



THE SCHOOL FOR EXCELLENCE
UNIT 4 CHEMISTRY 2008
COMPLIMENTARY WRITTEN EXAMINATION 2 - SOLUTIONS

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SECTION A - MULTIPLE CHOICE QUESTIONS

QUESTION 1 Answer is A

Note: State the species with the lowest pH first.

The pH is dependent upon the amount of H_3O^+ ions in solution, which at constant temperature, volume and concentration is dependent upon acid strength.

Alternatively, $pH \propto \frac{1}{K_a}$ values. Sulfuric acid and nitric acid are both strong species and will produce solutions with low pH values. Sulfuric acid being a strong diprotic acid produces higher concentration of H_3O^+ and hence will display the lowest pH.

Answer is A or B.

Methanoic acid and benzoic acid are weak species – so we use their K_a values. As benzoic acid has the lower K_a value (use data booklet), it will produce fewer H_3O^+ ions, hence its pH will be higher. Answer is A.

QUESTION 2 Answer is A

The equation for the reaction is: $H_2SO_4(aq) + Ca(OH)_2(aq) \rightarrow CaSO_4(aq) + 2H_2O(l)$.

$n(H_2SO_4) = 0.2 \times 0.2 = 0.04 \text{ mol}$ and $n(Ca(OH)_2) = 0.1 \times 0.1 = 0.01 \text{ mol}$

$n(H_2SO_4) \text{ in excess} = 0.04 - 0.01 = 0.03 \text{ mol}$

$n(H^+)_{\text{excess}} = 0.03 \times 2 = 0.06$

$[H^+] = 0.06 / 0.30 = 0.2 \text{ M}$

$[H_3O^+] = [H^+] = 0.2 \text{ M}$

$pH = -\log_{10}(0.2) = 0.70$

QUESTION 3 Answer is B

$n(\text{butane}) = PV/RT = (1.5 \times 101.3) \times 4.0 / 8.31 \times (273 + 10) = 151.95 \times 4.0 / 8.31 \times 283 = 0.258 \text{ mol}$.

1 mol butane produces 2874 kJ of heat. Hence 0.258 mol produces $2874 \times 0.258 = 741.5 \text{ kJ}$

Use $E(J) = m \times c \times \Delta T$ for mass of water to heat. {Note : $\Delta T = 90$ }

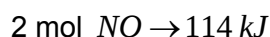
$\text{mass}(\text{H}_2\text{O}) = E(J) / 4.18 \times 90 = 741500 / 376.2 = 1970 \text{ mL}$

On each of the nights he can heat 986 mL of H_2O .

QUESTION 4 Answer is C

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{101.3 \times 1}{8.31 \times 2.71} = 0.045 \text{ mol}$$



$$x = 2.45 \text{ kJ}$$

Note: Answer must be positive as the question requires the amount of energy being released.

QUESTION 5 Answer is D

Reverse the first equation and change the sign of the ΔH .

Double the coefficients of the first equation and its ΔH .

Then add to the second equation.

$$\Delta H = -2(-146) + 418 = 710 \text{ kJ}$$

QUESTION 6 Answer is A

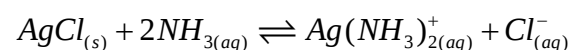
Nuclear fission reactions involve the splitting of large nuclei into smaller nuclei. Therefore, the mass number and atomic number of the products must decrease.

QUESTION 7 Answer is B

The greatest environmental damage would result from the dumping of waste into the ocean. Landfill, vitrification and high temperature incineration are typically used by industry.

QUESTION 8 Answer is C**QUESTION 9** Answer is C

The total reaction is the sum of the individual reaction and is written as



QUESTION 10 Answer is A

QUESTION 11 Answer is C

$$K = [\text{NO}_2(\text{g})][\text{Cl}_2(\text{g})] / [\text{NO}_2\text{Cl}(\text{g})]^2 = 0.558$$

$$[\text{NO}_2\text{Cl}(\text{g})] = 0.00424/4.0 = 0.00106\text{M}$$

$$[\text{Cl}_2(\text{g})] = 0.02152/4.0 = 0.00538\text{M}$$

$$\begin{aligned}\text{Hence, } [\text{NO}_2(\text{g})] &= [\text{NO}_2\text{Cl}(\text{g})]^2 \times 0.558 / [\text{Cl}_2(\text{g})] = (0.00106)^2 \times 0.558 / 0.00538 = 0.0001165 \\ &= 1.17 \times 10^{-4}\text{M}\end{aligned}$$

$$n(\text{NO}_2(\text{g})) = cV = 1.17 \times 10^{-4} \times 4 = 4.68 \times 10^{-4}$$

QUESTION 12 Answer is B

Reaction occurs between Cu^{2+} (in cathode) and Fe (in anode).

CH_3OH is not an electrolyte.

Ag^+ will migrate from salt bridge to cathode. As Ag^+ is a stronger oxidant than Cu^{2+} , it will react, interfering with cell processes. Therefore, cannot use AgNO_3 .

K^+ is a very weak oxidant – therefore, it will not interfere with reactions. OH^- will move into the anode where it reacts with Fe^{2+} to form a precipitate. Therefore, KOH cannot be used.

QUESTION 13 Answer is B

In the recharging process, the products are converted back to reactants. The negative electrode is the cathode where reduction takes place and the positive electrode is the anode where oxidation takes place. The oxidation state of Pb in PbSO_4 is +2, 0 in Pb and +4 in PbO_2 . Reduction is from PbSO_4 to Pb, which takes place at the negatively charged cathode.

QUESTION 14 Answer is A

List species in order from strongest oxidant to weakest oxidant.

From the given information:

When metal X is placed in a solution of Y^{2+} ions, Y and X^{2+} are formed

Since X displaces Y^{2+} ions in solution, Y^{2+} must be a stronger oxidant.

When both metals are placed in an acidified solution, no reaction occurs.

X and Y must have a higher E° value than H^+ for the reaction to be non-spontaneous.

QUESTION 15 Answer is A

Molar mass $MnO_2 = 86.9 \text{ g}$

$\therefore$ 1 mole MnO_2 produces $86.9 \times 2220 = 192,918 \text{ C}$

$\therefore$ 1 mole MnO_2 generates $\frac{192,918}{96,500} = 2 \text{ mole}$ of electrons

Oxidation number of Mn changes from +4 to +2.

QUESTION 16 Answer is D

The production of oxygen gas at the anode is a result of the oxidation of H_2O . Hence, no oxygen gas will be formed from molten substances. Iodide, I^- , is a stronger reductant than H_2O and would be preferentially oxidised at the cathode in aqueous potassium iodide. However, in aqueous sodium chloride, the H_2O is a stronger oxidant than the chloride, Cl^- , so oxygen gas would be produced.

QUESTION 17 Answer is B

To deposit Ni, and EMF of 1.46 V is required – which is more than the voltage being supplied. As Al^{3+} is a weaker oxidant than water, water will react at the cathode, and hence Al will not be produced. The last metal to be deposited is therefore Cu.

QUESTION 18 Answer is C

The reaction at the anode is $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

$n(Zn) = \text{mass}/\mathcal{M} = 1.2/65.4 = 0.0183 \text{ mol}$

$n(e^-) = 2 \times n(Zn) = 2 \times 0.0183 = 0.0367 \text{ mol}$

$Q = n(e^-) \times F = 0.0367 \times 96500 = 3541.55 \text{ C}$

$t = Q/I = 3541.55/0.05 = 70831 \text{ secs} = 1180 \text{ mins} = 19.7 = 20 \text{ hours.}$

QUESTION 19 Answer is C

$$\text{Slope} = \frac{n(e^-)}{\text{charge cation}}$$

The lower the charge on the ion, the steeper the plotted line.

QUESTION 20 Answer is D

Process C involves the conversion of the kinetic energy of steam to mechanical energy. Both energy forms are an example of kinetic energy, therefore, the answer is D.

SECTION B – SHORT ANSWER QUESTIONS

QUESTION 1

a. **Option A : $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$**

- (i) Sulfuric acid, H_2SO_4 [1 mark]
- (ii) Sulfuric acid is used to produce fertilisers, as a strong acid, an oxidant or as a dehydrating agent. [1 mark]

Option B : $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

- (i) Nitric acid, HNO_3 [1 mark]
- (ii) Nitric acid is used to produce fertilisers, explosives or nitrate salts. [1 mark]

Option C : $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$

- (i) Ammonia, NH_3 [1 mark]
- (ii) Ammonia is used to produce fertilisers, nitric acid and fibres such as nylon. [1 mark]

Option D : $\text{C}_3\text{H}_8(\text{g}) \rightleftharpoons \text{C}_2\text{H}_4(\text{g}) + \text{CH}_4(\text{g})$

- (i) Ethene, C_2H_4 [1 mark]
- (ii) Ethene is used to produce polymers and ethanol. [1 mark]

b. **Option A : $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$**

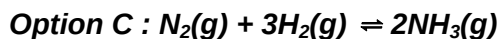
- (i) A high yield of SO_3 is favoured by low temperatures and high pressure. [1 mark]
- (ii) Low temperatures lead to an unacceptably slow rate of reaction, however, if the temperature is too high then the yield of SO_3 is too low. [1 mark]

A compromise in temperature of around 450°C is used to maintain the high yield of SO_3 whilst a catalyst is used to increase the rate of reaction. [1 mark]

Option B : $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$

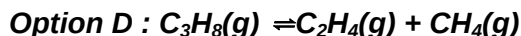
- (i) A high yield of NO_2 is favoured by low temperatures and high pressure. [1 mark]
- (ii) This reaction is unusual in that its rate actually increases as the temperature decreases. [1 mark]

Therefore, a compromise in temperature to maintain a high yield of NO_2 at an economically viable rate is unnecessary. [1 mark]



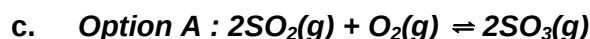
- (i) A high yield of NH_3 is favoured by low temperatures and high pressure. [1 mark]
- (ii) Low temperatures lead to an unacceptably slow rate of reaction, however, if the temperature is too high then the yield of NH_3 is too low. [1 mark]

A compromise in temperature of around 350 to 550°C is used to maintain the high yield of NH_3 whilst a catalyst is used to increase the rate of reaction. [1 mark]



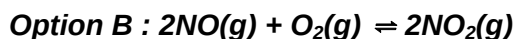
- (i) A high yield of C_2H_4 is favoured by high temperatures and low pressure. [1 mark]
- (ii) Although the reaction is favoured by high temperatures it must be carefully controlled to prevent the further cracking of the ethene. [1 mark] .

The gases are moved quickly (less than one second) through the furnace. This improves the yield of C_2H_4 . [1 mark]



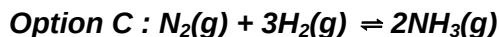
The SO_3 goes through a double absorption process to ensure that unreacted SO_2 is not emitted but recycled through the convertor. The energy released by the exothermic reactions is used to power the plant. [1 mark]

The solid waste of the spent catalyst, V_2O_5 , is buried in landfill. [1 mark]



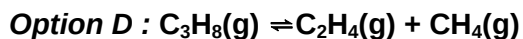
The NO and NO_2 gases from the absorption tower contribute to photochemical smog so their emissions are carefully limited by heating them over a catalyst to reduce them to N_2 . Additional absorption towers to improve conversion to HNO_3 . [1 mark]

The heat released by the reaction in the convertor is used to generate electricity. [1 mark]



The unreacted gases, H_2 and N_2 are recycled to maximise the yield of ammonia and reduce waste. [1 mark]

The energy released by the exothermic reactions is used to power the plant. [1 mark]



The hydrocarbons undergo desulfurisation to prevent the production of SO_2 at the high temperatures. [1 mark]

Unreacted feedstock gases such as ethyne, propene and propane are recycled through the furnace. Some gases such as methane or hydrogen may be extracted and used as fuels for the furnaces. [1 mark]

- d. (i) Reactions proceed as a result of successful collisions between molecules in which reactant bonds are broken.

An increase in the frequency of collisions and the force of these collisions results in an increase in reactant bond breakage and hence a faster rate of reaction.

Increasing the temperature increases the average kinetic energy of the molecules which then collide more frequently and with greater force, thus increasing the rate of reaction. [1 mark]

- (ii) When a small temperature increase occurs, the energy of each individual particle does not increase that significantly, however, the proportion of particles that now display the minimum energy to react can increase markedly. Hence reaction rates can increase markedly – even when the temperature change is relatively small. [1 mark]

QUESTION 2

- a. (i) Molar heat of combustion of ethanol is 1364 kJmol^{-1} (Use data booklet)

$$n(\text{ethanol}) = \frac{m}{M} = \frac{0.7663}{46} = 0.01666 \text{ mol}$$

$$1 \text{ mol} = 1364 \text{ kJ}$$

$$0.01666 \text{ mol} = x \text{ kJ}$$

$$x = 22.72 \text{ kJ} \quad [1 \text{ mark}]$$

$$CF = \frac{E(J)}{\Delta T} = \frac{22720}{24.64 - 20.62} = 5651.74 \text{ J}^\circ\text{C}^{-1} = 5.652 \text{ kJ}^\circ\text{C}^{-1} \quad [1 \text{ mark}]$$

- (ii) The combustion chamber in the bomb calorimeter is surrounded by water with a specific heat capacity of $4.18 \text{ J / g / }^\circ\text{C}$

If a liquid with lower specific heat capacity were used, less energy would be required to heat this new liquid/solution and hence the measured change in temperature would be higher. Therefore, the calibration factor would be lower in value. [1 mark]

b. (i) $E(J) = CF \times \Delta T$
 $= 5651.74 \times 6.44 \text{ J / ml}$
 $= 36397.21 \text{ J / ml}$ [1 mark]
 $= 36397.21 \times 1000 \text{ J / L}$
 $= 36.40 \text{ MJL}^{-1}$
 $= 36 \text{ MJL}^{-1}$ [1 mark]

(ii) Calculate the efficiency of the bomb if the energy density of diesel is 44.8 kJg^{-1} and its density is 0.85 kgL^{-1} .

$$44.8 \text{ kJg}^{-1}$$

$$d = 0.85 \text{ g / ml}$$

$$\frac{44.8}{1.1765} \text{ kJ / ml}$$

$$0.85 \text{ g} = 1 \text{ ml}$$

$$\therefore 1 \text{ g} = x$$

$$38.08 \text{ kJ / ml}$$

$$38.08 \times 10^3 \text{ kJ / L}$$

$$38.08 \text{ MJ / L}$$
 [1 mark]

$$0.85x = 1$$

$$x = 1.1765 \text{ ml}$$

$$\text{Efficiency} = \frac{38.08}{44.8} \times 100 = 85\%$$
 [1 mark]

c. (i) Vegetable oil and animal fat. [1 mark]

(ii) State any one of the following.
 [1 mark for energy source, 1 mark for advantage]

Renewable Energy Source	Advantage
Hydroelectric plants	Non-polluting and inexpensive to run.
Solar Energy	Non-polluting and inexpensive to run.
Wind Energy	Non-polluting and inexpensive to run.
Tidal	Non-polluting and inexpensive to run.
Geothermal	Non-polluting and inexpensive to run.
Biofuels	Re-use waste materials

QUESTION 3

Data relating to hypobromous acid may be found in the data booklet.

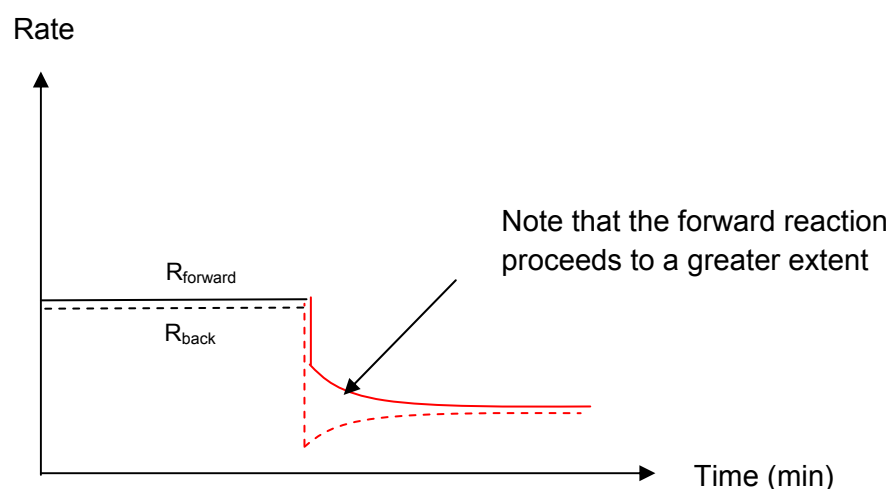
- a. $\text{HOBr(aq)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{OBr}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}); K_a = 2.4 \times 10^{-9} \text{M}$ [1 mark]
- b. $\text{HOBr} = 1.0 \text{M}, K_a = [\text{OBr}^-(\text{aq})][\text{H}_3\text{O}^+(\text{aq})] / [\text{HOBr(aq)}] = [\text{H}_3\text{O}^+(\text{aq})]^2 / [\text{HOBr(aq)}]$
- $[\text{H}_3\text{O}^+] = \sqrt{(2.4 \times 10^{-9} \times 1.0)} = 0.00004899 = 4.90 \times 10^{-5} \text{M}$ [1 mark]
- $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+] = -\log_{10}(4.90 \times 10^{-5}) = 4.3$ [1 mark]
- c. (i) As the solution has undergone a 1 in 10,000 dilution the pH has increased by 2 units (a 1 in 100 dilution changes the pH by 1 unit). Therefore, the final pH will be 6.3 and the indicator will change colour to yellow. [1 mark]
- (ii) Diluting will decrease the concentration of all species (except water). The system will oppose the introduced change by favouring the reaction that will increase particle concentration. A net forward reaction occurs. [1 mark]

Note: Ignore water as producing more or less will not affect its concentration.

	Increase	Decrease	No Change
Amount, in mole, of the bromous ion (OBr^-)	✓		
Concentration of bromous ion (OBr^-)		✓	
K_a value			✓

[1+1+1 = 3 marks]

- (iii) [2 marks]



When the solution is diluted, the concentration of all species (except water) decreases instantaneously. The probability of successful collisions between particles decreases and therefore, both the forward and back reaction rates decrease.

The system re-establishes equilibrium by favouring a net forward reaction, meaning that the forward reaction will occur more frequently than the back reaction. The reactant numbers gradually decrease, resulting in a decreasing reaction rate.

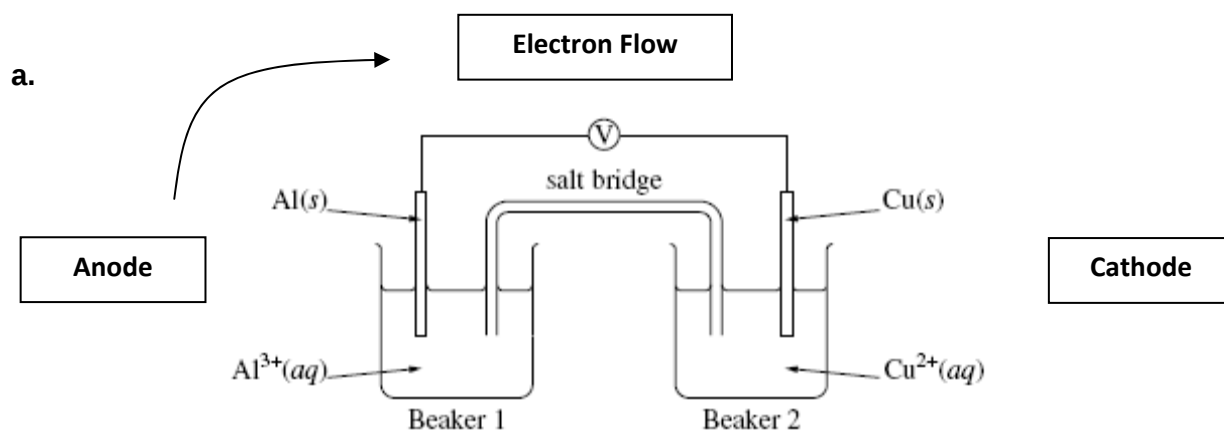
Conversely, the number of product particles gradually increases, resulting in a higher collision frequency and hence the rate of the back reaction increases.

The rate of the forward reaction will continue to decrease, the rate of the back reaction will continue to increase, until they become equal and equilibrium is re-established.

Note:

Final reaction rates are lower as the new equilibrium concentrations are lower (dilution effect). The lower concentrations of reactants and products results in less frequent collisions, therefore, reaction rates are lower.

QUESTION 4



[1 mark]

b. (i) Answer is D. The salt bridge is required to complete the circuit.

[1 mark]

(ii) Answer is C.

[1 mark]

(iii) Answer is B.

[1 mark]

(vi) Most of the chemical energy would be transferred directly into heat energy. Most correct answer is D.

[1 mark]

QUESTION 5

- a. (i) T_2 as it has the higher initial rate (most reaction rates increase with increasing temperature) and equilibrium is reached faster. [1 mark]
- (ii) Exothermic. As the temperature increases, the concentration and amount of product decreases, which means that a net back reaction is occurring. This occurs when the forward reaction is exothermic. [1 mark]
- b. (i) 4 times. [1 mark]
- (ii) Read the concentrations directly off the graph.

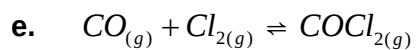
$$K = \frac{[COCl_2]}{[CO][Cl_2]} = \frac{0.02}{0.04 \times 0.08} = 6.25 \text{ M}^{-1} \quad [1 \text{ mark}]$$

- c. (i) As all concentrations have sharply increases, the volume of the container was reduced. [1 mark]
- (ii) As the changes in concentration at 8 minutes are gradual, a temperature change has occurred. As the concentration of $COCl_2$ has increased, a net forward reaction is occurring. As the forward reaction is exothermic, the temperature of the system was decreased. [1 mark]

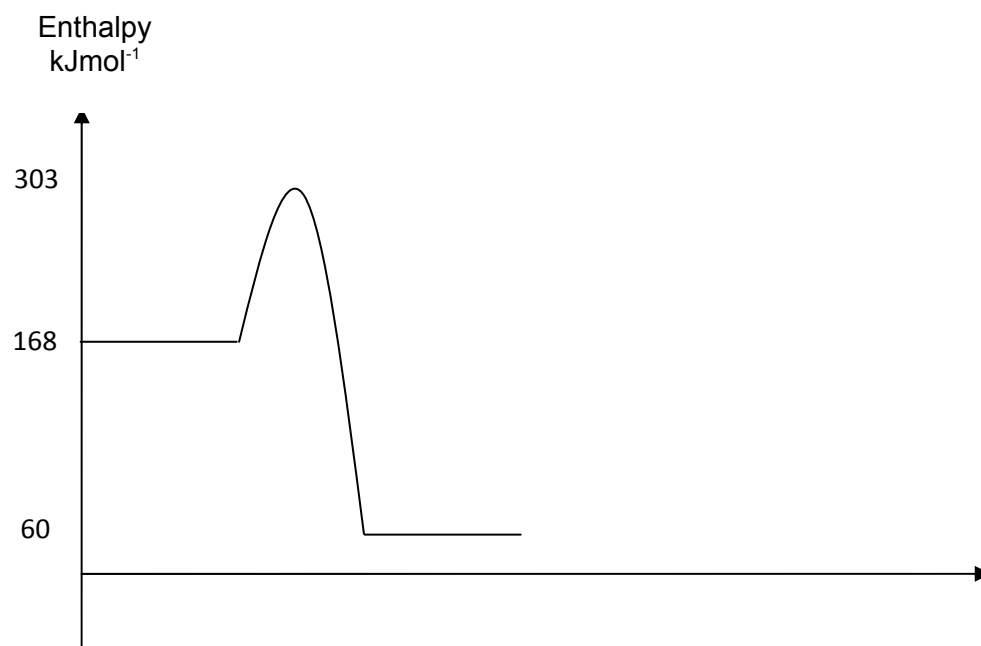
d.

	CO	Cl_2	$COCl_2$
Initial number of mole	5	4	0
Mole at equilibrium	?	?	3
Change in Mole	Decrease of 3 mol	Decrease of 3 mol	Increase of 3 mol
Mole at equilibrium	$5 - 3 = 2$	$4 - 3 = 1$	3
Equilibrium concentration $\left(c = \frac{n}{V} \right)$	$C = \frac{2}{2} = 1M$	$C = \frac{1}{2} = 0.5M$	$C = \frac{3}{2} = 1.5M$

$$K = \frac{[COCl_2]}{[CO][Cl_2]} = \frac{1.5}{1 \times 0.5} = 3.0 \text{ M}^{-1} \quad [3 \text{ marks}]$$



As reaction is exothermic - $\Delta H = -108 \text{ kJ / mol}$



$$\text{Energy Products} - \text{Energy Reactants} = -108$$

$$60 - \text{Energy Reactants} = -108$$

$$- \text{Energy Reactants} = -108 - 60$$

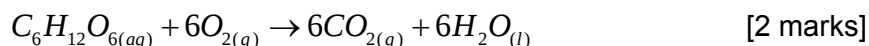
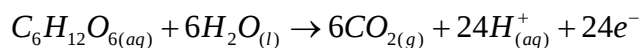
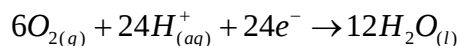
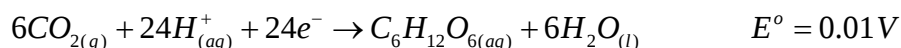
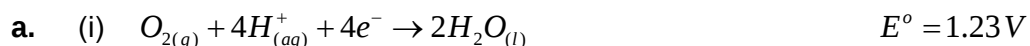
$$\text{Energy Reactants} = 168 \text{ kJ / mol}$$

$$\text{Top of the curve} = \text{Energy of Reactants} + \text{activation energy requirement} =$$

$$168 + 135 = 303 \text{ kJ / mol}$$

[2 marks]

QUESTION 6



(ii) $EMF = 1.23 - 0.01 = 1.22\text{ V}$ [1 mark]

- b. (i) Referring to the data sheet – the molar enthalpy of combustion of glucose is -2816 kJmol^{-1} .

At 95% efficiency – the **amount of energy** (answer must be positive) that could be released is $0.95 \times 2816 = 2675\text{ kJmol}^{-1}$ [1 mark]

- (ii) The chemical energy stored in the bonds of the fuel is directly converted into electrical energy with little energy being lost as heat. [1 mark]

- c. **Advantages:** One of - [1 mark]

End products/by products are environmentally friendly. End products of combustion of coal are significant contributors to the greenhouse effect and global warming.

Hydrogen is a renewable energy source – coal is not.

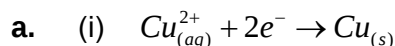
There are abundant supplies of hydrogen whereas the reserves of coal are rapidly depleting.

Disadvantages: One of – [1 mark]

Hydrogen is expensive to obtain from water – coal is more cost effective.

The unit required to combust hydrogen is expensive to run and not portable.

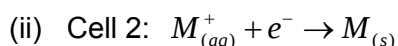
QUESTION 7



$$n(\text{Cu}) = \frac{m}{M} = \frac{0.0949}{63.6} = 0.001492 \text{ mol}$$

$$n(e^-) = 2 \times n(\text{Cu}) = 0.002984 \text{ mol}$$

$$\text{Number of Faradays} = 0.00298 \quad [1 \text{ mark}]$$



Note: Given - $M\text{NO}_{3(aq)}$ which tells us that the charge on M^{n+} is +1

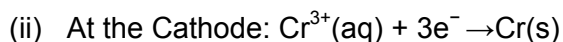
$$n = \frac{m}{M}$$

$$\therefore M = \frac{m}{n} = \frac{0.322}{0.002984} = 107.91 \quad [1 \text{ mark}]$$

The unknown metal is silver. [1 mark]

- b. (i) A solution of CrCl_3 indicates that H_2O is present. As it is the stronger reductant it will be oxidised at the anode, which is positively charged, to produce oxygen gas. [1 mark]

{Note: A mark can be awarded for indicating that some Cl_2 may be produced in addition to the oxygen due to 2.0M solution and competition at the anode}



$$n(\text{Cr}) = \text{mass}/M = 15.0/52 = 0.288 \text{ mol} \quad [1 \text{ mark}]$$

$$n(e^-) = 3 \times n(\text{Cr}) = 3 \times 0.288 = 0.864 \text{ mol} \quad [1 \text{ mark}]$$

$Q = It$, $It = n(e^-) \times F$, hence

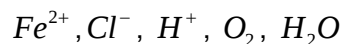
$$\begin{aligned} t &= n(e^-) \times 96500 / 30 = 0.864 \times 96500 / 30 \\ &= 2779 \text{ secs} = 46.3 \text{ min} \end{aligned} \quad [1 \text{ mark}]$$

At 75% efficiency, Actual $t \times 75/100 = 46.3$

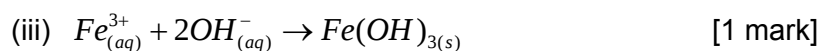
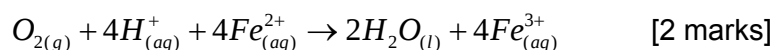
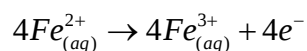
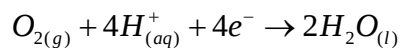
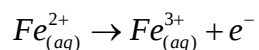
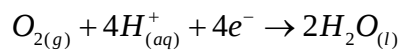
$$\text{Actual } t = 46.3 \times 100/75 = 61.7 = 62 \text{ mins.} \quad [1 \text{ mark}]$$

QUESTION 8

- a. (i) The following species could act as reactants:



Locate any equation in the electrochemical series that contains any combination of the potential reactants, then select the strongest species.



- b. The activation energy requirement for the reaction may be too high for the reaction to occur spontaneously under standard conditions. [1 mark]