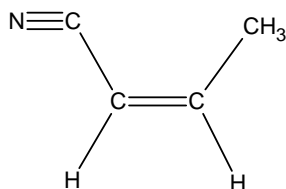


Please follow the instructions for each section of the exam. Show your work on all mathematical problems. Provide answers with the correct units and significant figures. Be concise in your answers to discussion questions.

Bonus (4 points). One day at the very beginning of class I wrote a value on the board and suggested that it be written down. Write that value here, with its correct units. _____

Complete all of problems 1-7.

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



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

Answer _____

2. A water sample is found to have 9.4 ppb of chloroform (CHCl₃). What mass of CHCl₃ would be in one glassful (250 mL) of water? (4 points)

- a. 2.35 g
- b. 2.35 mg
- c. 2.35 μg
- d. 2.35 ng

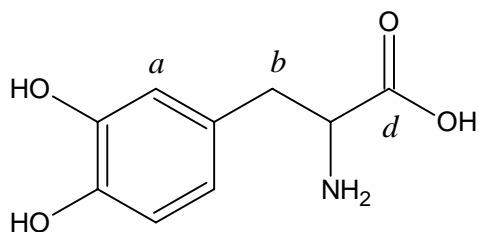
Answer _____

3. 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. sp²
- b. sp³
- c. sp³d
- d. sp³d²

Answer _____

4. For the following, consider the structure shown below of DL-Dopa, a drug often used to treat Parkinson's disease.



I. Circle and identify three functional groups in the molecule. (6 points)

II. What is the molecular formula for DL-Dopa? (3 points)

III. What is the hybridization and approximate bond angles at: (6 points)

i. carbon *a*?

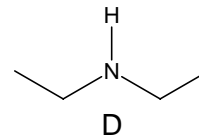
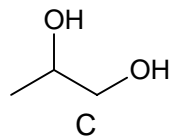
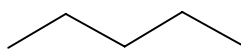
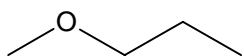
ii. carbon *b*?

iii. carbon *d*?

5. In the context of valence bond theory, describe 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. (15 points)

6. More complex theories must be developed to deal with the shortcomings of more basic theories. Shortcomings of valence bond theory are highlighted by the two experimental observations below. For **one** of the observations, clearly describe how molecular orbital theory can account for the observation. (15 points)
- Molecular oxygen (O_2) is paramagnetic.
 - Ozone (O_3) has only one type of O-O bond, not one single and one double bond.

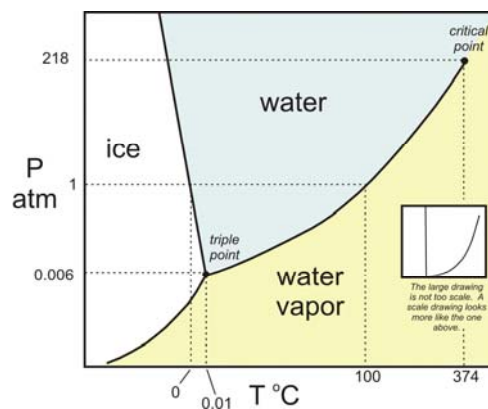
7. Consider the compounds below. Remembering that "*like dissolves like*," arrange the molecules in order of increasing solubility in water. Clearly justify your reasoning. Ignore any effects of molecular mass. (15 points)



Part II Answer two (2) of problems 8-11. Clearly mark the problems you do not want graded. 15 points each.

8. A forensic chemist is given a white solid that is expected of being pure cocaine ($C_{17}H_{21}NO_4$, 303.36 g/mol). She dissolves 1.22 g of the solid in 15.60 g of benzene ($K_b = 2.53^\circ\text{C kg/mol}$, $K_f = 5.12^\circ\text{C kg/mol}$). The freezing point is lowered by 1.32°C . Assuming a 1% uncertainty in her measurements, can the chemist state that the substance is likely to be cocaine?

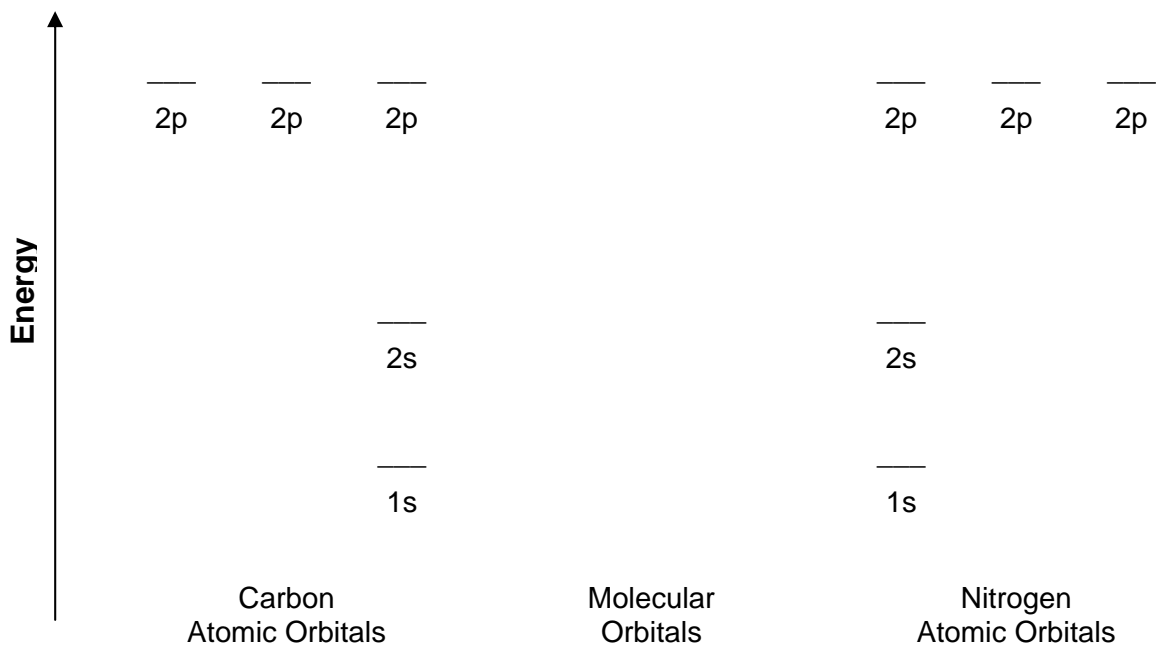
9. You decide to cool a can of soda (or pop depending on where you are from) quickly by placing it in the freezer. When you take the can out, the contents are still liquid, but when you open the can, the soda (or pop) immediately freezes. Explain why this happens. A phase diagram for water is shown below.



10. The atomic radius of tungsten, W, is 202 pm. If the density of W is 19.3 g/cm³, does tungsten form a face-centered cubic lattice? Justify your answer.

11. Answer the following questions regarding the CN⁻ ion:

- a. Complete and clearly label the molecular orbital diagram for CN⁻, whose molecular orbital energy levels are similar to those in N₂. Fill MO's with electrons as appropriate. For this problem, we will ignore any differences in the energies of the atomic orbitals in nitrogen as compared to carbon. (9 points)



b. Is CN⁻ paramagnetic? Justify your response. (3 points)

c. What is the bond order in CN⁻? Show how you arrived at your answer. (3 points)

Possibly Useful Information

$$R = 8.31441 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$R = 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$$

$$a^2 + b^2 = c^2$$

$$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$$

$$\Delta t_{\text{fp}} = k_{\text{fp}} m$$

$$\Delta t_{\text{bp}} = k_{\text{bp}} m$$

$$\Pi = MRT$$

$$P_{\text{soln}} = X_{\text{solvent}} P^{\circ}_{\text{solvent}}$$

Selected Constants

Solvent	Boiling Point (°C)	K _b (°C kg/mol)	Freezing Point (°C)	K _f (°C kg/mol)
Water	100.0	0.51	0	1.86
Benzene	80.1	2.53	5.5	5.12
Ethyl Ether	34.5	2.02	-116.2	1.79
Chloroform	61.2	3.63	-63.5	4.70

1 1A	2 2A												13 3A					14 4A	15 5A	16 6A	17 7A	18 8A													
1 H 1.00794	2 He 4.00260											3 Li 6.941	4 Be 9.01218											5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.1797						
11 Na 22.9898	12 Mg 24.3050	3 B 10.811	4 C 12.011	5 N 14.0067	6 O 15.9994	7 F 18.9984	8 Ne 20.1797	9 Li 6.941	10 Be 9.01218	11 B 10.811	12 C 12.011	13 N 14.0067	14 O 15.9994	15 F 18.9984	16 Ne 20.1797	17 Na 22.9898	18 Mg 24.3050	19 Al 26.9815	20 Si 28.0855	21 P 30.9738	22 S 32.066	23 Cl 35.4527	24 Ar 39.948												
19 K 39.0983	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.9961	25 Mn 54.9381	26 Fe 55.847	27 Co 58.9332	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.757	52 Te 127.60	53 I 126.904	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	57 *La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)	58 Ce 140.115	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.965	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967				
87 Fr (223)	88 Ra 226.025	89 †Ac 227.028	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Rg (272)																									

*Lanthanide series	58 Ce 140.115	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.965	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
†Actinide series	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

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