

**PART I (20 QUESTIONS - 60 POINTS)**

Questions 1 - 2: Choose from the following answers:

- A)  $1s^2 2s^2 2p^6 3s^2 3p^6$
- B)  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
- C)  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$
- D)  $1s^2 2s^2 2p^6 2d^{10} 3s^2 3p^6$
- E)  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$

E 1. Which is a ground state configuration for an atom of a transition metal?

A 2. Which is the ground state configuration of a positive ion of an alkali metal?

B 3. What is the wavelength of light that is emitted when an excited electron in the hydrogen atom falls from  $n = 5$  to  $n=3$ ?

- A)  $7.80 \times 10^5 \text{ m}$
- B)  $1.28 \times 10^{-6} \text{ m}$
- C)  $1.55 \times 10^{-19} \text{ m}$
- D)  $8.21 \times 10^{-7} \text{ m}$
- E) none of these

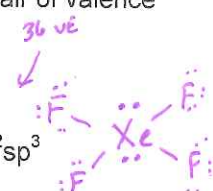
Handwritten calculations:  
 $E_5 = 8.712 \times 10^{-20} \text{ J}$   
 $E_3 = 2.42 \times 10^{-19} \text{ J}$   
 $\Delta E = 1.549 \times 10^{-19} \text{ J}$   
 $\lambda = 1.28 \times 10^{-6} \text{ m}$

E 4. Which of the following has a Lewis dot structure showing only one unshared pair of valence electrons?

- A)  $\text{Cl}_2$
- B)  $\text{N}_2$
- C)  $\text{H}_2\text{O}_2$
- D)  $\text{CCl}_4$
- E)  $\text{PH}_3$

E 5. The hybridization of Xe is in the  $\text{XeF}_4$  molecule is

- A)  $sp^2$
- B)  $sp^3$
- C)  $dsp^2$
- D)  $dsp^3$
- E)  $d^2sp^3$



D 6. Which term refers to a bond in which electrons are shared equally between two atoms?

- A) hydrogen bond
- B) metallic bond
- C) polar covalent bond
- D) nonpolar covalent bond
- E) ionic bond

C 7.  $\text{CCl}_4$ ,  $\text{CO}_2$ ,  $\text{PCl}_3$ ,  $\text{PCl}_5$ ,  $\text{SF}_6$  Which of the following does NOT describe any of these molecules?

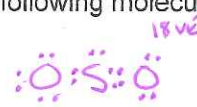
- ~~A) linear~~
- ~~B) octahedral~~
- ~~C) square planar~~
- ~~D) trigonal bipyramidal~~
- ~~E) tetrahedral~~

B 8. Which is used to explain the fact that the four bonds in methane,  $\text{CH}_4$ , are equivalent.

- A) Lewis structure
- B) Hybridization
- C) Ionic bonding
- D) Resonance
- E) Hydrogen Bonding

B 9. For which of the following molecules are resonance structures necessary to describe the bonding satisfactorily?

- A)  $\text{H}_2\text{S}$
- B)  $\text{SO}_2$
- C)  $\text{CO}_2$
- D)  $\text{OF}_2$
- E)  $\text{PF}_3$



A 10. Which set of quantum numbers can describe one of the outermost electrons in a strontium atom, in the ground state?

- A) 5, 0, 0,  $\frac{1}{2}$
- B) 5, 0, 1,  $\frac{1}{2}$
- C) 5, 1, 0,  $\frac{1}{2}$
- D) 5, 1, 1,  $\frac{1}{2}$
- E) 5, 2, 0,  $\frac{1}{2}$

E 11. The species,  $B^{4+}$ ,  $Be^{3+}$ ,  $Li^{2+}$ ,  $He^+$ , and  $H$  all have one electron; which has the smallest ionization energy?  
 A)  $B^{4+}$       B)  $Be^{3+}$       C)  $Li^{2+}$       D)  $He^+$       E)  $H$  *Least protons*

C 12. Which of the following molecules has the strongest bond between the atoms?  
 A)  $Li_2$       B)  $B_2$       C)  $N_2$       D)  $O_2$       E)  $F_2$

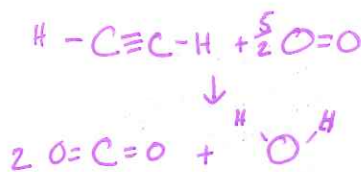
D 13. Which of the following is NOT isoelectronic with the others?  
 A)  $Cl^-$  *18*      B)  $Sc^{3+}$  *18*      C)  $Ar$  *18*      D)  $V^{4+}$  *19*      E)  $Si^{4+}$  *18*

B 14. Which of the following has the smallest ionic radius for its most commonly found ion?  
 A)  $Ba^{2+}$  *56p 54e-*      B)  $Mg^{2+}$  *12p 10e-*      C)  $N^{3-}$  *7p 10e-*      D)  $O^{2-}$  *8p 10e-*      E)  $K^+$  *19p 18e-*

B 15. Using the following bond energies, estimate the heat of combustion for one mole of acetylene.  
 $C_2H_2 + 5/2 O_2 \longrightarrow 2CO_2 + H_2O$

Bond	Bond Energy (kJ/mol)
$C \equiv C$	839
$C - H$	413
$O = O$	495
$O - H$	467
$C = O$	799

*Break 2 C-H 826  
 1 C≡C 839  
 5/2 O=O 1237.5  
 ---  
 form 4 C=O 3196  
 2 O-H 934*



- A) 1228 kJ  
 B) -1228 kJ  
 C) -447 kJ

- D) +447 kJ  
 E) +365 kJ

E 16. In which case(s) is (are) the bond polarity correct?

- I.  $\delta^+ H - F \delta^-$  ✓  
 II.  $\delta^+ Na - S \delta^-$  ✓  
 III.  $\delta^+ Br - Cl \delta^-$  ✓  
 IV.  $\delta^+ P - O \delta^-$  ✓

- A) I only  
 B) I and II only  
 C) II and III only

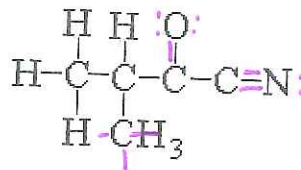
- D) I, II, and IV only  
 E) all are correct

A 17. Which of the following statements is (are) incorrect?

- I. The hybridization of boron in  $BF_3$  is  $sp^2$  ✓  
 II. The molecule  $XeF_4$  is nonpolar ✓  
 III. The bond order of  $N_2$  is 3 ✓  
 IV. The molecule  $HCN$  has two pi bonds and two sigma bonds ✓

- A) all four statements are correct  
 B) II is incorrect  
 C) I and IV are incorrect  
 D) II and III are incorrect  
 E) II, III, and IV are incorrect

- E 18. Complete the Lewis structure for the following molecule by adding in lone pairs and additional bonds (all atoms have a formal charge of zero):



This molecule has 13 sigma and 3 pi bonds.

- A) 4, 5  
 B) 6, 3  
 C) 11, 5  
 D) 13, 2  
 E) 13, 3

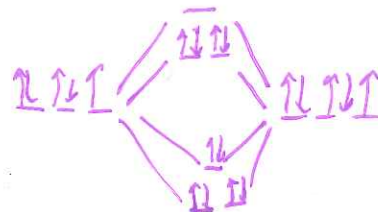
- B 19. The melting point of MgO is higher than that of NaF. Explanations for this observation include which of the following?

- I.  $\text{Mg}^{2+}$  is more positively charged than  $\text{Na}^+$  ✓  
 II.  $\text{O}^{2-}$  is more negatively charged than  $\text{F}^-$  ✓  
 III. The  $\text{O}^{2-}$  ion is smaller than the  $\text{F}^-$  ion

- (A) II only  
 (B) I and II only  
 (C) I and III only  
 (D) II and III only  
 (E) I, II, and III

- E 20. Which of the following species is NOT paramagnetic in its ground state?

- A)  $\text{O}_2$   
 B)  $\text{O}_2^+$   
 C)  $\text{B}_2$   
 D) NO  
 E)  $\text{F}_2$



Part 2: Short Answer

1. (20 pts) Use the principles of atomic structure and/or chemical bonding to explain each of the following. In each part, your answer must include references to both substances.

- a. Account for the difference between the radius of the Ca atom, which is 0.197 nanometers, and the  $\text{Ca}^{2+}$  ion, which is 0.099 nm.

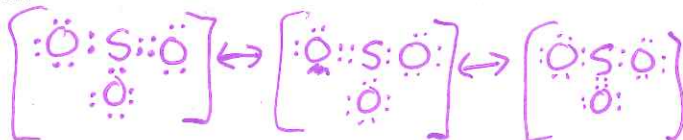
The Ca atom and  $\text{Ca}^{2+}$  ion both have 20 protons, however the Ca atom has 20 electrons whereas the  $\text{Ca}^{2+}$  ion ~~has~~ has only 18  $e^-$ . The electrons lost when the atom becomes an ion are those in the valence shell. The fewer the electrons, the more tightly the nucleus is able to hold onto the remaining electrons.

- b. Account for the fact that the first ionization energy of Mg is 738 kilojoules per mole, while that of Al is 578 kJ/mol.



It requires less energy to remove the outermost electron from Al because the 3p electron is being shielded from the nucleus by all the electrons (12 of them) in the 1s through 3s sublevels. The outermost  $e^-$  in Mg are in the 3s sublevel therefore they are shielded only by 10 inner electrons making them ~~easier~~ harder to be removed.

- c. The bond lengths in  $\text{SO}_3$  are all identical and are shorter than a sulfur-oxygen bond in a single bond.



Resonance shows that the double bond is distributed in three locations in this structure therefore each bond is equivalent to a  $1\frac{1}{3}$  bond. (slightly stronger + shorter than a single bond)

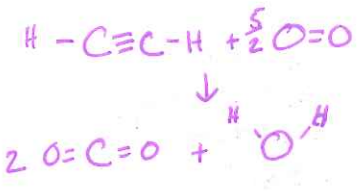
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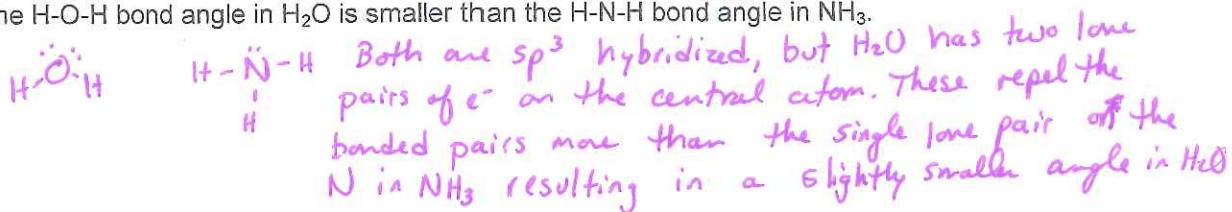
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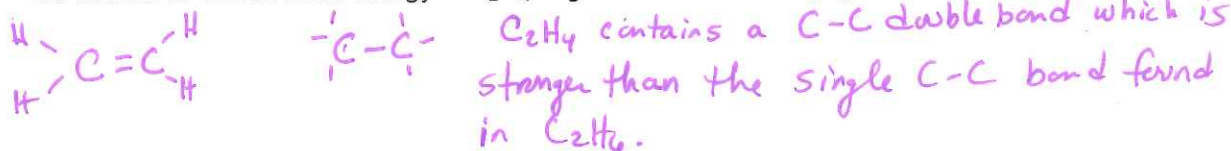
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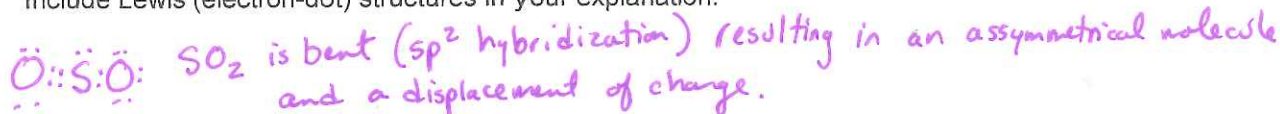
d. The H-O-H bond angle in H<sub>2</sub>O is smaller than the H-N-H bond angle in NH<sub>3</sub>.



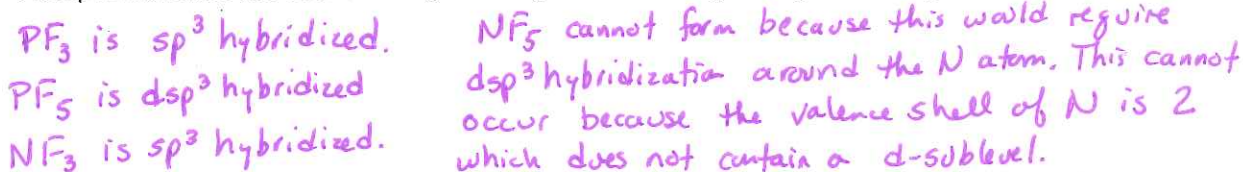
e. The carbon to carbon bond energy in C<sub>2</sub>H<sub>4</sub> is greater than it is in C<sub>2</sub>H<sub>6</sub>.



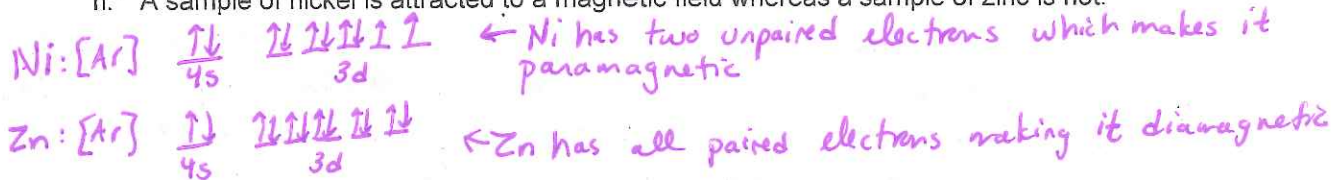
f. The SO<sub>2</sub> molecule has a dipole moment, whereas the CO<sub>2</sub> molecule has no dipole moment. Include Lewis (electron-dot) structures in your explanation.



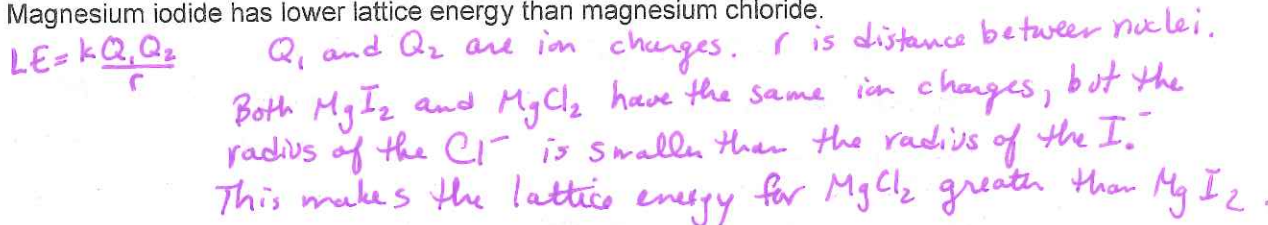
g. Phosphorus forms the fluorides PF<sub>3</sub> and PF<sub>5</sub> whereas nitrogen only forms NF<sub>3</sub>.



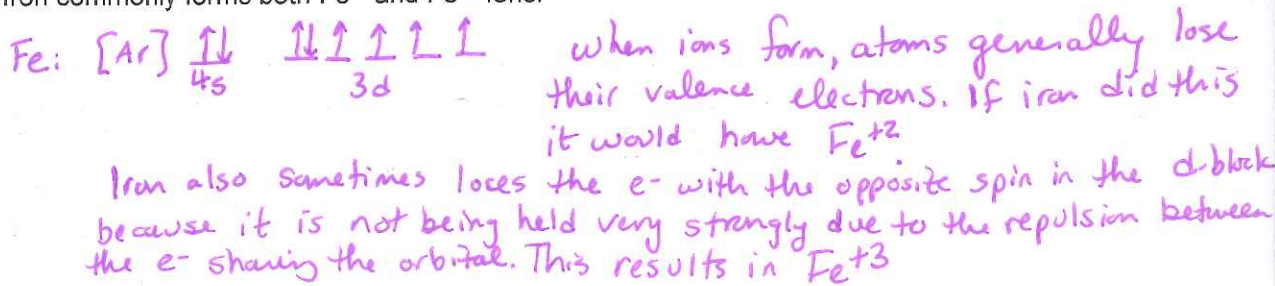
h. A sample of nickel is attracted to a magnetic field whereas a sample of zinc is not.



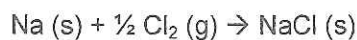
i. Magnesium iodide has lower lattice energy than magnesium chloride.



j. Iron commonly forms both Fe<sup>2+</sup> and Fe<sup>3+</sup> ions.

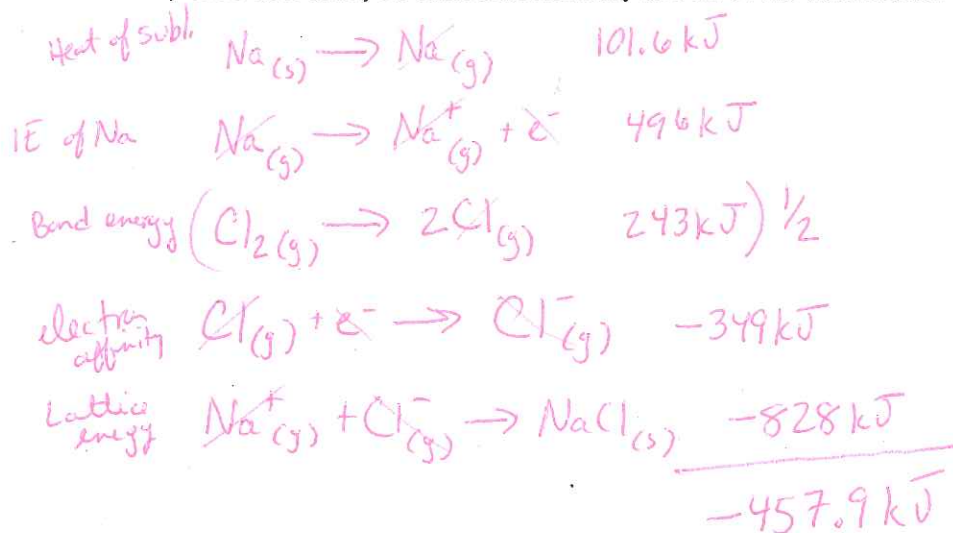


2. (6) Find the heat of reaction for the following reaction:

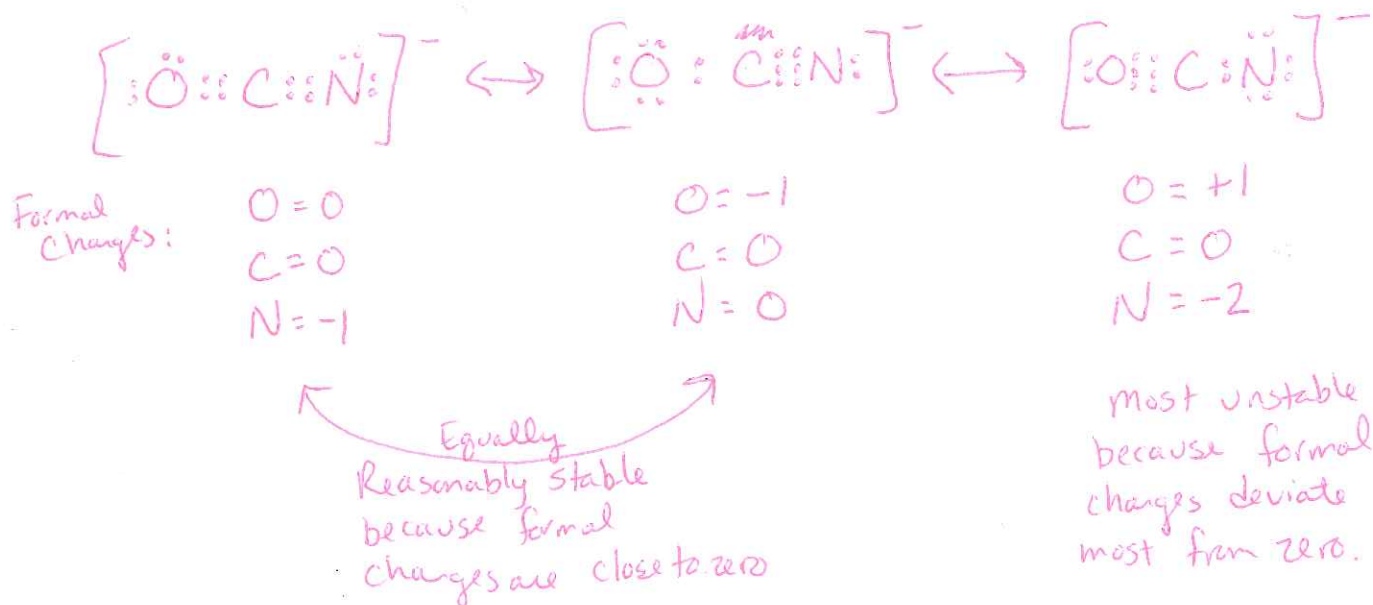


- Given:\*
- Lattice energy of NaCl = -828 kJ/mol
  - 1<sup>st</sup> Ionization energy of Na = 496 kJ/mol
  - 2<sup>nd</sup> Ionization energy of Na = 4560 kJ/mol
  - 1<sup>st</sup> Ionization energy of Cl = 1251 kJ/mol
  - 2<sup>nd</sup> Ionization energy of Cl = 2297 kJ/mol
  - Electron affinity of Na = -53 kJ/mol
  - Electron affinity of Cl = -349 kJ/mol
  - Heat of sublimation for Na = 101.6 kJ/mol
  - Heat of sublimation for Cl<sub>2</sub> = 111.5 kJ/mol
  - Bond energy Cl<sub>2</sub> = 243 kJ/mol

\*please note that you will not necessarily use all of this information.

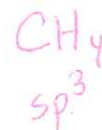
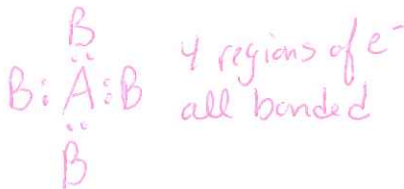
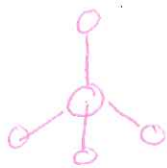


3. (6) Draw three reasonable resonance structures for the polyatomic ion, OCN<sup>-</sup>. (C is the central atom)  
For each structure, assign formal charges to each atom. Make a statement about stability of each of your structures based on the concept of formal charges.

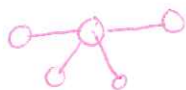


4. (8) Suppose that a molecule has the formula of  $AB_4$ . Sketch (ball and stick model) and name two shapes that this molecule may have. For each shape, describe under what conditions this shape will form. For each of the two shapes, give an example of a known molecule that has that shape. For each known molecule, state the hybridization of the central atom.

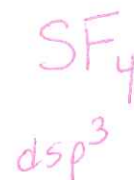
Tetrahedral:



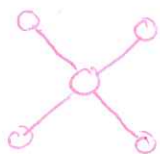
See-Saw:



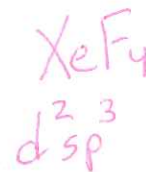
5 regions of  $e^-$   
4 bonded, 1 unbonded



Square planar:



6 regions of  $e^-$   
4 bonded, 2 unbonded



1pt each sketch corresponds w/name

1pt each explanation

1pt each example

1pt each hybridization