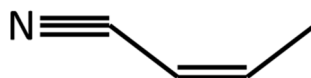


Please follow the instructions for each section of the exam. Show your work on all mathematical problems. Provide answers with the correct units and significant figures. Be concise in your answers to discussion questions.

Part 0: Warmup.

1. How many sigma bonds are there in the molecule below? (4 points)



- a. 3
b. 6
c. 9
d. 12

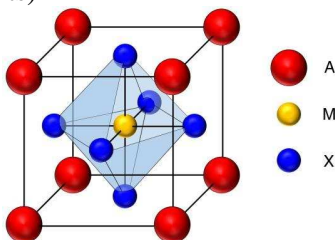
Answer _____

2. In order for an ion or molecule to have square planar geometry, valence bond theory would predict that the central atom must be _____ hybridized. (4 points)

- a. sp^2
b. sp^3
c. sp^3d
d. sp^3d^2

Answer _____

3. The mineral perovskite, consists of calcium, titanium and oxygen. Its unit cell is shown below, with Ti at the corners (A in the diagram), Ca in the center (M in the diagram) and O at each of the faces (X in the diagram). Since the stoichiometry of the unit cell must match that for the compound, what is the formula for perovskite? (4 points)



- a. $CaTi_8O_4$
b. $Ca_2Ti_4O_2$
c. $CaTiO_3$
d. $CaTiO$

Answer _____

4. Complete the following with *increases*, *decreases*, or *does not change*. (6 points)
- a. If the intermolecular forces in a liquid decrease, the normal boiling point of the liquid

_____.

- b. If the intermolecular forces in a liquid decrease, the vapor pressure of the liquid

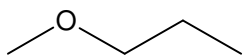
_____.

- c. If the temperature of a liquid increases, the equilibrium vapor pressure

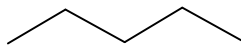
_____.

Part I: Complete all of problems 6-8

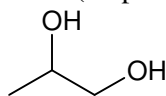
5. Consider the compounds below. Arrange the molecules in order of increasing boiling point. Clearly justify your reasoning. Ignore any effects of molecular mass. (12 points)



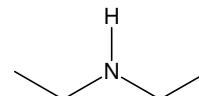
A



B



C



D

6. The compound oxygen difluoride is quite unstable, reacting with water to produce oxygen and hydrogen fluoride in an exothermic reaction with $\Delta H^{\circ}_{\text{rxn}} = -318 \text{ kJ}$. Use the table of bond energies to calculate the bond dissociation energy of the oxygen-fluorine bond in oxygen difluoride. (12 points)

Bond	H-F	F-F	F=F	H-H	O-H	O-O	O=O
Bond Energy (kJ/mol)	565	159	414	436	464	142	498

Answer _____

7. In the context of valence bond theory, explain how p-orbitals can form both sigma (σ) and pi (π) bonds, but s-orbitals do not. Feel free to use sketches to illustrate your points. (12 points)

8. Choose two (2) of the compounds below and draw Lewis structure, indicate the hybridization of the underlined atom and estimate all bond angles. Identify the strongest intermolecular interaction the molecule can participate in with another molecule of the same compound. (12 points)

a. CH₂O

b. NH₃

c. CO₂

Part II. Answer three (3) of problems 9-13. Clearly mark the problems you do not want graded. 12 points each.

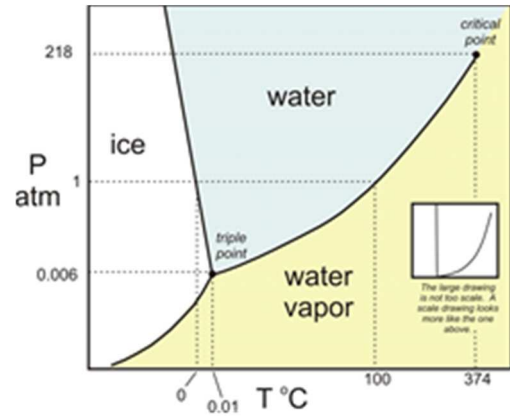
9. A certain liquid has a vapor pressure of 92.0 Torr at 23.0°C and 353.0 Torr at 45.0°C.
a. Calculate the enthalpy of vaporization ($\Delta H_{\text{vap}}^{\circ}$) for this liquid.

Answer _____

- b. Calculate the normal boiling point of this liquid.

Answer _____

10. You decide to cool a can of carbonated soda (or pop depending on where you are from) quickly by placing it in the freezer. When you take the can out, the contents are still liquid, but when you open the can, the soda (or pop) immediately freezes. Explain why this happens. You may assume that the soda behaves essentially like water. Use the phase diagram for water, shown below, to support your explanation.

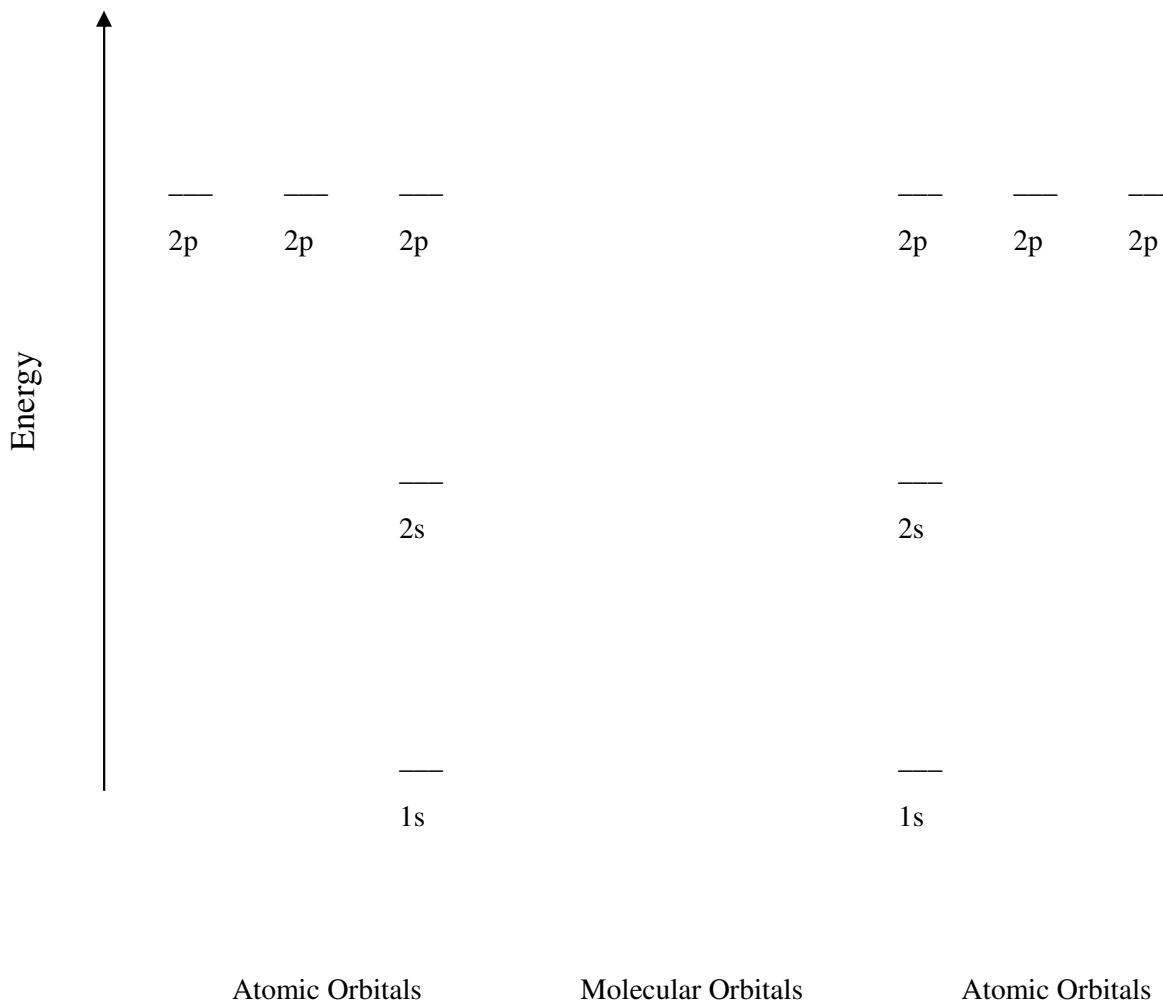


11. The atomic radius of tungsten, W, is 202 pm. If the W has a molar mass of 183.84 g/mol and has a density of 19.3 g/cm³, does tungsten form a face-centered cubic lattice? Justify your answer with a calculation.

12. Use valence bond theory to describe the bonding around the carbon atom in HCN. Identify the hybridization on the carbon atom and show how hybridization allows the formation of the necessary sigma and pi bonds in the compound. Drawings may be useful!

13. Answer the following questions about peroxide ion (O_2^{2-}).

a. Complete the MO diagram for peroxide below. Account for valence and core electrons. (6 points)



b. What is the bond order for peroxide? (2 points)

c. Is peroxide diamagnetic? Why or why not? (2 points)

d. Would you expect the peroxide ion to be more or less stable than molecular oxygen (O_2)? Why? (2 points)

Possibly Useful Information

$R = 8.31441 \text{ J mol}^{-1} \text{ K}^{-1}$	$R = 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$	$1 \text{ atm} = 760 \text{ Torr}$
$a^2 + b^2 = c^2$	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$	$\ln\left(\frac{P_2}{P_1}\right) = \frac{\Delta H_{\text{vap}}}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$
$\Delta H^\circ = \Sigma(\text{Bond Energy for bonds broken}) - \Sigma(\text{Bond energy for bonds formed})$		

Periodic Table of the Elements

1A 1	2A 2											VIIA 17	VIIIA 18																																	
H Hydrogen 1.008	He Helium 4.003											F Fluorine 18.998	Ne Neon 20.180																																	
3A 3	4A 4	5A 5	6A 6	7A 7	8A 8	9A 9	10A 10	11A 11	12A 12	13A 13	14A 14	15A 15	16A 16	17A 17	18A 18																															
Li Lithium 6.941	Be Beryllium 9.012	B Boron 10.811	C Carbon 12.011	N Nitrogen 14.007	O Oxygen 15.999	F Fluorine 18.998	Ne Neon 20.180	Na Sodium 22.990	Mg Magnesium 24.305	Al Aluminum 26.982	Si Silicon 28.086	P Phosphorus 30.974	S Sulfur 32.066	Cl Chlorine 35.453	Ar Argon 39.948																															
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798																													
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.93	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.905	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294																													
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [209]	86 Rn Radon [222]																													
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]																													
119 La Lanthanum 138.905	120 Ce Cerium 140.116	121 Pr Praseodymium 140.908	122 Nd Neodymium 144.242	123 Pm Promethium [144.913]	124 Sm Samarium 150.36	125 Eu Europium 151.964	126 Gd Gadolinium 157.25	127 Tb Terbium 158.925	128 Dy Dysprosium 162.500	129 Ho Holmium 164.930	130 Er Erbium 167.259	131 Tm Thulium 168.934	132 Yb Ytterbium 173.053	133 Lu Lutetium 174.967	134 Hf Hafnium 178.49	135 Ta Tantalum 180.948	136 W Tungsten 183.84	137 Re Rhenium 186.207	138 Os Osmium 190.23	139 Ir Iridium 192.217	140 Pt Platinum 195.085	141 Au Gold 196.967	142 Hg Mercury 200.592	143 Tl Thallium 204.383	144 Pb Lead 207.2	145 Bi Bismuth 208.980	146 Po Polonium [209]	147 At Astatine [209]	148 Rn Radon [222]	149 Fr Francium [223]	150 Ra Radium [226]	151 Ac Actinium [227]	152 Th Thorium [232]	153 Pa Protactinium [231]	154 U Uranium [238]	155 Np Neptunium [237]	156 Pu Plutonium [244]	157 Am Americium [243]	158 Cm Curium [247]	159 Bk Berkelium [247]	160 Cf Californium [251]	161 Es Einsteinium [254]	162 Fm Fermium [257]	163 Md Mendelevium [258]	164 No Nobelium [259]	165 Lr Lawrencium [262]

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