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VCE Chemistry ¾
Fuel Cells [1.9]
Homework Solutions

Homework Outline:

Compulsory Questions	Pg 2 – Pg 13
Supplementary Questions	Pg 14 – Pg 25

Section A: Compulsory Questions (50 Marks)

Sub-Section [1.9.1]: Write Fuel Cell Half & Overall Reactions in Acidic Conditions

Question 1 (2 marks)

Write the oxidation reactions of the following, remembering to include states.

a. Methane. (1 mark)

$CH_4(g) + 2H_2O(l) \rightarrow CO_2(g) + 8H^+(aq) + 8e^-$

b. Ethanol. (1 mark)

$C_2H_5OH(l) + 3H_2O(l) \rightarrow 2CO_2(g) + 12H^+(aq) + 12e^-$

Question 2 (2 marks)

Write the oxidation reaction for the biodiesel, $C_{15}H_{29}COOCH_3$.

$C_{15}H_{29}COOCH_3(l) + 32H_2O(l) \rightarrow 17CO_2(g) + 96H^+(aq) + 96e^-$

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Question 3 (5 marks)

Write the half-equation for the fuel cell reaction involving propan -1- ol and oxygen gas.

a. Reduction half-equation. (2 marks)

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

b. Oxidation half-equation. (2 marks)

$C_3H_7OH(l) + 5H_2O(l) \rightarrow 3CO_2(g) + 18H^+(aq) + 18e^-$

c. Overall reaction. (1 mark)

$2C_3H_7OH(l) + 9O_2(g) \rightarrow 6CO_2(g) + 8H_2O(l)$

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Sub-Section [1.9.2]: Identify Key Features of Fuel Cells Including Continuous Supply, Electrolyte Movement and Properties of Electrodes

Question 4 (4 marks)

Galvanic cells are often compared to fuel cells due to their characteristics.

a. State one similarity and one difference between them. (2 marks)

Similarity: Converts chemical to electrical energy, exothermic reaction.
Difference: Fuel cells require continuous supply of reactants.

b. State three properties of electrodes in fuel cells. (2 marks)

Electrodes: Must be Porous, Electrically Conductive, Catalytic, Inert.

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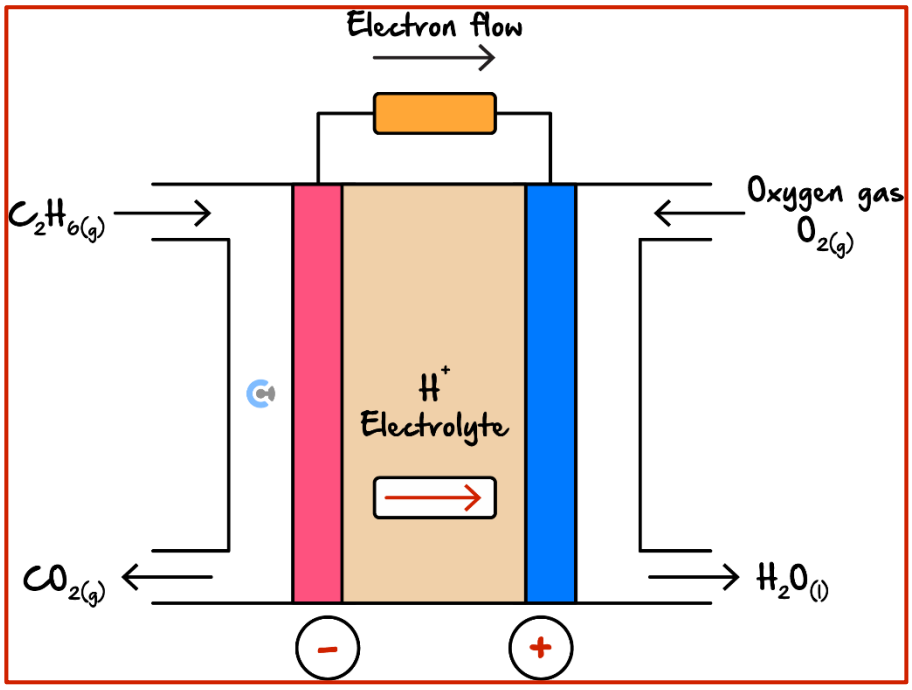
Question 5 (6 marks)

Consider the following fuel cell in acidic conditions.



a. Electrolytes are already present in the fuel cell.

i. Identify the direction of electrolyte movement. (1 mark)

ii. Explain the purpose of the electrolyte. (2 marks)

The electrolyte allows H^+ ions to travel from the anode to the cathode.

b. Identify the polarities of the fuel cell. (1 mark)

c. Write the half-equations of the fuel cell.

i. Oxidation. (1 mark)

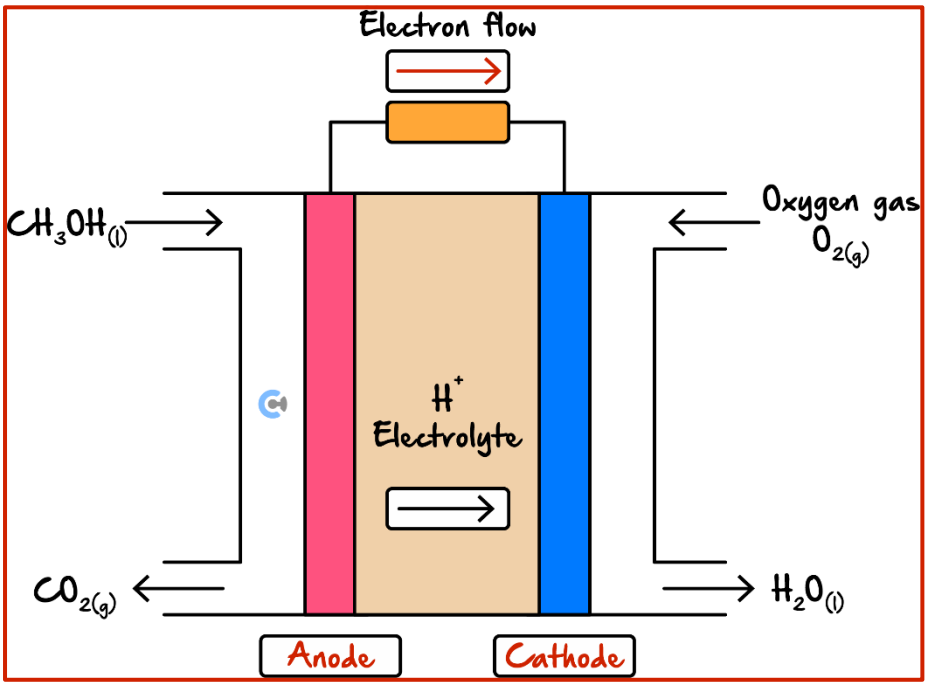
$$C_2H_6(g) + 4H_2O(l) \rightarrow 2CO_2(g) + 14H^+(aq) + 14e^-$$

ii. Reduction. (1 mark)

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

Question 6 (4 marks)

Consider the following fuel cell involving methanol.



a. Write the half-equations of the fuel cell. (2 marks)

$$CH_3OH(l) + H_2O(l) \rightarrow CO_2(g) + 6H^+(aq) + 6e^-$$
$$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$$

b. Label the cathode/anode. (1 mark)

c. Label the electron flow. (1 mark)

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Sub-Section [1.9.3]: Explain Advantages & Disadvantages of Fuel Cells with Reference to Green Chemistry Principles

Question 7 (2 marks)

One of the major advantages of a fuel cell is its energy efficiency. State the green chemistry principle that is related to this aspect and explain how it relates to greenhouse gas emissions, referring to item 26ii of the Data Book.

Principle: Design for energy efficiency. Processes/pathways should be designed for maximum energy efficiency with minimal negative environmental and economic impact. This relates to greenhouse gas emissions because if a fuel cell is efficient this means that for the same amount of energy as a traditional combustion engine, it will release less amount of greenhouse gas emissions.

Question 8 (2 marks)

One advantage of using methane in fuel cells rather than a gas-fired power station is their energy efficiency. State one other advantage of using methane in a fuel cell, referencing green chemistry principles, referring to item 26ii of the Data Book.

The methane used in a fuel cell can be sourced from biogas, which is a renewable source that is easy to input into fuel cells, aligning with the renewable feedstock aspect of green chemistry.

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Question 9 (3 marks)

State 2 disadvantages associated with fuel cells.

1: Expensive: Fuel cells are a relatively new technology and as such producing a fuel cell is expensive compared to using traditional sources of energy like a galvanic cell.
2: Noisier operation than traditional galvanic cells.

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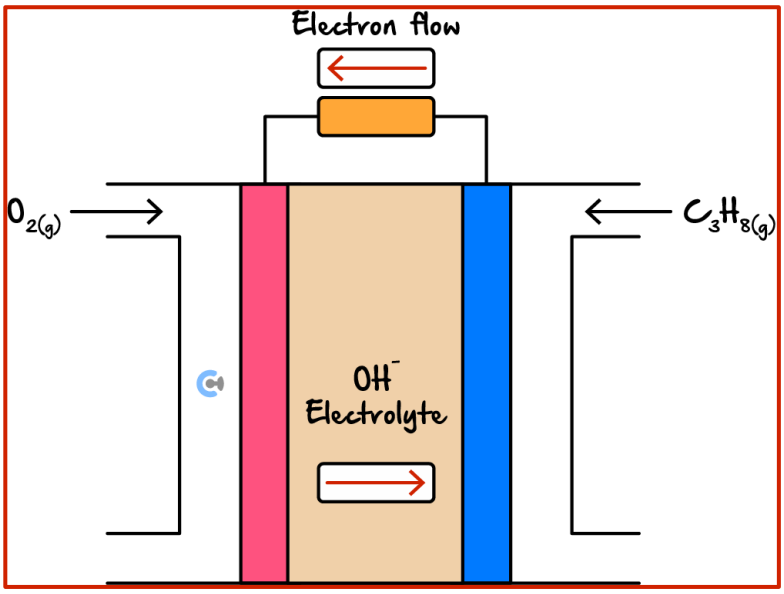
Sub-Section [1.9.4]: Write Fuel Cell Equations in Non-Acidic Conditions

Question 10 (4 marks)

Consider the following fuel cell involving propane and oxygen below.



a. Write the half-equations. (2 marks)

Reduction: $O_2 + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$
Oxidation: $C_3H_8(g) + 20OH^-(aq) \rightarrow 3CO_2(g) + 14H_2O(l) + 20e^-$

b. Label the direction of electrolyte and electron movement in the respective boxes in the provided space above. (2 marks)

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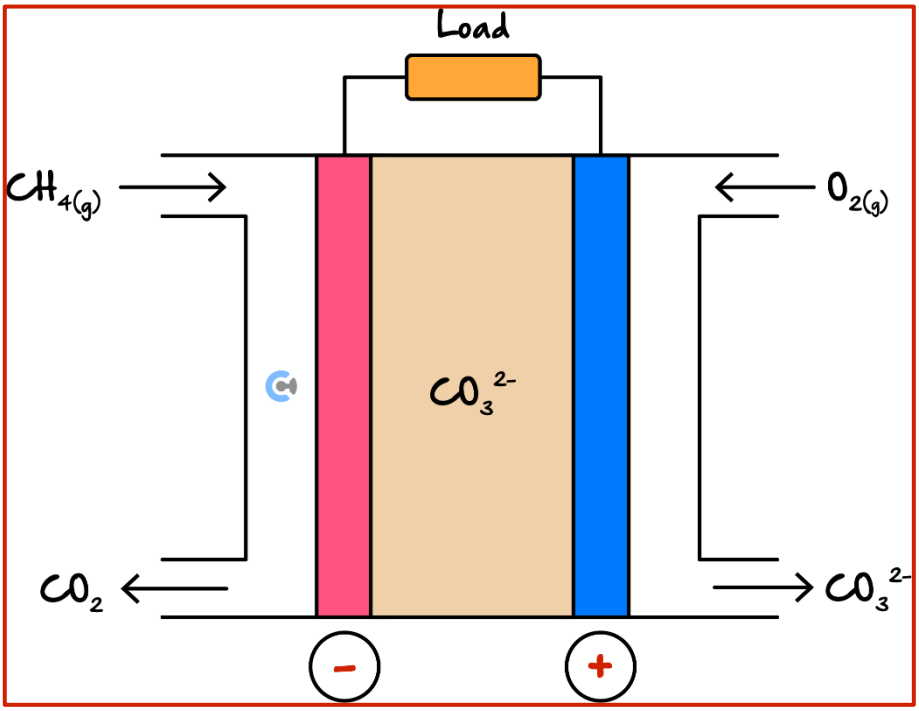
Question 11 (3 marks)

Consider the following fuel cell involving methane and oxygen gas, along with a carbonate electrolyte.



a. Label the polarities of the electrodes. (1 mark)

b. Write the associated half-equations of the fuel cell. (2 marks)

Reduction: $O_2 + 2CO_2(g) + 4e^- \rightarrow 2CO_3^{2-}(aq)$
Oxidation: $CH_4(g) + 3CO_3^{2-}(aq) \rightarrow 4CO_2(g) + 2H_2O(l) + 6e^-$

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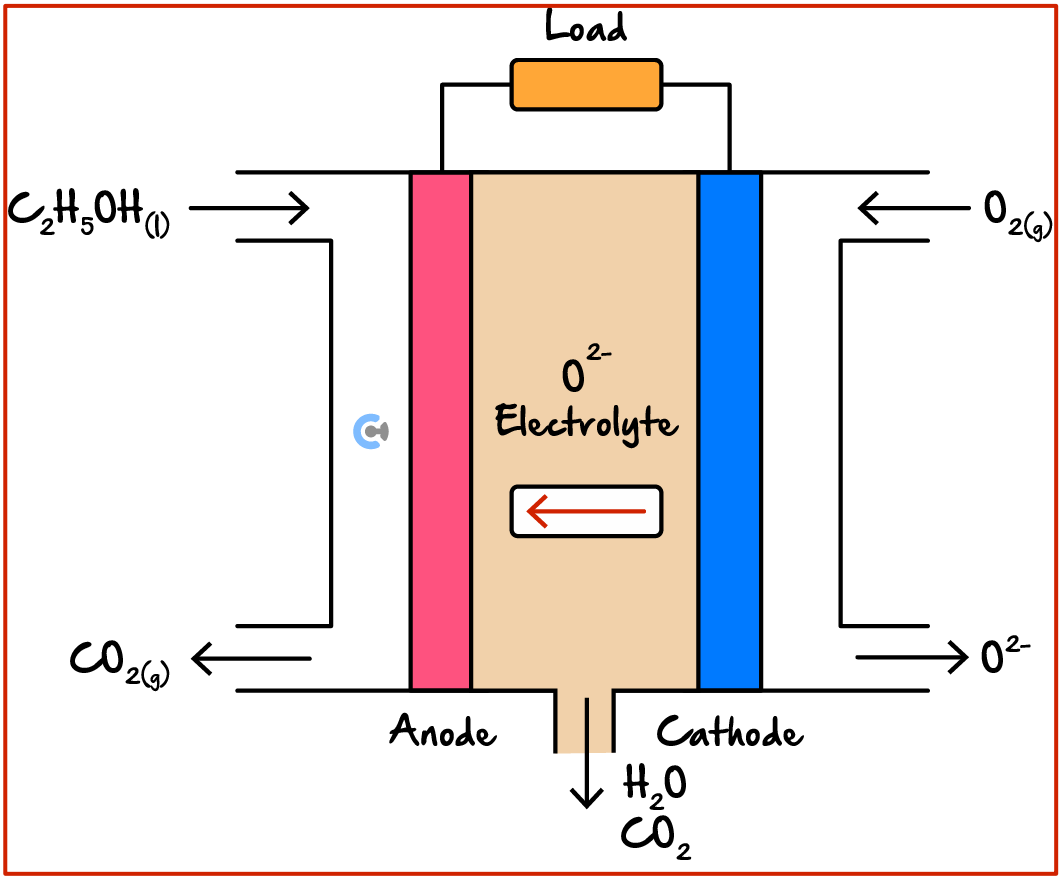
Question 12 (4 marks)

Consider the Solid Oxide Fuel Cell (SOFC) below, which uses ethanol as its primary fuel source.



a. Label the direction of electrolyte movement. (2 marks)

b. Write the half-equations associated with the fuel cell. (2 marks)

Oxidation: $C_2H_5OH(l) + 6O^{2-}(aq) \rightarrow 2CO_2(g) + 3H_2O(l) + 12e^-$
Reduction: $O_2(g) + 4e^- \rightarrow 2O^{2-}(aq)$

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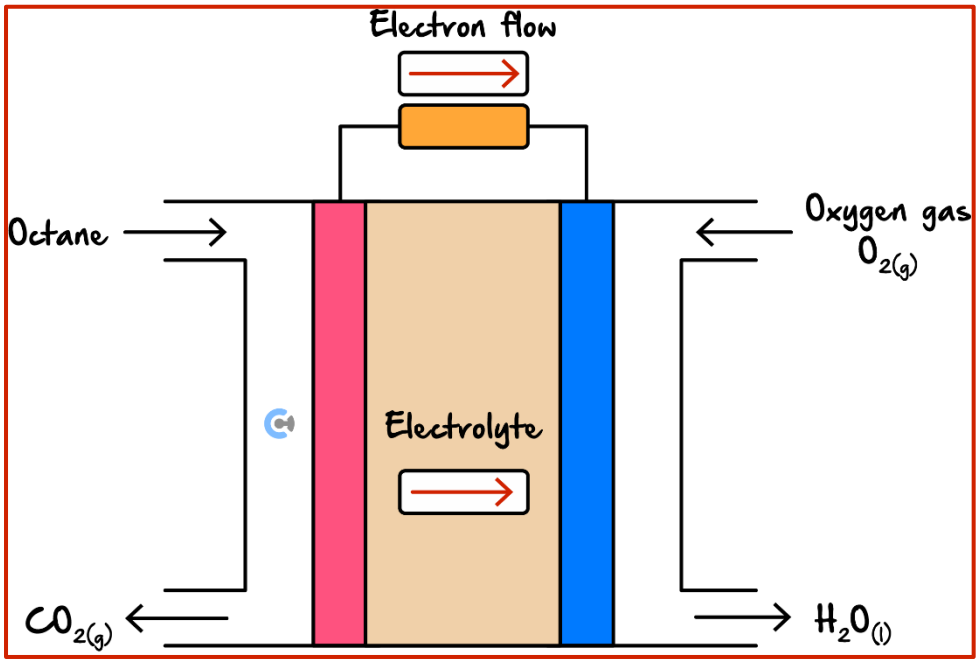
Sub-Section: The 'Final Boss'

Question 13 (9 marks)

Consider a fuel cell that uses octane, in **basic** conditions, as an innovative alternative to traditional combustion engines used in cars.



a. Identify a key characteristic of fuel cells. (1 mark)

Continuous Supply of reactants.

b. Write the half-equations occurring at the:

i. Positive electrode. (1 mark)

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

ii. Negative electrode. (1 mark)

$C_8H_{18}(l) + 50OH^-(aq) \rightarrow 8CO_2(g) + 34H_2O(aq) + 50e^-$

c. Identify the electron and electrolyte movement in the respective boxes provided above. (2 marks)

d. State and explain one advantage and disadvantage of using an octane fuel cell when compared to the usage of ethanol in an internal combustion engine. Justify your answer with reference to green chemistry principles on item 26ii of the Data Book. (4 marks)

ADVANTAGE: According to green chemistry principles, using an octane fuel cell is more energy efficient aligning as for the same amount of energy released, the fuel cell is more efficient leading to lower environmental impact.
DISADVANTAGE: Getting octane as a fuel is non-renewable as it is obtained from crude oil, therefore, not aligning with the green chemistry principle of renewable feedstocks whereas ethanol can be renewable if it is obtained from bioethanol which is gained from the anaerobic digestion of organic waste.

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Section B: Supplementary Questions (62 Marks)

Sub-Section [1.9.1]: Write Fuel Cell Half & Overall Reactions in Acidic Conditions

Question 14 (2 marks)

Consider a fuel cell between hydrogen gas, as the fuel, and oxygen gas. Remember to include states in your answer.

a. Hydrogen gas. (1 mark)

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

b. Oxygen gas. (1 mark)

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

Question 15 (3 marks)

For each of the following, write the balanced half-equation for the reaction occurring at the anode in acidic conditions. Assume that carbon dioxide is produced.

a. A fuel cell involving ethanol as a reactant. (1 mark)

$C_2H_5OH(l) + 3H_2O(l) \rightarrow 2CO_2(g) + 12H^+(aq) + 12e^-$

b. A fuel cell involving ethane as a reactant. (1 mark)

$C_2H_6(g) + 4H_2O(l) \rightarrow 2CO_2(g) + 14H^+(aq) + 14e^-$

c. A fuel cell involving propanol as a reactant. (1 mark)

$C_3H_9OH(l) + 5H_2O(l) \rightarrow 3CO_2(g) + 20H^+(aq) + 20e^-$

Question 16 (4 marks)

Write the half-equations for the fuel cell reaction involving butanol and oxygen gas.

a. Reduction half-equation. (1 mark)

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

b. Oxidation half-equation. (2 marks)

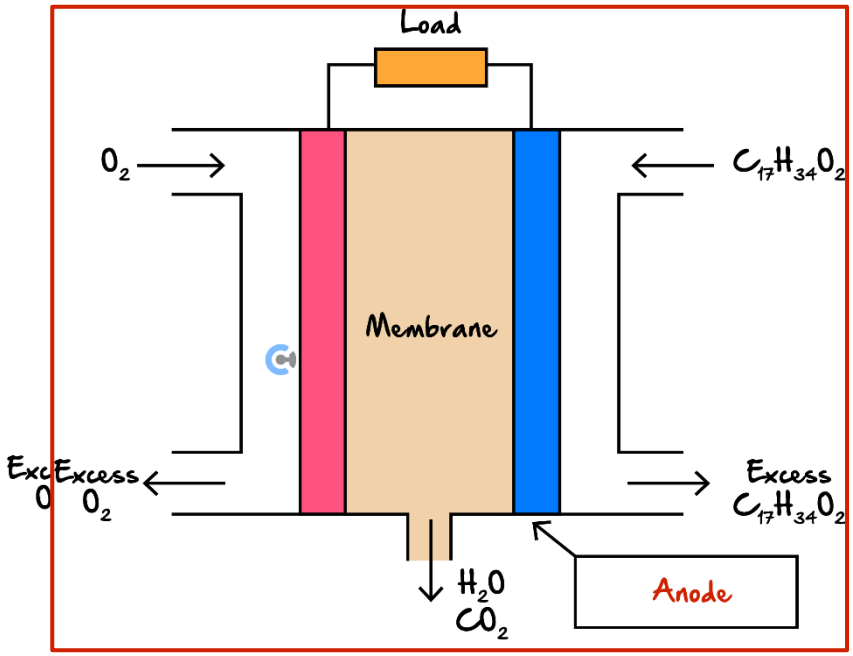
$C_4H_9OH(l) + 7H_2O(l) \rightarrow 4CO_2(g) + 24H^+(aq) + 24e^-$

c. Overall reaction. (1 mark)

$2C_4H_9OH(l) + 12O_2(g) \rightarrow 8CO_2(g) + 10H_2O(l)$

Question 17 (7 marks)

Biodiesels are an example of a renewable fuel. Some farming equipment manufacturers have tried to make a fuel cell in order to more efficiently use left over livestock feed. A diagram of an acidic biodiesel fuel cell is shown below.



a. Identify the electrode as either the cathode or the anode in the box provided in the diagram above. (1 mark)

b. Write the half-equation for the reaction occurring at the anode. (2 marks)

$C_{17}H_{34}O_2(l) + 34H_2O(l) \rightarrow 17CO_2(g) + 102H^+(aq) + 102e^-$

c. Write a balanced equation for the overall reaction which takes place at SLC. (2 marks)

$C_{17}H_{34}O_2(l) + \frac{49}{2}O_2(g) \rightarrow 17CO_2(g) + 17H_2O(l)$

d. Explain whether this cell would be considered renewable or not. (2 marks)

The cell is renewable. The biodiesel used in the fuel cell is produced through transesterification of fats and oils. Therefore, it can be produced in a relatively short time period by natural processes and hence, is renewable.

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Sub-Section [1.9.2]: Identify Key Features of Fuel Cells Including Continuous Supply, Electrolyte Movement and Properties of Electrodes

Question 18 (2 marks)

Explain the key characteristic of a fuel cell.

The continuous supply of reactants, this is due to it not starting with a set amount of reactants at either electrode.

Question 19 (3 marks)

For the following table, mark each statement as either True or False, with regards to a fuel cell involving methane and oxygen gas in acidic conditions.

Statement	True	False
a. The overall reaction is the same as combustion.	✓	
b. Electrons flow from anode to cathode.	✓	
c. Oxygen reacts at the anode.		✓
d. Electrodes must always be inert.	✓	
e. The energy conversion is direct.		✓

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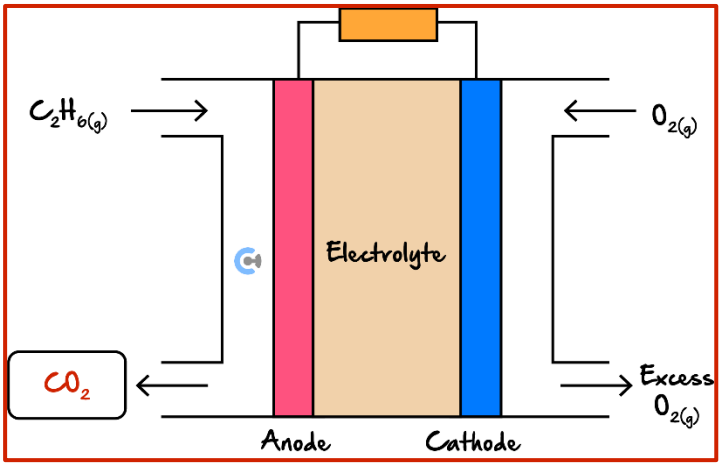
Question 20 (5 marks)

Ethane is a common fuel used in fuel cell.



a. Write the balanced redox reaction for:

i. The half-reaction occurring at the anode. (1 mark)

$C_2H_6 + 2H_2O(l) \rightarrow CO_2(g) + 10H^+(aq) + 10e^-$

ii. Label the main product in the blank box provided above. (1 mark)

b. State three different qualities electrodes in fuel cells must possess. (3 marks)

Any three of PICCY:
- Porous, Inert, Catalyst, Conduct Electricity.

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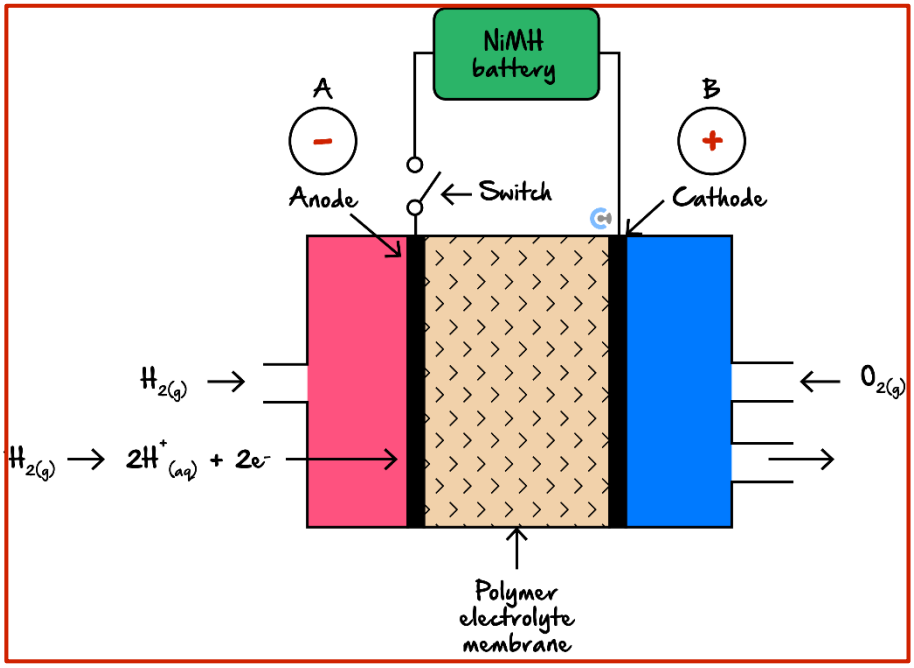
Question 21 (6 marks)

An example of the real-life design of a hydrogen fuel cell is shown below.



a. On the diagram above, indicate the polarity of the anode and cathode in circles *A* and *B*. (1 mark)

b. Write the overall reaction occurring in the cell. (1 mark)

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

c. Explain the function of the polymer electrolyte membrane in the operation of the cell. (2 marks)

The electrolyte allows for the flow of ions that are produced at one electrode to the other electrode. Additionally, it acts as a catalyst to increase the rate of reaction within the fuel cell.

d. State and explain whether this cell is more efficient than a typical combustion engine. (2 marks)

This cell is more efficient than a typical combustion engine as it converts chemical energy into electrical energy.

Sub-Section [1.9.3]: Explain Advantages & Disadvantages of Fuel Cells with Reference to Green Chemistry Principles

Question 22 (2 marks)

State and explain one reason why we would use a fuel cell over a galvanic cell.

Sample Response: Fuel cells are more efficient than galvanic cells while still achieving the same energy conversion, meaning for the same amount of energy less fuel is used.

Question 23 (2 marks)

One environmental advantage of using hydrogen fuel cells instead of gas-powered engines is the reduction of greenhouse gas emissions. State one other environmental advantage, referencing green chemistry principles.

Hydrogen fuel cells produce only water as a byproduct, eliminating harmful pollutants such as carbon monoxide and nitrogen oxides, which aligns with the green chemistry principle of design for degradation.

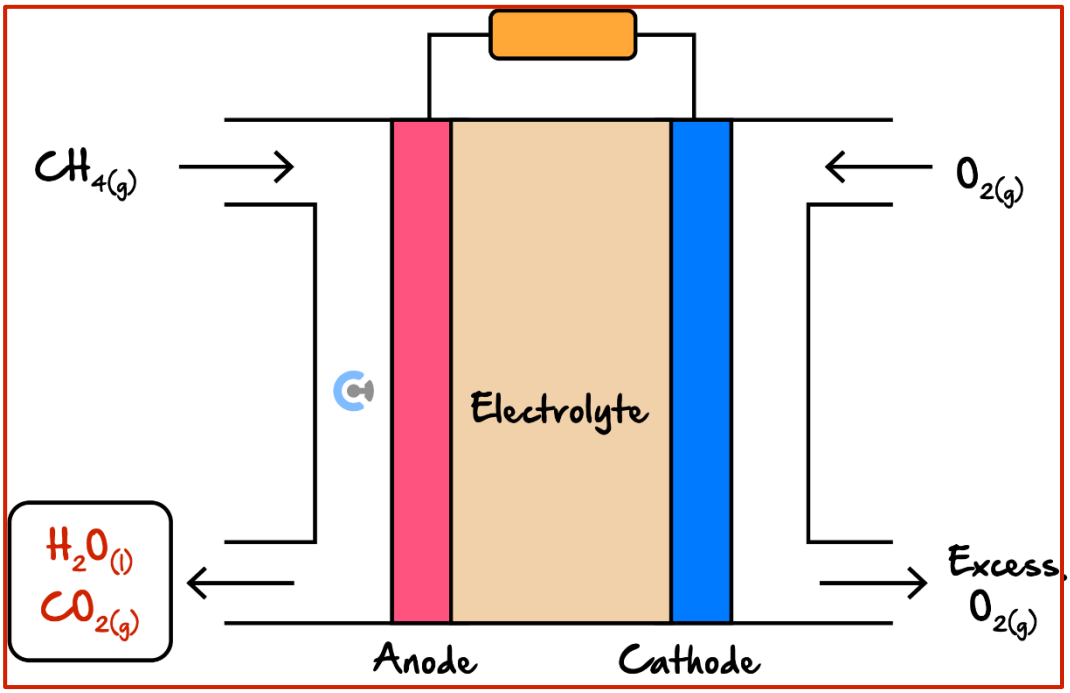
Question 24 (3 marks)

State two limitations of hydrogen fuel cells in practical applications.

- Storage challenge: Hydrogen gas is hard to store because of its danger (very flammable).
- Limited infrastructure: Hydrogen gas stations are hard to come by and so has limited area usage compared to a traditional petrol combustion engine.

Question 25 (7 marks)

Methane can be a source of energy in combustion engines. A fuel cell involving methane is shown below.



a. Write the balanced half-equations for the reactions occurring at the:

i. Anode. (1 mark)

$CH_4(g) + 2H_2O(l) \rightarrow CO_2(g) + 8H^+(aq) + 8e^-$

ii. Cathode. (1 mark)

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

b. In the diagram above, label the expected product(s) at the anode. (1 mark)

c. Compare the efficiency and viability of a combustion engine as opposed to a fuel cell, referencing green chemistry principles. (2 marks)

Fuel cells are more efficient as compared to combustion engines. This aligns with the green chemistry principle of efficiency as for the same amount of energy, less environmental impact is made.

d. A scientist is aiming to produce an engine that can produce mass amounts of energy at a single time. Explain whether he should use a fuel cell or an internal combustion engine. (2 marks)

The combustion engine can pack fuel densely and the fuel can be combusted instantly. The fuel cell requires a constant supply of reactants and must react on the electrode itself, which means not a lot of the fuel can be reacted at once, compared to a combustion engine.

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Sub-Section [1.9.4]: Write Fuel Cell Equations in Non-Acidic Conditions

Question 26 (1 mark)

Write the balanced oxidation half-equation in basic conditions of methane oxidising into carbon dioxide.

$$CH_4(g) + 8OH^-(aq) \rightarrow CO_2(g) + 6H_2O(l) + 8e^-$$

Question 27 (3 marks)

For each of the following, write the balanced oxidation half-equation in basic conditions. Assume CO_2 is the only carbon product formed.

a. A fuel cell involving ethane as a reactant. (1 mark)

$$C_2H_6(g) + 2H_2O(l) \rightarrow CO_2(g) + 10H^+(aq) + 10e^-$$
$$C_2H_6(g) + 10OH^-(aq) \rightarrow CO_2(g) + 8H_2O(l) + 10e^-$$

b. A fuel cell involving propanol as a reactant. (1 mark)

$$C_3H_7OH(l) + 5H_2O(l) \rightarrow 3CO_2(g) + 18H^+(aq) + 18e^-$$
$$C_3H_7OH(l) + 18OH^-(aq) \rightarrow 3CO_2(g) + 13H_2O(l) + 18e^-$$

c. A fuel cell involving methanol as a reactant. (1 mark)

$$CH_3OH(l) + H_2O(l) \rightarrow CO_2(g) + 6H^+(aq) + 6e^-$$
$$CH_3OH(l) + 6OH^-(aq) \rightarrow CO_2(g) + 5H_2O(l) + 6e^-$$

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Question 28 (5 marks)

The overall equation for an unknown fuel cell is shown below, in alkaline conditions.

$$X(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$$

a. What is the equation for the reaction that occurs at the cathode? (1 mark)

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

b. If the fuel itself was an alkane, what could its identity be? (2 marks)

Propane

c. Hence, write the half-equation for the reaction that would occur at the anode. (2 marks)

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

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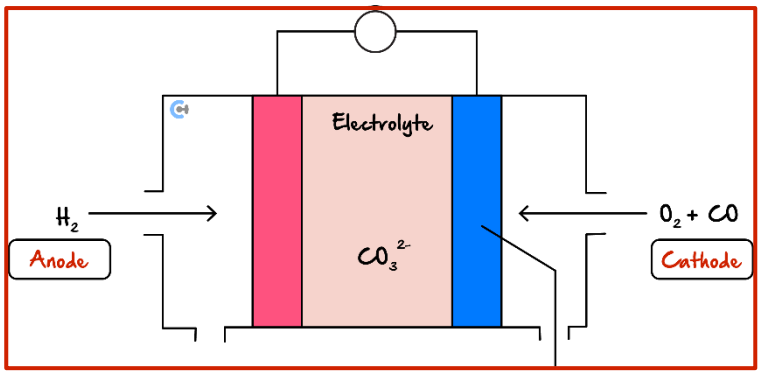
Question 29 (7 marks)

A simplified diagram of a molten carbonate fuel cell (MCFCs) is shown below.



In this MCFC, hydrogen is being used as a reactant alongside $O_2(g)$ in order to produce energy. The main carbon containing product of the cell is carbon monoxide.

a. On the diagram above, label the:

i. Anode and cathode along with the polarities of either electrode. (1 mark)

ii. The direction of electron flow in the external circuit. (1 mark) Solution Pending

b. Write a balanced half-equation for the cathode. (1 mark)

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

c. Write the balanced half-equation for the anode. (2 marks)

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

d. Explain one property of the electrodes in this fuel cell. (2 marks)

Any of PICCY – Porous, inert, catalysts, conducts electricity.

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