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

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

Sample Final — Time Limit: 2.5 hrs

SURNAME:_____ANSWER KEY_____ 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 18. The last sheet (pages 17 and 18), containing "Potentially Useful Information" and the Periodic Table, may be removed.
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. Gates
___102 (MWF 2:00) Dr. Krems
___103 (MWF 3:00) Dr. Dönnecke
___110 (MWF 10:00) Dr. Herring
___111 (MWF 11:00) Dr. Wolf
___122 (T, Th 2:00) Dr. Mehrkhodavandi
___133 (T, Th 3:30) Dr. Liu
___188 (T,Th 8:00) Dr. Kennepohl
___199 (T,Th 9:30) Dr. Bertram

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	18		
III	16		
IV	16		
V	18		
VI	14		
VII	8		
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.

1. What are the products of the reaction of potassium metal with water?

   (a) Pt_2O and H_2
   (b) PtOH and H_2
   (c) PtH and PtOH
   (d) H_2 and KOH
   (e) H_2 and K_2O

2. What is the molecular shape of NF_3?

   (a) tetrahedral
   (b) square-planar
   (c) seesaw
   (d) trigonal pyramidal
   (e) none of the above

3. Which of the following molecules is expected to exhibit the strongest hydrogen bonding?

   (a) PH_3
   (b) H_2CO
   (c) CH_3NH_2
   (d) CH_4
   (e) HI

4. Which of the following compounds results from treating aluminum oxide with excess aqueous sulfuric acid?

   (a) $AlSO_4$
   (b) $[Al(H_2O)_6]_2(SO_4)_3$
   (c) $H[Al(OH)_4]$
   (d) Al_2S_3
   (e) $Al(OH)_3$

5. Choose the INCORRECT statement about $[NH_2]^-$.

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

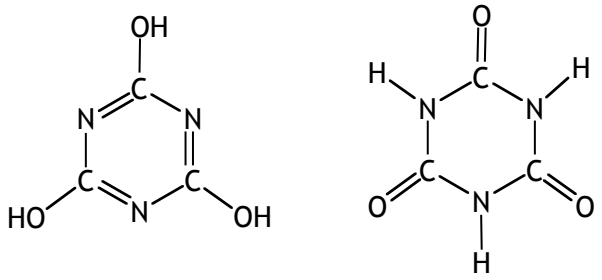
6. Which of the following elements does not react with oxygen (O_2) under any circumstances?

(a) Hydrogen
(b) Helium
(c) Aluminum
(d) Sodium
(e) Magnesium

7. Complete the following sentence. If an electron is confined to a box,

(a) it may violate the Heisenberg uncertainty principle.
(b) its kinetic energy is directly proportional to the length of the box.
(c) it can be found at any point inside the box with the same probability.
(d) it can never be at rest.
(e) it does not obey the de Broglie principle.

8. Cyanuric acid exists in two forms (**A** and **B**) (lone pairs are not shown).



A **B**

What is the maximum number of atoms that can lie in the same plane for form **A**?

(a) 6
(b) 8
(c) 9
(d) 10
(e) 12

9. What is the hybridization of each C and each N in form **B** of cyanuric acid (see question 8)?

(a) C = sp^3, N = sp^3
(b) C = sp, N = sp^3
(c) C = sp^3, N = sp^2
(d) C = sp^2, N = sp^2
(e) none of the above

10. Why is diamond an electrical insulator?

(a) The conduction band is full and, consequently, the electrons are localized.
(b) There are no π bonds.
(c) The energy gap between the valence band and the conduction band is large.
(d) The bonds in diamond are too strong to allow atoms to move so no current flows.
(e) There are no electrons in the valence band.

11. An sp^3d hybridized central atom can result in all of the following molecular shapes:

(a) trigonal planar, trigonal bipyramidal, linear
(b) T-shaped, linear, trigonal bipyramidal
(c) linear, square planar, T-shaped
(d) see-saw, T-shaped, bent
(e) none of the above

12. Which of the following sets contains no substances with ionic bonds?

(a) $NaClO_4$, C_4H_{10}, NH_3
(b) NaCl, CH_4, S_8
(c) CO_2, HCN, O_2
(d) CO_2, NH_4Cl, C_2H_6
(e) AgCl, ScF_3, P_4

13. Which of the following statements is INCORRECT?

(a) The radius of Cl^- is greater than the radius of F^-.
(b) The radius of S^{2-} is greater than the radius of S.
(c) The radius of Rb is greater than the radius of K.
(d) The radius of Ca^+ is greater than the radius of Br^{2+}.
(e) The radius of F is greater than the radius of B.

14. Which of the following elements (X) forms an amphoteric oxide with the empirical formula X_2O_3?

(a) Aluminum
(b) Silicon
(c) Phosphorus
(d) Sulfur
(e) Chlorine

15. Choose the INCORRECT statement.

(a) Electromagnetic radiation consists of propagating electric and magnetic fields.
(b) The velocity of ultraviolet light is greater than the velocity of X-rays.
(c) The energy of electromagnetic radiation is directly proportional to its frequency.
(d) Infrared light has a longer wavelength than ultraviolet light.
(e) A photon with a wavelength of 5000 Å has one-half as much energy as a photon with a wavelength of 2500 Å.

16. Consider a diatomic molecule with the x-axis as the bond axis. Which of the following atomic orbitals on adjacent atoms can form a π bond?

(a) $3d_{xz}$ and $3d_{xy}$
(b) $3d_{xz}$ and $3s$
(c) $2p_y$ and $3d_{x^2-y^2}$
(d) $3d_{x^2-y^2}$ and $3d_{x^2-y^2}$
(e) $3d_{xy}$ and $2p_y$

17. The zinc blende structure can be described as a face-centered cubic array of sulfide anions in which the zinc cations occupy half of the tetrahedral holes. What is the formula of zinc sulfide?

(a) ZnS
(b) ZnS_2
(c) Zn_2S
(d) Zn_2S_3
(e) Zn_2S_4

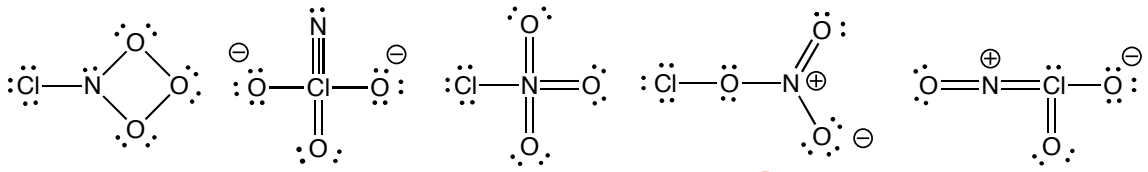
18. Choose the CORRECT statement.

(a) In the hydrogen atom, electronic transitions induced by light always have $\Delta n = \pm 1$.
(b) Absorption of electromagnetic radiation by a one-electron species can promote an electron from an *s*-orbital to a *d*-orbital.
(c) The energy of the 1*s* electron in He^+ is twice the energy of the 1*s* electron in hydrogen.
(d) The boron atom, with the electronic configuration $1s^2 2s^2 2p^1$, cannot emit radiation.
(e) The blue and red lines in the spectrum of hydrogen correspond to the same transition.

19. You are a chemist in charge of the hazardous material unit with the Province of British Columbia and must decide which of the following situations is most serious and must be dealt with first.

(a) A railway car carrying 1,000 kg of P_4S_3 has gone off the rails spilling its contents.
(b) A railway tanker carrying 20,000 L of aqueous concentrated sodium chloride solution has gone off the rails and is leaking into the ocean.
(c) A large leak in a 50 L xenon tank is discovered near a natural gas pipe in a residential area.
(d) A collision has occurred between two trucks; one carrying 200 L of household bleach and the other transporting 400 L of liquid nitrogen.
(e) A truck carrying 34,000 L of a dilute solution of phosphoric acid in water has crashed on the trans Canada highway next to a gas station.

20. The formation of Cl atoms in the stratosphere from CFC refrigerants (i.e. $CFCl_3$) is a major cause of the depletion of the ozone layer. The Cl atoms react with ozone to generate ClO and oxygen (O_2). Some of the depletion of the ozone layer is offset by reaction of ClO with NO_2 to give chlorine nitrate. Predict the most likely Lewis structure of chlorine nitrate ($ClNO_3$).



(a) (b) (c) (d) (e)

PART II. (18 marks total)

1. Complete the following sentences and phrases using proper chemical terminology (elemental symbols may be used).

(a) A __compound__ is a charge neutral substance made up of two or more elements.

(b) The energy change in the reaction below is the __electron affinity__ of bromine.

$$Br\,(g) + e^- \rightarrow Br^-\,(g)$$

(c) The energy change in the reaction below is the __bond dissociation energy__.

$$Br_2\,(g) \rightarrow 2\,Br\,(g)$$

(d) The elements of Group 13 all have the same number of __valence__ electrons.

(e) Dioxygen (O_2) and ozone (O_3) are two __allotropes__ of the element oxygen.

(f) In NOF_3 (nitrogen is the central atom) the formal charge on N is __+1__ whereas the oxidation state of N is __+5__.

(g) The intermolecular forces in solid Xe are called __London/dispersion/van der Waals forces__.

2. Predict the product(s) and balance each of the following reactions. Assume that conditions necessary to initiate a reaction are available (i.e. heating, burning, etc.).

(a) __2__ Al + __1__ $Fe_2O_3 \rightarrow$ Al_2O_3 + 2 Fe

(b) __2__ Mg + __1__ $CO_2 \rightarrow$ 2 MgO + C

(c) __1__ SO_3 + __1__ $H_2O \rightarrow$ H_2SO_4

(d) __1__ Xe + __1__ $PtF_6 \rightarrow$ $XePtF_6$

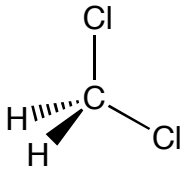
(e) __*n*__ $(CH_3)_2SiCl_2$ + __*n*__ $H_2O \rightarrow [(CH_3)_2SiO]_n$ + 2*n* HCl

or __1__ $(CH_3)_2SiCl_2$ + __2__ $H_2O \rightarrow [(CH_3)_2Si(OH)_2]$ + 2 HCl

3. Draw one perspective diagram showing the VSEPR predicted shape for each of the following species. The central atom is underlined. In each case, specify the name for the shape (i.e. the molecular geometry) you have drawn.

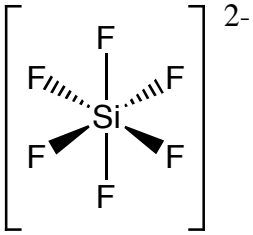
(a) $\underline{C}H_2Cl_2$

Shape:
tetrahedral



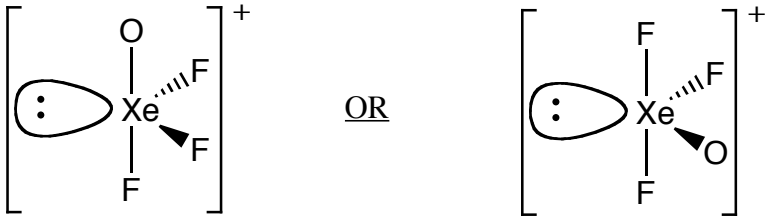
(b) $[\underline{Si}F_6]^{2-}$

Shape:
octahedral



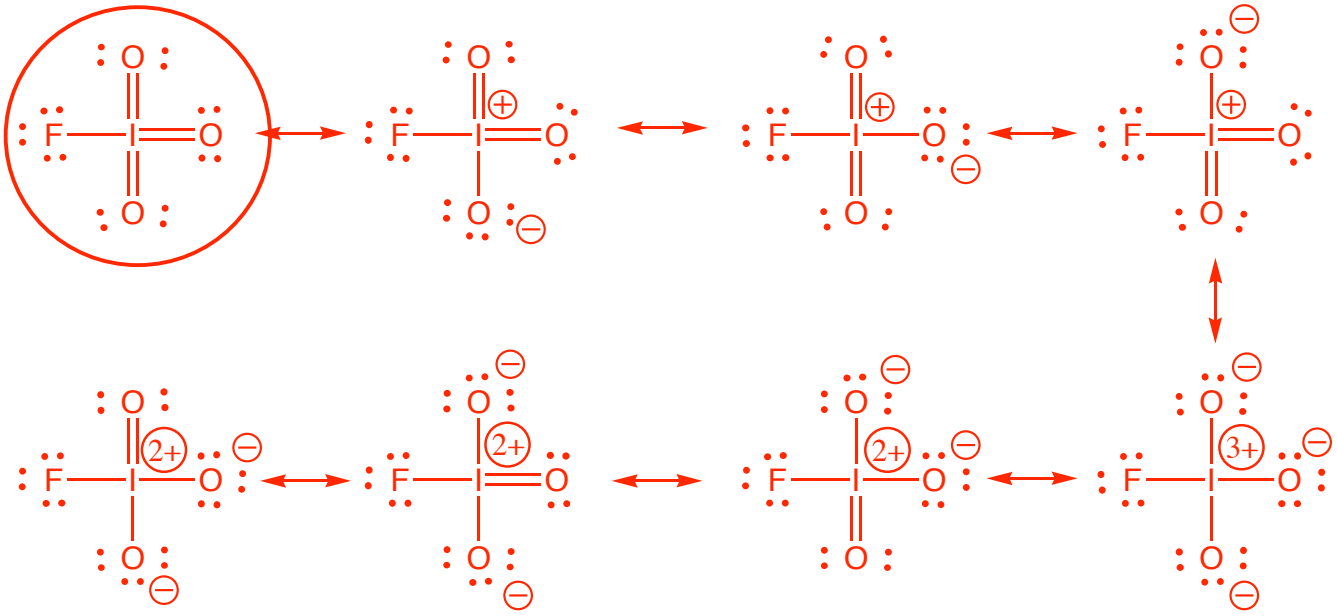
(c) $[\underline{Xe}OF_3]^{+}$

Shape:
seesaw

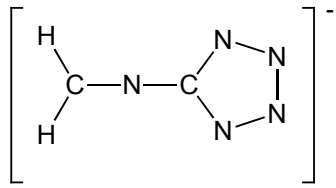


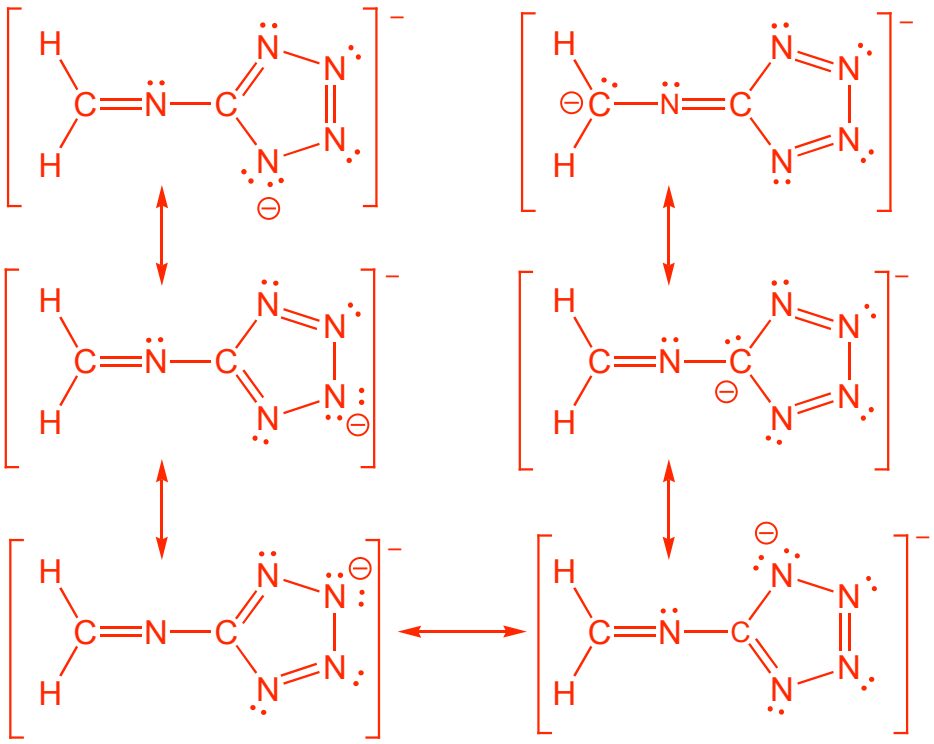
PART III. (16 marks total)

1. Draw ALL possible resonance structures for IO_3F (I is central atom) that contain only single and/or double bonds. Write any non-zero formal charges on the appropriate atoms, show all lone pairs of electrons as pairs of dots, and all bond pairs as lines. *Circle the best Lewis structure.*



2. Draw <u>ALL</u> possible resonance structures for the $[H_2C_2N_5]^-$ anion – all structures must have formal charges minimized. Write any non-zero formal charges on the appropriate atoms, show all lone pairs of electrons as pairs of dots, and all bond pairs as lines. The skeletal structure is:





3. A molecule with one lone pair of electrons has a pentagonal bipyramidal electron group geometry (EGG). Does the lone pair of electrons occupy an equatorial or an axial position? Briefly justify your answer.

In a pentagonal bipyramidal EGG, five electron groups occupy the equatorial plane, and two are in axial positions. The lone pair will occupy a position where lone-pair/bond-pair repulsions are minimized overall. If the lone pair is in the equatorial plane, there are two bond-pair neighbors with a lone-pair/central atom/bond-pair angle of 72°. If the lone pair is in the axial position, the closest bond-pairs have a lone-pair/central atom/bond-pair angle of 90°, thus the lone pair is expected to occupy the axial position.

PART IV. (16 marks total)

1. In a chemical factory, calcium phosphate (or calcium orthophosphate) (10 mol) is heated with coke (carbon) (80 mol) at 1200 °C to produce compound **X** (10 mol) and carbon monoxide (80 mol). Compound **X** is then ground into a fine powder. Water (60 mol) is then carefully added to **X** (10 mol) to afford calcium hydroxide (30 mol) and a colourless gas **Y** (20 mol). Compound **Y** is extremely poisonous and highly flammable. When **Y** (20 mol) is treated with **Z** (80 mol) and HCl (20 mol) a single product, $[P(CH_2OH)_4]Cl$, is formed. Analysis of **Z** revealed that it does not contain phosphorus. $[P(CH_2OH)_4]Cl$ is the key ingredient used to permanently flame-proof cotton cloth.

[space to show work]

(a) Give the chemical formulae for **X**, **Y** and **Z**.

X Ca_3P_2 **Y** PH_3 **Z** CH_2O

(b) The overall yield of $[P(CH_2OH)_4]Cl$ from calcium phosphate is 84 %. Calculate the mass of $[P(CH_2OH)_4]Cl$ that is isolated.

From stoichiometry: 10 mol $Ca_3(PO_4)_2$ → 20 mol $[P(CH_2OH)_4]Cl$ (theoretical yield)

→ Yield = 0.84 × 20 mol = 16.8 mol (actual yield $[P(CH_2OH)_4]Cl$)

Isolated Yield = 16.8 mol × 190.5 g mol^{-1}

= 3.2 kg

(c) What is the VSEPR predicted molecular shape at phosphorus in the $[P(CH_2OH)_4]^+$ cation?

Shape: tetrahedral

2. Balance the following redox equation.

3 $(CH_3)PCl_2$ + 4 SbF_3 → 3 $(CH_3)PF_4$ + 2 $SbCl_3$ + 2 Sb

PART V. (18 marks total)

1. Specify the number of radial and angular nodes for each of the following orbitals.

$n = 2,\ \ell = 0,\ m_\ell = 0$	angular___0___	radial___1___
$n = 4,\ \ell = 2,\ m_\ell = 0$	angular___2___	radial___1___
$n = 5,\ \ell = 2,\ m_\ell = -2$	angular___2___	radial___2___
$n = 10,\ \ell = 7,\ m_\ell = -7$	angular___7___	radial___2___

2. Which of the following sets of quantum numbers are allowed and which are forbidden for an atomic orbital. Circle the correct answer for each.

$n = 3,\ \ell = -2,\ m_\ell = 2$	allowed	**forbidden**
$n = 1,\ \ell = 0,\ m_\ell = 0$	**allowed**	forbidden
$n = 56,\ \ell = 2,\ m_\ell = -2$	**allowed**	forbidden
$n = 3,\ \ell = 2,\ m_\ell = -½$	allowed	**forbidden**

3. Complete the following table by providing the appropriate elemental symbol and the ground state electronic configuration.

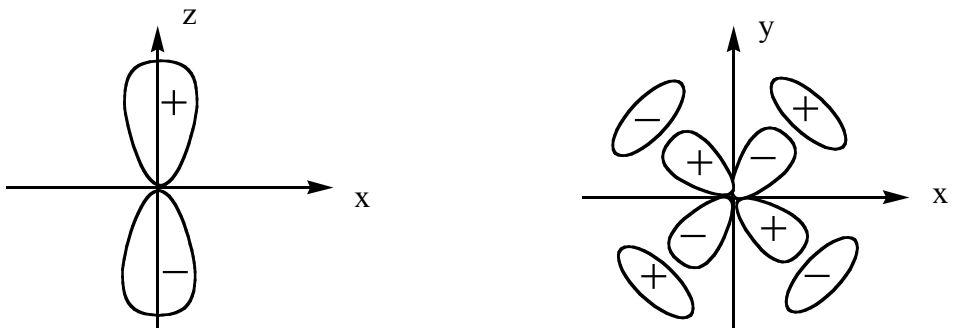
Species	Element	Electronic Configuration
The element with $Z = 7$.	N	$1s^2\ 2s^2\ 2p^3$
The fourth period atom with the most unpaired electrons.	Cr	[Ar] $4s^1\ 3d^5$

4. Complete the following table by providing the appropriate elemental symbol and the orbital diagram.

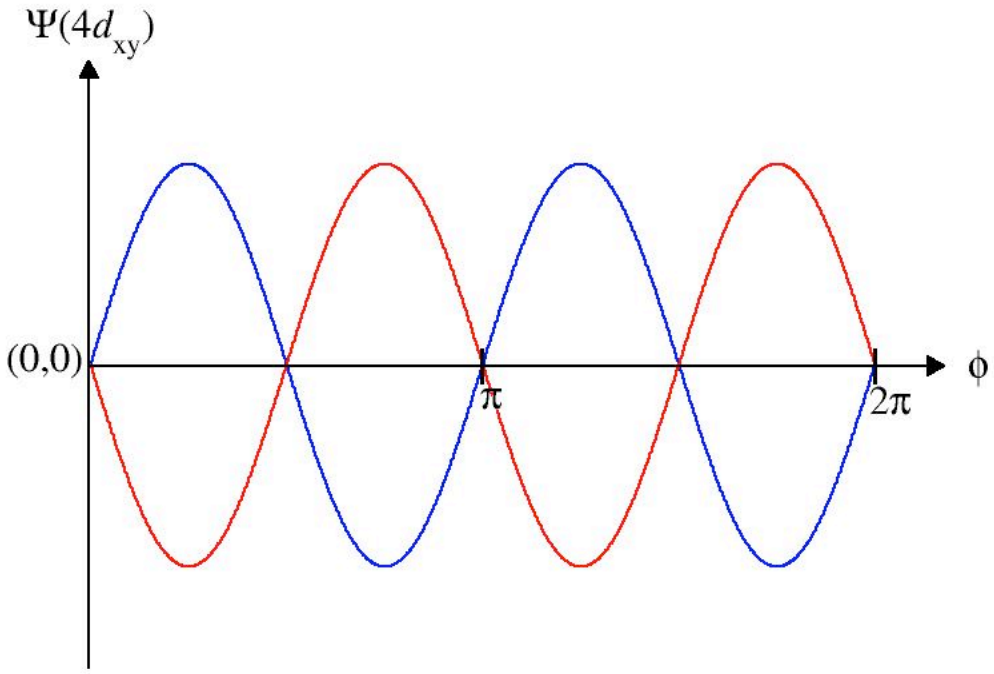
Species	Element	Orbital Diagram
An excited state of sulfur that is diamagnetic.		[Ne] ↑↓ (3s) ↑↓ ↑↓ □ (3p) other configurations are possible
The third period element that is a component of ruby.	Al	[Ne] ↑↓ (3s) ↑ □ □ (3p)

5. (a) Draw cross-sections for the following orbitals of the hydrogen atom. Show phases as (+) and (–) and label the axes.

$2p_z$ $4d_{xy}$



(b) Using your drawing of the $4d_{xy}$ orbital from part (a), sketch the wave function versus the spherical polar angle ϕ in the interval from 0 to 2π. Assume that $r > 0$.

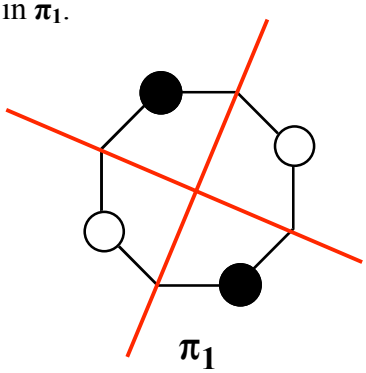


NOTE Mutiplying the wave function by –1 does not change its shape and has no physical consequence. Therefore, drawing either the blue function or the red function would be correct. Drawing both the red and the blue functions is incorrect.

PART VI. (14 marks total)

1. The cyclooctatetraene dication $[C_8H_8]^{2+}$ has a planar ring structure with delocalized π bonds.

(a) A π molecular orbital ($\boldsymbol{\pi_1}$) of the $[C_8H_8]^{2+}$ cation (top view) is shown below. The phase of the orbital is either shaded (+) or not shaded (–). On the diagram below draw lines to indicate the nodal planes in $\boldsymbol{\pi_1}$.

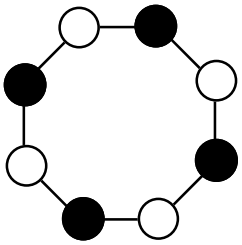


$\boldsymbol{\pi_1}$

(b) What is the total number of π molecular orbitals in $[C_8H_8]^{2+}$?

8

(c) Below are three additional π molecular orbitals in $[C_8H_8]^{2+}$. For each molecular orbital determine whether it is higher, lower or equal in energy to $\boldsymbol{\pi_1}$. Circle the correct answer.

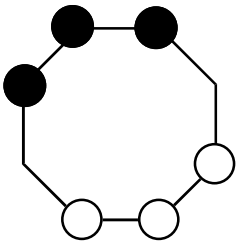


$\boldsymbol{\pi_2}$

Higher

Lower

Equal

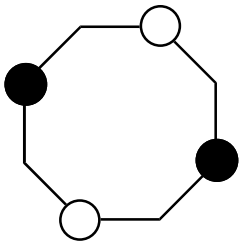


$\boldsymbol{\pi_3}$

Higher

Lower

Equal



$\boldsymbol{\pi_4}$

Higher

Lower

Equal

2. You are cleaning out a laboratory and find a vial containing an orange powder in the back of a cupboard (Unknown **A**). Unfortunately, the label on the vial has become unreadable except for the word "cesium". Magnetic measurements reveal that the diatomic anion in **A** has one unpaired electron. Reaction of 16.49 g of unknown **A** with 7.99 g bromine yields two products: 21.28 g of a solid which contains 37.55% Br and one other element, and 3.20 g of a paramagnetic gas with a molecular weight of 31.998 g mol^{-1}.

[space to show work]

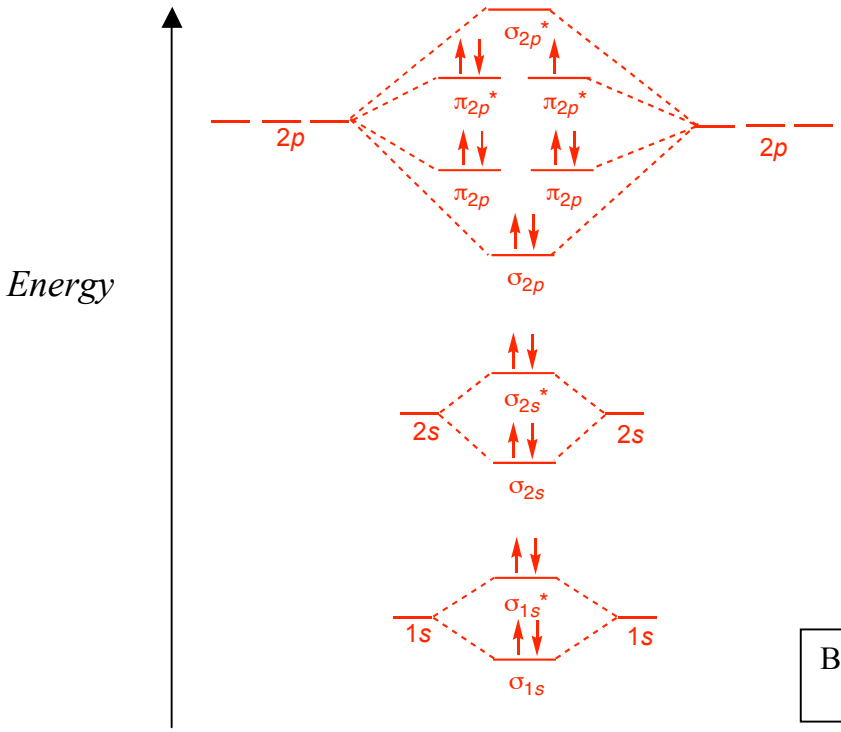
(a) Give the chemical formula for unknown **A**?

CsO_2

(b) Write a balanced equation for the reaction of **A** with bromine.

$CsO_2 + \frac{1}{2}Br_2 \rightarrow CsBr + O_2$

(c) On the scale below, draw an energy level diagram showing how the atomic orbitals interact to form the molecular orbitals of the diatomic anion in **A**. Label the atomic and molecular orbitals with the appropriate symbols and place the appropriate number of electrons in each orbital. Determine the bond order for the diatomic anion in **A**.



Bond Order: 3/2

PART VII. (8 marks total)

1. N^{6+} ions are generated in the $5p$ excited state by selective excitation. The excited state ions relax to the ground state by undergoing transitions to lower energy states. All transitions must follow the selection rules.

(a) List all the possible transitions between specific orbitals that would be expected in the atomic emission spectrum.

List of possible transitions:

$5p \rightarrow 4s$
$5p \rightarrow 3s$
$5p \rightarrow 2s$
$5p \rightarrow 1s$
$5p \rightarrow 4d$
$5p \rightarrow 3d$
$4s \rightarrow 3p$
$4s \rightarrow 2p$
$4d \rightarrow 3p$
$4d \rightarrow 2p$
$3s \rightarrow 2p$
$3d \rightarrow 2p$
$3p \rightarrow 2s$
$3p \rightarrow 1s$
$2p \rightarrow 1s$

(b) How many lines would be observed in the atomic emission spectrum.?

Answer:
9 lines

(c) The photons emitted from N^{6+} are allowed to strike a vanadium surface and one or more electrons are ejected. Given that the binding energy (or work function) for vanadium is 8.20×10^{-17} J photon^{-1}, calculate the kinetic energies and velocities of all electrons which are ejected.

$$E_{5\rightarrow1} = -2.18\times10^{-18}\,\text{J}\left(\frac{7^2}{1^2}-\frac{7^2}{5^2}\right) = 1.02\times10^{-16}\,\text{J}$$

$$E_k = 1.02\times10^{-16}J - 8.20\times10^{-17}\,\text{J}$$

$$= 2.05\times10^{-17}\,\text{J}$$

$$E_k = \frac{1}{2}mu^2 = 2.05\times10^{-17}\,\text{J}$$

$$u = \sqrt{\frac{2\times2.05\times10^{-17}\,\text{J}}{9.11\times10^{-31}\text{kg}}} = 6.72\times10^{6}\,\text{ms}^{-1}$$

END OF EXAMINATION