Question 1

A lead-acid battery is made up of six cells connected in series. When the battery is providing energy, the reactions occurring at the electrodes of a single cell are:

$Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$

$PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)$

a.

i. Give an equation for the net reaction that occurs while a lead-acid battery is providing energy.

$PbO_2(s) + Pb(s) + 2SO_4^{2-}(aq) + 4H^+(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

1 mark

ii. Give the formula of the oxidant and the formula of the reductant in the above reaction.

oxidant ------ *$PbO_2(s)$*

reductant ------ *$Pb(s)$*

b. What happens to the pH when the battery is being recharged? Explain

pH decrease as H^+ is produced by the reaction below

$2PbSO_4(s) + 2H_2O(l) \rightarrow PbO_2(s) + Pb(s) + 2SO_4^{2-}(aq) + 4H^+(aq)$

c. Write the equation occurring at the negative terminal when the battery is being recharged

The negative electrode is the cathode when recharging and reduction takes place at this electrode. It is the reverse reaction to the oxidation half-reaction when the battery is discharging.

$PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}(aq)$

d. NiCad batteries are secondary cells. The chemical reaction that occurs when a NiCad cell is being recharged can be represented by the chemical equation

$Cd(OH)_2\,(s) + 2\,Ni(OH)_2\,(s) \rightarrow Ni_2O_3\,(s) + Cd\,(s) + 3H_2O\,(l)$

i. What is the reductant when the NiCad cell is discharging?

When the cell is discharging the following reaction takes place

$Ni_2O_3\,(s) + Cd\,(s) + 3H_2O\,(l) \rightarrow Cd(OH)_2\,(s) + 2\,Ni(OH)_2\,(s)$

Cd is therefore the reductant.

ii. When a NiCad cell is being recharged what terminal of the external power supply must be attached to the cadmium electrode.

When recharging the following half-reaction must take place

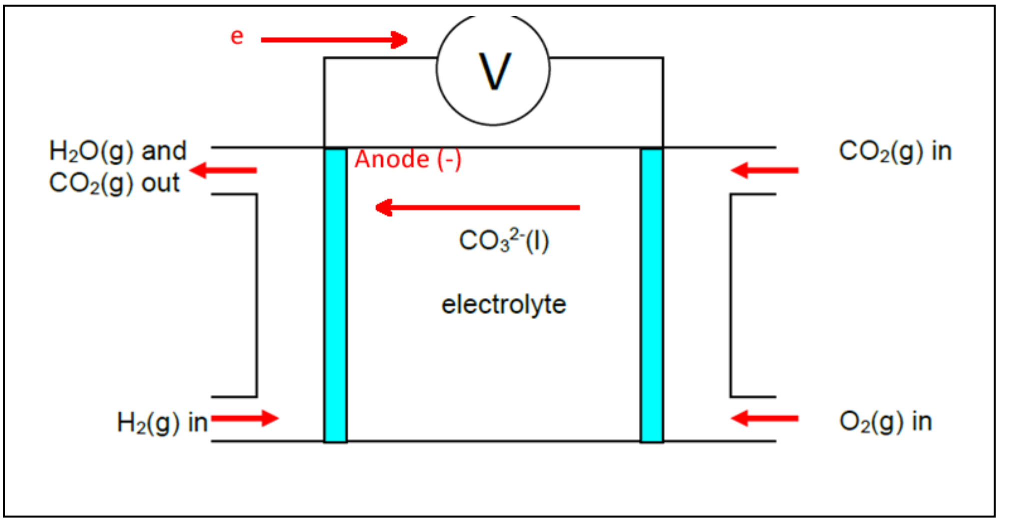
$2H^+(aq) + 2e + Cd(OH)_2\,(s) \rightarrow Cd\,(s) + 2H_2O\,(l)$

This is a reduction reaction and takes place at the negative cathode.

iii. Write a balanced chemical reaction, *with states*, that occurs at the cathode during recharge

$2H^+(aq) + 2e + Cd(OH)_2\,(s) \rightarrow Cd\,(s) + 2H_2O\,(l)$

2) A molten carbonate fuel cell (MCFC) uses a molten mixture of lithium carbonate, Li_2CO_3 and sodium carbonate, Na_2CO_3 as the electrolyte. Hydrogen gas is passed over one electrode and a combination of oxygen gas and carbon dioxide gas is passed over the other electrode, as shown in the diagram below. The net overall reaction is $H_2\ (g) + O_2\ (g) \rightarrow H_2O\ (g)$. There is no net gain or loss of the electrolyte.



a. Write a half equation for the overall cell reaction at the anode.

$H_2(g) + CO_3^{-2}(l) \rightarrow CO_2(g) + H_2O(g) + 2e$

b. Write a half equation for the overall cell reaction at the cathode.

$2CO_2(g) + O_2(g) + 4e \rightarrow 2CO_3^{-2}(l)$

c. On the diagram above, label

i. the anode and its polarity.

ii. the direction of electron flow.

iii. the direction of molten carbonate flow.

d. What is the net overall effect on the molten carbonate electrolyte as the cell produces energy?

Nil

$(H_2(g) + CO_3^{-2}(l) \rightarrow CO_2(g) + H_2O(g) + 2e)\ X\ 2$

+

$2CO_2(g) + O_2(g) + 4e \rightarrow 2CO_3^{-2}(l)$

=> $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

3) An experimental galvanic cell is being trialled that uses lithium metal and sulphur as reactants. The overall equation, states not shown, for this cell while discharging is given below.

$$16Li + S_8 \rightarrow 8Li_2S$$

The light weight and relatively cheap cell uses a polymer electrolyte rather than an aqueous solution to produce a voltage of 2.4 volts.

a) Explain why an aqueous solution is not used in this cell. Justify your answer with a balanced equation.
Lithium is a very reactive metal and as such will react with water to produce hydrogen gas, which explosive. Once the sulphur is used the next strongest oxidant is water which will react with lithium to produce hydrogen gas.
$2Li(s) + 2H_2O(l) \rightarrow 2Li(OH)_2(aq) + H_2(g)$ or $2Li(s) + 2H_2O(l) \rightarrow 2Li^+(aq) + 2OH^-(aq) + H_2(g)$

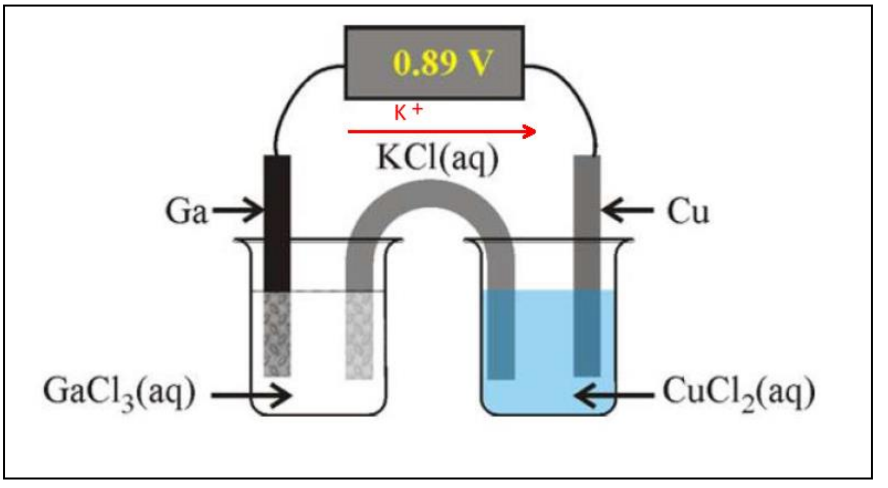
The half equation was also accepted
$2H_2O(l) + 2e \rightarrow 2OH^-(aq) + H_2(g)$

b) Write a balanced half-equation of the reactions occurring at the anode and the cathode.
anode – $Li(s) \rightarrow Li^+ + e$
cathode – $S_8 + 16e \rightarrow 8S^{-2}$

c) This cell is rechargeable. Write a balanced equation for the reaction taking place at the cathode when the cell is recharging.
$Li^+ + e \rightarrow Li$

Question 4

a. A galvanic cell was assembled by combining the Cu^{2+} (aq)/Cu(s) and Ga^{3+} (aq)/Ga(s) standard half-cells as shown in the diagram below.



The cell potential was measured at 0.89 V, with the copper electrode gaining mass when the cell was discharging.

i. Write an appropriate half-equation for the process that would be occurring at the gallium electrode.

Since the copper electrode is gaining mass reduction must be occurring at the copper electrode hence it is the cathode

$Cu^{2+}(aq) + 2e \rightarrow Cu(s)$

ii. Write an appropriate chemical equation for the overall reaction that would occur in this cell when it is discharging.

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

iii. Determine the standard electrode potential (E^o) for the Ga^{3+} (aq)/Ga(s) standard half-cell.

E^o (oxidant) – E^o(reductant) = EMF

=> E^o (Cu^{2+}) – E^o(Ga) = 0.89V

=> 0.34 – E^o(Ga) = 0.89V

=> E^o(Ga) = - 0.55V

iv. What voltage would be produced by a Ga^{+3}/Ga // Zn/Zn^{2+} galvanic cell at SLC?

-0.55 - -0.76 = 0.21V

iv. On the diagram **above** clearly label the direction of flow of the potassium ions in the salt bridge

v. With reference to any half equations, explain why potassium ions flow in this direction.

Since at the copper electrode C^{2+} ions are consumed according to the equation $Cu^{2+}(aq) + 2e \rightarrow Cu(s)$

k^+ flow into the cathode to replace lost positive ions and maintain half-cell neutrality.

Question 5

A hydrogen-oxygen proton exchange membrane fuel cell operates at 65% efficiency.

a. Write appropriate chemical half-equations for the reaction occurring at the cathode

$O_2(g) + 4H^+(aq) + 4e \rightarrow 2H_2O(l)$

b. Calculate the volume of hydrogen gas, at SLC, that would be required for the fuel cell to produce 300 MJ of electrical energy. *Be sure your answer is to the correct number of significant figures*.

Step 1 Find the total amount of energy required if the fuel cell is operating at 65% efficiency

=> x X 0.65 = 300,000 kJ

=> x = 300,000/0.65 = 461538 kJ

Step 2 fined the mol of hydrogen required

=> 461538 / 282 (from data book) = 1637 mol

Step 3 find the volume

=> 1636 X 24.8 = 4.1 X 10^4 litres (2 sig figs)

b. Explain one major issue associated with the use of hydrogen as a fuel.

- flammable

- industrial quantities obtained from steam reformation of fossil fuels which makes it non-renewable.

c. Write a balanced equation for the reaction that takes place at the anode of a propane / oxygen fuel cell that uses KOH(aq) as the electrolyte.

$C_3H_8(g) + 20\ OH^-(aq) \rightarrow 3CO_2(g) + 20e + 14H_2O(l)$