Write the first letter of your last name in this box. →

THE UNIVERSITY OF BRITISH COLUMBIA

Chemistry 121 Final Examination

December 8, 2005 Time Limit: 2.5 hrs

SURNAME:_____ GIVEN NAME(S):_____
(PRINTED CAPITALS IN INK) (PRINTED CAPITALS IN INK)

STUDENT NUMBER:_____ SIGNATURE:_____
(PRINTED IN INK) (SIGNED IN INK)

INSTRUCTIONS

1. Answer all questions on the examination paper.
2. Check that your examination contains pages numbered 1 through 16. You should also have a Supplemental Sheet containing a Periodic Table, "Potentially Useful Information" and coloured figures.
3. The only calculator permitted is the Sharp EL-510R. All oher calculators will be confiscated by the examiners.
4. Unassembled models are allowed.
5. No electronic communication devices are permitted.

Check √ your lecture section:

___101 (MWF 1:00) Dr. Orvig
___102 (MWF 2:00) Dr. Liu
___109 (MWF 9:00) Dr. Sauer
___110 (MWF 10:00) Dr. MacFarlane
___111 (MWF 11:00) Dr. Sauer
___122 (T, Th 2:00) Dr. Wolf
___133 (T, Th 3:30) Dr. Herring
___188 (T,Th 8:00) Dr. Wolf
___199 (T,Th 9:30) Dr. Gates

REGULATIONS FOR EXAMINATIONS

1. Each candidate must be prepared to produce, upon request, a Library/AMS card for identification.
2. No candidates shall be permitted to ask questions of the invigilators, except in the cases of supposed errors or ambiguities in examination questions.
3. No candidates shall be permitted to enter the examination room after the expiration of one-half hour from the scheduled starting time, or to leave during the first half-hour of the examination.
4. Candidates suspected of any of the following, or similar, dishonest practices shall be immediately dismissed from the examination and shall be subject to disciplinary action
   (a) Having at the place of writing any books, papers or memoranda, calculators, audio or visual cassette players or other memory aid devices, other than those authorized by the examiners.
   (b) Speaking or communicating with other candidates.
   (c) Purposely exposing written papers to the view of other candidates. The pleas of accident or forgetfulness shall not be received.
5. Candidates must not destroy or mutilate any examination material; must hand in all examination papers; and must not take any examination material from the examination room without permission of the invigilator.

Marks			
Part	Maximum	Obtained	Initials
I	30		
II	19		
III	18		
IV	20		
V	16		
VI	17		
Total	120		
Exam	60		
Midterm/Quizzes	20		
Lab	20		
TOTAL	100		

PART I. Multiple Choice (30 marks total)

For each numbered statement below, select the letter corresponding to the best answer. There is only one correct answer per question. Each correct answer is worth 1 mark for Questions 1-10 and 2 marks for Questions 11-20. There are no penalties for incorrect responses.

1. Which of the following covalent bonds is the most polar?

   (a) C—F
   (b) C—Cl
   (c) C—H
   (d) O—C
   (e) N—C

2. A test for the presence of sodium ions in an unknown sample of a salt involves

   (a) tasting the unknown chemical. If it has salty flavour, then it likely contains sodium.
   (b) dissolving the sample in water. If it dissolves, then it likely contains sodium.
   (c) placing a small quantity of the compound in a Bunsen flame. If it gives a yellow colour, then it likely contains sodium.
   (d) determining the molar mass of the sample to see if it corresponds to the atomic weight of sodium.
   (e) none of the above.

3. An electrostatic potential map is

   (a) a contour map showing the maximum electron density in an orbital.
   (b) a plot of $4\pi r^2 R(r)^2$ for a molecule.
   (c) a map of how charge is distributed in a molecule using a colour scale.
   (d) a map showing how the formal charge in a molecule varies from atom to atom.
   (e) a map of the electrostatic attraction of a molecule to a hydrogen atom.

4. Burning white phosphorus in a limited supply of pure oxygen gives which of the following as a compound that may be isolated?

   (a) P_4O_7
   (b) P_4O_6
   (c) P_3O_5
   (d) P_2O_6
   (e) PO_2

5. How many σ bonds and how many π bonds are present in the nitric acid molecule, HNO_3?

   (a) 1σ and 4π
   (b) 2σ and 3π
   (c) 3σ and 2π
   (d) 4σ and 1π
   (e) 5σ and 0π

6. Halogen nitrates adopt polar covalent structures where the atom connectivity is X-O-NO_2 (X = halogen). Given that the melting point of $ClONO_2$ is -107 °C, the most probable melting points of $FONO_2$ and $BrONO_2$ are predicted to be

(a) -78 °C ($FONO_2$) and 0 °C ($BrONO_2$)
(b) -87 °C ($FONO_2$) and -126 °C ($BrONO_2$)
(c) -105 °C ($FONO_2$) and -75 °C ($BrONO_2$)
(d) -175 °C ($FONO_2$) and -42 °C ($BrONO_2$)
(e) -190 °C ($FONO_2$) and -123 °C ($BrONO_2$)

7. The crown ether 18-crown-6 has a cavity size of 2.6 – 3.2 Å. Which of the following species would you expect 18-crown-6 to bind strongly? The ionic diameter for each species is given in parentheses.

(a) Cs^+ (3.34 Å)
(b) In^+ (2.80 Å)
(c) F^- (2.66 Å)
(d) In^{3+} (1.60 Å)
(e) both (b) and (c)

8. Which of the following statements about $[NH_2]^-$ is incorrect.

(a) there are no π bonds.
(b) there are two σ bonds.
(c) N is sp^3 hybridized.
(d) the molecule is bent.
(e) there is one lone pair on N.

9. Which of the following statements about the band theory of solids is true?

(a) metals have a completely filled conduction band.
(b) semiconductors have no band gap between occupied and unoccupied bands.
(c) insulators have a larger band gap than semiconductors.
(d) electrons in bands do not obey the Pauli Exclusion Principle.
(e) electrons in bands are localized in a covalent bond.

10. Which of the following substances in the solid state is expected to be the hardest?

(a) silicon carbide
(b) xenon
(c) copper
(d) potassium nitrate
(e) water

11. How many of the following molecules have a net dipole moment? The central atom is underlined in each molecule.

$\underline{P}Br_3$, $\underline{S}F_6$, $\underline{S}F_4$, $\underline{P}Cl_5$, $\underline{C}HCl_3$

(a) five
(b) four
(c) three
(d) two
(e) none

12. A green laser pointer emits light of wavelength 532 nm. If it emits 5 mW of light energy, how many moles of photons does it emit per second? (1 W = 1 J s^{-1})

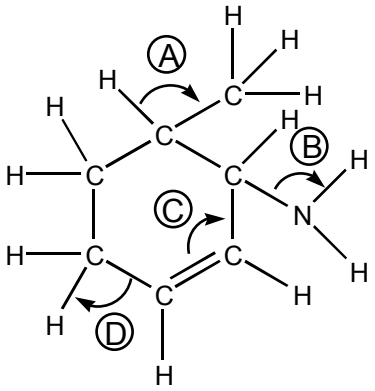
(a) 3.7 millimoles/s
(b) 2.2×10^{-8} mol/s
(c) 4.2 mol/s
(d) 1.4×10^{-4} mol/s
(e) 14×10^{3} mol/s

13. Which one of the following wavelengths of light will not cause an electron to be promoted from the ground state to an excited state in a hydrogen atom?

(a) 93.8 nm
(b) 92.4 nm
(c) 102.6 nm
(d) 121.6 nm
(e) 656.8 nm

14. What are the approximate bonding angles A, B, C and D in the neutral molecule below?

(a) A = 120°, B = 120°, C = 120°, D = 120°
(b) A = 109.5°, B = 109.5°, C = 120°, D = 109.5°
(c) A = 120°, B = 120°, C = 180°, D = 109.5°
(d) A = 109.5°, B = 120°, C = 120°, D = 109.5°
(e) A = 120°, B = 120°, C = 109.5°, D =120°



15. Which of the pairs of molecules below has the same hybridization on the central atom? The central atom is underlined in each molecule.

(a) $\underline{C}O_2$ and $\underline{C}H_4$
(b) $H_2\underline{C}O$ and $\underline{Be}H_2$
(c) $\underline{B}Cl_3$ and $H\underline{N}O$
(d) $\underline{Cl}F_3$ and $\underline{N}H_3$
(e) none of the above

16. The melting point of MgO (2852 ºC) is much higher than that of BaO (1913 ºC) because

(a) MgO has covalent bonds.
(b) Ba has a higher first ionization energy than Mg.
(c) Mg^{2+} is a smaller ion than Ba^{2+}.
(d) MgO is acidic while BaO is basic.
(e) there is strong metallic bonding in Mg.

17. Which statement is true about the following reaction?

$$Ba(s) + H_2O(l) \rightarrow \text{products}$$

(a) one of the products is $Ba^{+}(aq)$.
(b) Ba is reduced.
(c) the reaction produces an acidic solution.
(d) the reaction produces a neutral solution.
(e) the reaction produces a basic solution.

18. CN^{+} and CF^{-} are

(a) paramagnetic (CN^{+}) and diamagnetic (CF^{-}).
(b) paramagnetic (CN^{+}) and paramagnetic (CF^{-}).
(c) diamagnetic (CN^{+}) and paramagnetic (CF^{-}).
(d) diamagnetic (CN^{+}) and diamagnetic (CF^{-}).
(e) not enough information to decide.

19. Which of the following statements is false?

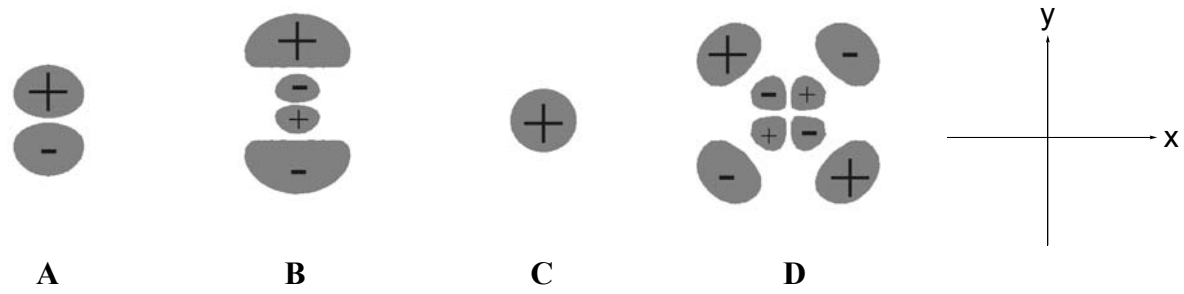
(a) antibonding molecular orbitals are produced by destructive interference of atomic orbitals.
(b) overlap of two atomic orbitals results in bonding orbitals that are always lower in energy than the corresponding antibonding orbitals.
(c) molecular orbitals are generally more delocalized than hybridized atomic orbitals.
(d) one of the shortcomings of molecular orbital theory is its inability to account for a triple bond in the nitrogen molecule, N_2.
(e) one of the shortcomings of valence bond theory is its inability to account for the paramagnetism of the oxygen molecule, O_2.

20. Which of the following statements is incorrect?

(a) iodine is an example of a network covalent solid.
(b) diamond is an example of a network covalent solid.
(c) dry ice (solid CO_2) is an example of a molecular solid.
(d) table salt is an example of an ionic solid.
(e) copper wire is an example of a metallic solid.

PART II. (19 marks total)

1. (a) Identify each of the orbitals of the hydrogen atom shown in cross section below. Add phases to the diagrams. The coordinate system for all the orbitals is shown on the right.



A **B** **C** **D**

Orbital:__2p__ Orbital:__3p__ Orbital:__1s__ Orbital:_4d___

(b) List the orbitals **A-D** in order of increasing energy.

_1s__ < __2p_ < __3p_ < _4d__

2. Given the following gas phase ionization energies for aluminum:

$Al \rightarrow Al^{+} + e^{-}$ $I_1 = 580$ kJ/mol

$Al^{+} \rightarrow Al^{2+} + e^{-}$ $I_2 = 1815$ kJ/mol

$Al^{2+} \rightarrow Al^{3+} + e^{-}$ $I_3 = 2740$ kJ/mol

$Al^{3+} \rightarrow Al^{4+} + e^{-}$ $I_4 = 11600$ kJ/mol

(a) Explain the trend in these ionization energies.

The effective nuclear charge (Z_{eff}) experienced by the electrons in the ions increases with increasing charge. Thus, removing an additional electron requires more energy the greater the charge on the ion, as a larger effective nuclear charge must be overcome to ionize the electron.

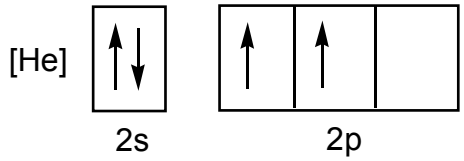
(b) Explain the large increase in ionization energies between I_3 and I_4.

Al^{2+} has a $[Ne]3s^1$ electron configuration, while Al^{3+} has the same electron configuration as Ne. Thus, ionizing Al^{2+} yields a stable noble gas configuration, while ionizing Al^{3+} requires the stable noble gas configuration to be broken requiring significantly more energy.

(c) List the four aluminum ions given above in order of increasing size.

__Al^{4+}__ < __Al^{3+}__ < __Al^{2+}__ < __Al^{1+}__

3. (a) Draw the orbital diagram showing the electron configuration of carbon in the ground state.



(b) Give the electron configuration of nickel in the ground state.

$[Ar]\ 4s^2 3d^8$

(c) Give the transition metal ground state species that has the same electronic configuration as Zn^{2+}.

Cu^+

4. (a) State the selection rule for $\Delta \ell$ in atomic spectroscopy.

$\Delta \ell = +1$ or -1

(b) Gas phase Be^{3+} ions are generated in an excited state with $n = 4$. The excited state ions relax to the ground state following the selection rules. The atomic emission spectrum is recorded and only three lines are observed.

(i) Give the value of ℓ for the hydrogen-like orbital that the excited Be^{3+} electron must be in for the above spectrum to be observed. Explain your answer with the aid of a diagram.

$\ell = 3$ (*f* orbital).

(ii) Calculate the wavelength (in nm) of the lowest energy line in the above spectrum.

The lowest energy line will be due to the $4f \rightarrow 3d$ transition.

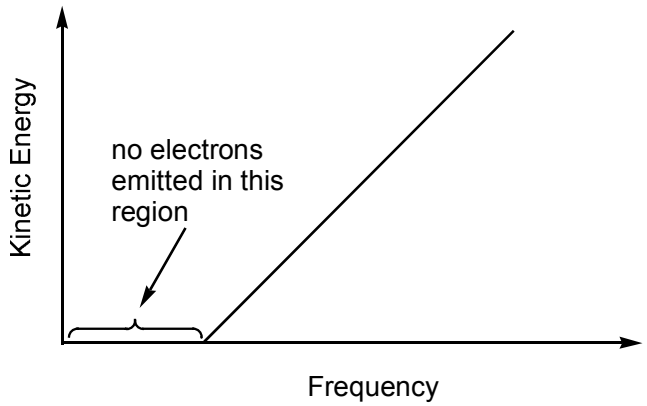
$$\Delta E = 2.179\times10^{-18} Z^2 \left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) = 2.179\times10^{-18} (4)^2 \left(\frac{1}{4^2} - \frac{1}{3^2}\right) = -1.69\times10^{-18}\ \text{J}$$

$$\lambda = \frac{hc}{E} = \frac{(6.626\times10^{-34}\ \text{Js})(3.00\times10^{8}\ \text{ms}^{-1})}{1.69\times10^{-18}\ \text{J}} = 1.18\times10^{-7}\ \text{m} = 118\ \text{nm}$$

PART III. (18 marks total)

1. In a photoelectric effect experiment, the kinetic energy of the emitted electrons is measured as a function of the wavelength of the incident light on a metal.

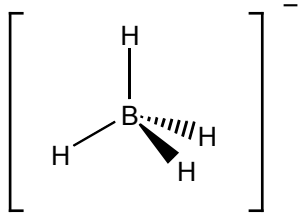
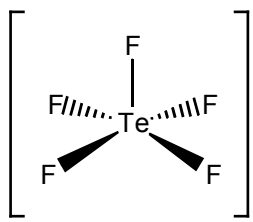
   (a) Sketch a plot of the kinetic energy of the emitted electrons vs. frequency of light on the axes below. On the plot, indicate using an arrow and a label, any region where electrons are not emitted from the metal.



   (b) Indicate how Planck's constant is related to this graph

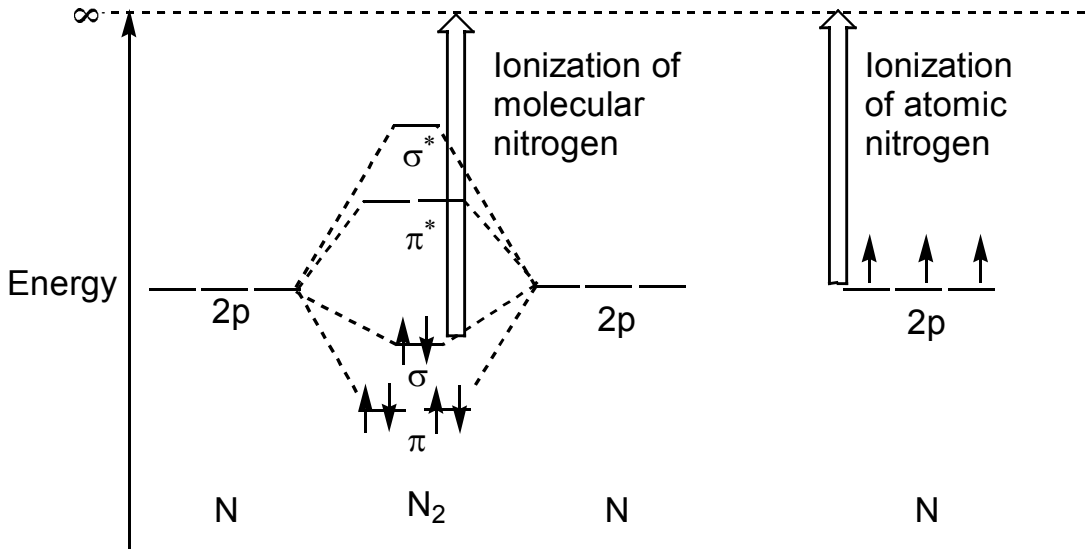
   Planck's constant is the slope of the graph.

2. Predict the molecular shape for each of the following anions. Draw the molecule, clearly indicating the three dimensional shape in your drawing.

Molecule	Molecular shape:	Drawing:
$[\underline{B}H_4]^-$	Tetrahedral	
$[\underline{Te}F_5]^-$	Square pyramidal	

3. Explain why the first ionization energy of N_2 (1501 kJ/mol) is greater than the first ionization energy of atomic nitrogen (1402 kJ/mol).

   The first ionization energy of atomic nitrogen corresponds to removing an electron from the highest occupied atomic orbital, a 2*p* orbital. The first ionization energy of N_2 corresponds to removal of an electron from the HOMO, the σ_{2p}. Because the bonding orbitals in N_2 formed by combination of the nitrogen 2*p* orbitals are lower in energy than the atomic orbitals, the ionization energy for N_2 is lower than for atomic nitrogen.



4. An electron is confined to a small nanoparticle of metal which is 1 nm in diameter. What is the minimum uncertainty for any possible measurement of this electrons velocity (in m/s)? (electron mass = 9.11×10^{-31} kg)

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

$$(1\times10^{-9}\,\text{m})m\Delta v \geq \frac{6.626\times10^{-34}}{4\pi}$$

$$\Delta v \geq \frac{6.626\times10^{-34}}{4\pi(1\times10^{-9}\,\text{m})(9.11\times10^{-31}\,\text{kg})}$$

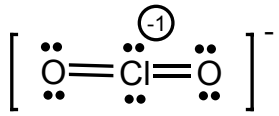
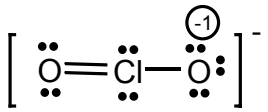
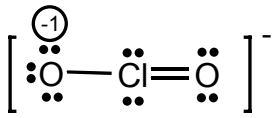
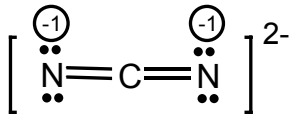
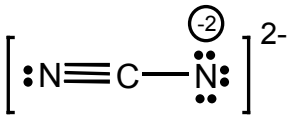
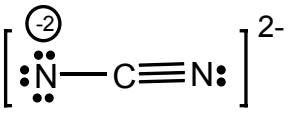
$$\Delta v \geq 5.8\times10^{4}\,\text{m/s}$$

5. On the Supplemental Sheet are diagrams of the electrostatic potential maps for HOCl, HOF and FOCl. In the box next to each formula below write the letter A, B or C corresponding to its electrostatic map. The central atom is underlined.

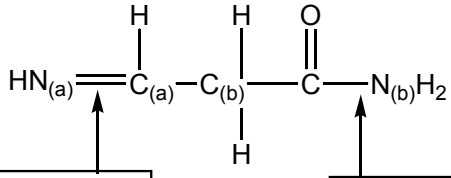
F<u>O</u>Cl = A	H<u>O</u>Cl = B	H<u>O</u>F = C

PART IV. (20 marks total)

1. For each of the ions below, draw Lewis structures, showing the best three resonance structures for each (one structure per box). For each structure, write any non-zero formal charges on the appropriate atoms. In each case, the central atom is underlined. Show all lone pairs as pairs of dots.

$[\underline{Cl}O_2]^-$		
		
$[\underline{C}N_2]^{2-}$		
		

2. Indicate the hybridization of the specified atoms in the following neutral molecule in the table to the right of the molecule. In the boxes below the molecule, indicate the hybrid and/or atomic orbitals that overlap to form the indicated bond(s) and the type of bond(s) they form.



σ: sp^2(N)-sp^2(C)

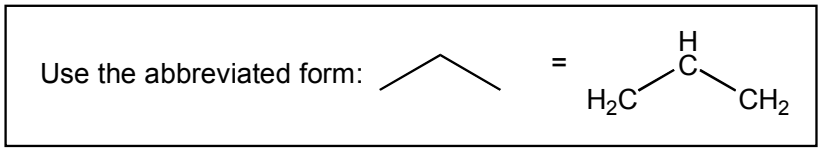
π: 2p(N)-2p(C)

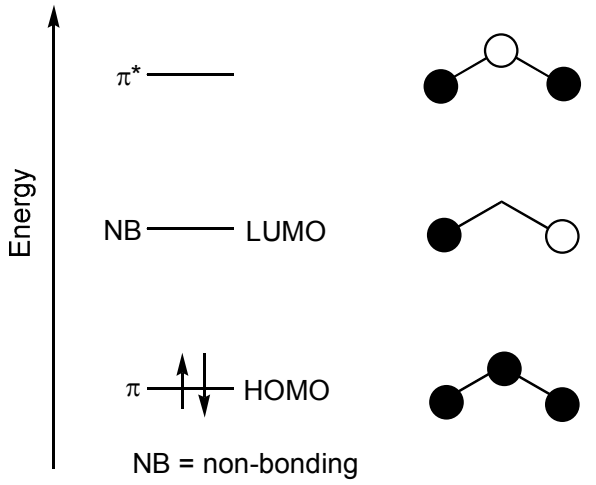
σ: sp^2(C)-sp^3(N)

Atom	Hybridization
$N_{(a)}$	sp^2
$N_{(b)}$	sp^3
$C_{(a)}$	sp^2
$C_{(b)}$	sp^3

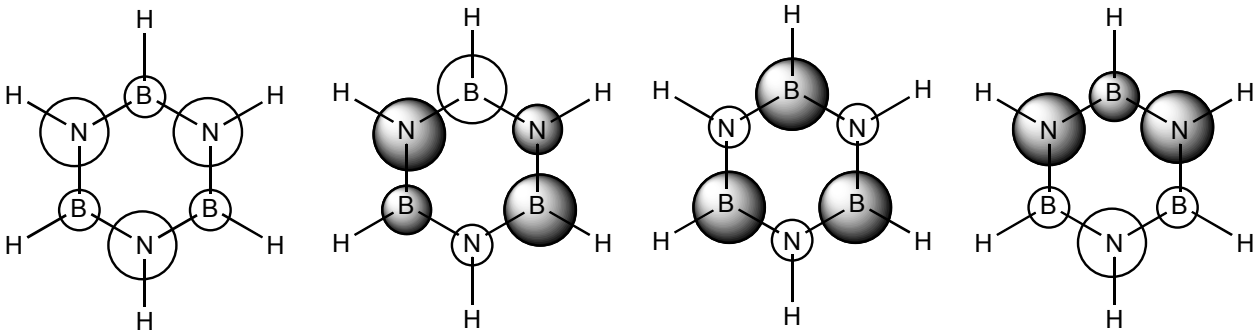
What is the maximum number of atoms that may be located in the same plane in this molecule?____9_____

3. On the energy axis below, draw and label the energy level diagram for the π molecular orbitals of the allyl cation, $[CH_2CHCH_2]^+$. Place the appropriate number of electrons on this diagram to show the ground state configuration of this cation. Label the HOMO and LUMO. Beside each energy level you have drawn sketch each molecular orbital, indicating phases, using the abbreviated form of the cation shown in the box.





4. Borazine, $N_3B_3H_6$, consists of a six-membered ring (hexagon) of alternating boron and nitrogen atoms with one hydrogen attached to each B and N. Borazine is isoelectronic with benzene (C_6H_6). Below are sketches of four (4) of the six (6) the π molecular orbitals of borazine (labeled **A**-**D**). The p-orbitals are drawn perpendicular to the plane of the paper, and the phase of the lobe pointing towards you is shaded (-) or unshaded (+).



A **B** **C** **D**

Arrange the π molecular orbitals of borazine (**A** to **D**) in order of increasing energy.

___A___ < ___D___ < ___B___ < ___C___

lowest E highest E

PART V. (16 marks total)

1. A compound containing Ag and O crystallizes as a fcc arrangement of Ag ions with O ions occupying two of the tetrahedral holes.

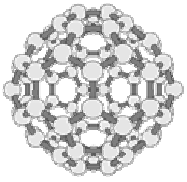
   (a) Calculate the empirical formula of the compound.

   Each unit cell contains 4 Ag ions. The two occupied tetrahedral holes are completely within the unit cell, thus each unit cell contains 2 O ions. Therefore, the empirical formula is Ag_2O.

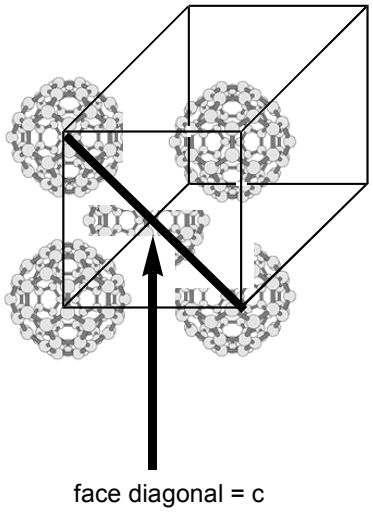
   (b) What is the coordination number of Ag in this compound___1_____

   (c) What is the coordination number of O in this compound___4_____

2. C_{84} is an allotrope of carbon with the molecular structure shown below. In the solid, the molecules form a fcc crystal lattice with an edge length of 1.59 nm.



   (a) Calculate the distance in nm between the centres of nearest neighbour C_{84} molecules.



Distance between nearest neighbors, b = ½ of the face diagonal, c.

$c^2 = 2(a^2)$

$c = \{2(1.59\ nm)^2\}^{1/2} = 2.25\ nm$

$b = c/2 = 1.12\ nm$

   (b) Calculate the radius in nm of the C_{84} molecule assuming that it is a perfect sphere.

$r = b/2 = 1.12/2 = 0.56\ nm$

(c) Calculate the density of the C_{84} crystal in g cm^{-3}.

In a fcc lattice, there are 4 C_{84} molecules in the unit cell.

The mass of the unit cell = $4(84 \times 12.01 \text{ g mol}^{-1})/6.022 \times 10^{23}) = 6.70 \times 10^{21}$ g

Volume of the unit cell = $(1.59 \times 10^{-7} \text{ cm})^3 = 4.02 \times 10^{-21} \text{ cm}^3$

Density = mass/volume = $(6.70 \times 10^{21} \text{ g})/(4.02 \times 10^{-21} \text{ cm}^3) = 1.67 \text{ g cm}^{-3}$

(d) Assuming an interplanar spacing (*d*) of 1.59 nm, calculate the angle in degrees at which X-rays of wavelength 0.154 nm would undergo third order diffraction from a C_{84} crystal.

$n\lambda = 2d\sin\theta$

$3(0.154 \text{ nm}) = 2(1.59 \text{ nm})\sin\theta$

$\theta = 8.35°$

PART VI. (17 marks total)

1. Complete the following sentences and phrases (elemental symbols may be used):

(a) Zeolites are composed primarily of the following three elements:

(i) ___aluminum_____

(ii) ___silicon_____

(iii) ___oxygen_____

(b) The industrial production of zeolites exceeds 10^4 tonnes per year and they find application as __molecular sieves or catalysts_____.

(c) The most abundant metallic lement in the Earth's crust is __aluminum_____. This element is found in gemstones and the metal is isolated using the ___Hall-Héroult____ Process. A major site for the refinement of this metal is in Kitimat, BC.

(d) ___Graphite_____ is an allotrope of carbon which finds application as a lubricant due to its sheetlike structure.

(e) The central processing unit (CPU) in computers is made using the semiconducting element ____silicon_____. The element can either p-doped with ___boron_____ which removes electrons from the __valence_____band, or n-doped with _____phosphorus_____ which adds electrons to the __conduction_____ band.

(f) The industrially important silicones are produced by the controlled reaction of __$(CH_3)_2SiCl_2$_____ with __water_____.

2. ALL unknown compound in this question contain the element xenon.

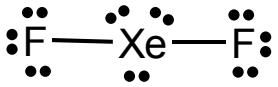
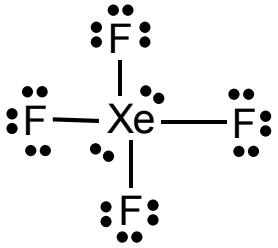
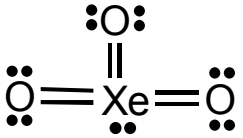
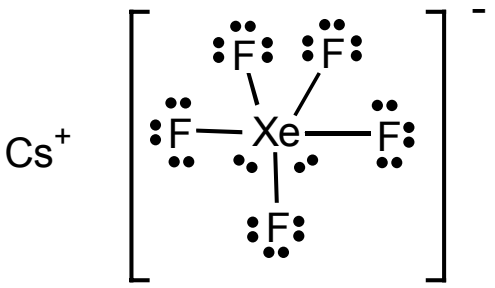
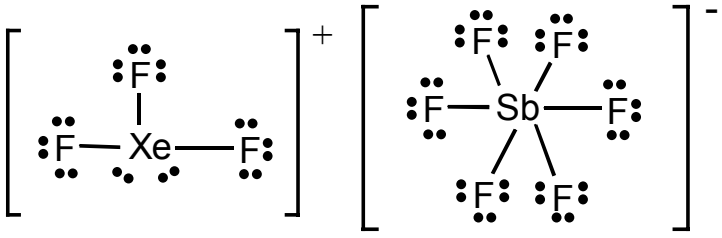
A mixture of gaseous xenon (13.1 g) and gaseous fluorine (3.8 g) was irradiated with sunlight and 16.9 g of a white crystalline solid (Compound **A**) was obtained. A dipole moment measurement revealed that compound **A** is nonpolar. In a separate experiment, a mixture of xenon (0.1 mol) and fluorine (0.5 mol) were heated to 400 °C and 0.1 mol of another white crystalline solid (Compound **B**) was deposited on the walls of the reaction vessel. Compound **B** has a molar mass of 207 g mol^{-1}. If compound **B** (0.100 mol) is exposed to water vapor (0.200 mol), it rapidly decomposes to form hydrogen fluoride (0.400 mol), xenon (0.067 mol), O_2 (0.050 mol) and 0.033 mol of an explosive molecule (Compound **C**) which possesses a net non-zero dipole moment. If compound **B** is kept free of water, then further reactions of it may be studied. For example, the reaction of compound **B** (0.02 mol) with cesium fluoride (0.02 mol) yields 0.02 mol of compound **D** and no other products. The reaction of 0.05 mol of compound **B** with 0.05 mol of the Lewis acid SbF_5 yields compound **E** (0.05 mol). Compound **E** is an ionic salt with the composition $XeSbF_9$. The anion in **E** carries a single negative charge.

Following the detailed instructions on the next page, draw Lewis structures and indicate molecular shape for each of the unknown compounds (**A** through **E**) in the table on the next page.

Use the space below for rough work (this will not be marked).

For Lewis structures: Draw the best Lewis structure for each unknown. If the unknown is ionic, a Lewis structure of each ion must be drawn. All lone pairs must be shown as pairs of dots, all non-zero formal charges must be shown, and ions must be shown in square brackets with their overall charge given.

For molecular shape: Indicate in words what the molecular shape of the xenon-containing species is for each unknown.

Compound	Lewis structure (see instructions above)	Molecular shape (see instructions above)
A		linear
B		square planar
C		trigonal pyramidal
D		pentagonal planar
E		T-shaped

END OF EXAMINATION