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

THE UNIVERSITY OF BRITISH COLUMBIA
Department of Chemistry
Chemistry 121 Final Examination

December 11, 2006 — Time Limit: 2.5 hrs

SURNAME: ANSWERS (PRINTED CAPITALS IN INK) GIVEN NAME(S):________________ (PRINTED CAPITALS IN INK)

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

INSTRUCTIONS
1. Answer all questions on the examination paper.
2. Check that your examination contains pages numbered 1 through 19. Page 19, the Periodic Table, may be removed. You should also have a Supplemental Sheet containing "Potentially Useful Information" and coloured figures.
3. The only calculator permitted is the Sharp EL-510R. All other 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. Krems
___102 (MWF 2:00) Dr. Herring
___109 (MWF 9:00) Dr. MacFarlane
___110 (MWF 10:00) Dr. Gates
___111 (MWF 11:00) Dr. Gates
___122 (T, Th 2:00) Dr. Wolf
___133 (T, Th 3:30) Dr. Liu
___188 (T,Th 8:00) Dr. Kennepohl
___199 (T,Th 9:30) Dr. Schafer

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	14		
III	13		
IV	19		
V	11		
VI	18		
VII	15		
Total	**120**		

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. What is the hybridization of oxygen in water?

(a) *s*
(b) *p*
(c) *sp*
(d) sp^2
(e) sp^3

2. Which of the following statements is TRUE.

(a) The atomic number is the same as the number of protons.
(b) The atomic radius increases from left to the right through the period of elements.
(c) The first ionization energy increases from right to left through a period of elements.
(d) The radius of all atoms can be measured precisely.
(e) Electronegativity decreases for elements from left to right across the period.

3. The quantum number m_ℓ for a valence electron of atomic sulfur in its ground state could be:

(a) ½
(b) 1
(c) 2
(d) 3
(e) 4

4. Which of the following elements (X) forms an oxide with the empirical formula X_2O_5?

(a) chlorine
(b) sulfur
(c) silicon
(d) aluminum
(e) phosphorus

5. The energy (in Joules) of the 3*p* orbital in the He^+ ion is:

(a) -2.18×10^{-18}
(b) $+2.18 \times 10^{-18}$
(c) -1.46×10^{5}
(d) $+9.68 \times 10^{-19}$
(e) none of the above

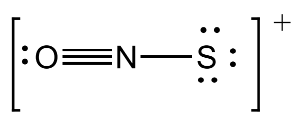
6. Which of the following species (oxidation state is given in parentheses) has the most unpaired electrons in its ground state?

(a) vanadium(I)
(b) chromium(0)
(c) manganese(I)
(d) iron(II)
(e) copper(0)

7. According to molecular orbital theory, which statement below is correct?

(a) A molecule with an even number of electrons must be diamagnetic.
(b) The number of bonds is defined by the number of electrons in bonding orbitals.
(c) Putting electrons in molecular orbitals follows the Aufbau principle.
(d) There are as many bonding as antibonding electrons in a molecule.
(e) All molecules contain π bonds.

8. A plausible Lewis structure for the $[ONS]^+$ cation is shown below (formal charges are not shown):



Complete the following sentence by circling the best answer. This is not the best Lewis structure for $[ONS]^+$ because:

(a) nitrogen prefers to form double bonds to sulfur rather than oxygen.
(b) oxygen does not have a completed octet.
(c) the predicted shape of $[ONS]^+$ is bent and not linear.
(d) sulfur has too many electrons in its valence shell.
(e) a formal positive charge should not be placed on the most electronegative element.

9. Which of the following is neither a network covalent solid nor a polymer?

(a) silicon
(b) diamond
(c) red phosphorus
(d) white phosphorus
(e) silicon dioxide

10. Porous crystalline solids composed of silicon, aluminum and oxygen are called

(a) pnictogens
(b) crown ethers
(c) bucky balls
(d) zeolites
(e) aromatics

11. Which of the following pairs of molecules or ions are isoelectronic?

(a) N_2 and O_2
(b) $[SCN]^-$ and $[OCN]^-$
(c) $[NO_3]^-$ and $[CO_3]^{2-}$
(d) OF_2 and OH_2
(e) CO and NO

12. Which of the following ionic compounds is predicted to have the largest lattice energy?

(a) NaF
(b) MgO
(c) NaCl
(d) BaO
(e) KF

13. Which of the following species is expected to have the largest number of unpaired electrons?

(a) CO
(b) $[O_2]^-$
(c) F_2
(d) $[Li_2]^+$
(e) B_2

14. Which of the following statements about atomic properties is TRUE?

(a) The electron affinity of fluorine is greater than that of oxygen.
(b) The atomic radius of boron is greater than that of beryllium.
(c) The radius of Si^+ is greater than that of aluminum.
(d) The atomic radius of argon is larger than that of I^-.
(e) Energy is always absorbed when an atom in the gas phase gains an electron.

15. Which of the following compounds is predicted to have the highest boiling point?

(a) OF_2 (O is central atom)
(b) HOBr (O is central atom)
(c) F_2
(d) Cl_2
(e) CF_4

16. What is the ground state electronic configuration of arsenic?

(a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^{10}\ 4p^4$
(b) [Ne] $4s^2\ 3d^{10}\ 4p^3$
(c) $1s^4\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4p^3$
(d) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^3$
(e) [Kr] $5s^2\ 4d^{10}\ 5p^3$

17. The carbon-carbon bond order in the $[C_2]^{2-}$ ion is

(a) 0
(b) 1
(c) 2
(d) 3
(e) 4

18. What is the best explanation for the term “node” as it pertains to orbitals of the hydrogen atom?

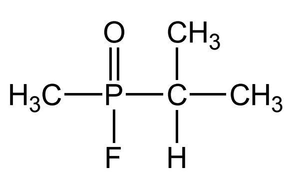
(a) The wave function describing the electron passes through zero and changes sign.
(b) An electron has nodes when behaving like a wave but not when behaving like a particle.
(c) The electron cannot exist at certain locations due to its attraction to the nucleus.
(d) The square of the wave function describing the electron is always negative.
(e) The wave function of the nucleus affects the area surrounding it in different ways, making it impossible for the electron to exist at certain locations.

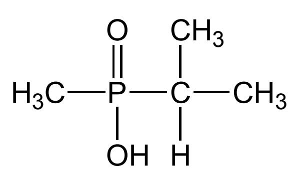
19. Silver is an FCC metal with cubic unit cell edge length 408 pm and threshold energy for the photoelectric effect (or work function) $\Phi = 7.58 \times 10^{-19}$ J. A sample of silver is irradiated with electromagnetic radiation of wavelength 154 pm (incident beam). Which of the following is correct?

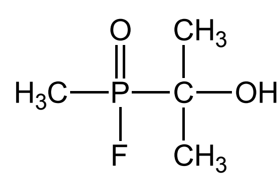
(a) No electrons will be emitted from the silver.
(b) Some of the radiation will be diffracted at $\theta = 22.2°$.
(c) All of the electromagnetic radiation will be reflected.
(d) No silver atoms will be ionized.
(e) Silver’s density is 14.3 g/cm^3.

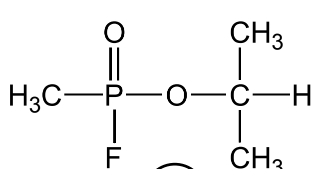
20. Sarin is a highly deadly nerve agent. Sarin can be prepared by the reaction of $(H_3C)POF_2$ (0.1 mol, P is the central atom) with 2-propanol $H_3C–\underset{\displaystyle OH}{\underset{|}{CH}}–CH_3$ (0.1 mol). Hydrogen fluoride (0.1 mol) is the sole byproduct.

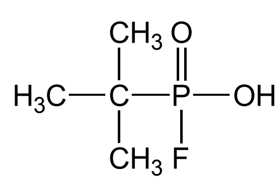
Based on the aforementioned information, the most plausible molecular structure of Sarin is:


(a)


(b)


(c)


(d)


(e)

PART II. (14 marks total)

1. Indicate if the orbital with the given quantum numbers can exist.

(a) $n = 3,\ \ell = 0, m_\ell = 0$ Yes No (circle the correct answer)

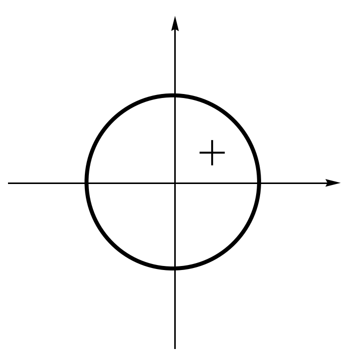
(b) $n = 4,\ \ell = 1, m_\ell = -2$ Yes No (circle the correct answer)

(c) $n = 2,\ \ell = 2, m_\ell = 0$ Yes No (circle the correct answer)

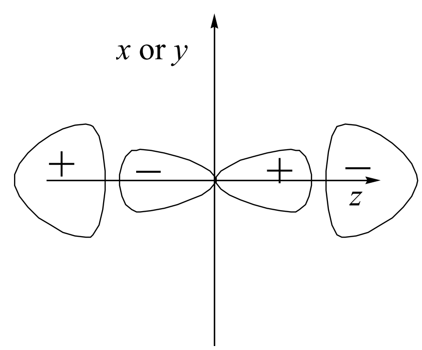
(d) $n = 128,\ \ell = 27, m_\ell = -12$ Yes No (circle the correct answer)

2. (a) Draw cross-sections for the following orbitals of the hydrogen atom. Be sure to show phases as (+) or (-) and label the axes.

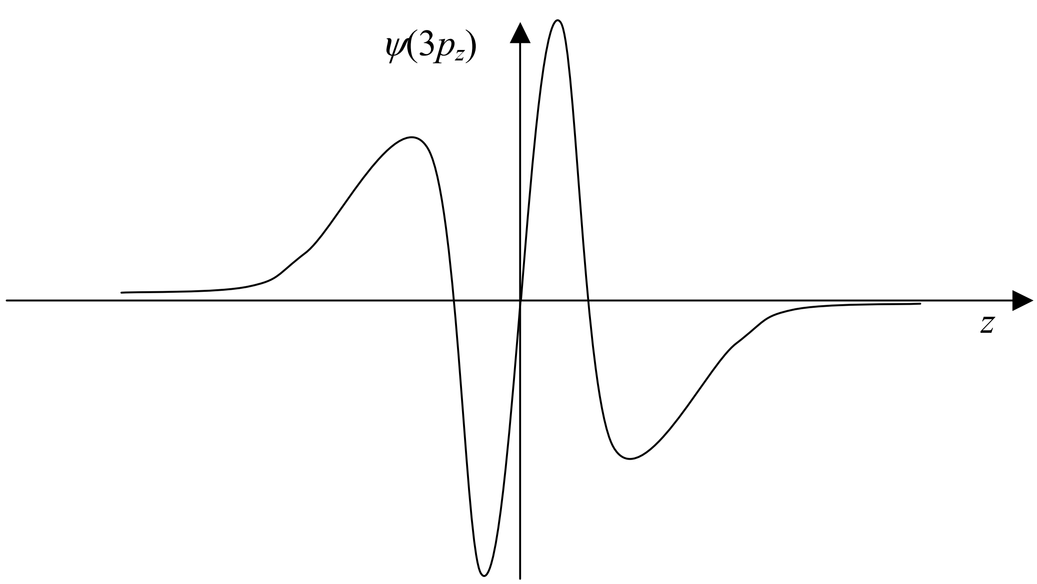
1*s*



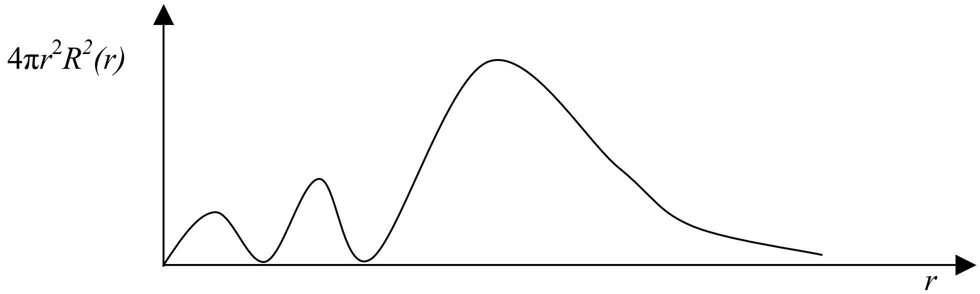
3*p*$_z$



(b) Using your drawing of the $3p_z$ orbital from part (a), sketch the wavefunction $\psi(3p_z)$ versus z on the axes below (a scale is not required).



3. On the axes below, sketch the radial probability distribution for the $5d_{z^2}$ orbital. Label the axes accordingly (a scale is not required).



4. (a) Calculate the energy (in Joules) to excite He^+ from the ground state to the 3*p* orbital.

$$\Delta E = R_H\left(\frac{Z^2}{1^2}-\frac{Z^2}{3^2}\right) = 2.18\times10^{-18}J\left(\frac{2^2}{1^2}-\frac{2^2}{3^2}\right)$$
$$= +7.75\times10^{-18}J$$

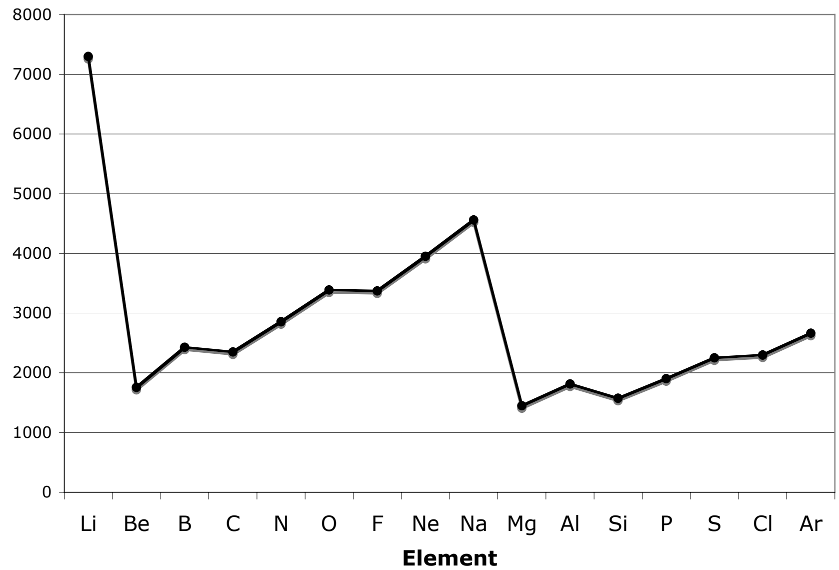
(b) The excited He^+ ions from part (a) collide with O^{7+} ions that are in the 4*s* state. In this process, as the He^+ relaxes to the ground state energy is transferred from He^+ to O^{7+} resulting in other excited states of O^{7+}. Determine the highest value of *n* in O^{7+} that can result from this energy transfer process.

He^{2+} relaxes from the $n = 3$ to $n = 1$ level and this energy is transferred to excite O^{7+} from the $n_i = 4$ level to an unknown final (n_f) energy level. n_f can be calculated as follows:

$$\Delta E = R_H Z_{He}^2\left(\frac{1}{n_i^2}-\frac{1}{n_f^2}\right) = -R_H Z_O^2\left(\frac{1}{n_i^2}-\frac{1}{n_f^2}\right)$$
$$= 2^2\left(\frac{1}{3^2}-\frac{1}{1^2}\right) = -8^2\left(\frac{1}{4^2}-\frac{1}{n_f^2}\right)$$
$$= 4\left(\frac{1}{9}-\frac{1}{1}\right) = -64\left(\frac{1}{16}-\frac{1}{n_f^2}\right) \quad\Rightarrow\quad \left(\frac{1}{9}-\frac{1}{1}\right) = -16\left(\frac{1}{16}-\frac{1}{n_f^2}\right)$$
$$= \frac{1}{9}-1 = \frac{16}{n_f^2}-1 \quad\Rightarrow\quad \frac{1}{9} = \frac{16}{n_f^2} \quad\Rightarrow\quad n_f^2 = 9\times16 = 144$$
$$n_f = 12$$

PART III. (13 marks total)

1. The graph below shows the *second ionization energies* (2^{nd} IE) for the elements of the $n = 2$ and $n = 3$ periods. Use it to answer the following questions.

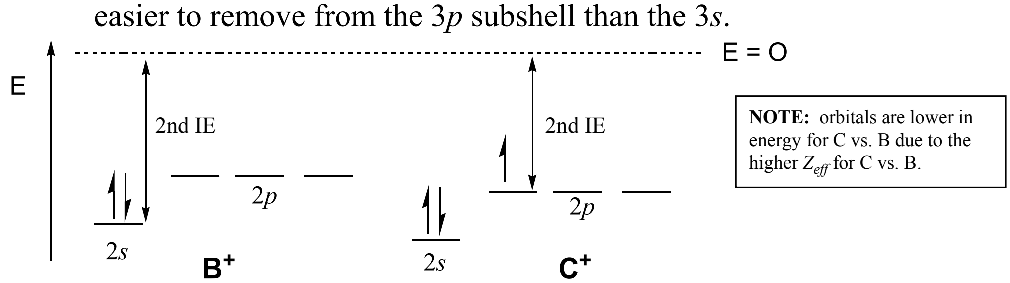


(a) Complete the equation below by filling in the boxes to show the second ionization energy (2^{nd} IE) for carbon.

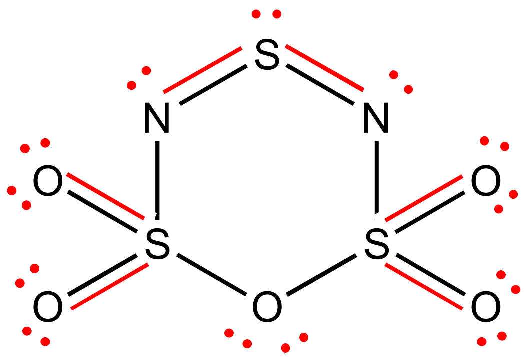
$$C^{\boxed{+}}_{(g)} \longrightarrow C^{\boxed{2+}}_{(g)} + \boxed{e^{-}}$$

(b) The 2^{nd} IE of an element generally increases across a period, however, there are exceptions at C and Si. Give an explanation for the anomalous 2^{nd} IE's of C and Si.

The energy required to remove an electron from C^+ is less than that of B^+. Similarly, the energy to remove an electron from Si^+ is less than that of Al^+. In the case of C^+ the electron is being removed from the 2*p* orbital whilst for B^+ the electron is being removed from the 2*s* orbital (see figure). Since the 2*p* is higher in energy than the 2*s*, it is easier to remove the electron from C^+ than B^+ and, consequently, C^+ has a lower IE than B^+. Similarly, for Si^+ vs. Al^+, the electron is easier to remove from the 3*p* subshell than the 3*s*.



2. The skeletal structure of $S_3N_2O_5$ is shown below. Complete the Lewis structure so that all atoms have a formal charge of zero. Show all lone pairs of electrons as pairs of dots. Where appropriate, add lines between atoms to represent multiple bonds.

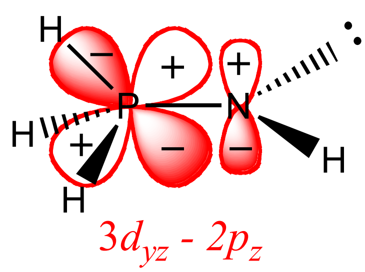


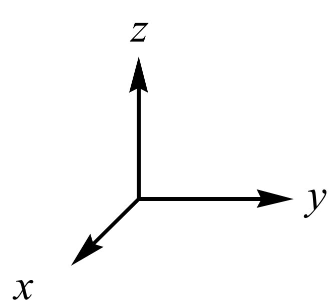
3. The perspective diagram below (part b) shows the σ-framework of $Cl_3P{=}NH$.

(a) Give the hybridization of P and N in $Cl_3P{=}NH$.

Hybridization: P ___sp^3___ N ___sp^2___

(b) On the molecular drawing below, sketch and name (i.e. 2*s*, $2p_x$, etc) the atomic orbitals that overlap to form the π-bond between phosphorus and nitrogen according to valence bond theory. Show phases as (+) or (–). An axis system is given to show the orientation of the molecule (P, N, H and the lone pair lie in the *xy* plane).

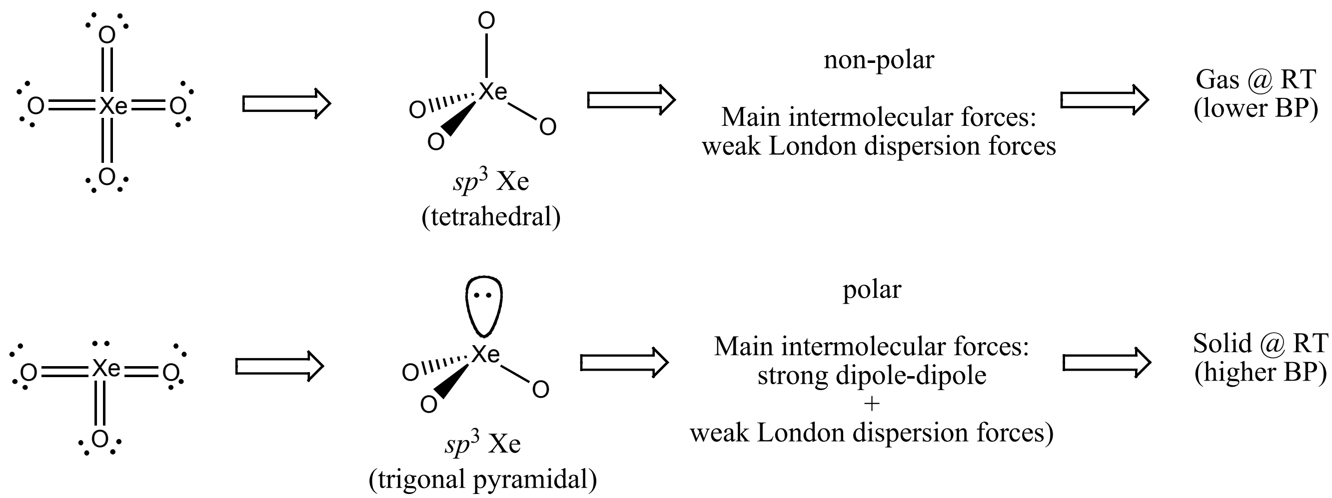




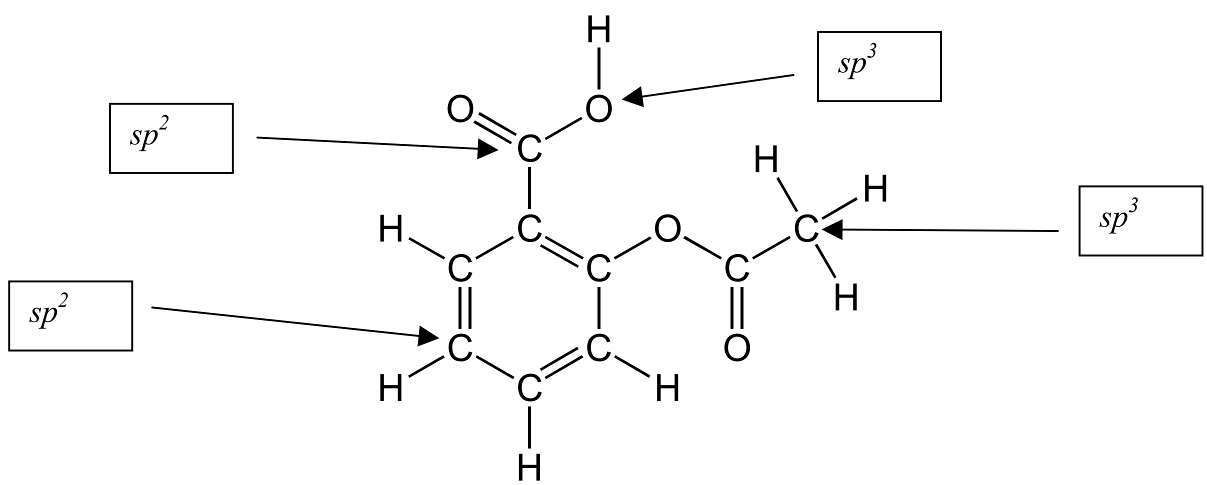
PART IV. (19 marks)

1. Despite the fact that XeO_4 has a higher molecular mass than XeO_3, XeO_4 exists as a gas at room temperature, whereas XeO_3 is a solid (Xe is the central atom in each molecule). Give a plausible rationale for this observation.

   To answer this question, the intermolecular forces in XeO_4 vs. XeO_3 must be considered. The fact that XeO_4 is more polarizable than XeO_3 due to its larger number of electrons and, consequently, the London dispersion forces are stronger in XeO_4. However, XeO_3 is polar and has dipole-dipole interactions whilst XeO_4 is nonpolar and no such forces are present. The strong dipole-dipole forces between XeO_3 molecules outweigh the small difference in London forces and, therefore, XeO_3 (a solid at 25 °C) has a higher BP than XeO_4 (a gas at 25 °C).



2. The molecular structure of acetylsalicylic acid, commonly known as Aspirin™, is shown below (lone pairs are not shown). In the boxes below, give the hybridization of the indicated atoms.

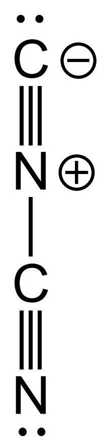
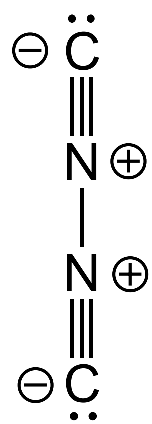
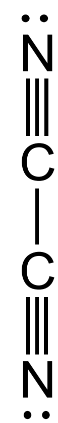


   What is the maximum number of atoms that may be located in the same plane in Aspirin™?

   19 ____________

3. Four different linear molecules having the formula C_2N_2 are possible. The connectivity of the atoms for each structure is shown in the table below.

(a) Draw the best Lewis structure for each C_2N_2 molecule. All atoms must have a completed octet. Write any non-zero formal charges on the appropriate atoms. Show all lone pairs of electrons as pairs of dots, and bond pairs as lines.

Structure #1 (C—C—N—N)	**Structure #2** (C—N—C—N)	**Structure #3** (C—N—N—C)	**Structure #4** (N—C—C—N)
			

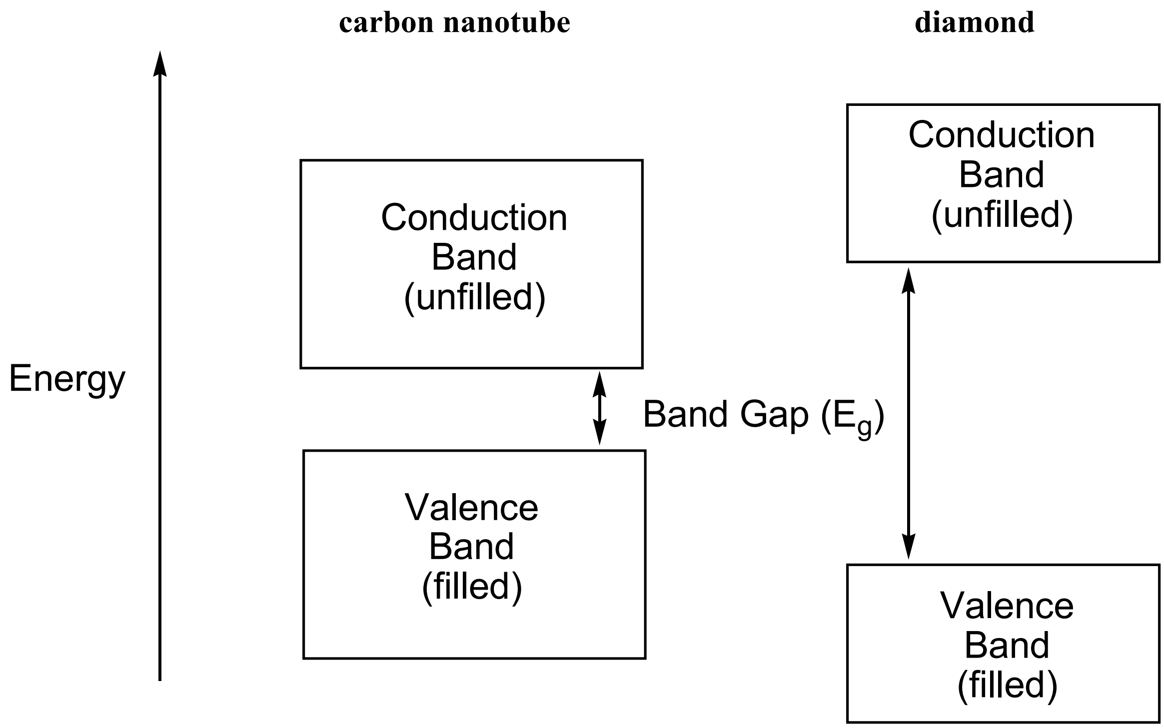
(b) Shown on the supplementary sheet are the electrostatic potential maps for the four possible structures of C_2N_2. In the table below, match each structure you have drawn (above) to each of the electrostatic potential maps shown on the supplementary sheet.

Structure	**Electrostatic Map** (**A**, **B**, **C** or **D**)
#1 (C—C—N—N)	**D**
#2 (C—N—C—N)	**B**
#3 (C—N—N—C)	**C**
#4 (N—C—C—N)	**A**

PART V. (11 marks total)

1. Carbon nanotubes are semiconductors and diamond is an electrical insulator.

   (a) On the energy scale below, draw band diagrams for a carbon nanotube (left) and diamond (right). In each case label the band gap, give the names of the bands and indicate whether the band is "filled", "partially filled" or "unfilled (empty)" with electrons.



(NOTE: Eg is larger for diamond than for the carbon nanotube.

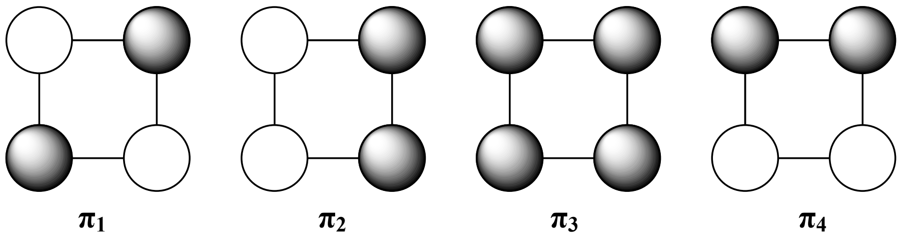
   (b) Give an element that could be used to p-type doped carbon nanotubes by replacement of a small percentage of the carbon atoms.

   Boron (+ others)

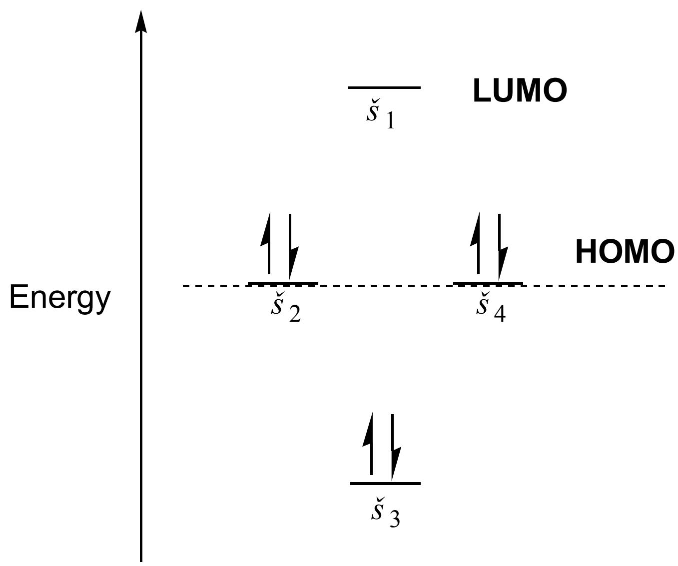
   (c) Give an element that could be used to n-type doped carbon nanotubes by replacement of a small percentage of the carbon atoms.

   Nitrogen (+ others)

2. The compound $[Se_4][AsF_6]_2$ contains the cyclic $[Se_4]^{2+}$ ion. Each Se atom in $[Se_4]^{2+}$ is sp^2 hybridized. Below are the π molecular orbitals of $[Se_4]^{2+}$ (top view). The phases of the orbitals are either shaded (+) or not shaded (–).



(a) Draw an energy level diagram showing the relative energy levels of each of the above orbitals and label each appropriately (i.e. π_1, π_2, π_3, π_4). Place the appropriate number of electrons in each orbital and determine whether $[Se_4]^{2+}$ is paramagnetic. Label the HOMO and LUMO.



Is $[Se_4]^{2+}$ paramagnetic?

YES (NO) (circle one)

(b) What is the expected bond order for each selenium-selenium bond in $[Se_4]^{2+}$? Briefly explain your answer.

The π MO's (*π_2 and π_4*) are degenerate, each has 1 node. Since there are three energy levels, these orbitals must be non-bonding. Alternatively, the same conclusion is reached if you consider each Se–Se interaction in *π_2 and π_4*. Each have two Se–Se bonding interactions and two anti-bonding interactions which suggests that they must be non-bonding.

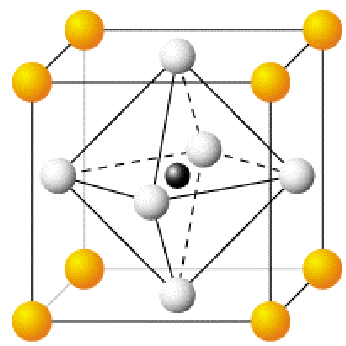
$$\pi(\text{BO}) = \frac{1}{2}(2-0) = 1 \text{ (delocalized over 4 Se - Se bonds)}$$

$$\therefore \text{ The } \pi(\text{BO}) \text{ for each Se - Se } = \frac{1}{4} = 0.25$$

$$\text{Overall BO for each Se - Se } = 1.25$$

PART VI. (18 marks)

1. The picture below shows the cubic unit cell of an ionic oxide where A is a 2+ cation (cube corners), O is the oxide ion (cube faces) and X is a cation (cube centre).



(a) How many of each ion (A, X and O) are in the unit cell?

A 1

X 1

O 3

(b) Given that A = Ba^{2+} and that the density of this ionic oxide is 5.85 g/cm^3, identify the ion X and give the chemical formula of the compound. The edge length of the unit cell is 404.5 pm.

$$density = 5.85 \text{ g cm}^{-3} = 5.85 \times 10^{6} \text{ g m}^{-3} = \frac{mass}{volume}$$

$$volume = a^3 = (404.5 \times 10^{-12} \text{ m})^3 = 6.62 \times 10^{-29} \text{ m}^3$$

$$mass = (density) \times (volume)$$

$$= (5.85 \times 10^{6} \text{ g m}^{-3}) \times (6.62 \times 10^{-29} \text{ m}^3)$$

$$= 3.872 \times 10^{-22} \text{ g}$$

$$\text{MW}(\text{BaXO}_3) = (mass) \times N_A = (3.872 \times 10^{-22} \text{ g}) \times (6.02 \times 10^{23} \text{ mol}^{-1})$$

$$= 233.08 \text{ g mol}^{-1}$$

$$\text{AW(X)} = \text{MW}(\text{BaXO}_3) - \text{AW(Ba)} - 3 \times \text{AW(O)}$$

$$= (233.08 - 137.33 - 3 \times 15.999) \text{ g mol}^{-1}$$

$$= 47.8 \text{ g mol}^{-1}$$

The only element with this atomic weight is Ti.

$\therefore$ X = Ti

FORMULA = $BaTiO_3$

2. Neutron diffraction is a crystallographic method used to determine the atomic structure of a material. In a neutron diffraction experiment, a sample is placed in a beam of neutrons and the neutrons are diffracted by the nuclei. First order diffraction is observed at an angle (θ) of 2.5° when a beam of neutrons strikes a crystal of silicon carbide (SiC; d = 1.52 Å = 152 pm). Calculate the velocity of the neutrons.

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

$$\lambda = \frac{2d\sin\theta}{n} = \frac{2\times(1.52\times10^{-10}\text{m})}{1} = 1.33\times10^{-11}\text{ m}$$

$$\lambda = \frac{h}{\rho} = \frac{h}{mu} \quad \text{(de Broglie Equation)}$$

$$\text{Rearranging: } u = \frac{h}{m\lambda} = \frac{6.626\times10^{-34}\text{ J s}}{(1.33\times10^{-11}\text{ m})\times(1.67\times10^{27}\text{ kg})}$$

$$= 2.99\times10^{4}\text{ m s}^{-1}$$

Units:

$$\frac{(\cancel{kg}\ m^{\cancel{2}}\ s^{\cancel{-2}\,-1})(\cancel{s})}{\cancel{m}\ \cancel{kg}} = \text{m s}^{-1}$$

3. You work for a company that tests drinking water for toxic heavy metals. A test for barium involves concentrating a 1000 L water sample to 1 L and then selectively precipitating ALL Ba^{2+} as an insoluble salt by adding a "precipitating solution". Following this procedure, 0.9374 g of a barium-containing salt was precipitated from the water supply.

(a) Given that ONLY 100 mL of each "precipitating solution" was available, deduce which of the following solutions was used? (Solubility information is available on the Supplemental Sheet)

0.32 M sodium sulfate (circled)

0.27 M sodium nitrate

0.0015 M sodium chromate

Circle the correct answer.

(b) If the maximum acceptable concentration of barium in drinking water is 2.0 mg/L, is the tested water fit for drinking? Justify your answer with a calculation.

Must calculate the amount of Ba^{2+} in the1000 L water sample. If < 2.0 mg / L then the water is safe for drinking. Given that all the Ba^{2+} in the water is precipitated as $BaSO_4$ (0.9374 g).

$$\text{FW(BaSO}_4) = (137.33 + 32.064 + 4\times15.999)\text{ g mol}^{-1} = 233.39\text{ g mol}^{-1}$$

$$\text{mol Ba}^{2+} = \frac{0.9374\text{ g}}{229.39\text{ g mol}^{-1}} = 4.01\times10^{-3}\text{ mol}$$

$$\text{mass Ba}^{2+} = (137.33\text{ g mol}^{-1})\times(4.01\times10^{-3}\text{ mol})$$

$$= 0.55\text{ g in 1000 L}$$

$$\text{conc Ba}^{2+} = \frac{0.55\text{ g}}{1000\text{ L}} = 5.5\times10^{-4}\text{ g L}^{-1} = 0.55\text{ mg L}^{-1} \quad (< 2\text{ mg L}^{-1} \quad \therefore \text{ SAFE})$$

PART VII. (15 marks)

1. Fill in the blanks below (parts a – h) with the appropriate third row element.

Third Row Elements: Na Mg Al Si P S Cl Ar

EACH ELEMENT CAN ONLY BE USED ONCE.

(a) This element reacts with water to give a salt with the formula __Na__OH.

(b) __Al__$_2O_3$ is amphoteric.

(c) This element forms a chloride with formula __Mg__Cl_2.

(d) __Ar__ is in the same group as the element first reacted at UBC.

(e) Aluminum reacts with this element to form Al_2__Cl__$_6$.

(f) __S__ has the most known allotropes of any third period element.

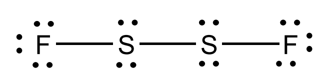
(g) __P__ forms neutral trigonal pyramidal and trigonal bipyramidal compounds with fluorine.

(h) The reaction of sand with coke (carbon) produces elemental __Si__.

2. The reaction of elemental sulfur (S_8) with excess AgF in a rigorously dried apparatus at 125°C affords compound **A** (Formula: S_2F_2) which has the connectivity F-S-S-F. Compound **A** is stable as a gas at low pressures.

(a) Draw the best Lewis structure for compound **A**. Show lone pairs as pairs of dots and bond pairs as lines.

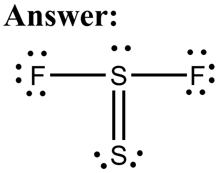
Answer:



When **A** (0.5 mol) is pressurized in the presence of NaCl (1×10^{-6} mol), 0.5 mol of **B** is obtained along with NaCl (1×10^{-6} mol). **B** is trigonal pyramidal.

(b) Draw the best Lewis structure for compound **B**. Show lone pairs as pairs of dots and bond pairs as lines.

Answer:



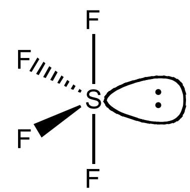
When **B** (0.2 mol) is warmed to 50 °C, elemental sulfur (0.0375 mol) and compound **C** (0.1 mol) are the only products.

(c) Give a balanced equation for the reaction described above to form compound **C**.

$$2\ S_2F_2 \rightarrow SF_4 + \frac{3}{8}\ S_8$$

(d) Draw a perspective drawing showing the VSEPR predicted shape of compound **C**.

Answer:



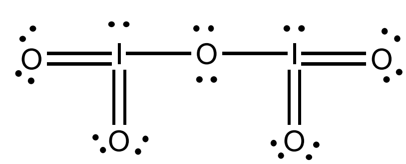
Reaction of **C** (0.5 mol) with **D** (0.1 mol) gives IF_5 (0.2 mol) and SOF_2 (0.5 mol) as the only products.

(e) Give a balanced equation for the reaction of **C** with **D**.

$$5\ SF_4 + I_2O_5 \rightarrow 2\ IF_5 + 5\ SOF_2$$

(f) Draw the best Lewis structure for **D**. Show lone pairs as pairs of dots, bond pairs as lines, and show all non-zero formal charges.

Answer:



END OF EXAMINATION

Supplemental Sheet

Potentially Useful Information

1 Hertz = 1 Hz = 1 s^{-1} 1 J = 1 kg m^2 s^{-2}
1 m = 10^6 μm = 10^9 nm = 10^{12} pm = 10^{10} Å
1 W = 1 J s^{-1} = 10^3 mW
h = Planck's constant = 6.626×10^{-34} J s
N_A = Avogadro's number = 6.022×10^{23} mol^{-1}
c = speed of light = 3.00×10^8 m s^{-1}
1 amu = 1 u = atomic mass unit = 1.66×10^{-27} kg
electron mass = 9.11×10^{-31} kg
neutron mass = 1.67×10^{-27} kg

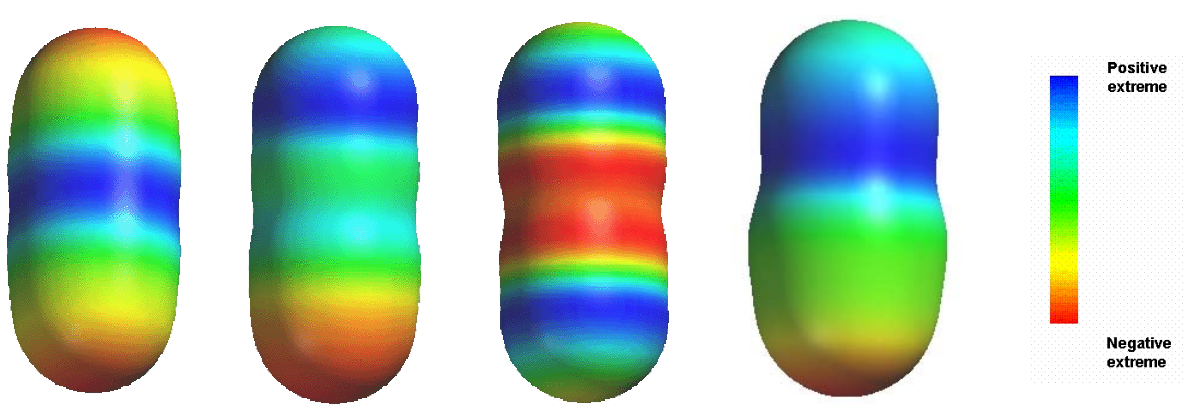
$n\lambda = 2d \sin\theta$

$E_n = -2.18 \times 10^{-18} \frac{Z^2}{n^2}$ J

Solubility in water at 25ºC

Anions / Cations	$[NO_3]^-$	$[SO_4]^{2-}$	$[CrO_4]^{2-}$	$[CO_3]^{2-}$	$[SO_3]^{2-}$
Na^+	soluble	soluble	soluble	soluble	soluble
Ba^{2+}	soluble	insoluble	insoluble	insoluble	insoluble

The figures below are the electrostatic potential maps, labelled A, B, C and D that are needed to answer Part IV, Question 3.



A B C D