SECTION 1: 25 multiple choice questions (25 marks 25 %)

Answer ALL questions in Part 1 on the Separate Multiple Choice Answer Sheet provided, using a 2B pencil. Each question in this part is worth 1 mark.

1b, 2c, 3c, 4b, 5b, 6a, 7a, 8d, 9c, 10c, 11a, 12d, 13b, 14c,

15d, 16b, 17d, 18a, 19a, 20a, 21c, 22d, 23c, 24b, 25d.

SECTION 2 13 questions (80 marks 40 %)

Answer ALL questions in Section 2 in the spaces provided below.

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1. Write equations for the reaction that occurs in each of the following procedures.
If no reaction occurs, write 'no reaction'.

In each case describe what you would observe, including any
* colour change
* odour
* precipitate (give the colour)
* gas evolutions (state the colour or describe as colourless)

If a reaction occurs but the change is not observable, you should state this.

Subscripts not required

(a) Oxygen gas is bubbled through an acidified solution of iron (II) sulfate.

Equation $O_2 + 4\,H^+ + 4\,Fe^{2+} \rightarrow 2\,H_2O + 4\,Fe^{3+}$

Observation **Pale green solution turns red/yellow/brown Oxygen dissolves**

Equation ionic = 2 full = 1 One observation = 1 (3marks)

(b) Ethene gas is bubbled through bromine water (aqueous solution of bromine).

Equation $C_2H_4 + Br_2 \rightarrow C_2H_4Br_2$

Observation **Brown colour of solution disappears / turns colourless**

Equation = 2 Observation = 1 (3marks)

2. For each of the following sets of observations:

(i) write a description of any **one** reaction that matches the observations, and

(ii) give an appropriate equation for **that** reaction.

e.g. A brown solution is added to a colourless solution, producing a brown precipitate.

Reaction *iron (III) nitrate solution is mixed with sodium hydroxide solution.*

Equation $Fe^{3+} + 3\ OH^- \rightarrow Fe(OH)_3$

a) A purple solution is mixed with a colourless solution, producing a colourless solution and a colourless gas

Reaction **Refer to the Data Sheet E° Table**

Acidified permanganate + oxalic acid → CO_2

Acidified permanganate + hydrogen peroxide → O_2

Equation

$$2\ MnO_4^- + 6\ H^+ + 5\ H_2C_2O_4 \rightarrow 2\ Mn^{2+} + 8\ H_2O + 10\ CO_2$$

$$2\ MnO_4^- + 6\ H^+ + 5\ H_2O_2 \rightarrow 2\ Mn^{2+} + 8\ H_2O + 5\ O_2$$

(3 marks)

b) A metal strip is placed in a green solution. Silvery-white crystals form on the strip and the green colour fades.

Reaction

Ni^{2+} / Fe^{2+} / Cr^{3+} salt + more reactive metal Zn / Mg / Al / Mn [not Na or lower]

Equation **examples**

$Fe^{2+} + Zn \rightarrow Fe + Zn^{2+}$ **accept Fe as shiny white**

$Fe^{2+} + Mg \rightarrow Fe + Mg^{2+}$

$Ni^{2+} + Zn \rightarrow Ni + Zn^{2+}$

$3\ Ni^{2+} + 2\ Al \rightarrow 3\ Ni + 2\ Al^{3+}$

$2\ Cr^{3+} + 3\ Mg \rightarrow 2\ Cr + 3\ Mg^{2+}$

$Cr^{3+} + Al \rightarrow Cr + Al^{3+}$

Metal must be below metal ion on E° table

Equation = 2 Reaction = 1

(3 marks)

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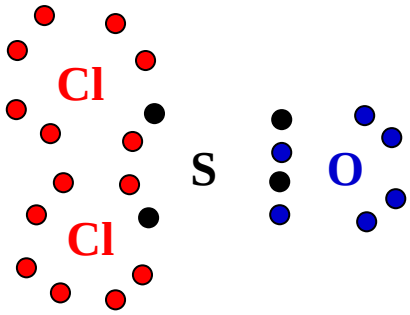
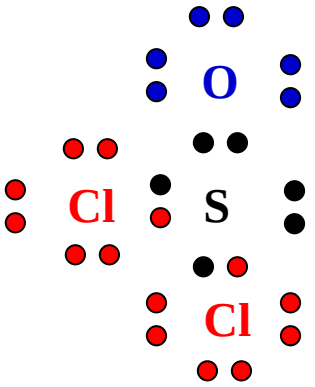
3. Draw electron-dot diagrams showing the arrangement of all valence electrons in the following chemical species.
Describe the shape of each (eg: linear/bent/etc)

$OSCl_2$ (2 possible)



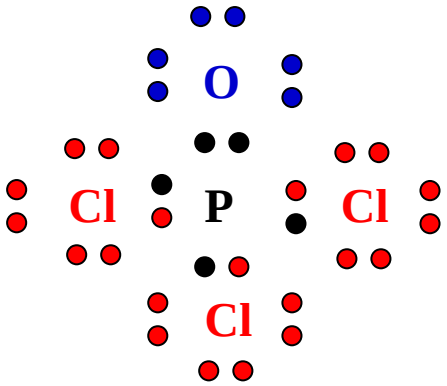
Shape **triangular planar**



Shape **pyramidal**

Deduct 1 mark per error

$OPCl_3$



Shape **tetrahedral**

(6 marks)

4. Methane reacts with fluorine to form four different fluorinated compounds.
Write the names and formulas of all the fluorinated methanes that are polar.

Fluoromethane	**CH_3F**
Difluoromethane	**CH_2F_2**
Trifluoromethane	**CHF_3**

3 = 4 marks
2 = 2 marks
1 = 1 mark

4 = 3 marks

(4 marks)

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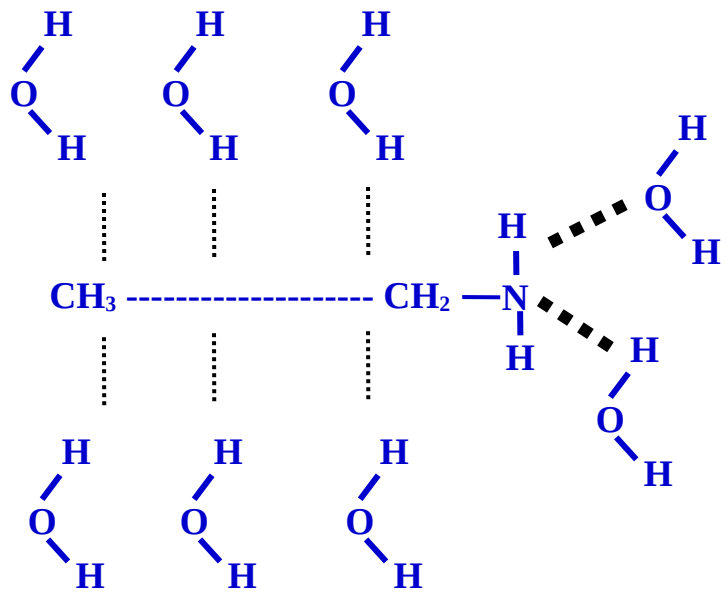
5. The following table shows the solubilities of two amines in water.

Amine	Methyl amine CH_3NH_2	Dodecyl amine $CH_3(CH_2)_{11}NH_2$
Solubility (g/100 mL)	108	0.05

Explain why their solubilities are so different. Include a labelled diagram.

2 well-explained reasons = 4 marks
diagram = 2 marks

- **New solute-solvent bonds should be at least as strong as original solute-solute and solvent-solvent bonds**
- **Both can hydrogen-bond, BUT dodecyl isomer has a long non-polar chain that can only interact with H_2O by dispersion force attraction,**
- **The new forces of attraction would be much weaker than the bonds broken between water molecules**



Strong H-bonds replacing strong H-bonding between H_2O molecules and NH_2 groups

Only weak dispersion forces replacing strong H-bonding between H_2O molecules

(6 marks)

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6. Three unlabelled beakers each contain the same volume of 1 mol L^{-1} solution. The three solutions are:

- sodium hydrogensulfate ($NaHSO_4$)
- sulfuric acid (H_2SO_4), and
- phosphoric acid (H_3PO_4).

The student is asked to identify the solutions. He is also given a bottle of sodium hydroxide (NaOH) solution, a choice of indicators and is allowed to use any other item of laboratory glassware. The student was successful.
How did the student correctly identify the acids?
Include equations to support your answer.

Add measured amount/volumes of NaOH solution to each (burette / graduated cylinder) **1**

$NaHSO_4$ is monoprotic acid – will need 1 volume **2**

$HSO_4^- + OH^- \rightarrow SO_4^{2-} + H_2O$

H_2SO_4 is diprotic acid – will need 2 volumes **2**

$H_2SO_4 + 2\ OH^- \rightarrow SO_4^{2-} + H_2O$

H_3PO_4 is triprotic acid – will need 3 volumes **2**

$H_3PO_4 + 3\ OH^- \rightarrow PO_4^{3-} + 3\ H_2O$

(7 marks)

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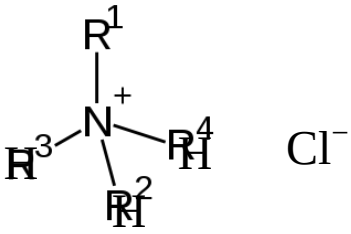
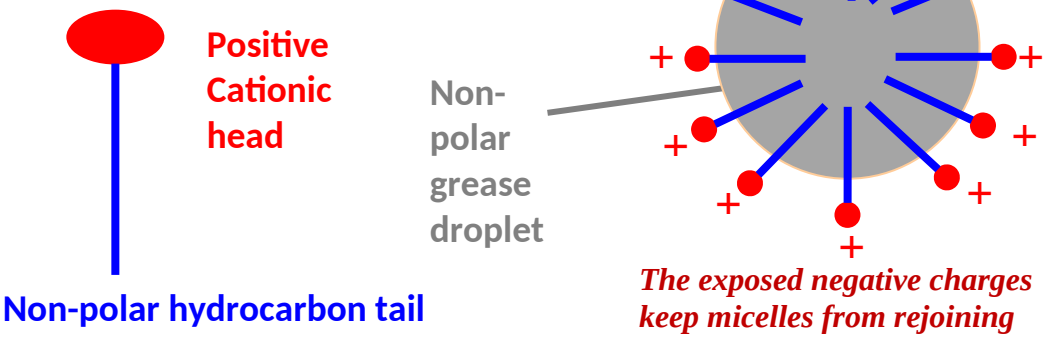
7. Quaternary ammonium salts can be represented by the following structural formula.
If the alkyl group (**R**) is long then the salt acts like a soap or detergent. If it is short the salt has no cleaning properties.
Explain these two differences in properties.
Include a labelled diagram.



2 well-explained reasons = 3 or 4 marks
diagram = 2 or 3 marks

- **Grease is non-polar**
- **Cleaning agent needs a long non-polar tail to stick deep into the layer of grease so that when the water is agitated and pulls at the polar head sticking out of the grease layer the tail will remain bonded in the grease**
- **A short tail will not provide sufficient dispersion interaction**
- ***Causing the grease to break up into micelles/globules that can be rinsed away (not required)***



The exposed negative charges keep micelles from rejoining

(6 marks)

Italicised parts not required

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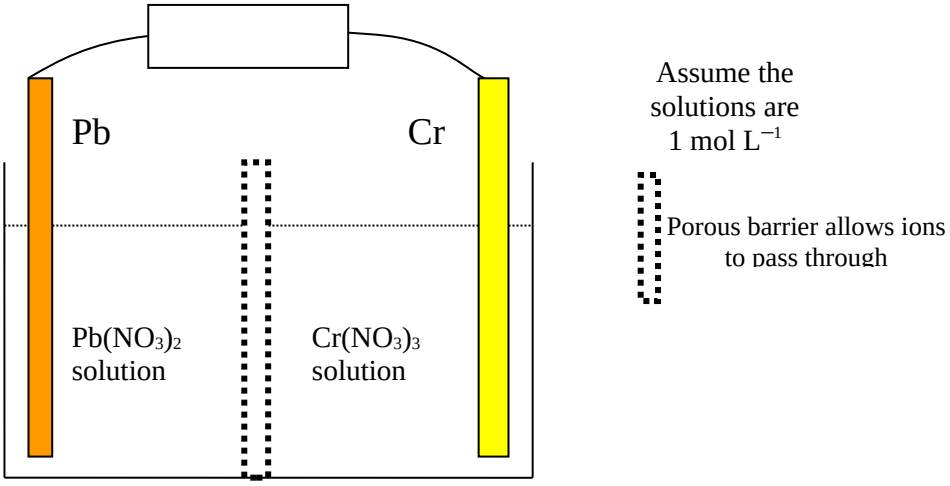
8. An electrochemical cell contains the two half cells separated by a porous membrane, which allows ions to migrate through. Each half cell has a metal rod placed in a solution of its nitrate.



(a) Write the two half reactions that occur, their standard reduction potentials and state whether each is oxidation, or reduction,

Pb^{2+} + 2e → Pb **Reduction** E^o = **− 0.13 V**

Cr → Cr^{3+} + 3e **Oxidation** E^o = **+ 0.74 V**

(4 marks)

(b) Write the equation for the net redox equation.

3 Pb^{2+} + 2 Cr → 3 Pb + 2 Cr^{3+} (2 mark)

(c) What is the emf (electromotive force, or voltage) of the cell?

0.61 V (1 mark)

(d) Draw an arrow in the top box to show the direction of current (electron flow) in the wire connecting the two electrodes. ←

(1 mark)

(e) What change (or changes) will be observed in the cell?

Lead rod becomes thicker *(accept shiny crystals form)*

Chromium rod becomes thinner

Chromium solution colour deepens (more green)

(3 marks)

9. A student is asked to identify four organic liquids, contained in four separate flasks.

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- Octene
- Hexan-3-ol (3-hexanol)
- Hexan-3-one (3-hexanone)
- Butanoic acid

The student has access to any chemicals and glassware required.
Describe the tests that should be carried out, and the observations, that enable the liquids to be identified.
Include equations to justify the choice of tests.

Mix each with bromine water
Octene will decolorise it
$C_8H_{16} + Br_2 \rightarrow C_8H_{16}Br_2$

2 marks for each test
May be in different order

Mix the remaining three with sodium carbonate solution
Butanoic acid will produce bubbling
$2\ C_3H_7COOH + Na_2CO_3 \rightarrow 2\ C_3H_7COONa + H_2O + CO_2$

Mix the remaining two with acidified potassium permanganate (or potassium dichromate) solution
Hexanol will turn purple permanganate (or green dichromate) colourless
$5\ C_6H_{14}O + 2\ MnO_4^- + 6\ H^+ \rightarrow 5\ C_6H_{12}O + H_2O$
3-hexanone

Hexanone will not decolorise the solutions as ketones are not oxidised with acidified potassium permanganate (or potassium dichromate)

Some students may state that octene reacts with acidified permanganate – but so does hexanol

(8 marks)

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10. The following table gives information about two substances. Use the information to determine whether each substance is acting as an oxidising agent (oxidant), or reducing agent (reductant) and provide a brief explanation to justify your answer.

Substance	Information	Oxidant, or reductant?
Concentrated sulfuric acid H_2SO_4	Reacts with copper to produce sulfur dioxide.	**Oxidant** 1 **S changes from +6 to +4 is reduced so must be an oxidant** 1
Hydrogen peroxide H_2O_2	Reacts with chlorine to produce chloride ion.	**Reductant** 1 **Cl changes from 0 to −1 is reduced so H_2O_2 must be a reductant** 1

(4 marks)

11. A student pours pours some silver nitrate solution into a bronze (copper-tin alloy) container.
Is this wise?
Explain why, or why not. Include an equation.

NO

Both copper and tin *are more reactive than Ag and* react with silver ion 1

The container will dissolve (how much depends on the moles of Ag^+ present) and contaminate the solution 1

$2\ Ag^+ + Cu \rightarrow 2\ Ag + Cu^{2+}$

$2\ Ag^+ + Sn \rightarrow 2\ Ag + Sn^{2+}$ 1

(3 marks)

12. Vinegar is about 4% by mass acetic acid and is safe to consume in foods. The same strength sulfuric acid is not safe to consume. Explain why. Include equations.

Sulfuric acid a strong acid and ionizes completely 1

$H_2SO_4 \rightarrow H^+ + HSO_4^-$ 1

then $H_2SO_4^- \rightleftharpoons H^+ + SO_4^{2-}$

Acetic acid (in vinegar) is a weak acid and ionizes to only a small extent *(about 1%)* 1

$CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$ 1

Sulfuric acid has a much higher hydrogen ion concentration

(4 marks)

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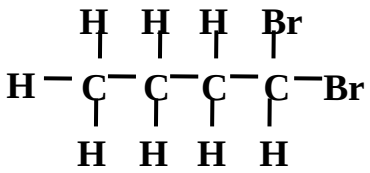
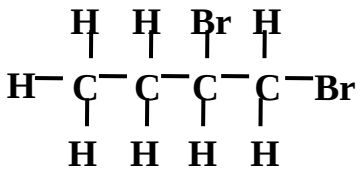
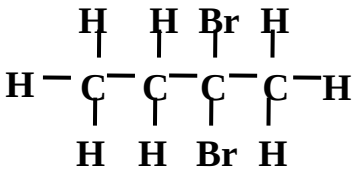
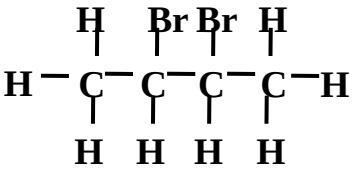
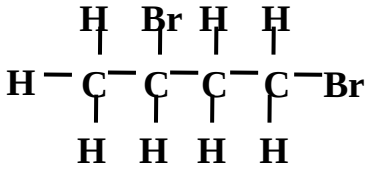
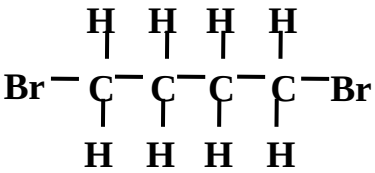
13. Name, and draw structural diagrams for, the following organic compounds.

Compound	Structural diagram	Name
An isomer of dibromobutane 2 + 1		**1,1 – dibromobutane**
		**1,2 - dibromobutane**
		**2,2 - dibromobutane**
		**2,3 - dibromobutane**
		**1,3 - dibromobutane**
		**1,4 - dibromobutane**

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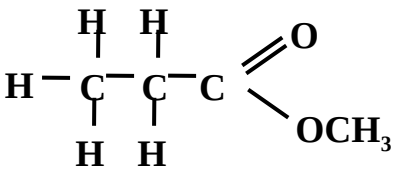
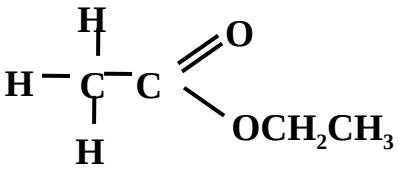
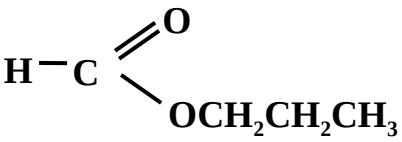
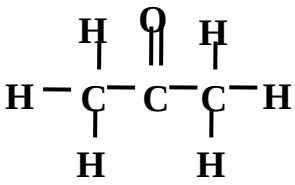
An ester containing 4 carbon atoms **2 + 1**	  	**methyl propanoate** **ethyl ethanoate** **propyl methanoate**
The ketone with the least number of carbon atoms **2 + 1**		**propanone** **acetone**

(9 marks)

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SECTION 3 5 questions (70 marks 35 %)

Extended answers
Answer ALL questions in Section 3 in the spaces provided.

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1. **Treatment of waste by-products in chemical industry** **16 marks**

In a chemical industries complex one production plant produces a waste caustic soda (NaOH) solution, which it stores in a large pond. Another production plant produces waste carbon dioxide. The chemical engineers decide to combine both wastes to produce the environmentally friendly by-product, sodium carbonate, by bubbling the carbon dioxide through the caustic soda solution.

$$2\ NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

The caustic soda pond contains 500 kL and has a hydroxide (OH^-) concentration of 1.00×10^{-2} mol L^{-1}.

(a) What is the pH of the solution?

$[H^+][OH^-] = 10^{-14}$ 1

$[H^+] = 10^{-14} / [OH^-] = 10^{-14} / 10^{-2} = 10^{-12}$ 1

$pH = -\log [H^+] = -\log [10^{-12}] = 12$ 1

(3 marks)

(b) What is mass of sodium hydroxide in the caustic soda pond?

$n = c\,V = (0.01)(500\,000) = 5\,000$ 1

$m = n\,M = (5\,000)(39.998) = 200\,000$ g (200 kg) 2

(3 marks)

(c) What mass of carbon dioxide is needed to completely react with sodium hydroxide?

***If you did not answer Part (b) above, use a mass of 100 kg* sodium hydroxide**

$2\ NaOH + CO_2$ 2 : 1 mol ration

$n(CO_2) = ½\ n(NaOH) = (0.5)(5\,000) = 2\,500$ 2

$m(CO_2) = n\,M = (2\,500)(44.01) = 110\,025$ g (110 kg) 1

55 kg for 100 kg NaOH

(4 marks)

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(d) The carbon dioxide is first cooled to 10°C and is pumped at a pressure of 200 kPa, delivering 150 L per minute.
How long does it take to complete the reaction?

PV = nRT

V = nRT / P = (2 500)(8.315)(273.1+10) / (200) = 29425 L **2**

Time = volume (L) / volume per minute (L^{-min}) **2**

= 29425 / 150 = 196 minutes **1**

98 minutes for 100 kg NaOH

(5 marks)

(e) (i) The pond solution is still found to be alkaline (pH of about 9).
Assuming all the carbon dioxide has reacted suggest a reason why is it still alkaline.

Sodium carbonate is a basic salt **1**

Carbonate ion hydrolyses to produce hydroxide ion
CO_3^{2-} + H_2O ⇌ HCO_3^- + OH^- **1**

(2 marks)

2. Production of phosphorus from fluoroapatite 16 marks

The mineral fluoroapatite [$Ca_{10}(PO_4)_6F_2$] is mixed with sand [SiO_2] and powdered carbon in a high temperature furnace. The phosphorus is produced as a gas [P_4], along with carbon monoxide. The reaction actually produces calcium oxide [CaO], which has a very high melting point. This would make the mixture difficult to control. So, as the calcium oxide is produced it reacts with the sand to form a low melting point slag, calcium silicate [$CaSiO_3$]. This liquid slag is easily separated from the furnace.
The reaction occurring is:

$$2Ca_{10}(PO_4)_6F_2\,(s) + 18\,SiO_2\,(s) + 30\,C\,(s) \rightarrow 3\,P_4\,(g) + 30\,CO\,(g) + 18\,CaSiO_3\,(l) + 2CaF_2\,(s)$$

(a) Is this reaction exothermic, or endothermic? **Endothermic** **1**

Give a reason for your choice.

Passage states reaction is carried out in a furnace, so reactants must require continuous heating **1**

(2 marks)

(b) The main reaction can be represented by the two half reactions:

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- phosphate ion producing phosphorus (P_4) and oxide ions (O^{2-}), and
- carbon reacting with oxide ion producing carbon monoxide

Which element, phosphorus or carbon, is being oxidised? **Carbon** 1

Justify your answer by referring to oxidation numbers.

ON of C = 0 **ON of C in CO = +2** ***increased*** 1

ON of P in PO_4^{3-} = +5 **ON of P in P_4 = 0** ***decreased*** 1

(c) List three elements whose oxidation states are not changing.

calcium oxygen silicon fluorine 3

(6 marks)

(d) Some of the oxide ions produced in Part (b) becomes part of the liquid slag by reacting with calcium ions and sand.
Write the equation for the formation of the slag.

Ca^{2+} + SiO_2 + O^{2-} → $CaSiO_3$

(2 marks)

(d) In a laboratory trial a 155 g sample of fluoroapatite (molar mass = 1008.62) is heated with excess sand and 25.0 g of carbon.
What mass of phosphorus would be produced?

$2Ca_{10}(PO_4)_6F_2$ (s) + 30 C (s) → 3 P_4 (g)

M = 1008.62 M = 12.01 M = 61.94 1

2 mol 30 mol 3 mol

Given
n = m / M
= 155 / 1008.62
= 0.15368

Given
n = m / M
= 25 / 12.01
= 2.0816 2

0.15368 mol fluoroapatite needs 30/2 x 0.15368 = 2.305 mol carbon
not enough carbon; carbon is limiting reactant 1

mol P_4 produced 3/30 x mol (C) = (0.1)(2.0816) = 0.20816 1

m (P_4) = n M = (0.20816)(4 x 30.97)
= (0.20816)(123.88) = 25.8 g 1

(6 marks)

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3. **Analysing an organic compound** **13 marks**

A certain organic compound is known to contain only carbon, hydrogen and oxygen.
The compound was analysed as follows.

- A 2.149 g sample was burned and the carbon dioxide produced was bubbled through a barium hydroxide solution, producing 11.27 g of barium carbonate ($BaCO_3$).

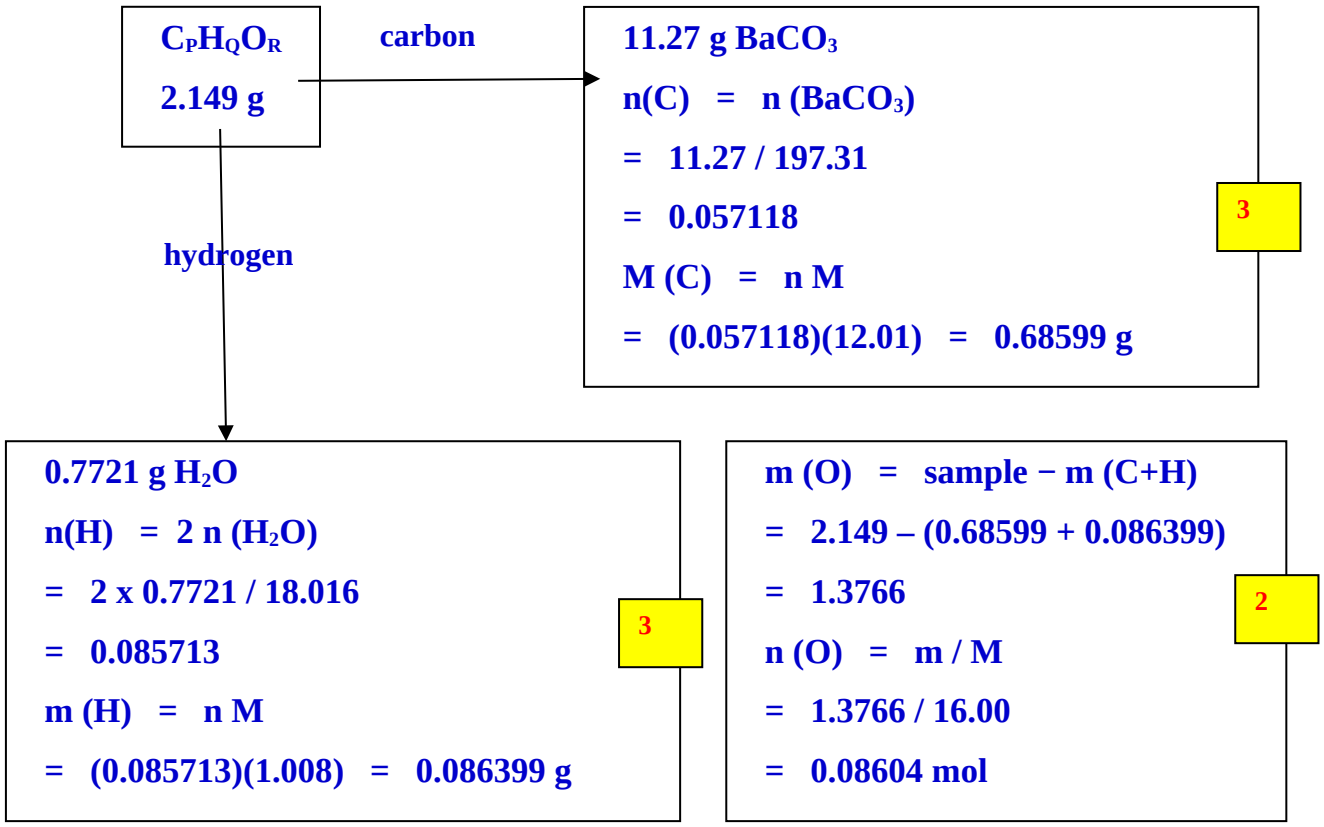
  $CO_2 + Ba(OH)_2 \rightarrow BaCO_3 + H_2O$
- The mass of water produced by burning of the sample was 0.7721 g
- The compound was found to have a molecular weight of 150.1

a) What is the empirical formula of the compound? (10 marks)

[*You may do this by finding the masses of carbon, hydrogen and oxygen in the sample*]

b) What is the molecular formula of the compound? (2 marks)

c) The compound is also known to be a carboxylic acid; that is, containing one COOH group.
Write the molecular formula in the form of $C_XH_Y O_Z$ COOH (giving values for X, Y and Z).
(1 mark)



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	C	H	O
mol	0.057118	0.085713	0.08604
ratio ÷ 0.057118	1 2	1.51 3	1.51 3
Empirical formula is $C_2H_3O_3$			

1

1

b) Empirical formula mass = 24 + 3 + 48 = 75

Molecular weight = 150.1 = 2 x empirical formula mass

So molecular formula is $C_4H_6O_6$

1

1

c) Taking COOH out of the formula leaves $C_3H_5O_4$

formula is $C_3H_5O_4$ COOH

1

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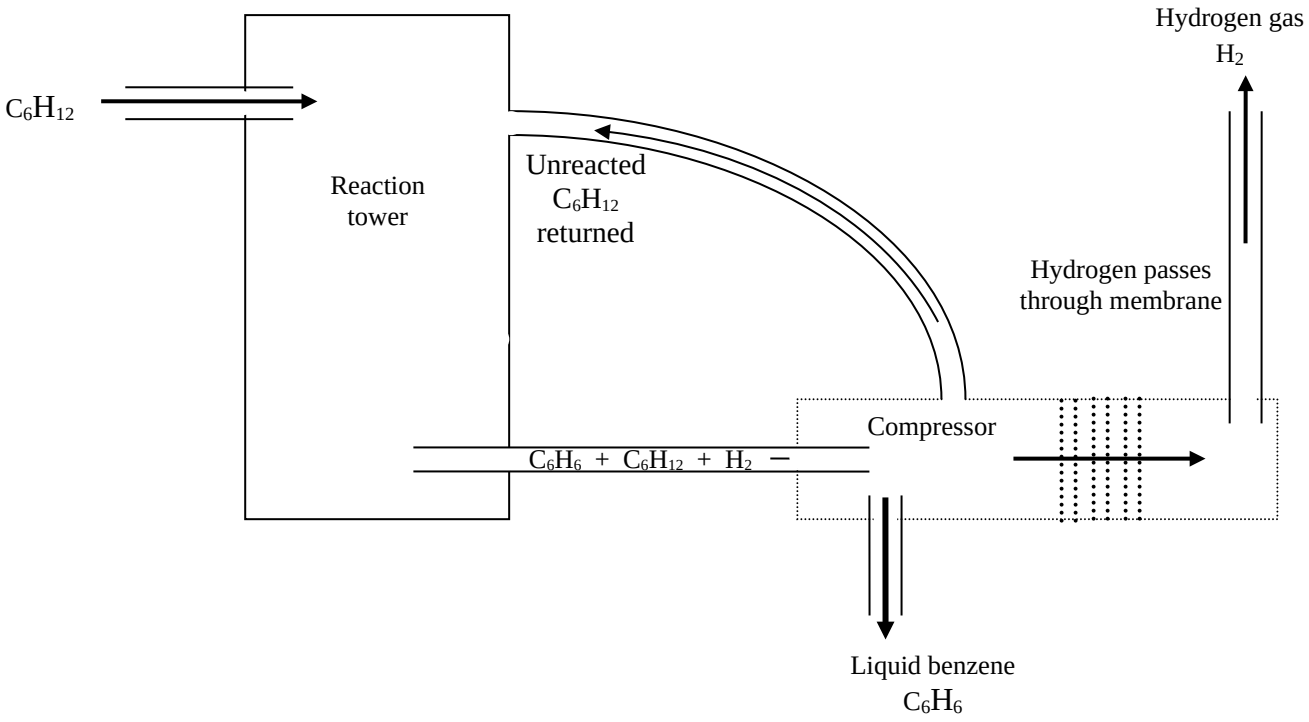
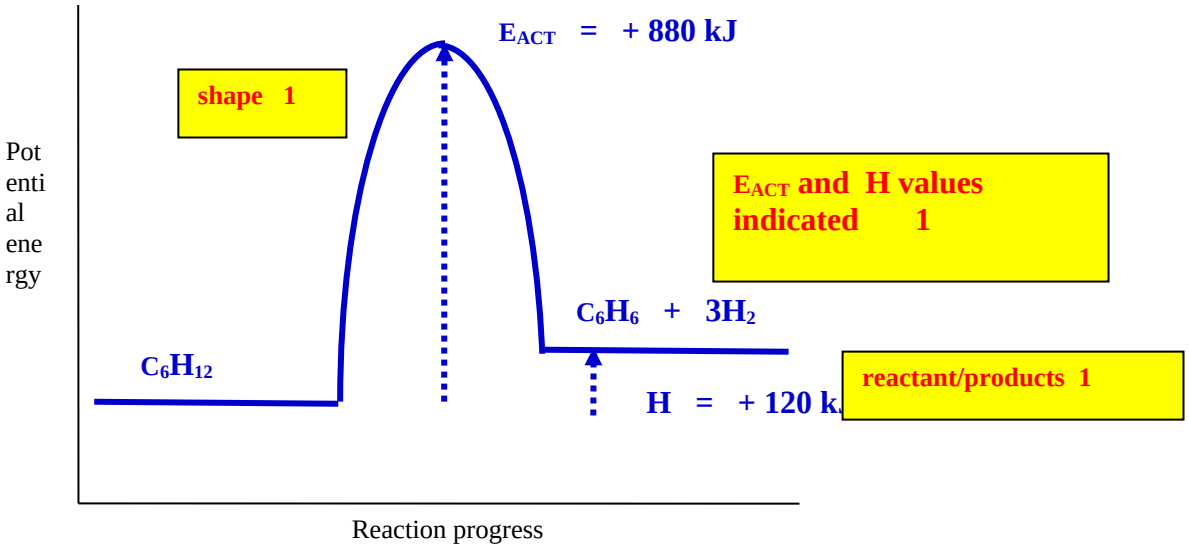
4. Production of benzene **14 marks**

Benzene (C_6H_6) can be produced by the dehydrogenation of cyclohexane (C_6H_{12}) gas. The reaction has a high activation energy (880 kJ mol^{-1}), is also endothermic and reversible. The cyclohexane (C_6H_{12}) passes through a special reaction tower where hydrogen is chemically removed. The benzene/cyclohexane/hydrogen mixture then passes through a compressor, where the benzene is liquefied. A special membrane in the compressor allows the small hydrogen molecules to pass through, and out. The unreacted cyclohexane (C_6H_{12}) gas is then returned to the reaction tower.

$$C_6H_{12}\ (g) + 120\ kJ \rightleftharpoons C_6H_6\ (g) + 3\ H_2\ (g)$$



a) Draw a labelled energy profile diagram for the reaction.



(3 marks)

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b) Write an equilibrium constant expression for the reaction.

$$K = \frac{[C_6H_6]\ [H_2O]^3}{[C_6H_{12}]}$$

(2 marks)

c) Under what conditions will the rate of the forward reaction be greatest?

High temperature

High pressure

Adding a catalyst

(3 marks)

d) For a mixture of all three gases at equilibrium in a sealed container, what conditions will produce the maximum yield of benzene?

High temperature

Low pressure

(2 marks)

e) Suggest conditions that would be used for the commercial production of benzene using this process.

Explain why you chose these conditions.

High temperature

Favours shift right and increases reaction rate 1

Compromise pressure

High pressure increases reaction rate but favours shift left

Low pressure decreases reaction rate but favours shift right 2

Catalyst

Increases reaction rate (of forward and reverse) so does not favour shift but allows product to form more quickly 1

(4 marks)

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5. **Determining concentration of cerium (II) sulfate solution by titration 10 marks**

Cerium (II) ion can be converted to cerium (III) ion by hydrogen peroxide.

$H_2O_2 + 2\ H^+ + 2\ Ce^{2+} \rightarrow 2\ H_2O + 2\ Ce^{3+}$ cerium is element 58

A solution of cerium (II) sulfate was analysed by the following steps:

I. 50.00 mL of the solution was diluted to 500.0 mL in a volumetric flask

II. 20.00 mL of this diluted solution was pipetted into a conical flask

III. About 20 mL of dilute sulfuric acid was added to the flask

IV. Standardised hydrogen peroxide solution of concentration 0.05145 mol L^{-1} was delivered from a burette

V. 35.45 mL of the hydrogen peroxide was required for complete reaction

What was the concentration in moles per litre (mol L^{-1}) and in grams per litre (g L^{-1}) of the original undiluted cerium sulfate solution?

n (H_2O_2) used in titration = c V

= (0.05145)(0.03545) 2

= 0.0018239

n (Ce^{2+}) consumed = 2 x n (H_2O_2)

= (2)(0.0018239) 2

= 0.0036478

present in 20.00 mL aliquot taken from the 500 ml vol flask

n (Ce^{2+}) in 500 mL flask

= (500 / 20)(0.0036478) 2

= 0.091195

this was in the original undiluted 50.00 mL solution

original concentration = n / V

= 0.091195 / 0.05000

= 1.824 mol L^{-1} 2

= nM grams per litre $CeSO_4$ **= 236.16** 1

= (1.8239)(218.16) = 431 g L^{-1} 1