1. A molten carbonate fuel cell (MCFC) uses iquid butane as a fuel. This fuel cell operates at 800°C and 100 kPa. The overall reaction for the combustion of butane is given below.

$2C_4H_{10}$ (l) + $13O_2$ (g) → $8CO_2$(g) + $10H_2O$(g).

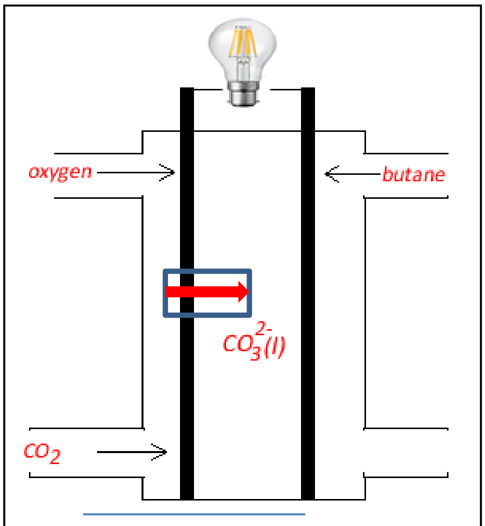

Diagram 1

a. Give the balanced half equations, with states, taking place at the:

i. Anode (2 marks)

$13CO_3^{2-}(l) + C_4H_{10}(l) \rightarrow 17CO_2(g) + 5H_2O(l) + 26e^-$

ii. Cathode (2 marks)

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

b. The exhaust gases coming out of the fuel cell at 800°C can be used to generate more electricity. Suggest how. (1 mark)

Gases can be used to drive a turbine to generate electricity via a generator. The high kinetic energy of the gas particles can be harnessed to drive the generator.

c. Indicate in the box shown in diagram 1 the direction of anion movement though the electrolyte. (1 mark)

d. An amount of 40.0 litres of liquid butane is burnt in the fuel cell. What is the total volume, in litres, of greenhouse gases produced? Density of butane 0.810 g/mL (4 marks)

Step 1 find the mass of butane.

=> mass = density X volume = 0.810 g/mL X 4.00×10^4 = 32400 g

Step 2 find the mol of butane

=> 32400g / 58.0 = 558.62 mol

Step 3 Since both CO_2 and H_2O are greenhouse gases calculate the mol of both.

$n_{carbon\ dioxide}$ = 4 X 558.62 = 2234

n_{water} = 5 X 558.62 = 2793

=> Total mol of gas molecules = 2234 + 2973 = 5027 mol

Step 4 find the volume in litres

=> V =nRT/P => 5027 X 8.31 X 1073 / 100 = 4.48×10^5

e. Compare the efficiency of the method of creating electrical energy with the exhaust gases, as suggested in question b. above, with the efficiency of the molten carbonate fuel cell. Explain your reasoning. (2 marks)

The efficiency is lower than the fuel cell in converting energy into electrical energy. The generator has more energy transformations than the single step transformation of the fuel cell. The generator converts the kinetic energy into mechanical energy in spinning a turbine. Then the mechanical energy is transformed into electrical energy. At every transformation step heat energy is lost.

f. Give two advantages and two disadvantages of operating at such high temperatures.

Advantage 1 – *Fast rates of reaction hence greater power is delivered*

Advantage 2 – *No need for expensive catalyst to speed up the reaction*

Disadvantage 1 – *high temperatures limit the life of the cell by causing side reactions to take place that can corrode the electrodes or the cell itself.*

Disadvantage 2 – *Expensive to operate and slow to start up as the temperature needs to reach its optimum.* (1+1+1+1 = 4 marks)

2. A Zn/MnO_2 rechargeable battery has the following overall, unbalanced chemical equation when discharging.

$$Zn + MnO_2 \rightarrow Zn(OH)_4^{2-} + Mn(OH)_2$$

a. Write the balanced half-equation for the reaction taking place at the anode during discharge.

Since the products contain hydroxide ions (OH^-) this is an alkaline battery.

$Zn \rightarrow Zn(OH)_4^{2-}$

$4H_2O + Zn \rightarrow Zn(OH)_4^{2-}$ *--- balance for oxygen by adding water*

$4H_2O + Zn \rightarrow Zn(OH)_4^{2-} + 4H^+$ *--- balance for hydrogen by adding water*

$4H_2O + Zn \rightarrow Zn(OH)_4^{2-} + 4H^+ + 2e^-$ *--- balance for charge*

$4H_2O + Zn \rightarrow Zn(OH)_4^{2-} + 4H^+ + 2e^-$ *--- remove H^+ by adding OH^-*

$4OH^- + 4H_2O + Zn \rightarrow Zn(OH)_4^{2-} + 4H^+ + 4OH^- + 2e^-$

$4OH^- + 4H_2O + Zn \rightarrow Zn(OH)_4^{2-} + 4H_2O + 2e^-$ *---- cancel for water*

$4OH^- + Zn \rightarrow Zn(OH)_4^{2-} + 2e^-$

b. Write the balanced half-equation for the reaction taking place at the cathode during **discharge**.

$MnO_2 \rightarrow Mn(OH)_2$

$2H^+ + MnO_2 \rightarrow Mn(OH)_2$ --- balance for hydrogen

$2e^- + 2H^+ + MnO_2 \rightarrow Mn(OH)_2$ --- balance for charge

$2e^- + 2H^+ + 2OH^- + MnO_2 \rightarrow Mn(OH)_2 + 2OH^-$ --- replace H^+ with OH^-

$2e^- + 2H_2O + MnO_2 \rightarrow Mn(OH)_2 + 2OH^-$ --- replace H^+ with OH^-

c. Write the balanced overall equation taking place during **discharge**.

1 --- $4OH^- + Zn \rightarrow Zn(OH)_4^{2-} + 2e^-$

+

2 ---$2e^- + 2H_2O + MnO_2 \rightarrow Mn(OH)_2 + 2OH^-$

=> $2OH^- + 2H_2O + MnO_2 + Zn \rightarrow Zn(OH)_4^{2-} + Mn(OH)_2$

d. Write the balanced half equation taking place at the negative electrode during **recharge**.

The negative electrode during recharge is the cathode. It is the site of reduction.

So flip the oxidation reaction that occurs during discharge.

$Zn(OH)_4^{2-} + 2e^- \rightarrow 4OH^- + Zn$

e. How does the pH of the electrolyte at the ***anode*** change as the cell:

i. recharges – *since the following reaction takes place at the anode during discharge, $4OH^- + Zn \rightarrow Zn(OH)_4^{2-} + 2e^-$, OH^- will be consumed hence the pH will fall.*

ii. recharges – *The following reaction takes place at the anode during recharge $Mn(OH)_2 + 2OH^- \rightarrow 2e^- + 2H_2O + MnO_2$. Since OH^- ions are consumed the pH will fall.*

3. Complete the table below comparing a primary cell during discharge and secondary cell during recharge.

	Primary cell during discharge	Secondary cell during recharge
Difference 1	*Energy transformation is Chemical → electrical*	*Energy transformation is Electrical → Chemical*
Difference 2	*Anode = negative polarity*	*Anode = positive polarity*
Similarity 1	*Anode is the site of oxidation* *or* *Cathode is the site of reduction*	*Anode is the site of oxidation* *or* *Cathode is the site of reductio*

4. Consider the setup shown below.

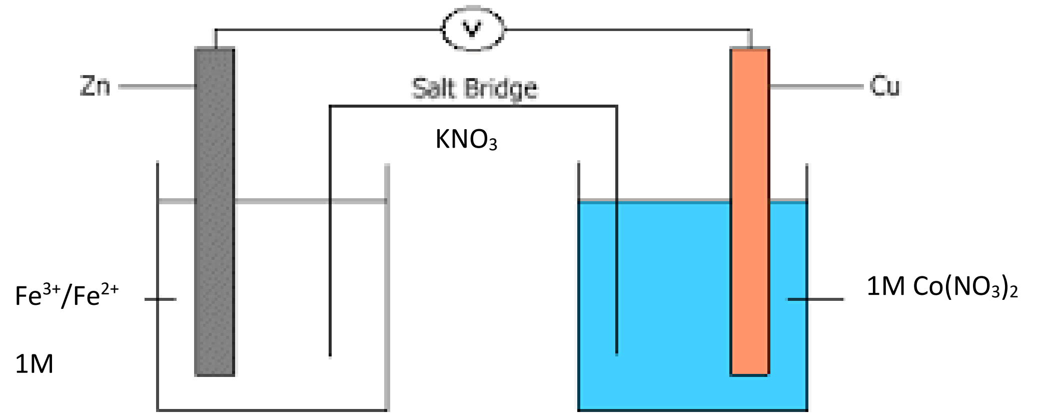

Diagram 2

a. Predict:

i. if a spontaneous reaction will occur. Yes / No . Justify your decision by writing the balanced overall reaction equation, states included. (2 marks)

Fe^{3+} (aq) is the strongest oxidant while Zn(s) is the strongest reductant. A negative gradient is formed on the electrochemical series between Fe^{3+} (aq) and Zn(s). This indicates a spontaneous reaction will occur but does not predict the rate of the reaction. $2Fe^{3+}$ (aq_ + Zn(s) → $2Fe^{2+}$ + Zn^{2+}(aq)

ii. the type of energy produced if the answer to i. is yes. Justify your decision (1 mark)

Since the strongest oxidant and the strongest reductant are in direct contact with each other the reaction will produce heat.

b. The Zn electrode is replaced with a graphite electrode.
Predict:

i. if a spontaneous reaction will occur. Yes / No . Justify your decision by writing the balanced overall reaction equation, states included. (2 marks)

The strongest oxidant is Fe^{3+}(aq) while the strongest reductant is Cu(s)
$2Fe^{3+}$(aq) + Cu(s) → Cu^{2+}(aq) + $2Fe^{2+}$(aq)

ii. the type of energy produced if the answer to i. is yes. Justify your decision (1 mark)

Since the Fe^{3+} (aq) and Cu(s) are in separate half-cells electrical energy is the dominant energy form produced.

iii. Predict what will happen to the reactions taking place in the galvanic cell if $AuNO_3$ is used instead of KNO_3.

Au^{+}(aq) is a strong oxidant that will come into direct contact with Cu(s) in the right half-cell. This will produce heat. It will also be in direct contact with Fe^{2+}(aq) in the right half-cell. This reaction will also produce heat.