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) → $CaSO_4$(aq) + $2H_2O$(l).

n(H_2SO_4)= 0.2×0.2=0.04mol and n($Ca(OH)_2$)=0.1×0.1=0.01mol

n(H_2SO_4) in excess=0.04 – 0.01= 0.03mol

n(H^+)excess = 0.03×2=0.06

[H^+]=0.06/0.30=0.2M

[H_3O^+]=[H^+]=0.2M

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

QUESTION 3 Answer is B

n(butane) = PV/RT = (1.5×101.3)×4.0/8.31×(273+10)=151.95×4.0/8.31×283 = 0.258mol.

1 mol butane produces 2874kJ of heat. Hence 0.258 mol produces 2874×0.258 = 741.5kJ

Use E(J) = m×c×ΔT for mass of water to heat. {Note : ΔT = 90}

mass(H_2O) = E(J)/4.18×90 = 741500/376.2 = 1970mL

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

QUESTION 4 Answer is C

$PV = nRT$

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

2 mol $NO \rightarrow 114\,kJ$
0.045 mol $NO \rightarrow x\,kJ$

$x = 2.45\,kJ$

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.

$$\Delta H = -2(-146) + 418 = 710\,kJ$$

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

$$AgCl_{(s)} + 2NH_{3(aq)} \rightleftharpoons Ag(NH_3)^{+}_{2(aq)} + Cl^{-}_{(aq)}$$

QUESTION 10 Answer is A

QUESTION 11 Answer is C

K = $[NO_2(g)][Cl_2(g)] / [NO_2Cl(g)]^2$ = 0.558

$[NO_2Cl(g)]$ = 0.00424/4.0 = 0.00106M

$[Cl_2(g)]$=0.02152/4.0 = 0.00538M

Hence, $[NO_2(g)] = [NO_2Cl(g)]^2 \times 0.558 / [Cl_2(g)] = (0.00106)^2 \times 0.558 / 0.00538 = 0.0001165$
$= 1.17\times10^{-4}$M

$n(NO_2(g))$=cV= $1.17\times10^{-4} \times 4 = 4.68 \times 10^{-4}$

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^o value than H^+ for the reaction to be non-spontaneous.

QUESTION 15 Answer is A

Molar mass $MnO_2 = 86.9\ g$

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

$\therefore$ 1 mole MnO_2 generates $\frac{192,918}{96,500} = 2\ mole$ 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) = mass/$\mathcal{M}$ = 1.2/65.4 = 0.0183 mol
$n(e^-)$ = 2×n(Zn)= 2×0.0183 = 0.0367 mol
Q = $n(e^-)$ × F = 0.0367 × 96500 = 3541.55 C
t = Q/I = 3541.55/0.05 = 70831secs = 1180 mins = 19.7 = 20 hours.

QUESTION 19 Answer is C

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

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 : $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$***

(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 : $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

(i) Nitric acid, HNO_3 [1 mark]

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

Option C : $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

(i) Ammonia, NH_3 [1 mark]

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

Option D : $C_3H_8(g) \rightleftharpoons C_2H_4(g) + CH_4(g)$

(i) Ethene, C_2H_4 [1 mark]

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

b. ***Option A : $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$***

(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 : $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

(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]

Option C : $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

(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]

Option D : $C_3H_8(g) \rightleftharpoons C_2H_4(g) + CH_4(g)$

(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]

c. ***Option A : $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$***

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]

Option B : $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

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]

Option C : $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

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]

Option D : **$C_3H_8(g) \rightleftharpoons C_2H_4(g) + CH_4(g)$**

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)

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

$$1\ mol = 1364\ kJ$$
$$0.01666\ mol = x\ kJ$$

$$x = 22.72\ kJ$$ [1 mark]

$$CF = \frac{E(J)}{\Delta T} = \frac{22720}{24.64 - 20.62} = 5651.74\ JC^{-1} = 5.652\ kJC^{-1}$$ [1 mark]

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

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) $E(J) = CF \times \Delta T$

$= 5651.74 \times 6.44\ J/ml$

$= 36397.21\ J/ml$ [1 mark]

$= 36397.21 \times 1000\ J/L$

$= 36.40\ MJL^{-1}$

$= 36\ MJL^{-1}$ [1 mark]

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

$44.8\ kJg^{-1}$

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

$38.08\ kJ/ml$

$38.08 \times 10^3\ kJ/L$

$38.08\ mJ/L$ [1 mark]

$d = 0.85\ g/ml$

$0.85\ g = 1\ ml$

$\therefore 1\ g = x$

$0.85x = 1$

$x = 1.1765\ ml$

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. $HOBr(aq) + H_2O(l) \rightleftharpoons OBr^-(aq) + H_3O^+(aq)$; $Ka = 2.4\times10^{-9}M$ [1 mark]

b. HOBr] = 1.0M, $Ka = [OBr^-(aq)][H_3O^+(aq)] / [HOBr(aq)] = [H_3O+(aq)]^2 / [HOBr(aq)]$

$[H_3O^+] = \sqrt{(2.4\times10^{-9} \times 1.0)} = 0.00004899 = 4.90\times10^{-5}M$ [1 mark]

$pH = {}^-log_{10}[H_3O^+] = {}^-log_{10}(4.90\times10^{-5}) = 4.3$ [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]

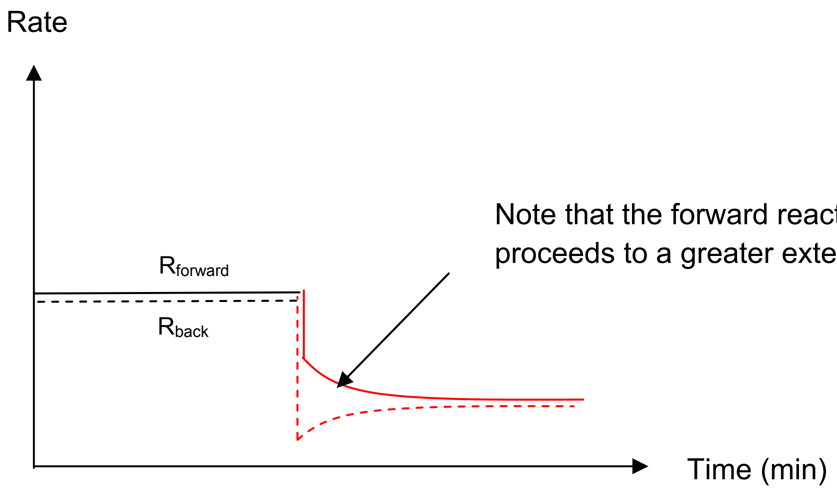
(ii) Diluting will decrease the concentration of all species (except water). The system will oppose the introduced change by favouring the reaction that will increase particle concentration. A net forward reaction occurs. [1 mark]

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.

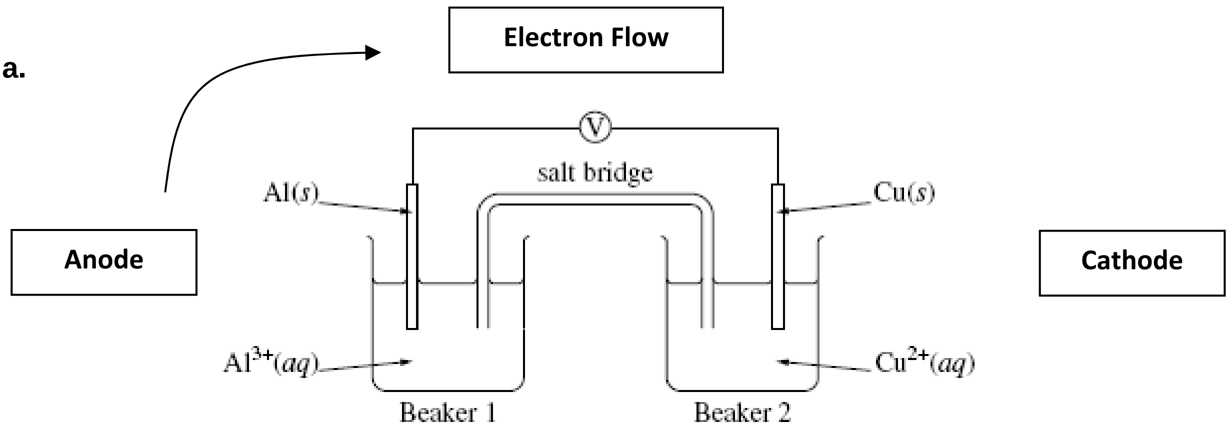
The rate of the forward reaction will continue to decrease, the rate of the back reaction will continue to increase, until they become equal and equilibrium is re-established.

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

a.



[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.

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

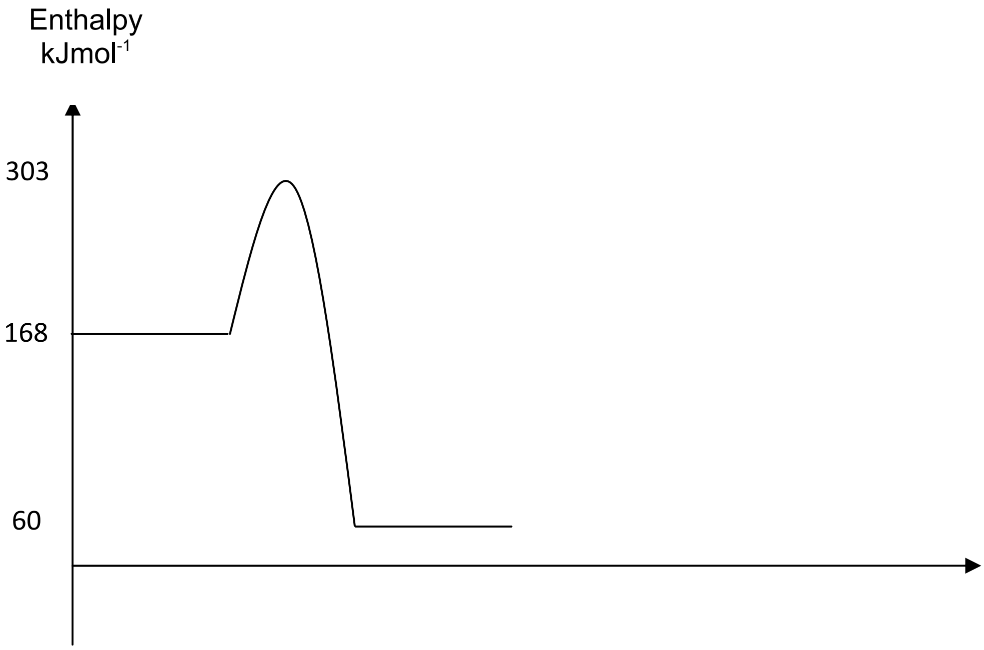
d.

	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 $\left(c = \frac{n}{V}\right)$	$C = \frac{2}{2} = 1M$	$C = \frac{1}{2} = 0.5M$	$C = \frac{3}{2} = 1.5M$

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

e. $CO_{(g)} + Cl_{2(g)} \rightleftharpoons COCl_{2(g)}$

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



Energy Products – Energy Reactants = -108
60 – Energy Reactants = -108
– Energy Reactants = $-108 - 60$
Energy Reactants = $168\ kJ/mol$

Top of the curve = Energy of Reactants + activation energy requirement = $168 + 135 = 303\ kJ/mol$

[2 marks]

QUESTION 6

a. (i) $O_{2(g)} + 4H^+_{(aq)} + 4e^- \rightarrow 2H_2O_{(l)}$ $E^o = 1.23V$

$6CO_{2(g)} + 24H^+_{(aq)} + 24e^- \rightarrow C_6H_{12}O_{6(aq)} + 6H_2O_{(l)}$ $E^o = 0.01V$

$6O_{2(g)} + 24H^+_{(aq)} + 24e^- \rightarrow 12H_2O_{(l)}$

$C_6H_{12}O_{6(aq)} + 6H_2O_{(l)} \rightarrow 6CO_{2(g)} + 24H^+_{(aq)} + 24e^-$

$C_6H_{12}O_{6(aq)} + 6O_{2(g)} \rightarrow 6CO_{2(g)} + 6H_2O_{(l)}$ [2 marks]

(ii) $EMF = 1.23 - 0.01 = 1.22\,V$ [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 $0.95 \times 2816 = 2675\ kJmol^{-1}$ [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

a. (i) $Cu^{2+}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$

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

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

Number of Faradays $= 0.00298$ [1 mark]

(ii) Cell 2: $M^+_{(aq)} + e^- \rightarrow M_{(s)}$

Note: Given - $MNO_{3(aq)}$ which tells us that the charge on M^{n+} is $+1$

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

$$\therefore M = \frac{m}{n} = \frac{0.322}{0.002984} = 107.91$$ [1 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}

(ii) At the Cathode: $Cr^{3+}(aq) + 3e^- \rightarrow Cr(s)$

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

$n(e^-)$ = 3×n(Cr) = 3×0.288=0.864mol [1 mark]

Q=It, It = $n(e^-)$×F, hence

t = $n(e^-)$ × 96500 / 30 =0.864×96500 /30
= 2779secs = 46.3min [1 mark]

At 75% efficiency, Actual t × 75/100 = 46.3
Actual t = 46.3×100/75 = 61.7 = 62mins. [1 mark]

QUESTION 8

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

$Fe^{2+}, Cl^{-}, H^{+}, O_2, H_2O$

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

$O_{2(g)} + 4H^{+}_{(aq)} + 4e^{-} \rightarrow 2H_2O_{(l)}$
$Fe^{2+}_{(aq)} \rightarrow Fe^{3+}_{(aq)} + e^{-}$

$O_{2(g)} + 4H^{+}_{(aq)} + 4e^{-} \rightarrow 2H_2O_{(l)}$
$4Fe^{2+}_{(aq)} \rightarrow 4Fe^{3+}_{(aq)} + 4e^{-}$

$O_{2(g)} + 4H^{+}_{(aq)} + 4Fe^{2+}_{(aq)} \rightarrow 2H_2O_{(l)} + 4Fe^{3+}_{(aq)}$ [2 marks]

(iii) $Fe^{3+}_{(aq)} + 2OH^{-}_{(aq)} \rightarrow Fe(OH)_{3(s)}$ [1 mark]

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