer on the diagram).



g. Use the diagram above (in f) to complete the electronic configuration of BeH·. What is the bond order of BeH·?

bond order: 1