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VCE Chemistry ¾
Features of Electrolytic Cells [2.2]
Homework Solutions

Admin Info & Homework Outline:

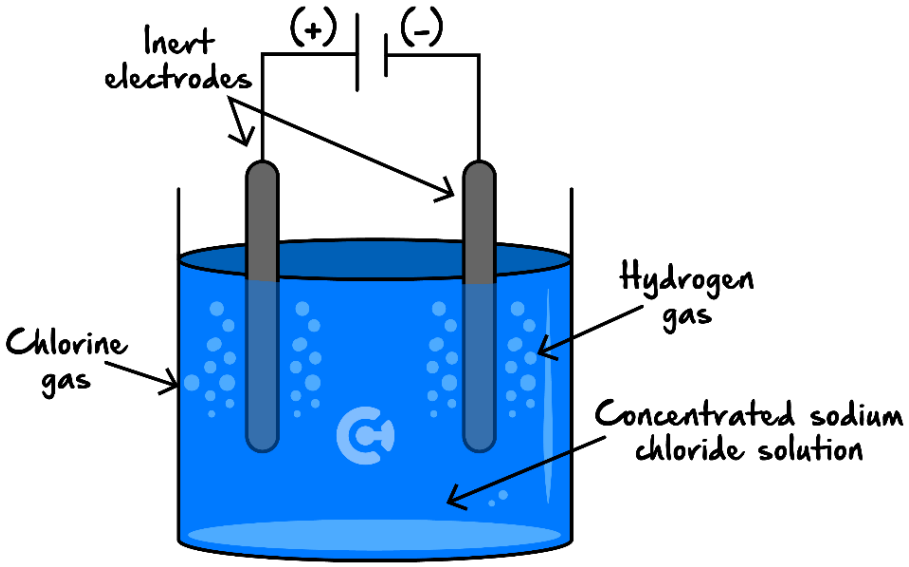
Student Name	
Questions You Need Help For	
Compulsory Questions	Pg 2 – Pg 11
Supplementary Questions	Pg 12 – Pg 23

Section A: Compulsory Questions (46 Marks)

Sub-Section [2.2.1]: Find Electrolytic Reactions in Non-Standard Conditions (Molten & High Concentration)

Question 1 (5 marks)

An electrolytic cell containing a concentrated solution of sodium chloride is being electrolysed. A diagram of the cell is shown below.



a. Write the reaction occurring at the:

i. Positive Electrode. (1 mark)

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

ii. Negative Electrode. (1 mark)

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

b. What is the required voltage for the cell to operate? (1 mark)

$+1.36 - (-0.83) = \text{Greater than } 2.19\ V$

c. Explain the change in pH, if any, that is observed in the cell. (2 marks)

Increase in pH since OH^- is being produced which increases the cell's pH.

Question 2 (3 marks)

Consider an electrolytic cell that involves molten magnesium bromide using a copper cathode and a graphite anode.

a. Write the half-equation for the reduction reaction. (1 mark)

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

b. Write the half-equation for the oxidation reaction. (1 mark)

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

c. State whether or not you would observe an increase in size at an electrode. (1 mark)

No change in size at any electrode

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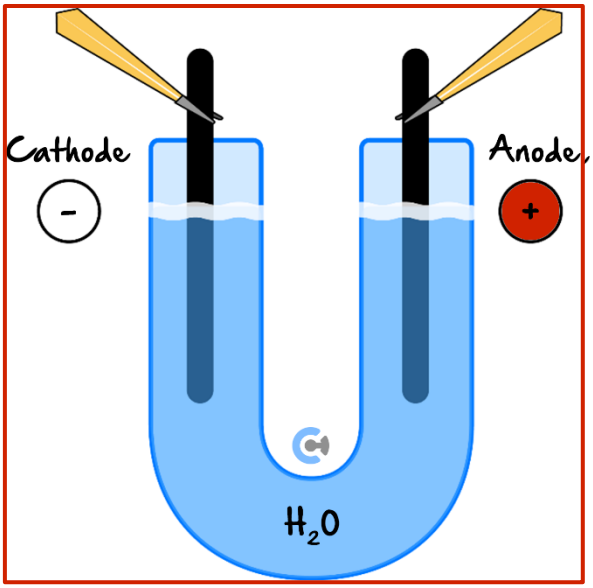
Question 3 (4 marks)

An electrolytic cell that electrolyses deionised water is shown below.



a. Label the polarity of the cathode and anode in the circles above. (1 mark)

b. Write the balanced half-equation for the reaction occurring at the anode. (1 mark)

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

c. If some amounts of iron were found to be deposited at the cathode, suggest a reason why this might've been the case. (2 marks)

This is because the water isn't actually deionised and there are trace amounts of metals in it that are a stronger oxidant than water itself and hence would be reduced preferentially.

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Sub-Section [2.2.2]: Identify Features of Electrolytic Cells & their Purpose

Question 4 (2 marks)

Explain why we would rather have totally inert electrodes rather than an electrode that changes in size for an electrolytic cell.

By having inert electrodes, if it was an anode, it will eventually stop touching the electrolyte if it becomes small enough and hence the cell would stop working. So, by having inert electrodes, we can ensure that the cell operates for longer.

Question 5 (3 marks)

Aluminium is an important metal that can be extracted from aluminium oxide (Al_2O_3), which is found in the ore bauxite.
Explain how aluminium can be produced from aluminium oxide in an electrolytic cell and describe how cryolite (Na_3AlF_6) helps with this process.

Aluminium can be electrolysed from aluminium oxide if we do it molten conditions because it removes water, which is a stronger oxidant than aluminium ions. The cell would consist of a graphite cathode and a carbon anode. The molten aluminium oxide is mixed with the cryolite in order to lower its melting point to make it more economical to operate the cell.

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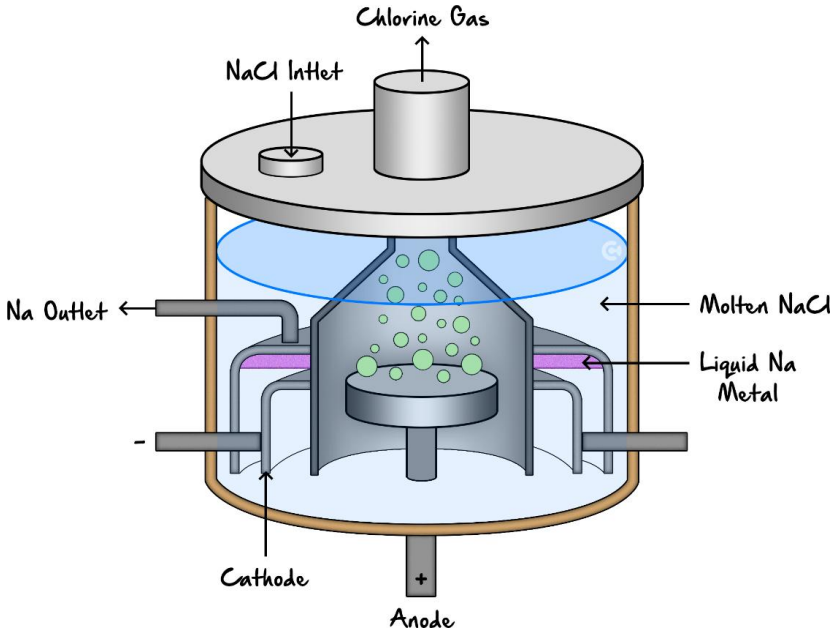
Question 6 (6 marks)

Consider the following cell that aims to produce pure sodium.



a. What is the overall reaction occurring here? (1 mark)

$2NaCl(l) \rightarrow 2Na(l) + Cl_2(g)$

b. $CaCO_3$ is sometimes added to make the cell more economically efficient. Explain how $CaCO_3$ does this. (2 marks)

$CaCO_3$ can act to reduce the melting point of NaCl through weakening the ionic bonds that hold NaCl together. Therefore, less energy required to maintain molten temperatures which reduces energy costs and hence makes the cell cheaper to operate.

c. Generally, graphite electrodes are used in this cell. However, iron electrodes are cheaper and hence preferred. Would using iron electrodes at specific electrodes affect the final reaction that occurs in this cell? (3 marks)

Iron can be used as the cathode but not the anode. If at anode, it will oxidise in preference over chlorine since it's a stronger reductant. Therefore, the iron will become iron ions. The cell will stop operating after a while. At the cathode however, iron will not oxidise as only reduction can take place at the cathode, which makes it effectively inert.

Sub-Section [2.2.3]: Identify Key Features, Write Reactions & Relate to sustainability & Green Chemistry Principles regarding Production of Green Hydrogen (PEM & Artifical Photosynthesis)

Question 7 (2 marks)

Explain a similarity and a difference with the usage of a PEM Electrolyser against an Artificial Photosynthesis Cell.

The PEM Electrolyser uses a solid electrolyte whereas artificial photosynthesis requires an aqueous one. They are both methods to produce high purity hydrogen gas.

Question 8 (4 marks)

Artificial photosynthesis is a relatively new method to produce hydrogen gas on large scale.

a. During artificial photosynthesis, water is split into hydrogen and oxygen. Write the half-equations for both the oxidation and reduction reactions involved. (2 marks)

$$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$$
$$2H^+(aq) + 2e^- \rightarrow H_2(g)$$

b. Explain whether artificial photosynthesis relates to the green chemistry principle of "design for energy efficiency". (2 marks)

Artificial photosynthesis relates to "design for energy efficiency" by having no intermediate energy conversions, and it has a catalyst which reduces the energy input that is required to run the cell.

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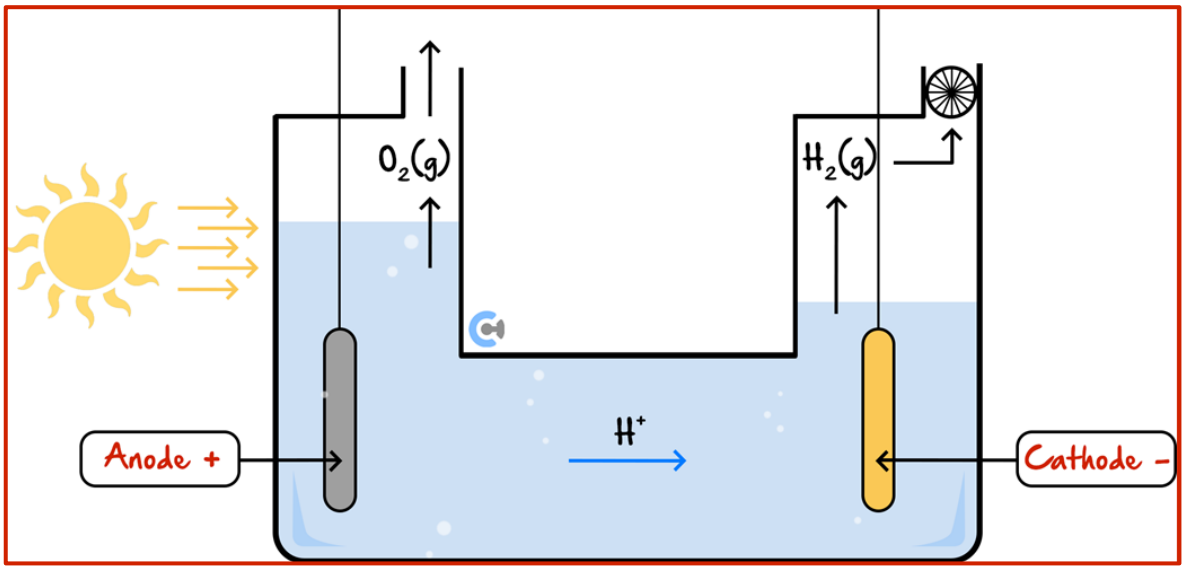
Question 9 (6 marks)

Photoelectrochemical cells leverage the intricate interplay of light absorption and semiconductor behaviour to produce energy. A diagram of one such cell is shown below.

a.



i. Write the overall balanced equation of the cell. (1 mark)

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

ii. Hence, label the anode and the cathode in the boxes provided above. (1 mark)

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

b. Compare the efficiency of this cell to a typical simple electrolytic cell. (2 marks)

This cell is more inefficient as it uses solar power. This is due to it not being able to convert 100% of the sun's energy into usable energy, whereas electrolytic cells can utilise most of the energy provided from a battery/power source.

c. Explain which green chemistry principle this cell would relate to. (2 marks)

This cell would relate to the green chemistry principle of 'prevention of waste' as no waste is produced as H_2 is used as fuel and O_2 gas is released into the atmosphere.

Sub-Section: Final Boss

Question 10 (11 marks)

Hydrogen gas is a very innovative material that can be obtained through various processes that you have learned such as electrolytic cells, PEM electrolysers and artificial photosynthesis.

a. Hydrogen gas is much more dangerous than other flammable gases such as methane. Explain why. (2 marks)

Hydrogen gas is colourless and odourless, meaning it is impossible to detect. Other gases such as methane may have colours or odours which makes it easier to detect earlier.

b. When hydrogen is stored, it is suspended in a liquid. How does this benefit its transit? Explain how we can store it in this way. (2 marks)

As a liquid, it is easier to transport as it is denser than when in a gas. Therefore more H_2 can be stored in the same volume. We store it this way by keeping it at very low temperatures and high pressures to compress it as much as possible.

c. PEM Electrolysers are compared to other methods of obtaining hydrogen gas.

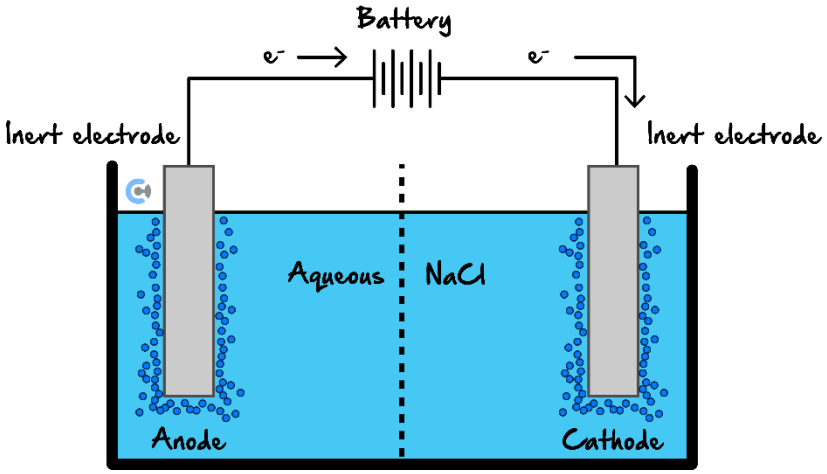
i. Identify **two** advantages of a PEM electrolyser over the electrolysis of water. Justify your answer. (2 marks)

A PEM electrolyser is easier to transport around as opposed to a water electrolytic cell as it uses a solid electrolyte rather than a liquid one. In addition to that, PEM electrolysers use wind/solar energy to convert to electrical energy that is then converted to chemical energy, meaning that the power source can be more renewable than a normal electrolytic cell.

ii. Compare its renewability of a PEM electrolyser compared to steam reforming to produce hydrogen gas. (2 marks)

Steam reforming is not renewable and contributes to carbon emissions due to how it is obtained and where it comes from. On the other hand, PEM electrolysers get their hydrogen via solar and wind energy which is then converted eventually to hydrogen gas making it greener.

d. Another method to obtain hydrogen gas is through the electrolysis of 4.0 *M* sodium chloride. The cell is shown below.



i. Write formula for the expected products at both electrodes. (1 mark)

$Cl_2(g)$ and $H_2(g)$

ii. Electrolysis through this method involves a membrane in the middle of the electrolyte. List **two** purposes of this membrane. (2 marks)

To separate products ($Cl_2(g)$ and $H_2(g)$) apart, and allow ions to pass through.

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Section B: Supplementary Questions (47 Marks)

Sub-Section [2.2.1]: Find Electrolytic Reactions in Non-Standard Conditions (Molten & High Concentration)

Question 11 (3 marks)

A solution of Magnesium Bromide is being electrolysed using a copper cathode and carbon anode at molten conditions.

a. Write a balanced half-equation (including states) for the reaction occurring at the:

i. Anode. (1 mark)

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

ii. Cathode. (1 mark)

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

b. State the voltage required for this cell to operate. (1 mark)

Greater than $3.46\ V$.

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Question 12 (4 marks)

Molten aluminium nitrate is being electrolysed using a nickel cathode and iron anode.

a. Write the balanced half-equation occurring at the:

i. Negative electrode. (1 mark)

$Al^{3+}(l) + 3e^- \rightarrow Al(l)$

ii. Positive electrode. (1 mark)

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

b. If we changed the nickel cathode into a zinc cathode, state any changes that might occur to the reaction. (2 marks)

No change in the reaction since at the cathode only reduction can occur so even though zinc in essence is a stronger reductant than iron, but it cannot react.

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Question 13 (2 marks)

An electrolytic cell is set up using inert electrodes inside a 1.0 *M* solution of NaCl. A diagram of the shell is shown below.

a. Over the progression of the reaction.

A. Bubbles will be served at both electrodes.

B. Sodium metal will begin to plate the cathode and chlorine gas at the anode.

C. Sodium ions will be produced at the positive electrode and chlorine gas will be produced at the cathode.

D. Bubbles will only appear at one of the electrodes.

b. The concentration of NaCl is then increased to 5.0 *M*. The reaction at the negative electrode will now be,

A. $Na^+(aq) + e^- \rightarrow Na(s)$

B. $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

C. $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

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

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Question 14 (6 marks)

A molten cell is set up containing a solution of potassium sulphate and is mixed with a solution of lithium fluoride. The electrolytic cell is then set up using a graphite cathode and lead anode.

a. Write the half-equation occurring at the:

i. Anode. (1 mark)

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

ii. Cathode. (1 mark)

$K^+(l) + e^- \rightarrow K(l)$

b. Explain an observation that takes over the course of the reaction. (2 marks)

The lead anode will decrease in size as it undergoes oxidation into lead ions.

c. Suggest an improvement to this cell which would allow it to be operational over a longer period of time. (2 marks)

Swap the anode and cathode, as then the lead electrode will no longer degrade over time. Or else, once the electrode is witted down to the point where it doesn't touch the electrolyte, the cell will stop working.

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Sub-Section [2.2.2]: Identify Features of Electrolytic Cells & their Purpose

Question 15 (2 marks)

a. Which of the following is an advantage of using a molten electrolyte in an electrolytic cell?

A. Molten electrolytes reduce the melting point of the electrodes.

B. Molten electrolytes decrease the conductivity of the cell.

C. Molten electrolytes allow for the electrolysis of compounds that are insoluble.

D. Molten electrolytes prevent any ion movement.

b. Why might an electrolytic cell use a lead anode in the electrolysis of a fluoride salt?

A. Lead reacts vigorously with fluorine gas, enhancing the reaction.

B. Lead is a poor conductor of electricity.

C. Lead is resistant to oxidation and minimises anode degradation.

D. Lead actively releases oxygen gas when in contact with fluoride ions.

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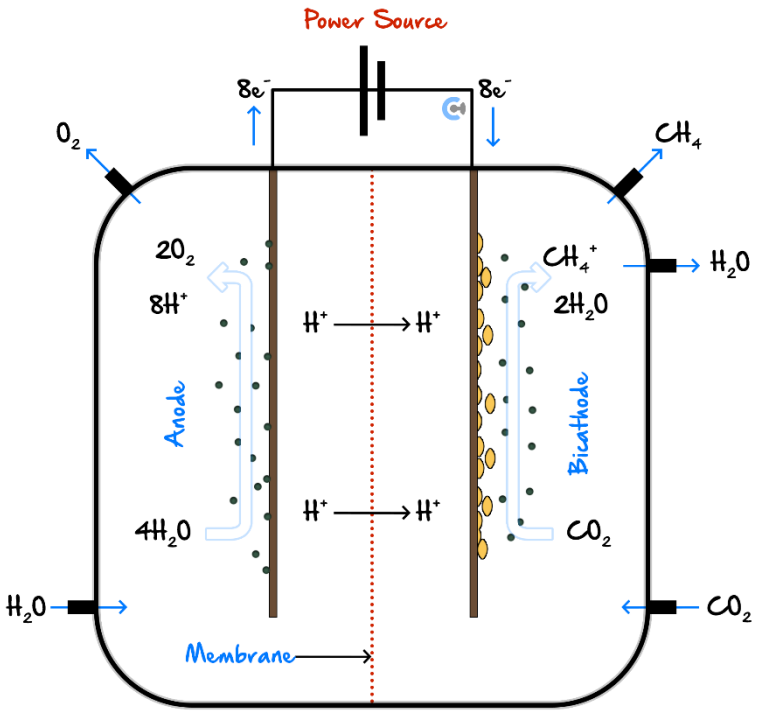
Question 16 (3 marks)

Electromethanogenesis cells use bacteria and organic matter to turn CO_2 back into CH_4 (biogas) as a form of renewable energy production. A diagram is shown below.



a. What is the reaction that occurs at the anode? (1 mark)

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

b. Biogas is the primary product, is it renewable? Explain. (2 marks)

It depends on where the power source is sourced from, if the power source comes from a traditional source then it isn't renewable since it is still derived from fossil fuels.

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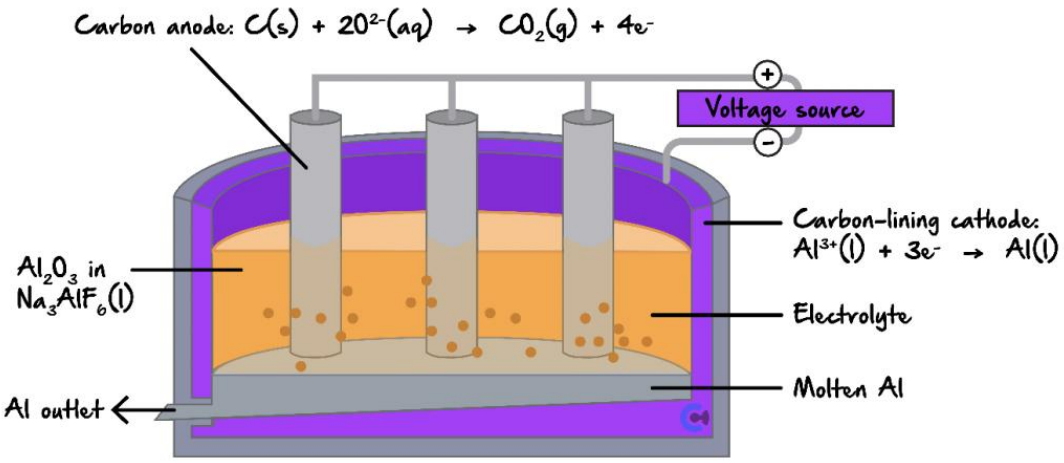
Question 17 (5 marks)

Consider the following Hall-Heroult cell.



a. If the cell is typically enclosed, explain why it is necessary to include a gas pump that is separate from the Al outlet. (2 marks)

This is because if the cell is enclosed there would be a gas buildup, and if the gas buildup is too much the battery would burst from the internal pressure.

b. If the aluminium oxide was dissolved in a solution of water, what would occur to the aluminium being produced? (2 marks)

It would undergo water electrolysis instead.

$$2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-$$
$$2H_2O \rightarrow O_2(g) + 4H^+ + 4e^-$$

c. What is the overall reaction occurring in the cell? (1 mark)

$$2Al_2O_3(l) + 3C(s) \rightarrow 4Al(l) + 3CO_2(g)$$

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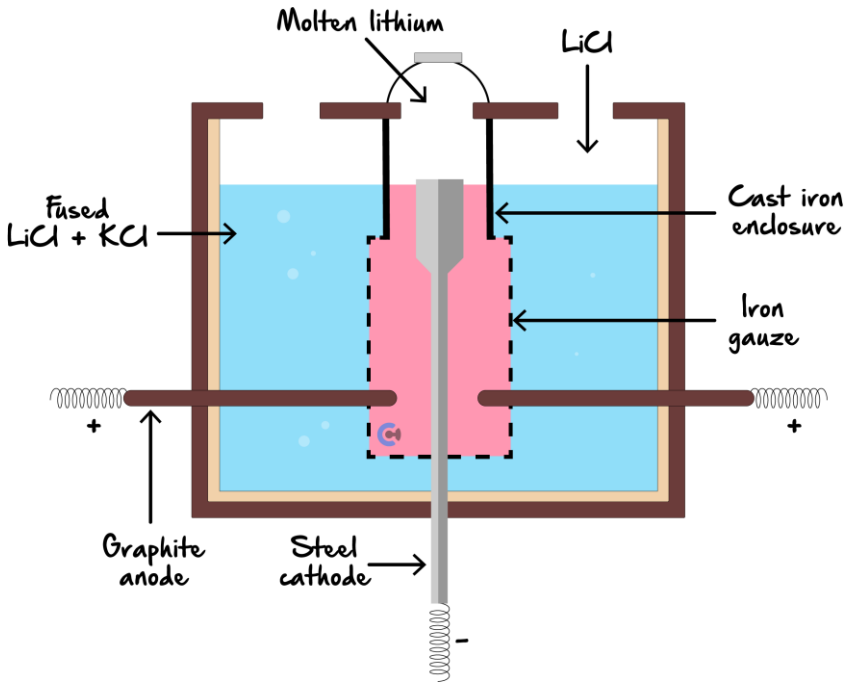
Question 18 (7 marks)

Lithium, an alkali metal exhibits a diverse array of scientific applications, which is increasingly important in today's digital society. The below is an example of an industrial cell that uses lithium.



a. Write the reaction occurring at the:

i. Anode. (1 mark)

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

ii. Cathode. (1 mark)

$K^+(l) + e^- \rightarrow K(l)$

b.

i. By using molten conditions, the cell operates much more safely than under standard conditions. Explain how this is possible. (2 marks)

Under standard conditions, water will be present. Hence, as lithium is a strong reductant and will react with water causing the production of H_2 gas which is flammable can cause explosion.

ii. Is the production of pure lithium possible under standard conditions? (1 mark)

No, it is not because water will always reduce in preference over lithium because it is a weak oxidant.

c. An iron gauze is placed around the cathode, explain its purpose. (2 marks)

Iron gauze prevents lithium metal produced to react with any other products or ions, keeping the lithium obtained pure as it is very reactive.

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Sub-Section [2.2.3]: Identify Key Features, Write Reactions & Relate to Sustainability & Green Chemistry Principles Regarding Production of Green Hydrogen (PEM & Artificial Photosynthesis)

Question 19 (2 marks)

What is a key challenge with the practical usage of artificial photosynthesis, with regards to the product created?

As the main product is hydrogen gas, the storage of it is important because it is a flammable gas which may cause an explosion is not handled properly.

Question 20 (3 marks)

The PEM Electrolyser is an innovative method of producing hydrogen gas.

a. Write its half-equations for the reactions at both the cathode and anode. (2 marks)

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

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

b. The setup of a PEM Electrolyser is very specific. Describe the qualities of a typical electrode you might find in one of these cells. (1 mark)

The electrode needs to be PICCY (porous, inert, catalytic, conducts electricity).

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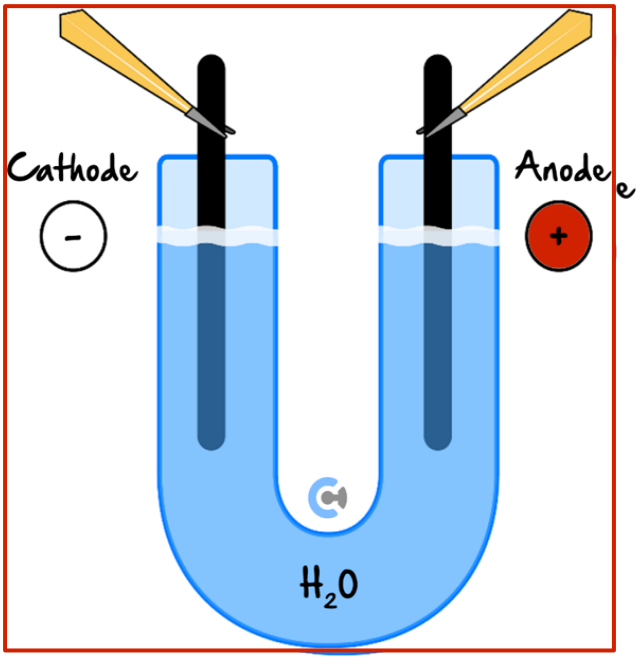
Question 21 (3 marks)

Explain the environmental advantages that you would get if you preferred to use artificial photosynthesis over a PEM electrolyser to produce hydrogen gas.

Artificial photosynthesis uses sunlight to power the electrochemical cell whereas the PEM electrolyser still requires a traditional power source that is from either solar or wind but it is then converted to electrical first before chemical. This makes artificial photosynthesis better as it is derived from the sun directly and there are no intermediate conversions.

Question 22 (7 marks)

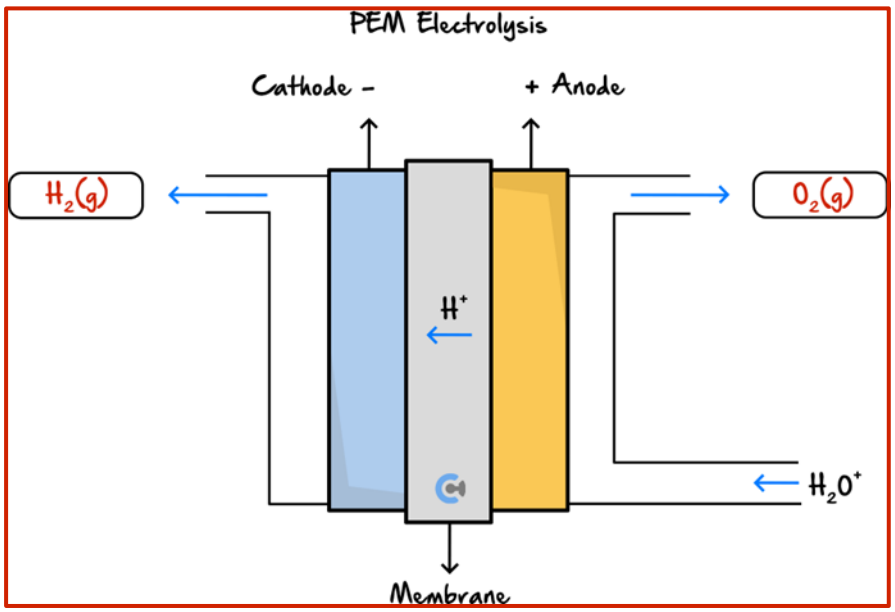
Hydrogen production can be done through two primary ways, electrolysis and steam reforming. An example of an electrolytic cell producing hydrogen gas is shown below.



a. This cell does not produce 'green' hydrogen. Explain why. (2 marks)

The energy that is used for hydrogen gas production in a simple electrolytic cell could be from any number of sources. With most of these sources being through unsustainable practice such as coal fired plants.

Polymer electrolyte membrane electrolysers (PEMs) are a method of producing green hydrogen gas.



b. On the diagram above, label the products at the anode and cathode in the boxes provided. (1 mark)

c.

i. Explain how hydrogen gas produced through PEM electrolysis can be considered 'green' whereas, that from simple electrolysis cannot. (2 marks)

A PEM electrolyser uses photovoltaic (solar) or wind energy to power the electrolytic reactions. Therefore, there are no harmful emissions in the entire process of using hydrogen gas, hence making the production of H2 completely sustainable and green. Simple electrolysis can source energy from anywhere, and as such could be from unsustainable sources.

ii. Hence or otherwise, comment on the sustainability of the PEM electrolyser ensuring that you reference green chemistry principles and sustainable development goals. (2 marks)

Catalysis (green chem principle)
Clean water and sanitation, affordable and clean energy, climate action, sustainable cities and communities, industry, innovation and infrastructure, responsible consumption and production (Sustainable development goals).

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