DAWSON COLLEGE

DEPARTMENT OF CHEMISTRY & CHEMICAL TECHNOLOGY

FINAL EXAMINATION
CHEMISTRY 202-NYA-05
December 21, 2011
9:30 A.M. – 12:30 PM

Print your Name:_____

Student Number: _____

INSTRUCTORS: ***Please circle the name of your instructor:***

J. Ali	D. Baril	Y. Brouillette	I. Dionne
M. Di Stefano	N. Duxin	S. Holden	H. Khouri
S. Mutic-Sajnovic	J. Rahil	R. Squire	

INSTRUCTIONS:

This exam set consists of **17** questions. Please ensure that your copy of this examination is complete.

Answer all questions in the space provided.

1. Calculators may not be shared. Programmable calculators are not permitted.
2. No books or extra paper are permitted.
3. In order to obtain full credit, you must show the method used to solve all problems involving calculations and express your answers to the correct number of significant figures.
4. If a mathematical equation is used to solve a problem, the equation should be clearly written.
5. Your attention is drawn to the College policy on cheating.
6. A Periodic Table is provided.

USEFUL DATA:

Bohr constant : $B = 2.178 \times 10^{-18}$ J

Rydberg constant: $R_H = 1.0974 \times 10^{7}$ m^{-1}

Avogadro's number: $N_A = 6.0221 \times 10^{23}$ mol^{-1}

Planck's constant: $h = 6.626 \times 10^{-34}$ J·s

Speed of light: $c = 2.998 \times 10^{8}$ m·s^{-1}

Gas constant: $R = 0.08206$ L·atm·mol^{-1}·K^{-1} = 8.314 L·kPa·mol^{-1}·K^{-1}

1 atm = 760 mmHg = 101.3 kPa = 760 torr

1 J = 1 kg·m^2·s^{-2} 101.3 J = 1 L·atm 0°C = 273.15 K

MARK DISTRIBUTION

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14.	/ 8
15.	/ 4
16.	/ 4
17.	/ 4
Sig. Fig. and units	/ 1
TOTAL	**/100**

Question 1

Give the name or formula for the following compounds: (5 marks)

a. potassium dichromate .....

b. sodium thiosulfate .....

c. lead(IV) sulfide .....

d. tetraphosphorous decoxide .....

e. sulfurous acid .....

f. $Ca(HSO_4)_2$ .....

g. Na_2O_2 .....

h. N_2O_5 .....

i. Hg_2Cl_2 .....

j. $CaCl_2 \cdot 2H_2O$ .....

Question 2

a. The 1981 Canadian penny has a mass of 2.80 g and is composed of 98% copper (by mass). How many copper atoms are there in this penny? (2 marks)

answer: .....

b. A compound contains 38.67% K, 13.85 % N, and 47.47 % O by mass. What is the empirical formula of the compound? (2 marks)

answer: .....

c. The empirical formula of maleic acid is CHO. Its molar mass is 116.1 g/mol. What is its molecular formula? (1 mark)

answer: .....

Question 3

a. Balance the following chemical equations using the smallest combining ratio (no fraction allowed). (3 marks)

i. $P_4O_{10}(s) + H_2O(l) \longrightarrow H_3PO_4(s)$

ii. $H_2C_2O_4(s) + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$

iii. $CaSiO_3(s) + HF(g) \longrightarrow CaF_2(s) + SiF_4(s) + H_2O(l)$

---

b. Give the balanced equation for each of the following reactions (2 marks)

i. Calcium oxide reacts with pure aluminum producing pure calcium and aluminum oxide.

ii. Copper(II) oxide reacts with sulfuric acid producing copper(II) sulfate and water.

---

c. If 7.80 g of chromium is burned (according to the **unbalanced** equation below), what mass of oxygen does it combine with? (2 marks)

$$Cr(s) + O_2(g) \rightarrow Cr_2O_3(s)$$

answer: .....

Question 4

a. If you mix 100. mL of 0.40 *M* $AlCl_3$(aq.) solution with 200. mL of 0.33 *M* Na_2CO_3(aq.) solution what is the maximum mass of precipitate (molar mass $Al_2(CO_3)_3$: 234.0 g/mol) that you would expect to produce? (3 marks)

answer: .....

b. To identify the contents of an unlabeled gas tank (containing a noble gas), a sample was collected and found to have a density of 3.432 g/L at 15.0°C and 736 mmHg pressure. (3 marks)

i. What is the molar mass of the gas? (Assume ideal gas behaviour)

ii. What is the chemical symbol of the gas? _____

Question 5

a. Classify each of the following reactions as precipitation, acid-base, or oxidation-reduction, and write the net ionic equations. (3 marks)

i. $2HgO(s) \longrightarrow 2Hg(l) + O_2(g)$ Net ionic equation:	☐ precipitation ☐ acid - base ☐ oxidation- reduction
ii. $H_3PO_4(aq) + 3KOH(aq) \longrightarrow K_3PO_4(aq) + 3H_2O(l)$ Net ionic equation:	☐ precipitation ☐ acid - base ☐ oxidation- reduction
iii. $NiCl_2(aq) + Na_2S(aq) \longrightarrow NiS(s) + 2\ NaCl(aq)$ Net ionic equation:	☐ precipitation ☐ acid - base ☐ oxidation- reduction

b. For each of the following reactions, complete and balance the formula equation with the proper physical states (or state of matter) and give the net ionic equation. (3 marks)

i. $K_3PO_4(aq) + ZnCl_2(aq) \longrightarrow$

Net ionic equation:

ii. $Pb(NO_3)_2(aq) + NaI(aq) \longrightarrow$

Net ionic equation:

iii. $H_2SO_4(aq) + Ba(OH)_2(aq) \longrightarrow$

Net ionic equation:

Question 6

Permanganate ion and iodide ion react in **basic aqueous solution** to produce manganese(IV) oxide and iodine. (4 marks)

$$MnO_4^-(aq) + I^-(aq) \longrightarrow MnO_2(s) + I_2(aq)$$

a. Use the half-reaction method to balance the equation.

b. Identify the oxidizing agent: _____ c. Identify the reactant that is reduced _____ (1 mark)

Question 7

Figure 1 shows the line spectra of the hydrogen atom with its characteristic three spectral series, Lyman, Balmer and Paschen. Figure 2 shows the electron transitions pertaining to these series. Please answer the following related questions:

Line spectra of the hydrogen atom

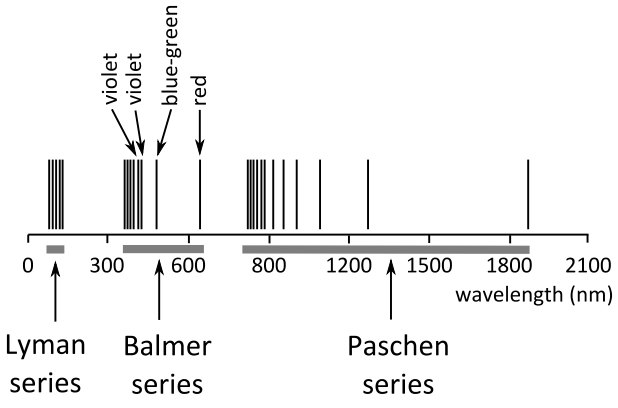


Fig. 1

Electron transitions diagram

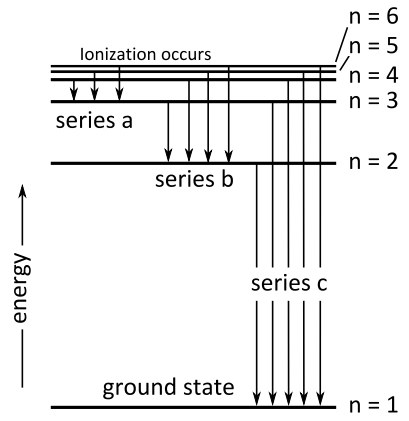


Fig. 2

a. The three hydrogen spectral series appear at three different regions of the electromagnetic spectrum. Match the electron transitions series (a, b, or c) if Fig. 2 with the names of the spectral series in Fig. 1: (1.5 marks)

Series a ..... Series b ..... Series c .....

b. In what spectral regions (visible, ultraviolet, infrared, microwave, radio waves) do transitions from the series "a" and "c" appear? (1 mark)

Series a ..... Series c .....

c. Calculate the wavelength (in nm) of spectral line associated with the $n = 6$ to $n = 3$ electron transition in a hydrogen atom (1.5 marks)

answer: .....

Question 8

a. Indicate whether each of the following set of quantum numbers is permitted or not permitted.
(1.5 marks)

		Permitted	Not Permitted
i.	$n = 1,\ \ell = 0,\ m_\ell = 0,\ m_s = -½$	☐	☐
ii.	$n = 5,\ \ell = 2,\ m_\ell = -2,\ m_s = +½$	☐	☐
iii.	$n = 5,\ \ell = 5,\ m_\ell = 5,\ m_s = +½$	☐	☐

b. Label the following statements as true or false. (1 mark)

		True	False
i.	Hund's Rule states that no two electrons in an atom may have exactly the same set of quantum numbers.	☐	☐
ii.	A consequence of Pauli's Exclusion Principle is that each orbital of a set of degenerate orbitals (ex: 3p) can only have a maximum of two electrons.	☐	☐

c. Give the maximum number of electrons in an atom that can have these quantum numbers:
(1 mark)

i. $n = 1,\ \ell = 0,\ m_\ell = 0$ .....

ii. $n = 2,\ \ell = 1,\ m_\ell = -1$ .....

d. How many elements from Z = 1 to Z = 36 have **only two** unpaired electrons in their ground state?
(1.5 mark)

answer: .....

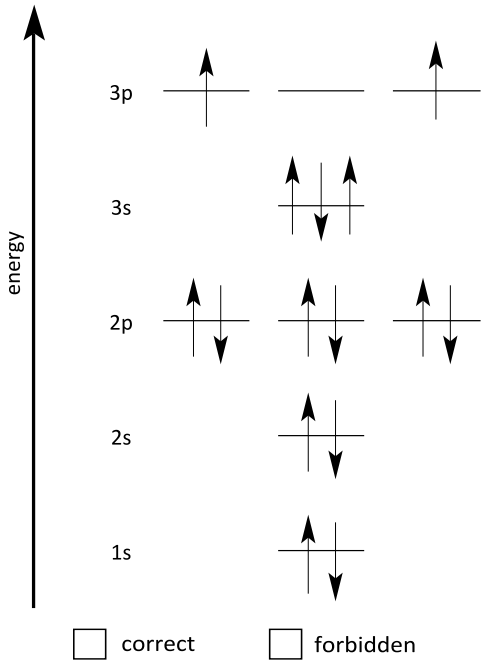
Question 9

The figure below shows the energy level diagram, orbital diagram and electron configuration for three different atoms. (3 marks)

a. Indicate whether each representation is correct or forbidden for the atom in its ground state.

b. For those that are forbidden, state what is wrong.

c. If the diagram is correct, give the **name** and **symbol** of the element whose atom is represented.

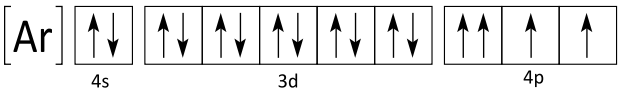


☐ correct ☐ forbidden

.....

.....

.....



☐ correct ☐ forbidden

.....

.....

.....

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^5$

☐ correct ☐ forbidden

.....

.....

.....

.....

d. Write the **complete** electronic configuration (spdf) of aluminum at ground state. (1 mark)

e. Write the set of quantum numbers (n, ℓ, m_ℓ, m_s) for all the valence electrons in "Al" at ground state. (3 marks)

Question 10

a. Use the proposed words to complete the following sentence:

neutrons, pH, ion, charge, ionization, addition, removal, proton, energy, electrons, aqueous, solid, gaseous.

Electron Affinity is the _____ change associated with the _____ of one mole of _____ to one mole of a _____ atom. (2 marks)

---

b. An element has the following ionization energies (I_n) and electron affinity (*EA*) (1.5 marks)

	I_1	I_2	I_3	*EA*
Energy in kJ/mol	+735	+1445	+7730	+19

i. How many electrons are on the valence shell of this atom? _____

ii. Is this element a **metal** , a **nonmetal** or a **metalloid**? (circle one answer)

iii. Given that the element is in period 3 of the periodic table, give the name of the element _____

---

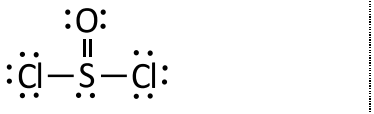
c. Multiple choice questions. Circle only one answer for each of the following: (2.5 marks)

i.	Which atom has the biggest atomic radius:	F	P	S	Cl
ii.	Which atom has the lowest first ionization energy:	Na	K	O	F
iii.	Which ion has the smallest ionic radius:	S^{2-}	Cl^{-}	K^{+}	Ca^{2+}
iv.	Which cation has the biggest ionic radius:	Li^{+}	Na^{+}	K^{+}	Ca^{2+}
v.	Which atom is the most electronegative:	B	N	O	S

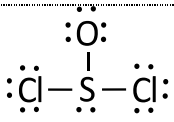
Question 11

a. The Lewis structure of PH_3 shows that the central phosphorous atom has _____ bonding electron and _____ nonbonding electrons. (1 mark)

b. Assign the formal charges to each atom in the resonance form for $SOCl_2$ given below. (2 marks)

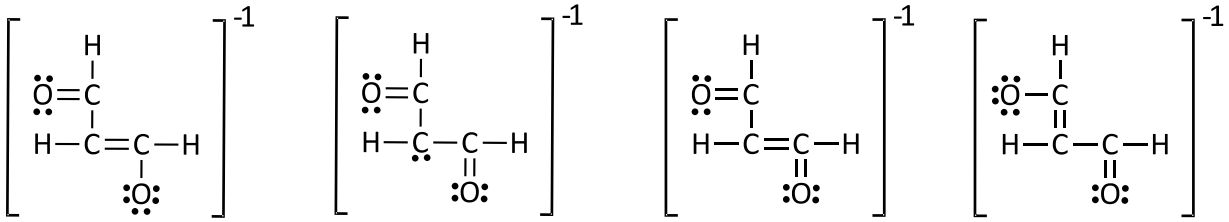


For Cl: ____ For S ____ For O: ____



For Cl: ____ For S ____ For O: ____

c. Consider the following Lewis structures: (2 marks)

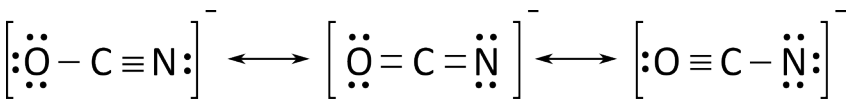


1 2 3 4

i. Which structure cannot exist? _____

iii. Which two are completely equivalent resonance structures? _____and _____

d. The following Lewis structures are the principal resonance forms of OCN^-.
Circle the structure that is the **least** contributor to the actual bonding state, and **briefly** explain why it contributes the least. (2 marks)



I II III

Explanation: .....

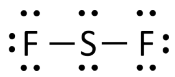
.....

.....

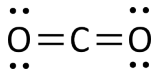
.....

Question 12

a. List the molecular structures (1 to 5) that fit the descriptions below. (*A structure can be used more than once, only one answer per question.)* (5 marks)



1



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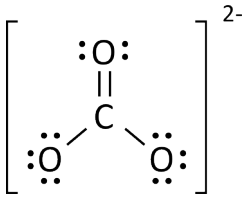

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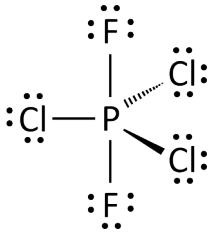

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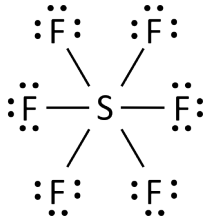


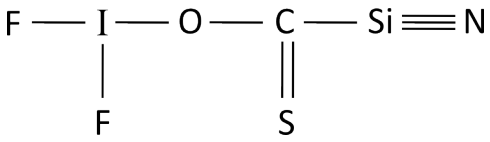
5

	Description	answer
i.	Contains a central atom with sp^2 hybridization:	.....
ii.	Has an overall dipole moment:	.....
iii.	The shape of the molecule is trigonal bipyramidal:	.....
iv.	Has only 180° angle between bonds:	.....
v.	The arrangement of electron pairs around the central atom is octahedral	.....

b. Draw a 3-D structure of ClF_3 using the VSEPR model and give the name of this molecular structure. Include all lone pairs and the bond angles (including distortions if any)
State whether the ClF_3 molecule is polar or not and draw the overall molecular dipole moment on the structure if necessary. (4 marks)

Question 13

Consider the following incomplete Lewis structure



a. Complete the Lewis structure with electron lone pairs where ever needed. (2 marks)

b. How many σ and π bounds are found in this molecule: (1 mark)

σ : ..... π : .....

c. For this molecule, complete the following table (4 marks)

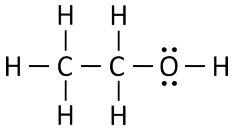
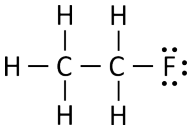
atom	hybridization	bond angle around the atom
I		
O		
C		
Si		

Question 14

a. For each of the following pairs, which member has the lowest boiling point at a given temperature? (Circle your choices.) (3 marks)

i. C_2H_6 or C_4H_{10}

ii. NH_3 or PH_3

iii.  or 

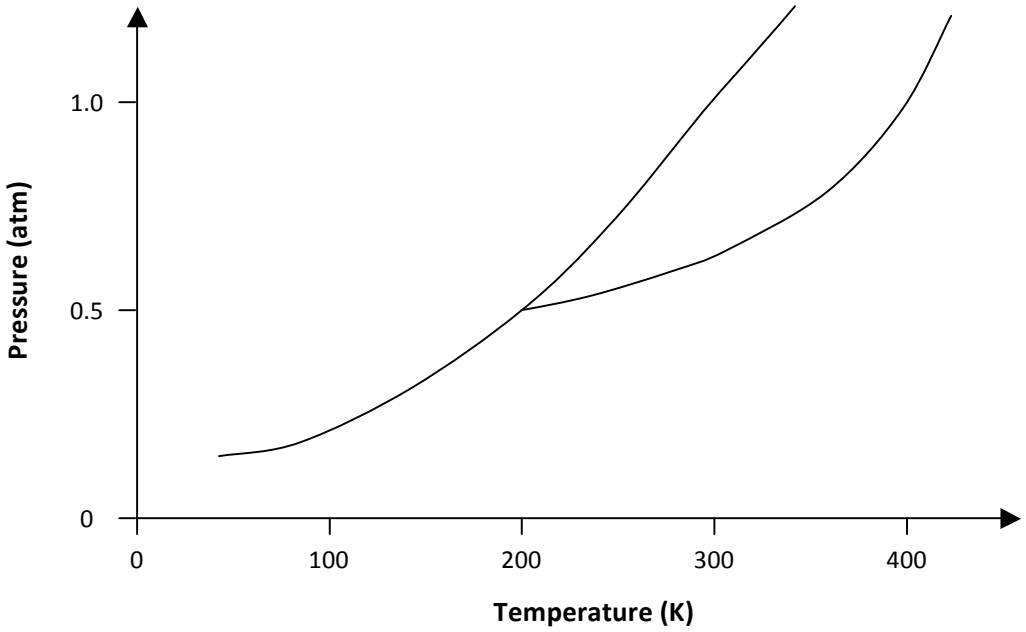
b. What is the strongest intermolecular force in each of the following pure substances? (1.5 marks)

i. CH_3Cl .....

ii. CH_3CH_3 .....

iii. NH_3 .....

c. The schematic phase diagram for a substance is given below. (2.5 marks)



i. Estimate the normal boiling point (P = 1 atm): _____

ii. Estimate the normal freezing point of the substance (P = 1 atm): _____

iii. What is the physical state of the substance at:

T = 150 K, P = 0.2 atm: _____

T = 100 K, P = 0.8 atm: _____

T = 300 K, P = 1.0 atm: _____

iv. Draw on the graph the position of the critical point. What is the meaning of this point? (1 mark)

Question 15

When a 4.25-g sample of solid ammonium nitrate dissolves in 60.0 g of water in a coffee cup calorimeter, the temperature of the solution drops from 22.0°C to 16.9°C. Assume that the specific heat of the solution is the same as for pure water: s = 4.18 $J.g^{-1}.K^{-1}$ and that no heat is lost or absorbed by the calorimeter.

a. Calculate ΔH (in kJ/mol NH_4NO_3) for the solution process. (3.5 marks)

answer: .....

b. Is this process **endothermic** or **exothermic** ? (circle one answer) (0.5 mark)

Question 16

a. From the balanced equation:

$$2\ NH_4Cl(s) + 4\ O_2(g) \longrightarrow 2\ NO_2(g) + 4\ H_2O(g) + Cl_2(g) \qquad \Delta H^\circ = -271.8\ kJ$$

Given that: $\Delta H_f^o[NO_2(g)] = 33.1$ kJ/mol and $\Delta H_f^o[H_2O(g)] = -241.8$ kJ/mol

Calculate the standard molar enthalpy of formation for $NH_4Cl(s)$. (2 marks)

Answer: _____

b. Given the reactions:

$$CH_4(g) \longrightarrow C(g) + 4H(g) \qquad \Delta H^\circ = 1656\ kJ$$

$$HC \equiv CH(g) \longrightarrow 2C(g) + 2H(g) \qquad \Delta H^\circ = 1648\ kJ$$

What is the estimated C ≡ C bond energy in $kJ \cdot mol^{-1}$ (2 marks)

Answer: _____

Question 17

Laboratory: Experiment 2

Stoichiometry

The chemical reaction for the laboratory is:

$$Na_2CO_3(s) + 2\ HCl(aq) \rightarrow 2\ NaCl(aq) + H_2O(l) + CO_2(g)$$

HCl is added in excess.

a. Complete the following laboratory data sheet (1 mark).

DATA SHEET

Mass of empty evaporating dish after initial heating, *g*	57.0197
Mass of evaporating dish plus sodium carbonate, *g*	57.3224
Mass of sodium carbonate, *g*	
Mass of evaporating dish and sodium chloride (after final weighing), *g*	57.3368
Mass of sodium chloride, *g*	
Theoretical yield of sodium chloride, *g*	
Percentage yield of sodium chloride	

Sample calculations:

b. Theoretical yield of sodium chloride (2 marks)

c. Percent yield of sodium chloride: (1 mark)

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Sig. Fig. and units	/ 1
TOTAL	**/100**

Question 1

Give the name or formula for the following compounds: (5 marks)

a. potassium dichromate — $K_2Cr_2O_7$

b. sodium thiosulfate — $Na_2S_2O_3$

c. lead(IV) sulfide — PbS_2

d. tetraphosphorous decoxide — P_4O_{10}

e. sulfurous acid — $H_2SO_3(aq)$

f. $Ca(HSO_4)_2$ — Calcium hydrogen sulfate (or bisulfate)

g. Na_2O_2 — Sodium peroxide

h. N_2O_5 — Dinitrogen pentoxide

i. Hg_2Cl_2 — Mercury(I) chloride

j. $CaCl_2 \cdot 2H_2O$ — Calcium chloride dihydrate

Question 2

a. The 1981 Canadian penny has a mass of 2.80 g and is composed of 98% copper (by mass). How many copper atoms are there in this penny? (2 marks)

moles of copper:

$$n_{Cu} = 2.80\ g \times \frac{98}{100} \times \frac{1\,mol}{63.55\,g} = 4.32 \times 10^{-2}\ mol$$

number of atoms:

$$\#atom = N_A \times n_{Cu} = 6.022 \times 10^{23}\ mol^{-1} \times 4.32 \times 10^{-2}\ mol = \mathbf{2.6 \times 10^{22}\ atoms}$$

answer: .....

b. A compound contains 38.67% K, 13.85 % N, and 47.47 % O by mass. What is the empirical formula of the compound? (2 marks)

Work with exactly 100 g of material:

moles of each component:

$$n_K = 100\ g \times \frac{38.67}{100} \times \frac{1\,mol}{39.10\,g} = 0.9890\ mol\ K$$

$$n_N = 100\ g \times \frac{13.85}{100} \times \frac{1\,mol}{14.01\,g} = 0.9886\ mol\ N$$

$$n_O = 100\ g \times \frac{47.47}{100} \times \frac{1\,mol}{16.00\,g} = 2.967\ mol\ O$$

Search for the smallest whole number ratio:

$$\frac{0.9890}{0.9886} = 1K \quad , \quad \frac{0.9886}{0.9886} = 1N \quad , \quad \frac{2.967}{0.9886} = 3O$$

Therefore the empirical formula is: **KNO_3**

answer: .....

c. The empirical formula of maleic acid is CHO. Its molar mass is 116.1 g/mol. What is its molecular formula? (1 mark)

The formula mass of CHO is:

$$(12.01 + 1.008 + 16.00)\frac{g}{mol} = 29.02\frac{g}{mol}$$

$$\frac{\text{molar mass}}{\text{empirical formula mass}} = \frac{116.1\frac{g}{mol}}{29.02\frac{g}{mol}} = 4.$$ Therefore, the molecular formula is **$C_4H_4O_4$**

Question 3

a. Balance the following chemical equations using the smallest combining ratio (no fraction allowed). (3 marks)

i. $P_4O_{10}(s) + \mathbf{6}H_2O(l) \longrightarrow \mathbf{4}H_3PO_4(s)$

ii. $\mathbf{2}H_2C_2O_4(s) + O_2(g) \longrightarrow \mathbf{4}CO_2(g) + \mathbf{2}H_2O(g)$

iii. $CaSiO_3(s) + \mathbf{6}HF(g) \longrightarrow CaF_2(s) + SiF_4(s) + \mathbf{3}H_2O(l)$

---

b. Give the balanced equation for each of the following reactions (2 marks)

i. Calcium oxide reacts with pure aluminum producing pure calcium and aluminum oxide.

$$\mathbf{3CaO + 2Al \longrightarrow 3Ca + Al_2O_3}$$

ii. Copper(II) oxide reacts with sulfuric acid producing copper(II) sulfate and water.

$$\mathbf{CuO + H_2SO_4 \longrightarrow CuSO_4 + H_2O}$$

---

c. If 7.80 g of chromium is burned (according to the **unbalanced** equation below), what mass of oxygen does it combine with? (2 marks)

$$\mathbf{4}Cr(s) + \mathbf{3}O_2(g) \rightarrow \mathbf{2}Cr_2O_3(s)$$

Moles of chromium burned:

$$n_{Cr} = 7.80\ g \times \frac{1\ mol}{52.00\ g} = 0.150\ mol\ Cr$$

moles of O_2 consumed:

$$n_{O2} = 0.150\ mol\ Cr \times \frac{3\ mol\ O_2}{4\ mol\ Cr} = 0.112_5\ mol\ O_2$$

Mass of O_2 consumed:

$$\text{Mass } O_2 = 0.112_5\ mol\ O_2 \times \frac{32.00\ g}{1\ mol} = \mathbf{3.60\ g\ O_2}$$

answer: .....

Question 4

a. If you mix 100. mL of 0.40 *M* $AlCl_3$(aq.) solution with 200. mL of 0.33 *M* Na_2CO_3(aq.) solution what is the maximum mass of precipitate (molar mass $Al_2(CO_3)_3$: 234.0 g/mol) that you would expect to produce? (3 marks)

Reaction: $2AlCl_3(aq) + 3Na_2CO_3(aq) \rightarrow Al_2(CO_3)_3(s) + 6NaCl(aq)$

If $AlCl_3$ is the limiting reactant, the number of mole of $Al_2(CO_3)_3$ obtained will be:

$$n\ Al_2(CO_3)_3(s) = (100.\ mL) \times \frac{1\,L}{1000\,mL} \times 0.40\,\frac{mol}{L} \times \frac{1\,Al_2(CO_3)_3}{2\,AlCl_3} = 2.0 \times 10^{-2}\ mol$$

If Na_2CO_3 is the limiting reactant, the number of mole of $Al_2(CO_3)_3$ obtained will be:

$$n\ Al_2(CO_3)_3(s) = (200.\ mL) \times \frac{1\,L}{1000\,mL} \times 0.33\,\frac{mol}{L} \times \frac{1\,Al_2(CO_3)_3}{3\,Na_2CO_3} = 2.2 \times 10^{-2}\ mol$$

The actual limiting reactant is $AlCl_3$ and the maximum mass of precipitate expected is:

2.0×10^{-2} mol x 234.0 g/mol = **4.7 g $Al_2(CO_3)_3$(s)**

answer:

b. To identify the contents of an unlabeled gas tank (containing a noble gas), a sample was collected and found to have a density of 3.432 g/L at 15.0°C and 736 mmHg pressure. (3 marks)

i. What is the molar mass of the gas? (Assume ideal gas behaviour)

Ideal gas, therefore, PV = nRT The number of mol of gas is obtained with: $n = \frac{PV}{RT}$

For 1 L of gas: $n = \frac{PV}{RT} = \frac{(736\,mmHg) \times \frac{1\,atm}{760\,mmHg} \times 1.000\,L}{0.08206\,\frac{L.atm}{K.mol} \times (273.15 + 15.0)K} = \frac{0.9684\,atm.L}{23.65\,atm.L.mol^{-1}} = 4.095 \times 10^{-2}$ mol.

For 1 L of gas the mass is 3.432 g, therefore, the molar mass of the gas is

$$\text{molar mass} = \frac{3.432\,g.L^{-1}}{0.04095\,mol.L^{-1}} =$$ **83.8 g/mol Kr (or krypton gas)**

ii. What is the chemical symbol of the gas? _____

Question 5

a. Classify each of the following reactions as precipitation, acid-base, or oxidation-reduction, and write the net ionic equations. (3 marks)

i. $2HgO(s) \longrightarrow 2Hg(l) + O_2(g)$

Net ionic equation:

$2HgO(s) \longrightarrow 2Hg(l) + O_2(g)$

☐ precipitation
☐ acid - base
■ oxidation- reduction

ii. $H_3PO_4(aq) + 3KOH(aq) \longrightarrow K_3PO_4(aq) + 3H_2O(l)$

Net ionic equation:

$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$

☐ precipitation
■ acid - base
☐ oxidation- reduction

iii. $NiCl_2(aq) + Na_2S(aq) \longrightarrow NiS(s) + 2\ NaCl(aq)$

Net ionic equation:

$Ni^{2+}(aq) + S^{2-}(aq) \longrightarrow NiS(s)$

■ precipitation
☐ acid - base
☐ oxidation- reduction

b. For each of the following reactions, complete and balance the formula equation with the proper physical states (or state of matter) and give the net ionic equation. (3 marks)

i. $2K_3PO_4(aq) + 3ZnCl_2(aq) \longrightarrow Zn_3(PO_4)_2(s) + 6KCl(aq)$

Net ionic equation: $2PO_4^{3-}(aq) + 3Zn^{2+}(aq) \longrightarrow Zn_3(PO_4)_2(s)$

ii. $Pb(NO_3)_2(aq) + 2NaI(aq) \longrightarrow PbI_2(s) + 2NaNO_3(aq)$

Net ionic equation: $Pb^{2+}(aq) + 2I^-(aq) \longrightarrow PbI_2(s)$

iii. $H_2SO_4(aq) + Ba(OH)_2(aq) \longrightarrow 2H_2O(l) + BaSO_4(s)$

Net ionic equation: $2H^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + 2OH^-(aq) \longrightarrow 2H_2O(l) + BaSO_4(s)$

Question 6

Permanganate ion and iodide ion react in **basic aqueous solution** to produce manganese(IV) oxide and iodine. (4 marks)

$$MnO_4^-(aq) + I^-(aq) \longrightarrow MnO_2(s) + I_2(aq)$$

a. Use the half-reaction method to balance the equation.

Step 1: Separate the two half-reactions:

$$I^- \longrightarrow I_2$$
$$MnO_4^- \longrightarrow MnO_2$$

Step 2: Balance the elements (except O and H)

$$2I^- \longrightarrow I_2$$
$$MnO_4^- \longrightarrow MnO_2$$

Step 3: Balance O by adding H_2O

$$2I^- \longrightarrow I_2$$
$$MnO_4^- \longrightarrow MnO_2 + 2H_2O$$

Step 4: Balance H by adding H^+

$$2I^- \longrightarrow I_2$$
$$4H^+ + MnO_4^- \longrightarrow MnO_2 + 2H_2O$$

Step 5: Balance the charges with electrons

$$2I^- \longrightarrow I_2 + 2e^- \quad \text{(the oxidation reaction)}$$
$$3e^- + 4H^+ + MnO_4^- \longrightarrow MnO_2 + 2H_2O \quad \text{(the reduction reaction)}$$

Step 6: add-up both reactions, make sure the number of electrons are the same.

$$3x(2I^- \longrightarrow I_2 + 2e^-)$$
$$2x(3e^- + 4H^+ + MnO_4^- \longrightarrow MnO_2 + 2H_2O)$$

$$6I^- \longrightarrow 3I_2 + 6e^-$$
$$+ \quad 6e^- + 8H^+ + 2\,MnO_4^- \longrightarrow 2MnO_2 + 4H_2O$$
$$6I^- + 8H^+ + 2\,MnO_4^- \longrightarrow 3I_2 + 2MnO_2 + 4H_2O$$

Add OH^- to neutralize the acid (to get a basic solution)

$$8\,OH^- + 6I^- + 8H^+ + 2\,MnO_4^- \longrightarrow 3I_2 + 2MnO_2 + 4H_2O + 8OH^-$$
$$6I^- + 8H_2O + 2\,MnO_4^- \longrightarrow 3I_2 + 2MnO_2 + 4H_2O + 8OH^-$$

Finally: $\boxed{\mathbf{6I^- + 4H_2O + 2\,MnO_4^- \longrightarrow 3I_2 + 2MnO_2 + 8OH^-}}$

Check atoms: 6I, 8H, 12O, 2Mn = 6I, 8H, 12O, 2Mn
Check charges: -6 -2 = -8

b. Identify the oxidizing agent: __MnO_4^-__ c. Identify the reactant that is reduced _MnO_4^-_ (1 mark)

Question 7

Figure 1 shows the line spectra of the hydrogen atom with its characteristic three spectral series, Lyman, Balmer and Paschen. Figure 2 shows the electron transitions pertaining to these series. Please answer the following related questions:

Line spectra of the hydrogen atom

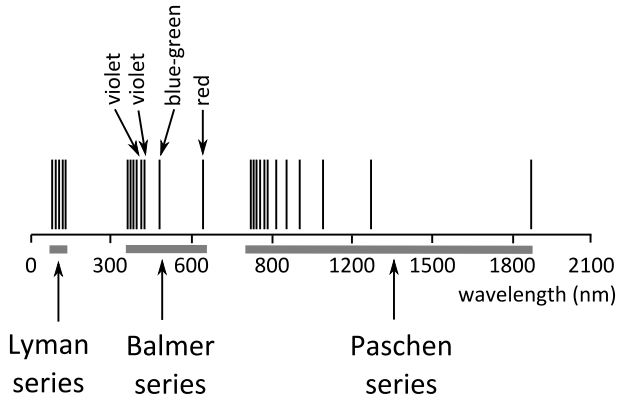


Fig. 1

Electron transitions diagram

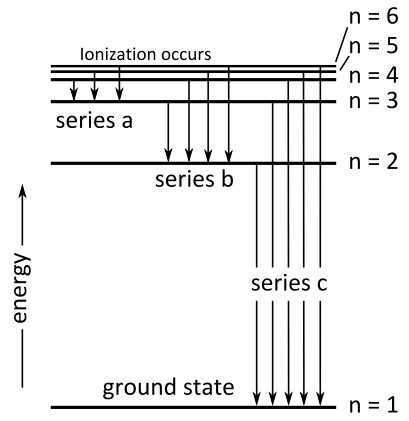


Fig. 2

a. The three hydrogen spectral series appear at three different regions of the electromagnetic spectrum. Match the electron transitions series (a, b, or c) if Fig. 2 with the names of the spectral series in Fig. 1: (1.5 marks)

Series a **Paschen** Series b **Balmer** Series c **Lyman**

b. In what spectral regions (visible, ultraviolet, infrared, microwave, radio waves) do transitions from the series "a" and "c" appear? (1 mark)

Series a **infrared** Series c **ultraviolet**

c. Calculate the wavelength (in nm) of spectral line associated with the $n = 6$ to $n = 3$ electron transition in a hydrogen atom (1.5 marks)

Bohr's atom

$E_n = -B\frac{Z^2}{n^2}$

$E_6 = -B\frac{1^2}{6^2}$, $E_3 = -B\frac{1^2}{3^2}$

$\Delta E_{atom} = E_3 - E_6 = (-B\frac{1}{9}) - (-B\frac{1}{36})$

$\Delta E_{atom} = -2.178 \times 10^{-18}\text{J}\ (0.0833 \times 10^{-2})$

$\Delta E_{atom} = -1.815 \times 10^{-19}\text{J}$

$|\Delta E_{atom}| = E_{photon} = h\nu$

Since $c = \lambda\nu$ then $E_{photon} = hc/\lambda$

Finally, $\lambda = hc / E_{photon} = (6.626 \times 10^{-34}\text{J.s})(2.998 \times 10^{8}\text{m.s})/(1.815 \times 10^{-19}\text{J}) = 1.094 \times 10^{-6}\text{ m}$

or Balmer-Rydberg equation

$\frac{1}{\lambda} = R_H(\frac{1}{n_{in}^2} - \frac{1}{n_{out}^2})$

$\frac{1}{\lambda} = 1.097 \times 10^{7}\text{m}^{-1}(\frac{1}{3^2} - \frac{1}{6^2})$

$\frac{1}{\lambda} = 9.145 \times 10^{5}\text{m}^{-1}$

$\lambda = 1.094 \times 10^{-6}$ m or **1094 nm**

Question 8

a. Indicate whether each of the following set of quantum numbers is permitted or not permitted. (1.5 marks)

		Permitted	Not Permitted
i.	$n = 1,\ \ell = 0,\ m_\ell = 0,\ m_s = -½$	■	□
ii.	$n = 5,\ \ell = 2,\ m_\ell = -2,\ m_s = +½$	■	□
iii.	$n = 5,\ \ell = 5,\ m_\ell = 5,\ m_s = +½$	□	■

b. Label the following statements as true or false. (1 mark)

		True	False
i.	Hund's Rule states that no two electrons in an atom may have exactly the same set of quantum numbers.	□	■
ii.	A consequence of Pauli's Exclusion Principle is that each orbital of a set of degenerate orbitals (ex: 3p) can only have a maximum of two electrons.	■	□

c. Give the maximum number of electrons in an atom that can have these quantum numbers:

i. $n = 1,\ \ell = 0,\ m_\ell = 0$ ..... **2** .....

ii. $n = 2,\ \ell = 1,\ m_\ell = -1$ ..... **2** .....

d. How many elements from Z = 1 to Z = 36 have **only two** unpaired electrons in their ground state? (1.5 mark)

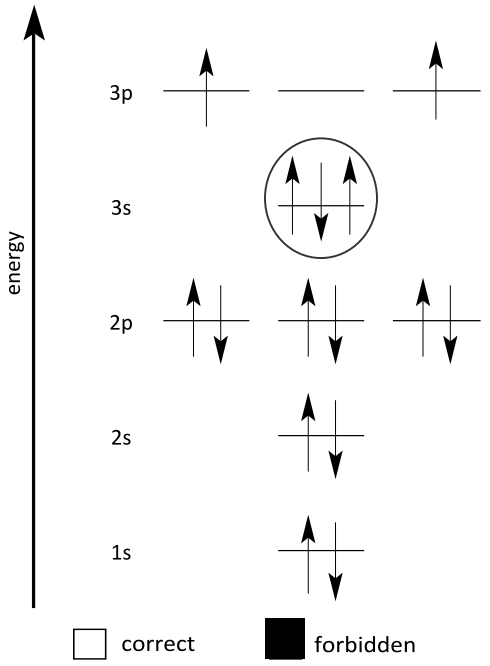
With $36e^-$, the electronic configuration is : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6$

You cannot have two unpaired electrons in an "s"orbital
You can have two unpaired electrons for each p orbital twice (p^2 and p^4)
therefore: "2p": C and O , "3p": Si and S, "4p": Ge and Se.
You can have two unpaired electrons for the "3d" orbital twice: Ti and Ni **total 8 elements**

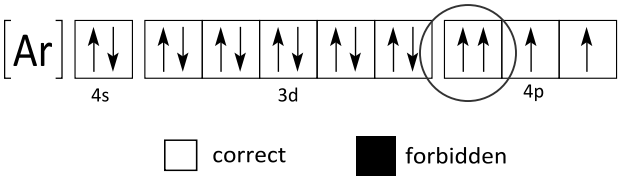
Question 9

The figure below shows the energy level diagram, orbital diagram and electron configuration for three different atoms. (3 marks)

a. Indicate whether each representation is correct or forbidden for the atom in its ground state.
b. For those that are forbidden, state what is wrong.
c. If the diagram is correct, give the **name** and **symbol** of the element whose atom is represented.



An orbital cannot hold more than two electrons. Here "3s" has 3 electrons.



Even though there is no more than two electrons per orbital, all electron should have their own set of quantum numbers. Not the case here in "4p".

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^5$

correct forbidden

This is the ground state electronic configuration of chromium (Cr) where one electron of the 4s orbital is added to the 3d orbital to get the half-filled highly stable configuration.

d. Write the **complete** electronic configuration (spdf) of aluminum at ground state. (1 mark)

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$

e. Write the set of quantum numbers (n, ℓ, m_ℓ, m_s) for all the valence electrons in "Al" at ground state. (3 marks)

There are three valence electrons in aluminum
(3, 1, -1, +1/2)
(3, 0, 0, +1/2)
(3, 0, 0, -1/2)

Question 10

a. Use the proposed words to complete the following sentence:

neutrons, pH, ion, charge, ionization, addition, removal, proton, energy, electrons, aqueous, solid, gaseous.

Electron Affinity is the _energy___ change associated with the _addition_ of one mole of _electrons__ to one mole of a _gaseous_ atom. (2 marks)

---

b. An element has the following ionization energies (I_n) and electron affinity (*EA*) (1.5 marks)

	I_1	I_2	I_3	*EA*
Energy in kJ/mol	+735	+1445	+7730	+19

i. How many electrons are on the valence shell of this atom? ____**2**_____

ii. Is this element a (**metal**), a **nonmetal** or a **metalloid**? (circle one answer)

iii. Given that the element is in period 3 of the periodic table, give the name of the element __**Mg**_

---

c. Multiple choice questions. Circle only one answer for each of the following: (2.5 marks)

i. Which atom has the biggest atomic radius: F **P** S Cl

ii. Which atom has the lowest first ionization energy: Na **K** O F

iii. Which ion has the smallest ionic radius: S^{2-} Cl^{-} K^{+} **Ca^{2+}**

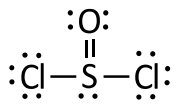
iv. Which cation has the biggest ionic radius: Li^{+} Na^{+} **K^{+}** Ca^{2+}

v. Which atom is the most electronegative: B N **O** S

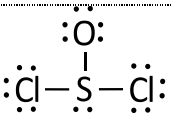
Question 11

a. The Lewis structure of PH_3 shows that the central phosphorous atom has __**6**__ bonding electron and __**2**__ nonbonding electrons. (1 mark)

b. Assign the formal charges to each atom in the resonance form for $SOCl_2$ given below. (2 marks)

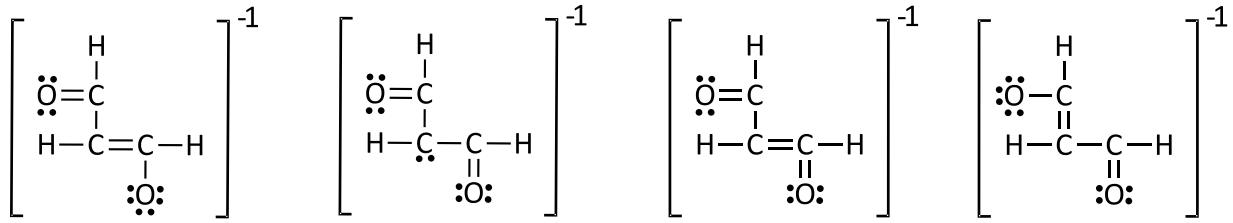


For Cl: __**0**__ For S __**0**__ For O: _**0**__



For Cl: _**0**_ For S _**+1**_ For O: _**-1**_

c. Consider the following Lewis structures: (2 marks)

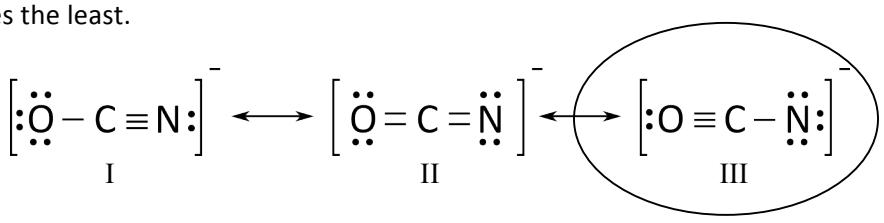


1 2 3 4

i. Which structure cannot exist? ___**3** it has a carbon with 5 bonds____

iii. Which two are completely equivalent resonance structures? ___**1**___and ___**4**___

d. The following Lewis structures are the principal resonance forms of OCN^-.
Circle the structure that is the **least** contributor to the actual bonding state, and **briefly** explain why it contributes the least. (2 marks)



I II III

Explanation:

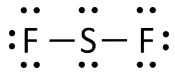
Nitrogen has a formal charge of -2 (highly unstable)

Also, the most electronegative atom of this molecule

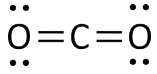
(Oxygen) has a positive formal charge

Question 12

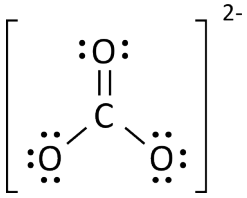
a. molecular structures (1 to 5) that fit the descriptions below. (*A structure can be used more than once, only one answer per question.)* (5 marks)



1



2



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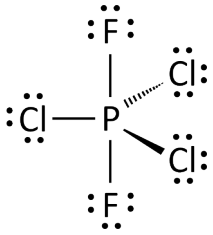
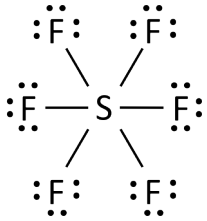


4

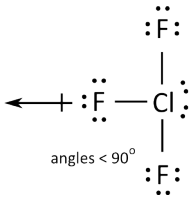


5

	Description	answer
i.	Contains a central atom with sp^2 hybridization:	**3**
ii.	Has an overall dipole moment:	**1**
iii.	The shape of the molecule is trigonal bipyramidal:	**4**
iv.	Has only 180° angle between bonds:	**2**
v.	The arrangement of electron pairs around the central atom is octahedral	**5**

b. Draw a 3-D structure of ClF_3 using the VSEPR model and give the name of this molecular structure. Include all lone pairs and the bond angles (including distortions if any)
State whether the ClF_3 molecule is polar or not and draw the overall molecular dipole moment on the structure if necessary. (4 marks)

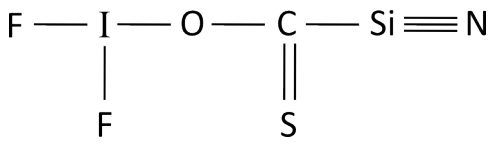
Name of the molecule: T-Shaped



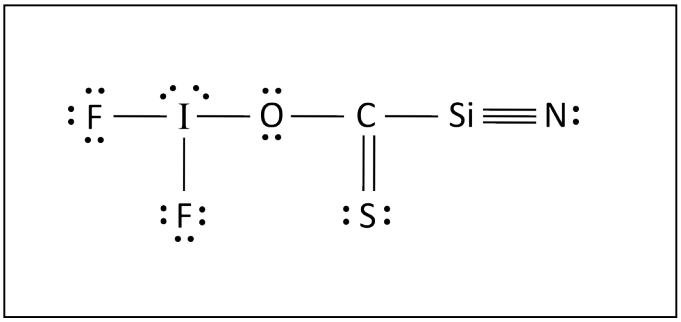
The molecule is polar.

Question 13

Consider the following incomplete Lewis structure



a. Complete the Lewis structure with electron lone pairs where ever needed. (2 marks)



b. How many σ and π bounds are found in this molecule: (1 mark)

σ : **7** π : **3**

c. For this molecule, complete the following table (4 marks)

atom	hybridization	bond angle around the atom
I	**sp^3d**	**< 90°**
O	**sp^3**	**< 109.5°**
C	**sp^2**	**120°**
Si	sp	**180°**

Question 14

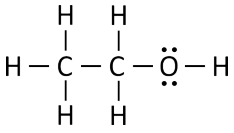
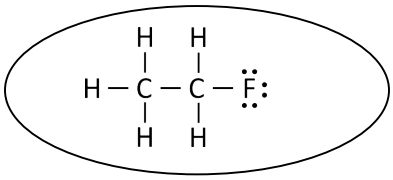
a. For each of the following pairs, which member has the lowest boiling point at a given temperature? (Circle your choices.) (3 marks)

i. C_2H_6 or C_4H_{10}

Small non polar molecule has weak London dispersion forces. Small intermolecular forces

ii. NH_3 or PH_3

NH_3 has stronger intermolecular forces (H-bonding) than PH_3 (London dispersion). Therefore, PH_3 has a lower boiling point.

iii.  or 

C_2H_5OH is capable of H-bonding intermolecular interactions while C_2H_5F cannot (dipole - dipole).

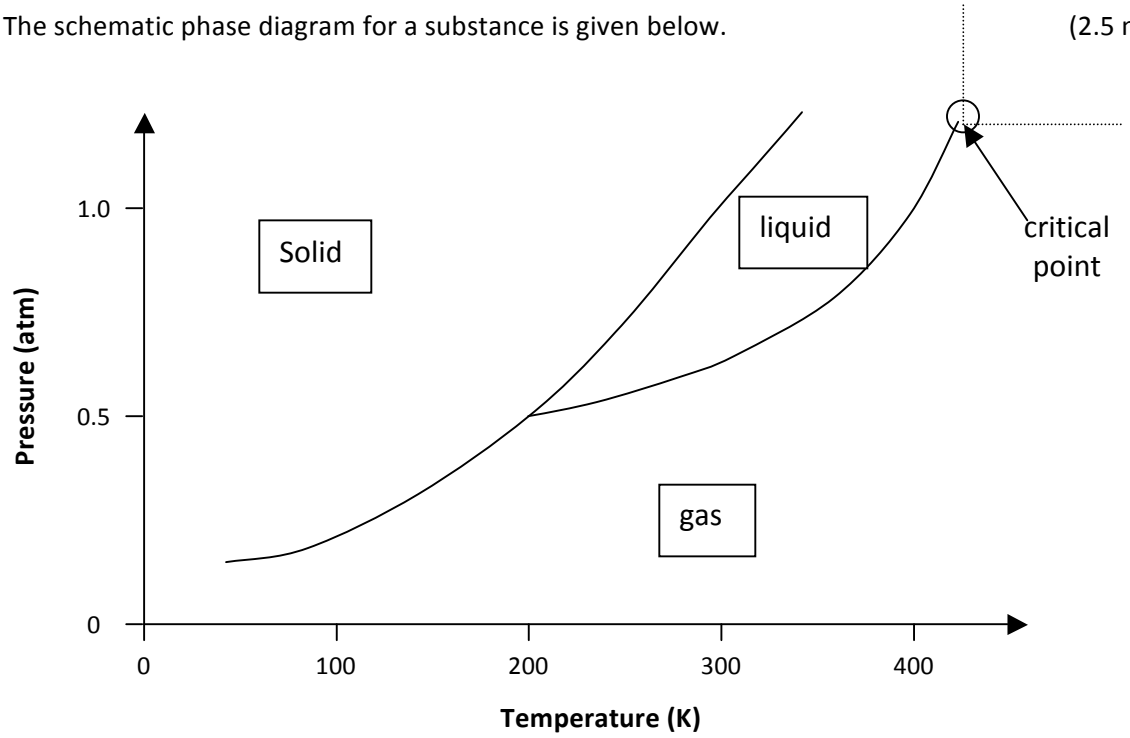
b. What is the strongest intermolecular force in each of the following pure substances? (1.5 marks)

i. CH_3Cl Dipole - dipole

ii. CH_3CH_3 London dispersion forces

iii. NH_3 H-bonding

c. The schematic phase diagram for a substance is given below. (2.5 marks)



i. Estimate the normal boiling point (P = 1 atm): _____**400 K**_____

ii. Estimate the normal freezing point of the substance (P = 1 atm): _____**300 K** _____

iii. What is the physical state of the substance at:

T = 150 K, P = 0.2 atm: _____**gas**_____

T = 100 K, P = 0.8 atm: _____**Solid**_____

T = 300 K, P = 1.0 atm: ___**both liquid and solid**__

iv. Draw on the graph the position of the critical point. What is the meaning of this point? (1 mark)

At this point, distinct liquid and gas phases do not exist.
The state of matter is more a "fluid" than a liquid or a gas.
Beyond this temperature and pressure, it is impossible to liquefy a gas.

Question 15

When a 4.25-g sample of solid ammonium nitrate dissolves in 60.0 g of water in a coffee cup calorimeter, the temperature of the solution drops from 22.0°C to 16.9°C. Assume that the specific heat of the solution is the same as for pure water: $s = 4.18\ J.g^{-1}.K^{-1}$ and that no heat is lost or absorbed by the calorimeter.

a. Calculate ΔH (in kJ/mol NH_4NO_3) for the solution process. (3.5 marks)

$q_{water} = m \times s_p \times \Delta T = (60.0 + 4.25)g \times 4.18\ J.g^{-1}.K^{-1} (16.9 + 22.0)°C = -1.369.X10^3\ J$

note: specific heat unit = K. However, Celsius values were used since here $\Delta T_{°C} = \Delta T_K$.

$q_{water} + q_{reaction} = 0$ (conservation of the energy) then:

$q_{reaction} = +1.369.X10^3\ J$ (endothermic)

Molar mass NH_4NO_3 : 2(14.01 g) + 4(1.008 g) + 3(16.00 g) = 80.05 g/mol

The number of mole of NH_4NO_3 is: $4.25\ g \times \frac{1\,mol}{80.05\,g} = 5.31x10^{-2}$ mol.

Finally, $\Delta H = \frac{q_{reaction}}{n} = \frac{1.369x10^3\ J}{5.31x10^{-2}\ mol} = 2.578x10^4\ J/mol = +\mathbf{25.8\ kJ/mol}$

answer: .....

b. Is this process **endothermic** or **exothermic** ? (circle one answer) (0.5 mark)

Question 16

a. From the balanced equation:

$$2\ NH_4Cl(s) + 4\ O_2(g) \longrightarrow 2\ NO_2(g) + 4\ H_2O(g) + Cl_2(g) \qquad \Delta H^\circ = -271.8\ kJ$$

Given that: $\Delta H_f^o[NO_2(g)] = 33.1$ kJ/mol and $\Delta H_f^o[H_2O(g)] = -241.8$ kJ/mol

Calculate the standard molar enthalpy of formation for $NH_4Cl(s)$. (2 marks)

$\Delta H^\circ = \Sigma \Delta H_f^o$ products - ΔH_f^o reactants

Since ΔH_f^o of O_2 and $Cl_2(g)$ is zero, then:

$$\Delta H^\circ = 2\ \Delta H_f^o NO_2(g) + 4\ \Delta H_f^o H_2O(g) - 2\ \Delta H_f^o NH_4Cl(s)$$

$$-[\Delta H^\circ - 2\ \Delta H_f^o NO_2(g) - 4\ \Delta H_f^o H_2O(g)\ ] / 2 = \Delta H_f^o NH_4Cl(s)$$

$$-[\ -271.8\ kJ - (2\ mol \times 33.1\ kJ/mol) - (4\ mol \times -241.8\ kJ/mol)\ ] / 2 = \mathbf{-314.6\ kJ/mol}$$

Answer: _____

b. Given the reactions:

$$CH_4(g) \longrightarrow C(g) + 4H(g) \qquad \Delta H^\circ = 1656\ kJ$$

$$HC \equiv CH(g) \longrightarrow 2C(g) + 2H(g) \qquad \Delta H^\circ = 1648\ kJ$$

What is the estimated C ≡ C bond energy in $kJ \cdot mol^{-1}$ (2 marks)

HC ≡ CH(g) has 1 C ≡ C and 2 C-H bonds.

The average energy of one mol of C-H bond is: $\Delta H^\circ = 1656$ kJ / 4 C-H bond = 414 kJ / C-H bond

Therefore, the value of the C ≡ C bond is equal to HC ≡ CH(g) – 2 C-H bonds:

1648 kJ – 2 (414 kJ) = **820 kJ / mol C ≡ C bond**

Answer: _____

Question 17

Laboratory: Experiment 2

Stoichiometry

The chemical reaction for the laboratory is:

$$Na_2CO_3(s) + 2\,HCl(aq) \rightarrow 2\,NaCl(aq) + H_2O(l) + CO_2(g)$$

HCl is added in excess.

a. Complete the following laboratory data sheet (1 mark).

DATA SHEET

Mass of empty evaporating dish after initial heating, *g*	57.0197
Mass of evaporating dish plus sodium carbonate, *g*	57.3224
Mass of sodium carbonate, *g*	**0.3027**
Mass of evaporating dish and sodium chloride (after final weighing), *g*	57.3368
Mass of sodium chloride, *g*	**0.3171**
Theoretical yield of sodium chloride, *g*	**0.3338**
Percentage yield of sodium chloride	**95.01%**

Sample calculations:

b. Theoretical yield of sodium chloride (2 marks)

$$Na_2CO_3(s) + 2\,HCl(aq) \rightarrow 2\,NaCl(aq) + H_2O(l) + CO_2(g)$$

Na_2CO_3 is the limiting reactant (mol. mass : 106.0 g/mol)

Mol of NaCl formed: $0.3027\ g\ Na_2CO_3 \times \frac{1\,mol}{106.0\,g} \times \frac{2\,NaCl}{Na_2CO_3} = 5.711 \times 10^{-3}\ mol\ NaCl$

Theoretical yield: $5.711 \times 10^{-3}\ mol\ NaCl \times \frac{58.44\,g}{mol} = 0.3338\ g\ NaCl$

c. Percent yield of sodium chloride: (1 mark)

$$Yield\% = \frac{actual\ yield}{theoretical\ yield} \times 100\% = \frac{0.3171}{0.3338} \times 100\% = \mathbf{95.01\%}$$