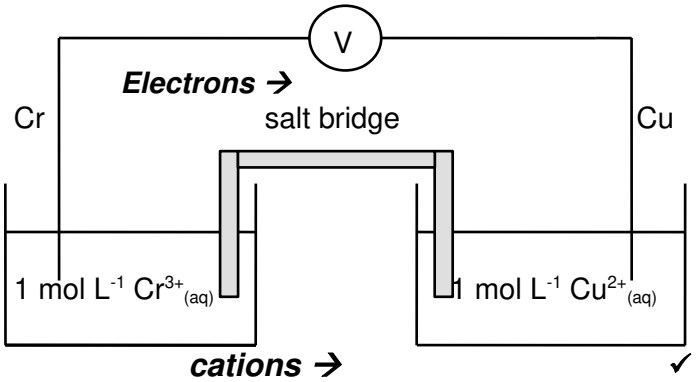
Section 1: Multiple-choice **25% [25 Marks]**

1.	**D**	**6.**	**C**	**11.**	**B**	**16.**	**B**	**21.**	**D**
2.	**B**	**7.**	**C**	**12.**	**B**	**17.**	**D**	**22.**	**B**
3.	**B**	**8.**	**D**	**13.**	**A**	**18.**	**B**	**23.**	**A**
4.	**C**	**9.**	**B**	**14.**	**B**	**19.**	**B**	**24.**	**A**
5.	**C**	**10.**	**A**	**15.**	**B**	**20.**	**C**	**25.**	**D**

Section 2: Short answer **35% [70 Marks]**

Question 26 **[10 marks]**

An electrochemical cell using Cu/Cu^{2+} and Cr/Cr^{3+} is shown below



✓ ✓

(a) Write the cathode and anode reactions for this cell:

cathode ***$Cu^{2+}(aq)$ +2e- → Cu(s)*** anode ***Cr → Cr3+ + 3e-***

✓✓

[2 marks]

(b) On the diagram show the flow of electrons and the direction in which the anions move.

[2 marks]

(c) A strong electrolyte is usually used as a salt bridge. Why is sodium carbonate solution, $Na_2CO_3(aq)$, unsuitable ?

Both the copper and chromium ions would precipitate as solid carbonates. ✓

(equations not necessary, explanation above is sufficient)

$Cu^{2+}(aq) + CO_3^{2-} \rightarrow CuCO_3(s)$ ***$2Cr^{3+} + 3CO_3^{2-} \rightarrow Cr_2(CO_3)_3(s)$***

Precipitation leads to reduced efficiency in the cell ✓

[2 marks]

(d) Both electrodes have a mass of 10.0g at the start of the operation of the cell. After 10 minutes the mass of one electrode has changed to 10.56g. What is mass of the other electrode?

m(Cu) = 0.56g
n(Cu = 0.56/63.55 = 0.0088 mol ✓

$3Cu^{2+}(aq) + 2Cr(s) \rightarrow 3Cu(aq) + 2Cr^{3+}(aq)$ ✓

n(Cr) = 2/3 x 0.0088mol = 0.0059mol
m(Cr) = 0.0059 x 52 = 0.3055g ✓
Mass of the other electrode = 10.00 – 0.3055 g = 9.69 g (3 sf) ✓

4 marks]

Question 27 **[8 marks]**

Information for two acids are as follows :

0.001 mol L^{-1} solution of $HC\ell O_4$ has a pH = 3 and 0.001 mol L^{-1} solution of $HC\ell O$ has a pH = 5.3.

(a) Using information given above explain, with equations if possible, why $NaC\ell O_4(aq)$ has a pH = 7 but NaClO(aq) has a pH > 7

[$HClO_4$] = [H^+] = 0.001mol L-1 complete dissociation; $HClO_4$ is a strong acid ✓

$NaClO_4$ is a neutral salt; its ions are not proton acceptors or donors. ✓

[HClO] = 0.001 mol L^{-1}; [H+] < 0.001 mol L^{-1} so weak acid

NaClO is a base; ClO^- is cb of weak acid

$ClO^- + H_2O \rightarrow HClO + OH^-$ ✓

[4 marks]

(b) Again, using the given information, what chemicals could be used for a buffer solution?

HClO and ClO- or HClO and a salt such as NaClO ✓

[1 mark]

(c) Explain what happens with the aid of appropriate equations equation if HCℓ (aq) is added to the buffer in (b).

buffer equation $HClO + H_2O \leftrightarrow ClO^- + H_3O^+$ ✓

add H_3O^+ $ClO^- + H_3O^+ \leftrightarrow HClO + H_2O$ ✓

As H_3O^+ ***is added to the buffer equilibrium shifts to the left (LCP) and pH remains stable.***

✓

[3 marks]

Question 28 **[6 marks]**

The pH of pure water at 90°C is 6.13.

(a) What is the K_w, the equilibrium constant for water, at 90°C ? Show all working.

$[H^+] = 10^{-6.13}$ ✓

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

$[H^+] = [OH^-]$ ✓

$Kw = (10^{-6.15})^2 = 10^{-12.26} = 5.50 \times 10^{-13}$ ✓

[3 marks]

(b) Using this information determine whether the self ionization of water, $H_2O(\ell) \rightleftarrows H^+(aq) + OH^-(aq)$, is an exothermic or endothermic reaction. Show all working.

At 25^0C $Kw = 10^{-14}$

As T increases Kw increases

As T increases endo reaction is favoured and a K increases equil shifts right

Therefore forward rection is endothermic ✓

Therefore ENDOTHERMIC ✓

[3 marks]

Question 29 **[8 marks]**

The products when the oxidants nitric acid, HNO_3 and sulfuric acid, H_2SO_4 are reacted with copper metal and zinc depend on the concentration of the acids.

If the concentrated HNO_3 acid is used a brown gas is obtained and if concentrated H_2SO_4 is used sulfur dioxide gas is produced.

(a) Write the half equation for concentrated nitric acid producing a brown gas.

$NO_3^-(aq) + 2H^+(aq) + e^- \rightarrow NO_2(g) + H_2O(l)$ ✓✓

[2 marks]

(b) Now write the full equation for the reaction between copper and concentrated nitric acid.

$Cu(s) + 4H^+(aq) + 2NO_3^-(aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(l)$ ✓✓

[2 marks]

(c) In relation to the reduction potential for Cu^{2+} to Cu, what can you say about the reduction potential of concentrated nitric acid?

greater ✓

[1 mark]

(d) Write the full equation for the reaction between concentrated sulfuric acid and zinc.

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ ✓

$SO_4^{2-}(aq) + 4H^+(aq)\ 2e^- \rightarrow SO_2(g) + 2H_2O(l)$ ✓

$Zn(s) + SO_4^{2-}(aq) + 4H^+(aq) \rightarrow SO_2(g) + 2H_2O(l) + Zn^{2+}(aq)$ ✓

[3 marks]

Question 30 **[4 marks]**

Glycine is an amino acid with the formula $H_2\mathbf{N}CH_2\mathbf{C}O\mathbf{O}H$

(a) Give the shape about the following highlighted atoms:

N ***pyramidal*** ✓

C ***triangular (trigonal) planar*** ✓

O ***bent (V- shaped)*** ✓

[3 marks]

(b) Write the formula of the species that is present when the glycine molecule is placed in a neutral solution (pH = 7).

$^{+}H_3NCH_2COO^{-}$ ✓

[1 mark]

Question 31 **[3 marks]**

The first four successive ionization energies ($kJmol^{-1}$) for three elements X, Y and Z are listed below.

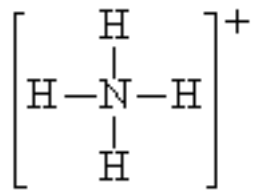
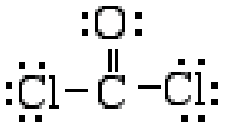
These elements could be Mg, Li, Ca or Na.

Place your choice for X, Y and Z into the last column of the table.

element	1st value	2nd value	3rd value	4th value	answer
X	738	1450	7733	10542	***Mg***
Y	598	1145	4912	6491	***Ca***
Z	496	4562	6910	9543	***Na***

Question 32 **[4 marks]**

Draw the valence structures (electron dot diagrams) for the following, showing all valence electrons as either .. or – .

NH_4CN	$COC\ell_2$
 	 ✓✓**each** **(non bonding pairs incorrect -1)**

Question 33 **[6 marks]**

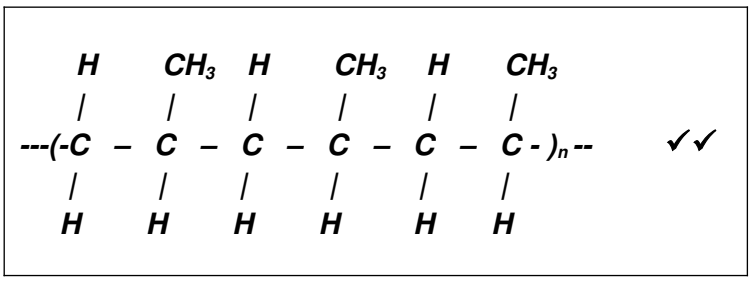
When two compounds, X and Y, are reacted with $Br_2(aq)$ in the absence of light, the final product in both reactions was 1,1,2 tribromopropane

(a) Draw the structure and give the IUPAC name of X and Y.

compound	structure	name
X	**Br** **CH_3** | | **C = C** ✓ | | **H** **H**	***Cis-bromopropene*** ✓
Y	**H** **CH_3** | | **C = C** ✓ | | **Br** **H**	***Trans bromopropene*** ✓

[4 marks]

(b) Draw a piece of the addition polymer polypropene giving three repeating units in your answer.



✓✓

[2 marks]

Question 34 **[5 marks]**

When compounds **A** and **B** are reacted in the presence of concentrated sulfuric acid, a sweet smelling liquid **X** with formula $\mathbf{CH_3CH_2COOCH_2CH_3}$ is produced.

Compound **A** can also be oxidized using acidified potassium permanganate to give compound **C** that reacts with $\mathbf{Na_2CO_3(s)}$ to give a colourless gas.

(a) IUPAC Name of **X** ***ethyl propanoate*** ✓ [1 mark]

(b) Write the IUPAC name and the structure of compound **B**

Structure ***CH_3CH_2COOH*** Name ***propanoic acid*** ✓✓
[2 marks]

(c) Write an ionic equation for reaction between compound **C** and $\mathbf{Na_2CO_3(s)}$

$$2CH_3COOH(aq) + Na_2CO_3(s) \rightarrow 2Na^+(aq) + 2CH_3COO^-(aq) + CO_2(g) + H_2O(l)$$

✓✓

[2 marks]

Question 35 **[12 marks]**

When chlorine gas is added to water, the following equilibrium is established:

$$Cl_2(g) + H_2O(\ell) \rightleftarrows HClO(aq) + H^+(aq) + Cl^-(aq) \qquad \Delta H > 0$$

(a) Write the equilibrium constant expression for this reaction.

$$K = \frac{[HClO]\,[H^+]\,[Cl^-]}{[Cl_2]}$$

✓

[1 mark]

(b) Complete the following table. Answers should be given as "increase", "decrease" or "no change".

Change made to the equilibrium system	Effect on rate of forward reaction after equilibrium has been re-established	Effect on pH of solution after equilibrium has been re-established
Decrease the temperature of the system at constant volume.	***decrease***	***increase***
Acidify the system by the addition of a small quantity of concentrated nitric acid	***increase***	***decrease***
Addition of a small amount of silver nitrate solution	***decrease***	***decrease***
Decrease the pressure of Cl_2(g) at constant temperature.	***decrease***	***Increase***

1 ✓ each

[8 marks]

(c) When a change was made to the system, the K value increases.

(i) What change was made to the system? ***Temperature was increased*** ✓[1 mark]

(ii) Explain your answer

T increases; since endo reaction shifts right so [P] increases so K increases

[2 marks]

Question 36 **[4 marks]**

The boiling point of ethanol, CH_3CH_2OH is lower than the boiling point of butan-1-ol, $CH_3CH_2CH_2CH_2OH$ but the solubility of ethanol in water is higher than the solubility of butan-1-ol in water. Explain these facts.

Boiling Point

Butan-1-ol has the highest BP because:

H – bonding is the predominant IM force in both but equivalent (one –OH on each molecule) ✓

Dispersion forces on butan-1-ol greater than ethanol (more electrons). ✓

Solubility

-OH end of both molecules can form H – bonds with water. ✓

There are greater dispersion forces between the butan-1-ol molecules. Interactions between the water and the non polar hydrocarbon end of the molecule are weaker than those on the ethanol molecules making butan-1-ol less soluble

✓

END OF SECTION 2

Section 3: Extended answer **40% [80 Marks]**

This section contains **five** questions. You must answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Express numerical answers to three significant figures and include appropriate units where applicable.

Spare pages are included at the end of the booklet. They can be used for planning your responses and/ or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time for this section is 70 minutes.

Question 37 **[19 marks]**

There are numerous trends and patterns that occur in chemistry. Many of these can be explained using a knowledge of bonding.

(a) The electronegativity of an element was first proposed by Linus Pauling and can be used to explain some physical properties of substances.

(i) State how electronegativity changes down Group 1 and explain why this trend occurs.

Decreases

nuclear charge increases ✓

shielding increases ✓

electrons further from the nucleus ✓

[3 marks]

(ii) State how electronegativity changes across Period 3 and explain why this trend occurs.

Increases

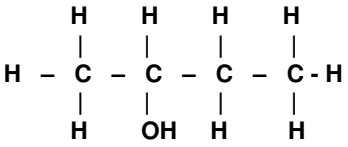
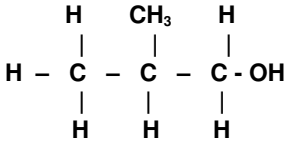
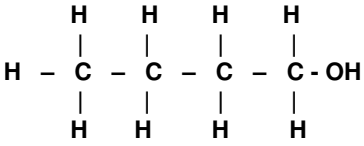
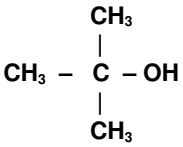
Nuclear charge increases ✓

Shielding is the same ✓

Electrons are the same distance from the nucleus ✓

[3 marks]

(b) The boiling points of alcohols with the molecular formula $C_4H_{10}O$ are 82°C, 99°C, 108°C and 118°C. The secondary alcohol has a boiling point of 99°C and has been added to the table for you.

Structure of isomer	Class of alcohol	Boiling Point (°C)
	Secondary	99
	**primary**	**108**
	**primary**	**118**
	**tertiary**	**82**

1 mark each

[10 marks]

(c) Explain why the isomers with the **lowest** and **highest** boiling points differ.

All alcohols have 1 –OH so the magnitude of the H-bonding is equivalent. ✓

Butan 1-ol has the highest BP.

Of all the alcohols it has the greatest surface area in contact , therefore the highest dispersion forces ✓

2,2 dimethyl propanol has the lowest BP.

The molecule is the bulkiest with least surface area in contact therefore smallest dispersion forces. ✓

[3 marks]

Question 38 **[16 marks]**

An alloy containing iron and manganese was analysed using the following method.

Step 1: 2.30 g of the alloy was first warmed with 100 mL of dilute nitric acid creating a solution of Fe^{3+} and Mn^{2+} ions.

Step 2: Excess sodium bismuthate, $NaBiO_3$, was then added to the solution of Fe^{3+} and Mn^{2+} ions. When treated with sodium bismuthate, the bismuthate ion, BiO_3^-, forms Bi^{3+} and Mn^{2+} forms MnO_4^-.The resulting solution turned purple.

Step 3: Bismuthate ions were then removed and the solution acidified. The solution produced in Step 2 was diluted to a total volume of 250 mL. Three 20.0 mL aliquots were titrated with 0.0920 mol L^{-1} of iron (II) sulfate. The resulting average titre of iron (II) sulfate with the solution was found to be 25.3 mL.

(a) What is the oxidation number of Bi in BiO_3^- ion?

+5 ✓

[1 mark]

(b) Write a balanced half equation for the reduction process in Step 2.

$BiO_3^- + 6H^+ + 2e^- \rightarrow Bi^{3+} + 3H_2O$ ✓✓

[2 marks]

(c) Write a balanced half equation for the oxidation process in Step 2.

$Mn^{2+} + 4H_2O \rightarrow MnO_4^- + 8H^+ + 5e^-$ ✓

[1 mark]

(d) Write the overall equation that occurs in Step 2.

$5\ BiO_3^- + 14\ H^+ + 2\ Mn^{2+} \rightarrow 5\ Bi^{3+} + 2\ MnO_4^- + 7\ H_2O$ ✓✓

[2 marks]

(e) Write a balanced redox equation for the titration in Step 3 between Fe^{2+} and MnO_4^-.

$5Fe^{2+} + MnO_4^- + 8\ H^+ \rightarrow 5Fe^{3+} + 2\ Mn^{2+} + 4\ H_2O$ ✓✓

[2 marks]

(f) Determine the % by mass of manganese in the alloy.

1. n(Fe2+) used in step 3

n = c x V = 25 x 10-3 x 0.0920 = 2.3276 x 10-3 mol ✓

2. n(MnO4-) in 250 mL used in step 3

In 20 mL n(MnO4-) = 2.3276 x 10-3/ 5 = 4.655 x 10-4 mol

In 250mL n(MnO4-) = 4.655 x 10-4 x 250/20 = 5.819 x 10-3 mol

= 5.82 x 10-3 mol (3 sf) ✓✓

3. % Mn in the alloy

n(Mn) = n(MnO4-) = 5.819 x 10-3

m(Mn) = 5.819 x 10-3 x 54.94 = 0.3197g

% Mn = 0.3197/2.30 x 100/1 = 13.9% (3sf) ✓✓

[5 marks]

(g) Suggest why hydrochloric acid would have been an unsuitable choice for acidifying the solution in Step 3 of the method used. Give a suitable equation to justify your answer.

Explanation

Cl^- ions can be oxidised by MnO_4^- ✓

Increases volume of MnO_4^- used ✓

Equation

$10Cl^- + 2\ MnO_4^- + 16\ H^+ \rightarrow 5\ Cl_2 + 2\ Mn^{2+} + 8\ H_2O$ ✓

[3 marks]

Question 39 **[16 marks]**

Guanine is one of the building blocks that makes up DNA. Guanine contains only carbon, nitrogen, oxygen and hydrogen. To determine the empirical formula of guanine a series of experiments were conducted.

Combustion Analysis
Combustion of 6.15 g of guanine produced 8.95 g of carbon dioxide.
In a separate combustion reaction, a 5.20 g mass of guanine produced 1.55 g of water.

Conversion of Nitrogen to Ammonia
A further sample of 4.00 g of guanine was boiled with an excess of sulfuric acid and then neutralised with sodium hydroxide. This converts all the nitrogen in guanine to ammonia.

Volumetric Analysis
The resulting solution was titrated with 5.91 mol L^{-1} hydrochloric acid until the solution was neutralised. Using a suitable indicator for the reaction, the titre was found to be 22.4 mL.

(a) Determine the empirical formula of guanine.

Combustion analysis

$n(CO_2)$ = 8.95 / 44.01 = 0.2034 mol

m(C) = 0.2034 x 12.01 = 2.443 g

%C = 2.443 / 6.15 x 100/1 = 39.72% ✓✓

$n(H_2O)$ = 1.55 / 18.016 = 0.08603 mol

n(H) = 2 x 0.08603 = 0.17206 mol

m(H) = 0.17206 x 1.008 = 0.1734 g

% H = 0.1734 / 5.20 x 100/1 =3.335% ✓✓

Volumetric analysis

n(HCl) = cV = 5.91 x 0.0.0224 = 0.1324 mol

$n(NH_3)$ = n(HCl) = 0.1324 mol

n(N) = 0.1324 mol

m(N) = 0.1324 x 14.01 = 1.855 g

% N = 1.855/4.0 x 100/1 = 46.375% ✓✓

% O = 100 – 39.72 – 3.33 – 46.375 = 10.585% ✓

	C		***H***		***O***		***N***	
100g	***39.72***	***:***	***3.335***	***:***	***10.585***	***:***	***46.375***	
n	***3.31***	***:***	***3.31***	***:***	***0.661***	***:***	***3.31***	✓
=	***1***	***:***	***1***	***:***	***0.2***	***:***	***1***	
=	***5***	***:***	***5***	***:***	***1***	***:***	***5***	✓

EF = $C_5H_5N_5O$

[9 marks]

(b) When vapourised at 300°C at a pressure of 111.1 kPa, a 2.65 g sample of guanine was found to occupy a 752 mL volume. Determine the molecular mass and then the molecular formula for guanine.

PV = mRT/M

111.1 x 0.752 = 2.65 x 8.31 x 573 / M ✓

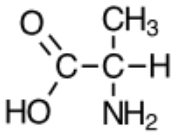
M = 151 g mol^{-1}

M(EF) = 151 g mol^{-1} ✓

MF = EF = $C_5H_5N_5O$ ✓

[3 marks]

(c) Amino acids are the building blocks of substances called peptides. The structure for alanine is shown below.



Alanine

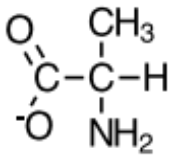
Draw the structure of the peptide formed when three alanine molecules react.

$_2$HN-CH(CH_3) – CO – NH – CH(CH_3) – CO – NH – CH(CH_3) – COOH

with or without bracket and n repeats ✓✓

[2 marks]

(ii) Draw the structure of alanine in a high pH solution.



✓✓

[2 marks]

Question 40 **[14 marks]**

An industrial method for the production of hydrogen cyanide (HCN) occurs by the reaction of carbon monoxide with ammonia gas in the presence of platinum:

$$2\ CH_4\,(g) + 2\ NH_3\,(g) + 3\ O_2\,(g) \rightleftarrows 2\ HCN\,(g) + 6\ H_2O\,(g) \qquad \Delta H = -481\ kJ$$

(a) Discuss how you could change the following conditions of this reaction to achieve the maximum yield and rate of production of hydrogen cyanide and explain your choices using appropriate theories.

(i) Temperature

High temperature favours high rate of reaction. ✓

As T increases, KE of the particles increases leading to a greater number of collisions with energy > Ea, favouring the formation of products ✓

Reaction is exothermic. Low T favours the exothermic process and the yield of HCN (LCP) ✓

Ideal T is a compromise temperature to achieve an acceptable rate and yield. ✓

(4 marks)

(ii) Pressure

High pressure favours high rate of reaction

Greater number of particles in a given volume leads to a greater number of collisions with energy > Ea, favouring the formation of products. ✓

Low pressure favours the process forming greater number of particles (LCP) ✓

Ideal P is a compromise temperature to achieve an acceptable rate and yield. ✓

[3 marks]

(iii) Catalyst

A catalyst increases the forward and reverse reaction rates equally by providing an alternative reaction pathway with a lower activation energy. ✓

Equilibrium position is unchanged, therefore yield is unchanged. ✓

[2 marks]

(b) Hydrogen cyanide has a molar mass of 27.03 g mol^{-1} and boils at 26.0°C. Nitrogen gas has a molar mass of 28.02 g mol^{-1} and boils at -196°C. Account for the difference in boiling points.

N_2 is a non polar molecule. ***HCN is linear and polar*** ✓

H - C ≡ N | ✓

Dispersion forces are similar because both molecules have the same number of electrons

✓

IM forces in N2 are dispersion only ✓

IM forces in HCN are dipole – dipole and dispersion, giving HCN a higher BP. ✓

[5 marks]

Question 41 **[13 marks]**

29.0 mL of 0.312 $molL^{-1}$ sodium phosphate and 29.0 mL of 0.438 $molL^{-1}$ cobalt (II) chloride solutions were mixed together. A precipitate was formed. (Assume volumes are additive)

(a) Write an ionic equation for the reaction.

$3Co^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Co_3(PO_4)_3(s)$ ✓✓

(2 marks)

(b) Determine the limiting reagent for the reaction. Justify your answer with appropriate calculations.

$n(Na_3PO_4) = 0.029 \times 0.312 = 0.009048\ mol$ ✓

$n(CoCl_2) = 0.029 \times 0.438 = 0.0127\ mol$ ✓

1 mol Na_3PO_4 requires 3/2 mol of $CoCl_2$ for complete reaction

0.009048 mol requires 3/2 x 0.009048 = 0.01357 mol $CoCl_2$ ✓

$n(CoCl_2)$ *required* $> n(CoCl_2)$ *actual* ✓

$CoCl_2$ *is LR* ✓

[5 marks]

(c) Determine the dry mass, in grams, of the precipitate formed.

$n(Co_3(PO_4)_3)$ *1/3* $n(CoCl2) = 0.004324\ mol$ ✓

$m(Co_3(PO_4)_3) = 0.004324 \times 366.73 = 1.55\ g$ ✓

[2 marks]

(d) Using the information from parts (a) and (b) give a full observation for the chemical reaction.

A pink solution and a colourless solution are combined producing a pink solid in a colourless solution

1 ✓ final c'less solution
1 ✓ remainder

(e) Determine the concentrations, in mol L^{-1}, of the ions remaining in solution.

$3Co^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Co_3(PO_4)_3(s)$

$n(PO_4^{3-})used = 2/3\ n(Co^{2+}) = 0.0127 \times 2/3 = 0.008467$

$n(PO_4^{3-})$ remaining = n(initial) - n(used) = 0.009048 - 0.008467 = 0.0005813 mol ✓

$n(Na^+) = 3 \times n(Na_3PO_4) = 3 \times 0.009048 = 0.027144$ mol

$n(Cl^-) = 2 \times n(CoCl_2) = 2 \times 0.0127 = 0.0254$ mol

Vtotal = 58 mL = 0.058 L

$[PO_4^{3-}] = 0.005813/0.058 = 1.00 \times 10\text{-}2$ molL-1 ✓

$[Na^+] = 0.027144/0.058 = 4.68 \times 10\text{-}1$ molL-1 ✓

$[Cl^-] = 0.0254/0.058 = 4.37 \times 10\text{-}1$ molL-1 ✓