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VCE Chemistry ¾

Secondary Cells & Connected Cells [2.3]

Homework Solutions

Admin Info & Homework Outline:

Student Name	
Questions You Need Help For	
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Section A: Compulsory Questions (45 Marks)

Sub-Section [2.3.1]: Write Discharge & Recharge Reactions in Secondary Cells & Redox Flow Batteries

Question 1 (3 marks)

Nickel hydroxide rechargeable batteries, commonly known as nickel-metal hydride (NiMH) batteries, utilise nickel hydroxide as the positive electrode material. These batteries offer a higher energy density compared to traditional nickel-cadmium batteries, making them popular choices for portable electronics and hybrid vehicles due to their improved performance and reduced environmental impact.

When the cell is being used, the electrode reactions are represented by the following equations during recharge:

$$Ni(OH)_2(s) + 2OH^-(aq) \rightarrow NiO_2(s) + 2H_2O(l) + 2e^-$$

$$Cd(OH)_2(s) + 2e^- \rightarrow Cd(s) + 2OH^-$$

a.

i. State the species found at the positive electrode during discharge. (0.5 marks)

$NiO_2(s)$ or $Ni(OH)_2(s)$ & $OH^-(aq)$

ii. Hence or otherwise, write the reaction occurring at the negative electrode during discharge. (1 mark)

$Cd(s) + 2OH^-(aq) \rightarrow Cd(OH)_2(s) + 2e^-$

b. Suggest a suitable electrolyte for the battery. (0.5 marks)

$OH^-(aq)$

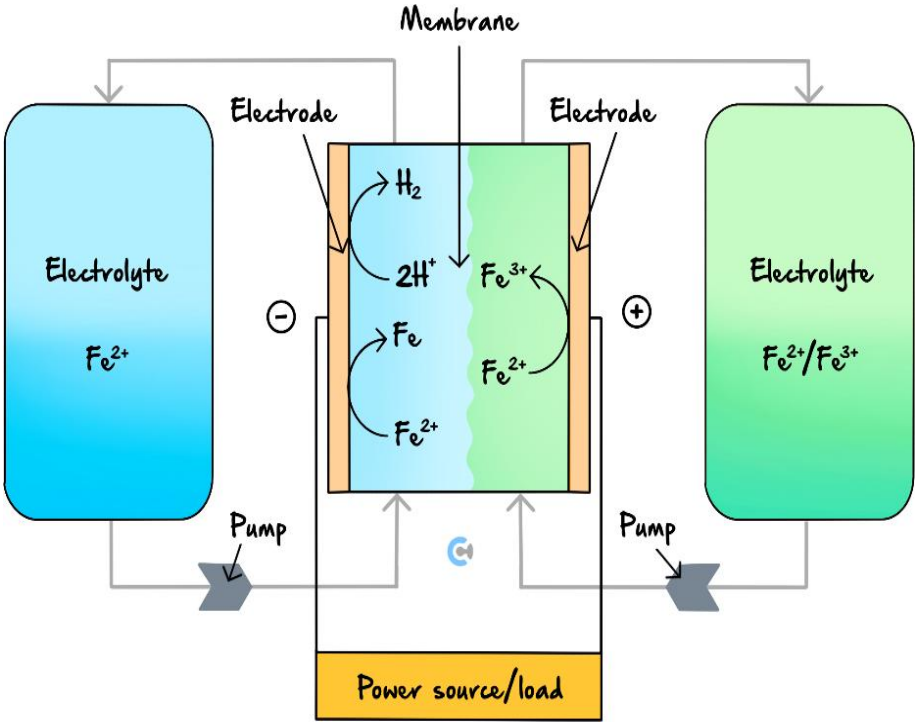
c. Determine whether this is a primary, secondary, or fuel cell and state why. (1 mark)

Secondary cell, it can be recharged.

Question 2 (4 marks)

A Fe-Fe redox flow battery is theorised to be able to produce high voltages in high temperatures, and as such have relevant applications in industrial machinery.

A theoretical diagram of a Fe-Fe redox flow battery is shown below.



a. Write the reaction occurring at the anode during the recharge of the Fe-Fe redox flow battery. (1 mark)

$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$

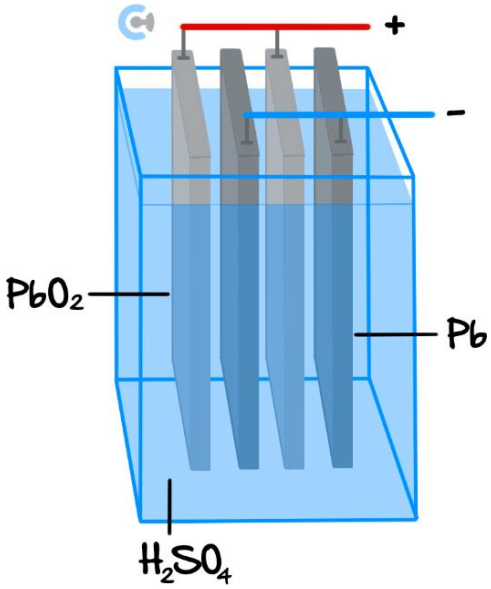
b. When the cell is undergoing recharge and discharge, the location of the positive and negative polarities remains the same. Explain how the polarities remain the same, yet it swaps from anode to cathode, and cathode to anode. (3 marks)

During discharge, the anode is negative and the cathode is positive. Electrons are moving naturally, and as such will be attracted towards the positive cathode, where they are gained by oxidants. In recharge, electricity is inputted to force them the opposite direction. However, the cathode is still where reduction takes place, meaning that electrons must be gained at the cathode. Therefore, electrons are pushed towards the negative electrode. In this, the location of postive and negative does not have to change, only the anode and cathode change.

Question 3 (3 marks)

The most common battery in combustion-powered vehicles is the lead-acid accumulator. The reaction that occurs during discharge is shown below.

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$$



a. Write the balanced half-equation occurring at the positive electrode when the cell is producing electrical energy. (1 mark)

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

b. Write the balanced half-equation occurring at each electrode as electrical energy is being inputted into the cell.

i. Positive electrode. (1 mark)

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

ii. Negative electrode. (1 mark)

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

Sub-Section [2.3.2]: Identify Factors which Affect Rechargeability & Compare Similarities/Differences Between Secondary Cells and Other Cells

Question 4 (2 marks)

a. A secondary cell requires: (1 mark)

A. A continuous supply of reactants.

B. Specific operational temperatures.

C. A positive anode and a negative cathode.

D. An external electrical power source.

b. Which of the following statements is correct about secondary cells? (1 mark)

A. Unlike fuel cells, secondary cells are able to discharge through non-spontaneous reactions.

B. Secondary cells require products of discharge to remain in contact with electrodes.

C. An example of a secondary cell is a non-rechargeable AA battery.

D. Secondary cells primarily undergo chemical to electrical energy conversions.

Space for Personal Notes

Question 5 (2 marks)

a. Which of the following statements about the energy conversions in secondary cells is correct? (1 mark)

A. Secondary cells undergo fully efficient chemical to electrical-energy conversions whereby no thermal energy is produced.

B. Secondary cells remain electrically imbalanced throughout recharge by not discharge.

C. Secondary cells can be theoretically used indefinitely as chemical energy is reformed during recharge.

D. Secondary cells have minimal self-discharge reactions that produce electrical or thermal energy.

b. Which of the following is a benefit to using secondary cells over primary cells? (1 mark)

A. Primary cells are more expensive to produce due to specific reactive electrodes.

B. Secondary cells are more energy efficient.

C. Primary cells have to be discarded after use, which is unsustainable.

D. Secondary cells contain a lower amount of heavy metals than primary cells.

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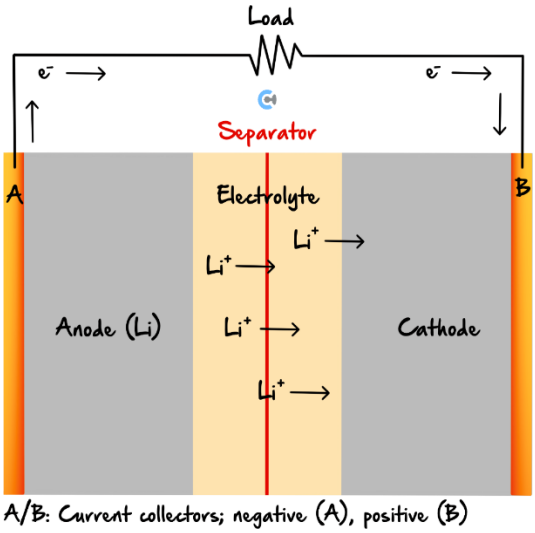
Question 6 (5 marks)

Lithium-ion batteries are used in modern-day phones as an extremely dense way of storing energy within batteries. A simplified lithium-ion battery is shown below.



a. Write the net ionic reaction occurring at the positive electrode during recharge. (1 mark)

$Li(s) \rightarrow Li^+(aq) + e^-$

b. Electrode *B* is made up of an inert material.

i. During discharge, state the observation that will be seen at the electrode *B*, and hence explain the relationship between the mass of electrode *B* and the battery life of the cell. (2 marks)

As the cell is being discharged, the reaction at electrode *B* is: $Li^+(aq) + e^- \rightarrow Li(s)$.
Therefore during discharge, the mass of the electrode will increase.
When the battery is completely discharged, the mass of electrode *B* will be at its highest.

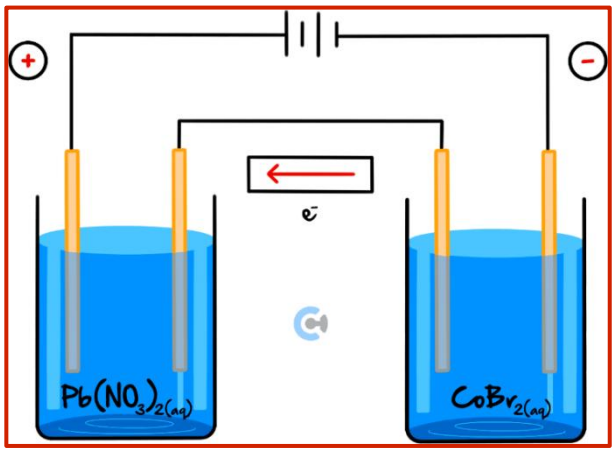
ii. Phones at very high temperatures can start to have a reduced battery life. Explain why this observation is seen. (2 marks)

At very high termperatures, the solid reactants at either the cathode or anode can begin to slide off as the bonds adhereing them to the electrodes are weakened. This leads to a decrease in battery life, as reactants that have fallen to the bottom of the cell are now unable to access electrons and hence cannot react.

Sub-Section [2.3.3]: Find Reactions Occurring in Connected Cells

Question 7 (5 marks)

Two cells are connected together in series using a wire. Inert electrodes are used in both cells. A diagram of the connected cells is shown in the diagram below.



a. In the spaces provided above, label the polarities of the electrodes and the direction of electron flow. (1 mark)

b. Write the balanced half equations that occur in the cell containing $Pb(NO_3)_2$:

i. Reduction. (1 mark)

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

ii. Oxidation. (1 mark)

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

c. Write the balanced half-equation which occurs in the cell containing $CoBr_2$:

i. Reduction. (1 mark)

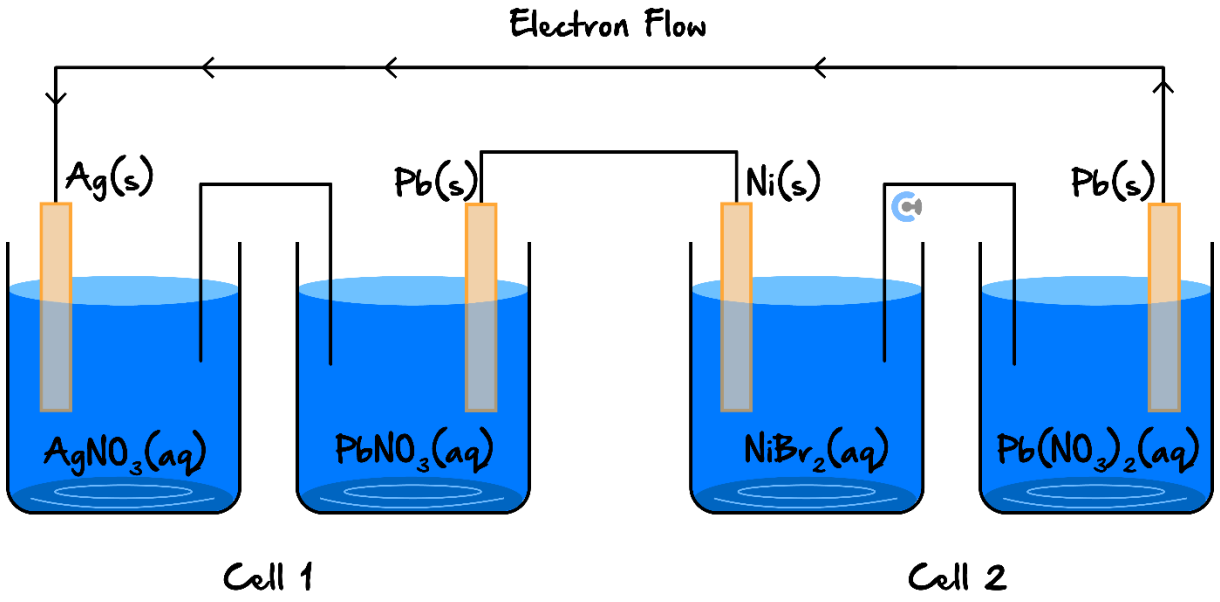
$Co^{2+}(aq) + 2e^- \rightarrow Co(s)$

ii. Oxidation. (1 mark)

$2Br^-(aq) \rightarrow Br_2(l) + 2e^-$

Question 8 (5 marks)

A diagram of a connected cell is shown below.



a.

i. State the energy conversions occurring in cell 2. (1 mark)

Electrical to chemical.

ii. Hence or otherwise, write the overall reaction occurring in cell 1. (2 marks)

$2Ag^+(aq) + Pb(s) \rightarrow 2Ag(s) + Pb^{2+}(aq)$

b. State and explain whether this cell would be able to be recharged. (2 marks)

Yes. The Ag/Pb cell produces 0.93 V, whereas the Pb/Ni electrolytic cell requires a voltage of > 0.12 V.

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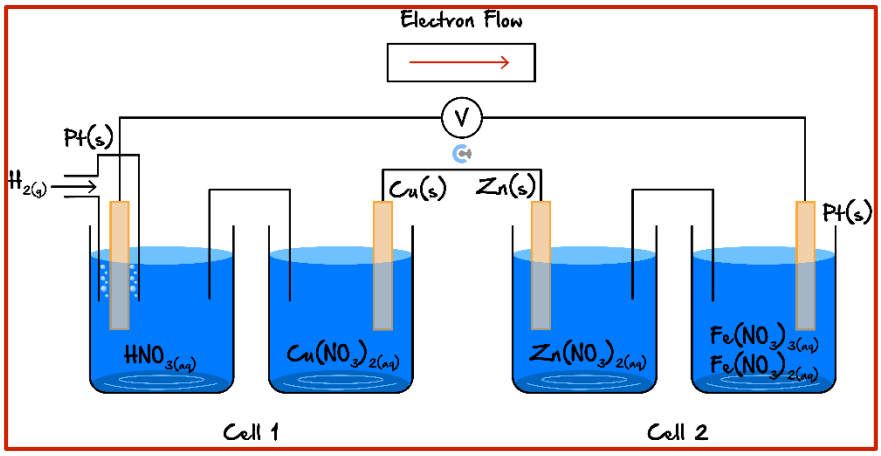
Question 9 (8 marks)

A connected galvanic cell is shown below, with each electrolyte containing 1.0 *M* of the substance shown at SLC.



a. In the box provided above, indicate the direction of electron flow. (1 mark)

b. Identify the copper electrode as the cathode or the anode. (1 mark)

Cathode

c. Write the balanced half-equations which occur within cell 1. (2 marks)

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

Anode: $H_2(g) \rightarrow 2H^+(aq) + 2e^-$

d. Write the balanced half-equations which occur within cell 2. (2 marks)

Positive electrode: $Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$

Negative electrode: $Zn(s) \rightarrow Zn(s) \rightarrow 2e^-$

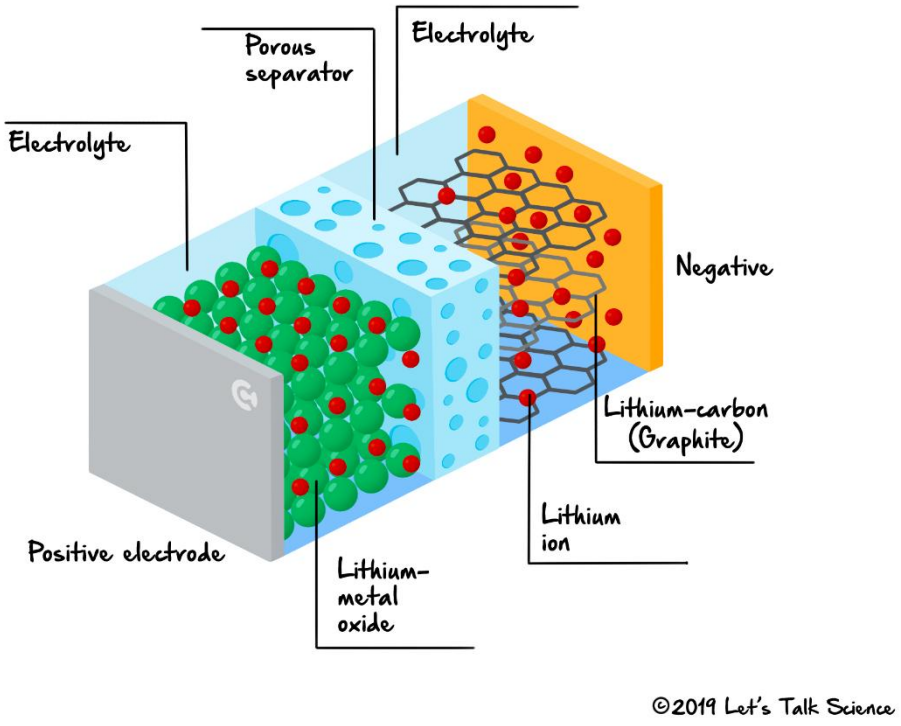
e. Find the theoretical maximum EMF produced. (2 marks)

Cell 1: 0.34 *V*
Cell 2: 1.53 *V*
Total: 1.87 *V*

Sub-Section: The 'Final Boss'

Question 10 (8 marks)

Lithium-ion batteries are commonly used in electrical devices due to the high voltage they can produce. A diagram of one is shown below.



The following reactions occur within a lithium-ion battery during discharge:

$$LiC_6(s) \rightarrow C_6(s) + Li^+(aq) + e^-$$

$$CoO_2(s) + Li^+(aq) + e^- \rightarrow LiCoO_2(s)$$

a. Write the reaction occurring at the positive electrode during recharge. (2 marks)

$LiCoO_2(s) \rightarrow CoO_2(s) + Li^+(aq) + e^-$

b.

i. List 2 observations that will be seen during the recharge cycle. (2 marks)

- Decrease in mass of the anode.
- Increase in mass of the cathode.

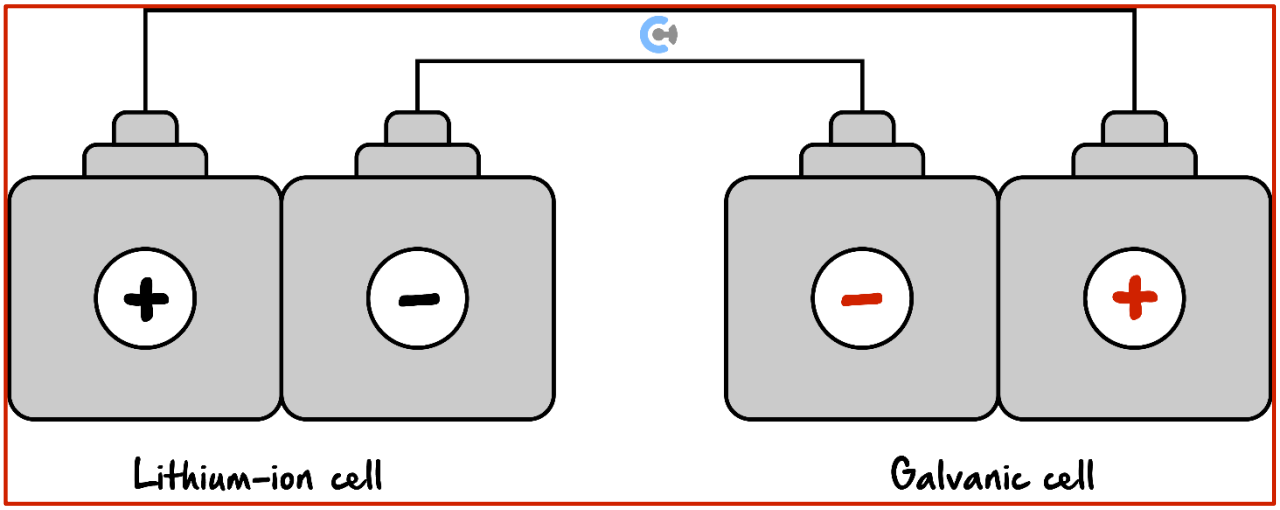
ii. Explain why it is important that the products of discharge are solid. (2 marks)

The products of discharge must remain in contact with the electrode as they have to accept/donate electrons to the electrodes during recharge. If they fall off the electrodes, they no longer are able to access electrons.

iii. $Li^+(aq)$ ions are not solid, suggesting what their role in the cell is. (1 mark)

$Li^+(aq)$ acts as the electrolyte.
Additionally, it undergoes oxidation and reduction in order to produce.

The lithium-ion battery is then recharged by connecting it to a galvanic cell, as shown below.



c. Label the polarities of the galvanic cell in the diagram above. (1 mark)

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Section B: Supplementary Questions (46 Marks)

Sub-Section [2.3.1]: Write Discharge & Recharge Reactions in Secondary Cells & Redox Flow Batteries

Question 11 (2 marks)

a. Zinc-bromine rechargeable batteries are commonly used within electric vehicles for efficient and quick releases of large amounts of energy.

The reactions occurring in a Zinc-Bromine cell during discharge are shown below.

$$Zn(s) + Br_2(l) \rightarrow ZnBr_2(s)$$

An observation noted during recharge will be: (1 mark)

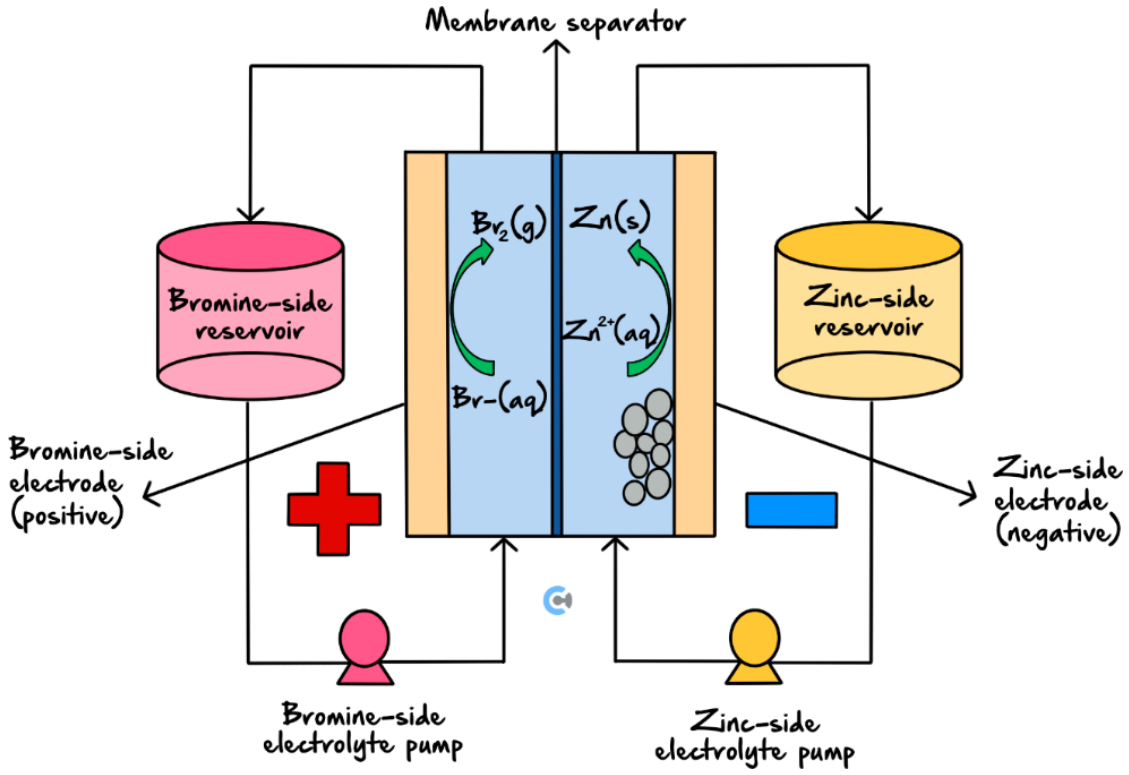
A. Decrease in mass of the cathode.

B. Increase in intensity of brown in the electrolyte.

C. Release of thermal energy.

D. A voltage produced of $+1.85\ V$.

b. An image of a Zinc-Bromine redox flow battery is shown below.



It can both discharge and recharge. The reactions that occur within the cell are shown below:

$$Br_2(l) + 2e^- \leftrightharpoons 2Br^-(aq) E^0 = +1.09\,V$$

$$Zn^{2+}(aq) + 2e^- \leftrightharpoons Zn(s) E^0 = -0.76\,V$$

An observation that would be made during the recharge of the cell would be: (1 mark)

A. Increase in mass at the bromine-side reservoir.

B. Decrease in mass at the zinc-side reservoir.

C. Brown bromine liquid being produced at the anode.

D. Zinc solid being produced at the anode.

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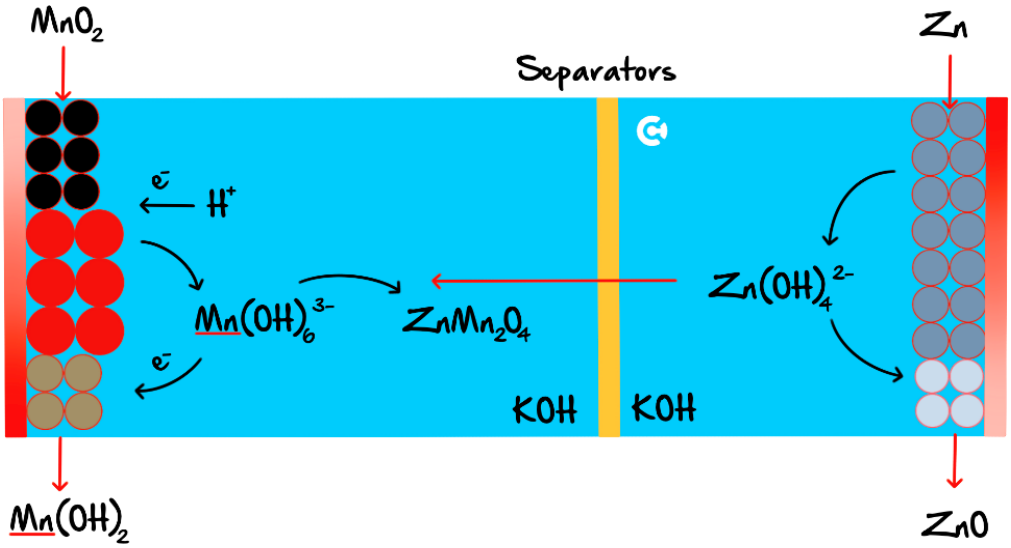
Question 12 (4 marks)

A manganese dioxide zinc half-cell is shown below. It uses multi-step reactions to both recharge and discharge.



The overall reaction occurring during discharge is shown below:

$$MnO_2(s) + Zn(s) + H_2O(l) \rightarrow ZnO(s) + Mn(OH)_2$$

a. Write the balanced equation for the reaction that occurs at the anode during discharge. (1 mark)

$Zn(s) + 4OH^-(aq) \rightarrow ZnO(s) + 2H_2O(l) + 4e^-$

b. Write the balanced equation for the oxidation reaction occurring during recharge. (1 mark)

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

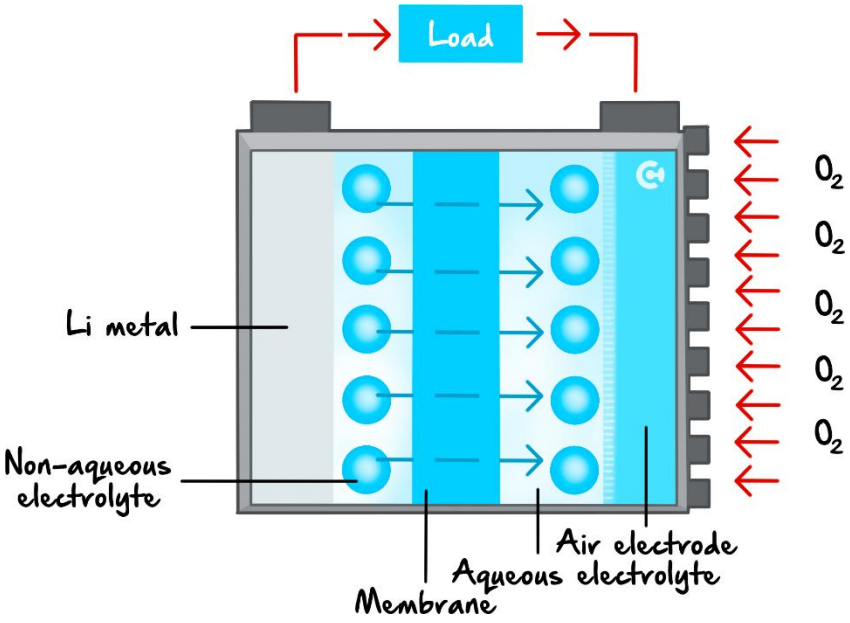
c. Explain the purpose of the separator in this secondary cell. (2 marks)

To allow for the flow of $Zn(OH)_4^{2-}$ ions.
Allow for the balance of the build up of charge.

Question 13 (6 marks)

Lithium-air batteries, celebrated for their promising high energy density, hold potential as next-generation power sources in various applications.

A diagram of a lithium-air battery is shown below.



The following reaction occurs in an acidic electrolyte whilst the cell is undergoing discharge:

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

a.

i. Write the reaction occurring at the cathode as the cell is producing energy. (1 mark)

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

ii. Hence or otherwise, identify the conjugate oxidant of the discharge reaction. (1 mark)

$Li^+(aq)$

b. Determine the voltage that must be inputted in order for the cell to be recharged. (1 mark)

$> 4.27\ V$

c. A non-aqueous electrolyte is used within some part of the cell. Explain a potential hazard in using an aqueous electrolyte throughout the entire cell. (3 marks)

A non-aqueous electrolyte contains no water. The lithium metal is a very strong reductant, and will spontaneously react with water under the reaction $H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$. In this, it produces $H_2(g)$ which is highly flammable, which can lead to an explosion.

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Sub-Section [2.3.2]: Identify Factors which Affect Rechargeability & Compare Similarities/Differences Between Secondary Cells and Other Cells

Question 14 (1 mark)

Secondary cells are used in phone batteries due to their rechargeability. Which of the following is a unique feature of the reactions in secondary cells?

A. The reactions both require the input of electrical energy in order to operate.

B. The products of discharge remain in contact with the electrodes.

C. The electrodes are inert and allow for theoretically indefinite rechargeability.

D. The discharge reactions of the cathode will occur at the other electrode during recharge.

Question 15 (2 marks)

a. Which of the following statements about secondary cells is correct? (1 mark)

A. Secondary cells can force electrons to travel against natural electrostatic forces to make the cathode negative.

B. Secondary cells minimise side reactions by always having a membrane between electrodes.

C. Secondary cells typically operate using porous electrodes in order to increase surface area and increase the rate of reaction.

D. Secondary cells allow electrons to always follow natural electrostatic forces.

b. Which of the following statements accurately describes a feature of secondary cells? (1 mark)

A. Exhibit minimal self-discharge rates compared to primary cells.

B. Predominantly used in low-drain devices due to their limited capacity.

C. Rely on non-reversible chemical reactions for energy conversion.

D. Typically operate optimally in extreme temperature conditions due to their robust design.

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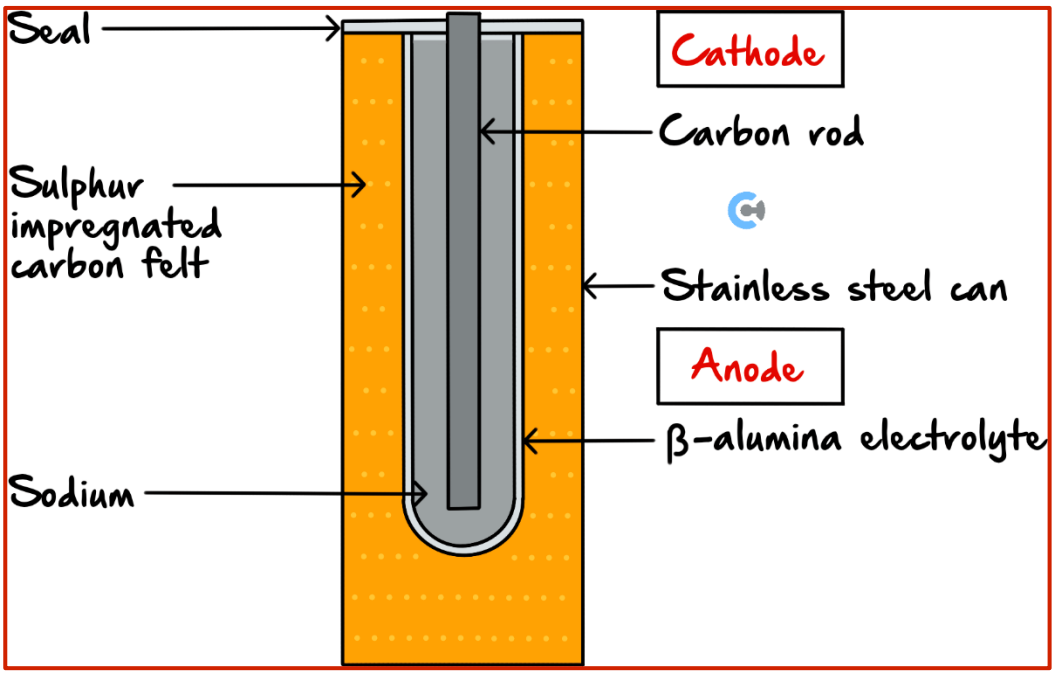
Question 16 (6 marks)

Sodium-sulphur batteries are used for large-scale energy production and storage due to their high energy density and long life cycle. This allows them to have applications in storing renewably generated energy from sources such as wind and solar. It utilised molten sodium and sulphur, with a solid β-alumina electrolyte. A diagram of a sodium-sulphur cell is shown below.



The overall reaction occurring within the cell during discharge is:

$$Na(l) + S(l) \rightarrow Na_2S(l)$$

a. In the boxes provided above, label the location of the anode and cathode during discharge. (1 mark)

b. Write the reaction for the reaction occurring at the positive electrode as energy is being produced. (1 mark)

$S(l) + 2e^- \rightarrow S^{2-}(l)$

c.

i. β-alumina is added to the electrolyte for proper operation of the cell, it can be collected and reused after the reaction has been completed. Explain the role of the β-alumina within the cell. (2 marks)

Alumina is reducing the melting point of the substances within the cell through forming temporary partial ionic bonds within the metallic/ionic lattices of the products/reactants. This then allows for a lower temperature to be matinained and as such less energy has to be inputted.

ii. There is a separator between either of the electrodes that allows for the flow of $Na^+(aq)$ ions. Explain two purposes for Na^+ions within the cell. (2 marks)

Na^+ acts as the electrolyte within the cell. It balances the build up of charge to ensure that the cell remains electircally neutral, allowing intended reactions to occur.

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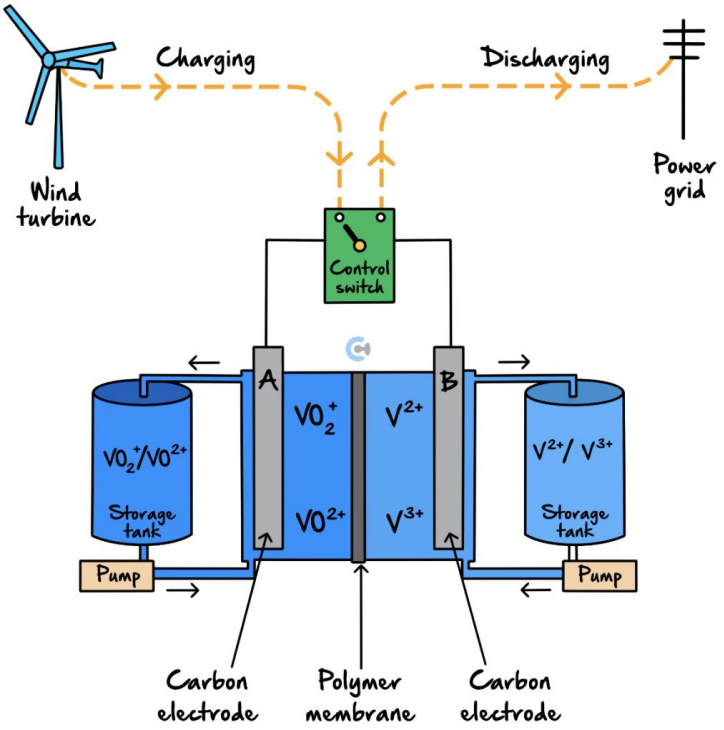
Question 17 (9 marks)

Vanadium redox flow batteries can be used as a means of adding energy generated by solar or wind energy to the power grid. An example of a typical vanadium redox flow battery is shown below.



a.

i. Given that electrode *B* is negative during discharge, state the reaction occurring at electrode *A* during recharge. (2 marks)

@ negative electrode *B* during discharge: $V^{2+} \rightarrow V^{3+} + e^-$
Positive *A* recharge is an oxidation, therefore: $VO^{2} + + H_2O \rightarrow VO_2^+ + 2H^+ + e^-$

ii. Hence or otherwise, explain why a polymer membrane must be added to the cell using relevant half-equations to support your response. (2 marks)

A polymer membrane prevents the movement of the products electrolysis from spontaneously reacting with one another. The reaction $V^{2} + + VO_2^+ + 2H^+ \rightarrow CO^{2+} + V^{3+} + H_2O$, which would cause the production of thermal energy as opposed to electrical energy.

b. Explain how the control switch will allow for non-spontaneous reactions to occur when taking energy from the wind turbine. (3 marks)

When the control switch is set to discharging, electrons are travelling in their natural directions towards the positive cathode, where they are gained by oxidants to undergo reduction. When the wind turbine produces electrical energy that is inputted to the redox flow battery that forces electrons to move in the against their natural electrostatic attraction. Therefore, the electrons travel towards the negative electrode, whereby they must be gained, causing non-spontaneous reduction to occur.

c. It can be claimed that the cell could be considered a fuel cell. Comment on the accuracy of this claim. (2 marks)

A fuel cell is one that requires a constant supply of reactants in order to operate. In this case, the cell could be considered to have a constant supply of reactants as they are continuously pumped in from the storage tanks. However, fuel cells only convert chemical energy into electrical energy, whereas this redox flow battery is able to both convert chemical into electrical and electrical into chemical.

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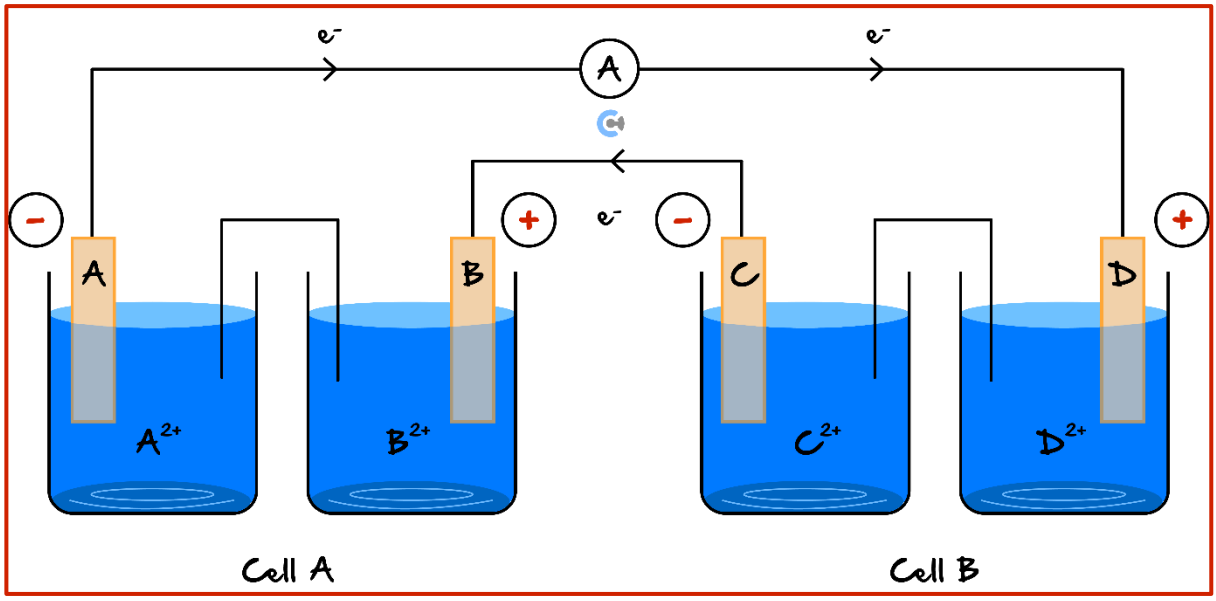
Sub-Section [2.3.3]: Find Reactions Occurring in Connected Cells

Question 18 (3 marks)

Two galvanic cells are connected together, as shown in the diagram.



a. Label the polarities of each electrode in the box provided above. (1 mark)

b. Write the half-equation which occurs at the following electrodes. States are not required.

i. Electrode *A*. (1 mark)

$A \rightarrow A^{2+} + 2e^-$

ii. Electrode *D*. (1 mark)

$D^{2+} + 2e^- \rightarrow D$

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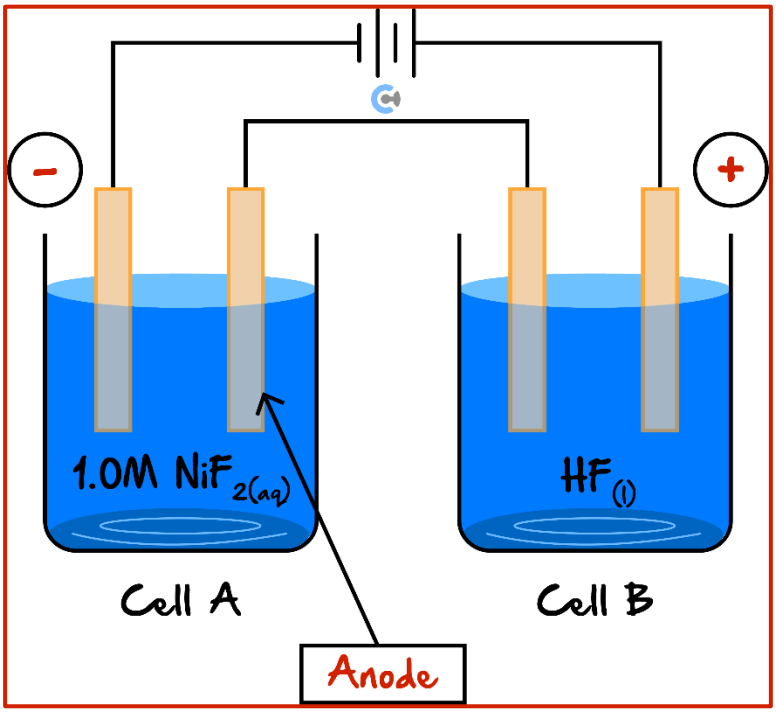
Question 19 (6 marks)

The following connected cell is constructed and is connected to a power source.



a. Write the polarities of the two electrodes in the circles provided above. (1 mark)

b. Label the electrode labelled in the diagram as the cathode or the anode. (1 mark)

c. Write the half-equations occurring at the anode of:

i. Cell *A*. (1 mark)

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

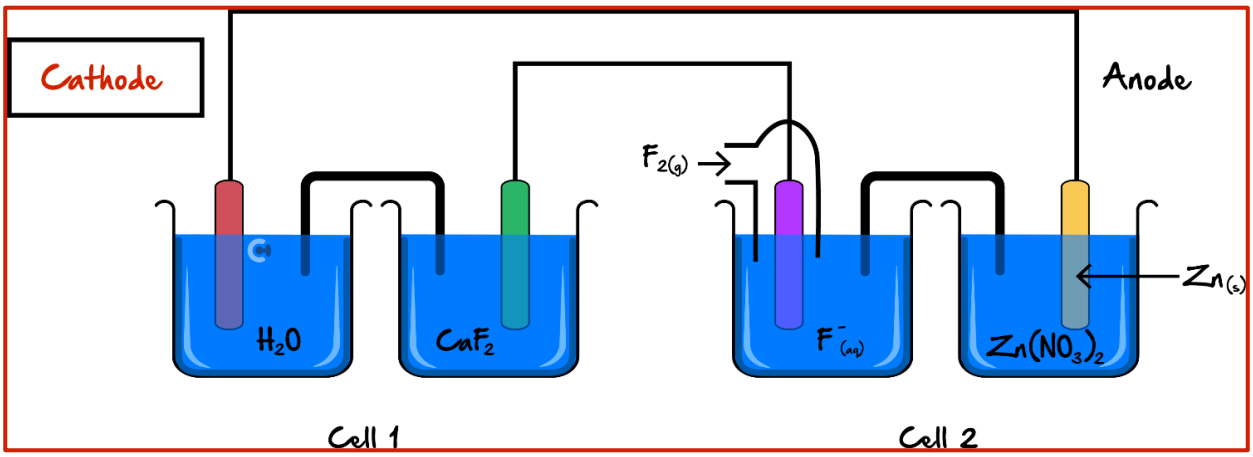
ii. Cell *B*. (1 mark)

$2F^-(l) \rightarrow F_2(g) + 2e^-$

d. Find the total voltage that the power source must supply for the cell to operate. (2 marks)

Cell 1: Requires $> 1.28\ V$
Cell 2: Requires $> 2.87\ V$
Total EMF required $> 4.15\ V$

Question 20 (7 marks)



a. In the box provided above, label whether the electrode indicated is the anode or cathode. (1 mark)

b.

i. Using relevant half-equations, justify whether cell 2 is a galvanic or electrolytic cell. (2 marks)

Cell 2 has a zinc anode. Therefore, the fluorine half cell is the cathode. The spontaneous reaction between zinc and fluorine will have fluorine be the cathode since it is a stronger oxidant than Zn^{2+}. Therefore, cell 2 must be a galvanic cell as indirect spontaneous reactions are taking place.

ii. Hence or otherwise, determine the overall reaction occurring in cell 1. (1 mark)

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

iii. If the $F^-(aq)/F_2(g)$ half cell is swapped out for a $Cu^{2+}(aq)/Cu(s)$ half cell, explain whether the entire cell will operate. (3 marks)

If swapped with a Cu^{2+}/Cu half-cell, Cell 2 will still operate as a galvanic cell. It will produce a voltage of $+1.10\ V$. However Cell 1, which is the reduction and oxidation of water, requires a voltage input of $> 2.09\ V$. Therefore, the electrolytic cell will not operate any longer.

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