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VCE Chemistry ¾
Fuel Cells [0.8]
Workshop

Error Logbook:

Mistake/Misconception #1		Mistake/Misconception #2	
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Section A: Recap (5 Marks)

Learning Objective: [1.9.1] - Write fuel cell half & overall reactions in acidic conditions

- Reactant is a _____.
- Overall Reaction: Usually a _____ reaction.
- **Hydrogen** Fuel Cell Equations (acidic and basic) in ECS: *(Label Below)*

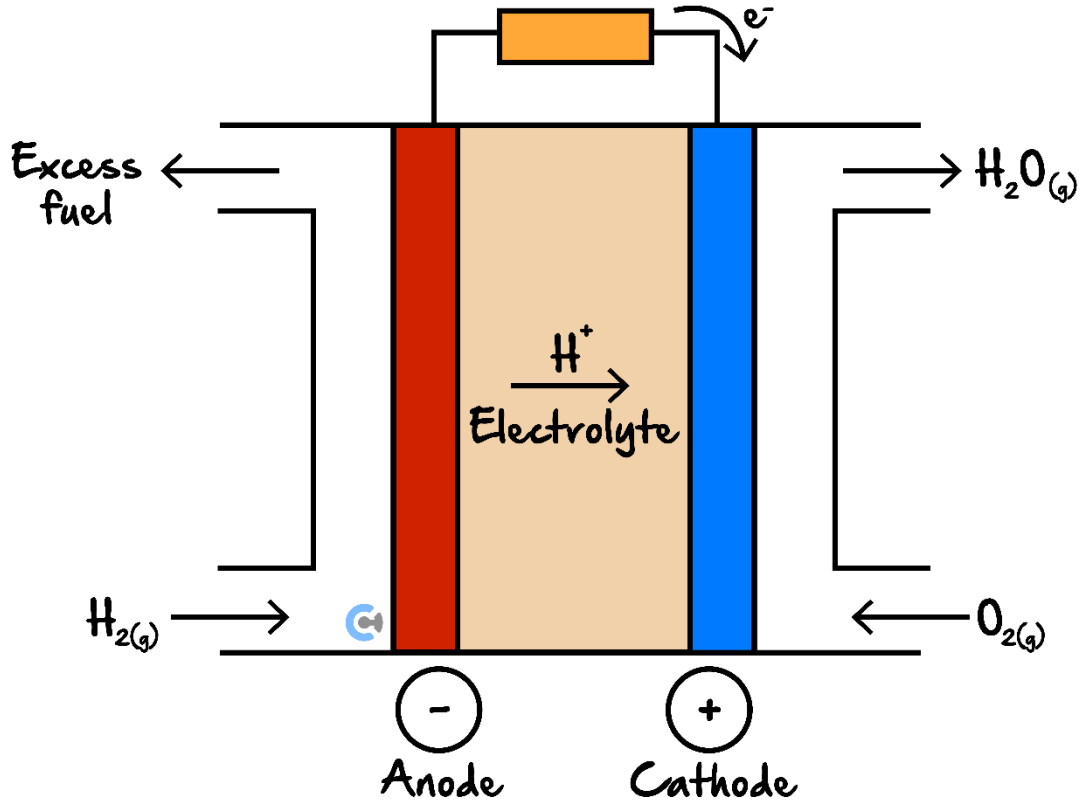
Reaction	Standard electrode potential ($E°$) in volts at 25°C
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$MnO_4^-(aq) + 8H^+ + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$PbO_2(aq) + 4H^+ + 2e^- \rightleftharpoons Pb^{2+}(aq) + 2H_2O(l)$	+1.47
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
_____ $+ 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$2H^+(aq) + 2e^- \rightleftharpoons$ _____	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	−0.28
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	−1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	−1.66

- **Maximum theoretical EMF produced:** $+1.23\ V$.

- Balancing Half-Equations for Carbon Containing Fuels:
  - Unless otherwise specified, assume carbon-containing fuel oxidises into _____.
  - Method used to balance: _____
- All fuel cells have:
  - O_2: [reduces] / [oxidises] at the [cathode] / [anode].
  - Fuel: [reduces] / [oxidises] at the [cathode] / [anode].
- Checking Overall Equation: _____.
  - The electrolyte should **always** _____.

Learning Objective: [1.9.2] - Identify key features of fuel cells including continuous supply, electrolyte movement and properties of electrodes (PICCY)

- **Key Characteristic:** _____



- **Energy Conversion:** _____.
- **Electrolyte Purpose**: Similar to salt bridge – to balance the _____.
- **Electrolyte Movement**: cations → [cathode] / [anode], anions → [cathode] / [anode].
- **Electron Flow:** _____.
- **Properties of Electrodes Acronym:** Stands for... *(Label Below)*

- Reasons for porous electrodes:
  - _____
  - _____

Learning Objective: [1.9.3] - Explain the advantages & disadvantages of fuel cells with reference to green chemistry principles

- **Energy efficiency and pollution in a fuel cell Sample Response**
  - _____ energy conversion from chemical → Electrical energy.
  - [more] / [less] / [same] energy loss, [more] / [less] / [same] energy efficient.
  - [more] / [less] / [same] fuel is required in a fuel cell to produce the [more] / [less] / [same] amount of energy.
  - Less overall CO_2 emissions overall.

Advantages	Disadvantages
Main Advantage: More energy efficient, less fuel required	

- Green Chemistry Principles:
  - _____
  - _____

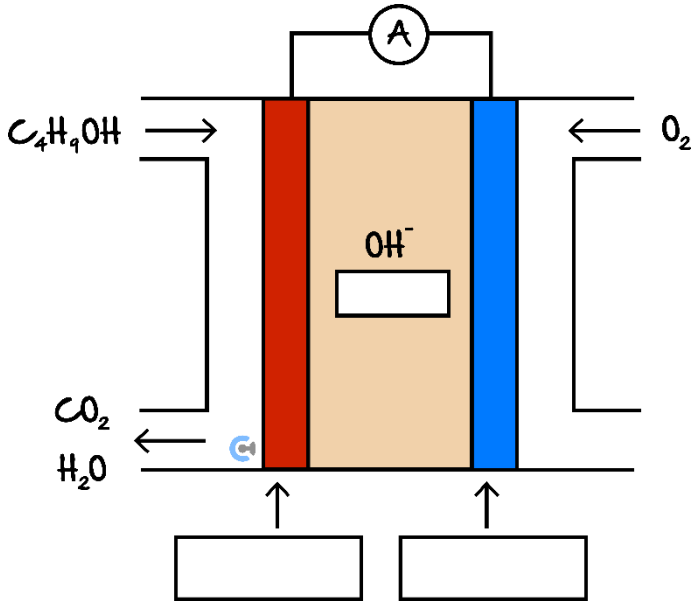
Learning Objective: [1.9.4] - Write fuel cell equations in non-acidic conditions

- Steps to Balance in Alkaline/Basic Conditions:
  - Balance in acidic conditions using _____
  - Balance equation in basic conditions by adding _____ to _____.

Space for Personal Notes

Question 1 (5 marks) **Walkthrough.**

The following fuel cell is considered, including butanol as the fuel which produces carbon dioxide and water at SLC.



a. Label the cathode and anode in the boxes above. (1 mark)

b. Label the direction of movement of the electrolyte above. (1 mark)

c. Write the balanced equation for the overall reaction which takes place. (1 mark)

_____

_____

d. Write the balanced half-equation for the reaction taking place at the:

i. Cathode. (1 mark)

_____

_____

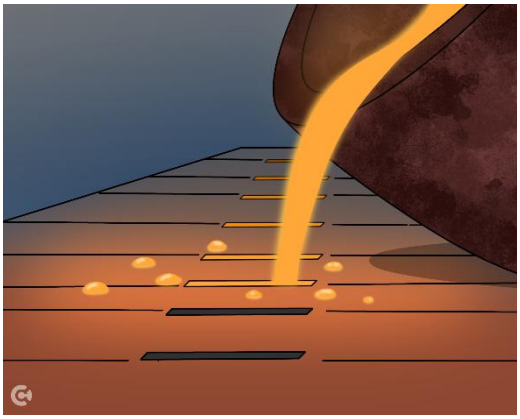
ii. Anode. (1 mark)

_____

_____

Section B: Molten Conditions (Extension) (4 Marks)

Molten



- **Definition:** The liquid form of a solid extremely hazardous substance at elevated temperatures, which is normally in solid form at SLC conditions.
- **Example:**
  - $Ca^{2+}(aq)$ ions are aqueous in state at SLC, meaning that the $Ca^{2+}(aq)$ ion is in the solid state but dissolved in water.
  - $Ca^{2+}(l)$ is considered to be in a molten state as it is now in liquid form, meaning that its temperature was increased until the initially solid Ca^{2+} melted.

Exploration: Molten Conditions

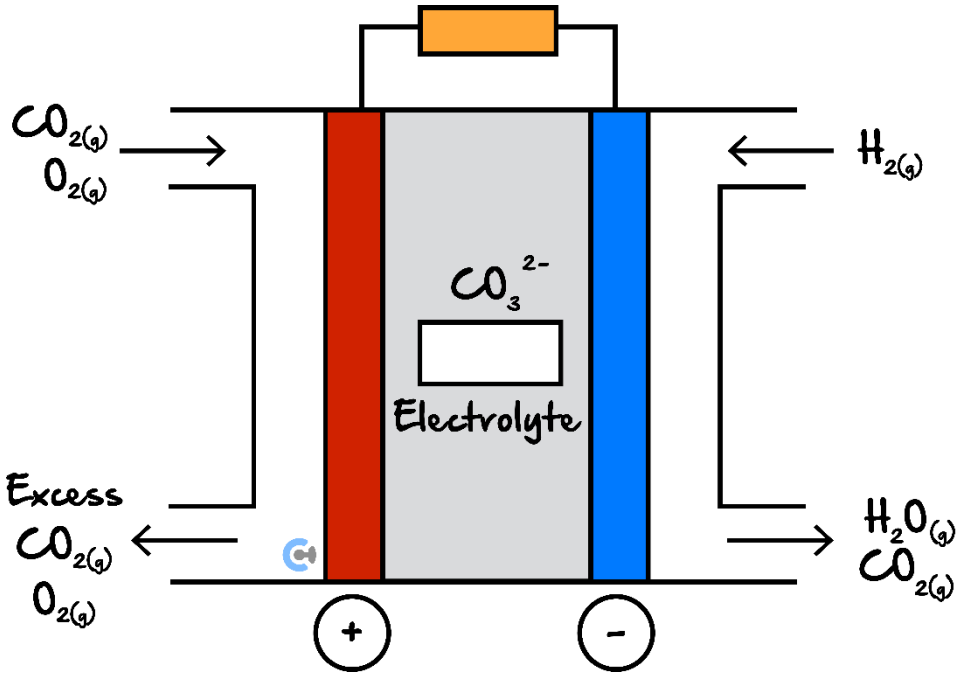
- Is there liquid water present in molten conditions? [Yes] / [No]
- Can we use KOHES to balance half-equations? [Yes] / [No]

Space for Personal Notes

How do we balance the equations then? Let's just have a look at a question together!

Question 2 (4 marks) **Walkthrough.**

Sometimes, hydrogen gas, H_2, are used in molten carbonate fuel cells (MCFCs) to produce electricity. The diagram below depicts the fuel cell in operation.



a. In the diagram above, label the direction of the movement of the electrolyte. (1 mark)

b. Write the balanced redox equation for:

i. The overall reaction. (1 mark)

_____

ii. The half-reaction occurring at the cathode. (1 mark)

_____

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

_____

To double-check, let's add the two half-equations together and see what we get for the overall equation!

NOTE: This is **barely tested**, but in molten conditions (will cover more in electrolysis), there is no water available at all, and thus both H^+ and OH^- are unavailable to be used as the electrolyte.

Definition

Balancing Fuel Cell Equations in Molten Conditions

- Steps:

1. For the half-equation, identify which electrode reaction occurs.
2. Check the **reactants coming in** and the **products coming out** at each electrode.
3. Identify the **direction in which the electrolyte** will move to balance the charge.

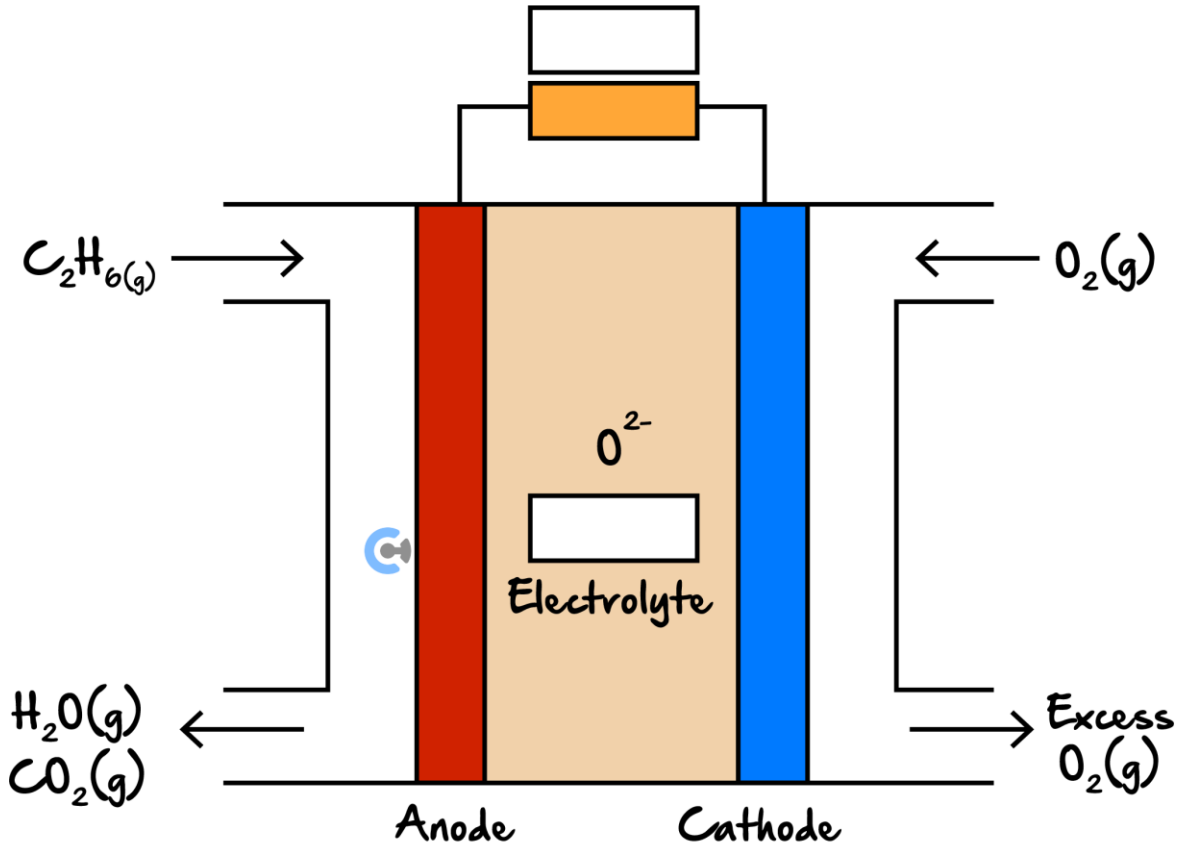
If Electrolyte Moves Towards Electrode	If Electrolyte Moves Away From Electrode
Electrolyte acts as [reactant] / [product]	Electrolyte acts as [reactant] / [product]

4. Balance the equation without using KOHES. Remember to balance out the charge by adding electrons.

Space for Personal Notes

Question 3 Walkthrough.

Sometimes, ethane gas, C_2H_6, are used in solid oxide fuel cells (SOFCs) to produce electricity. The diagram below depicts the fuel cell in operation.



a. In the diagram above, label the direction for the movement of the electrolyte and the electrons in the external circuit.

b. Write the balanced redox equation for:

i. The overall reaction.

_____

ii. The half-reaction occurring at the cathode.

_____

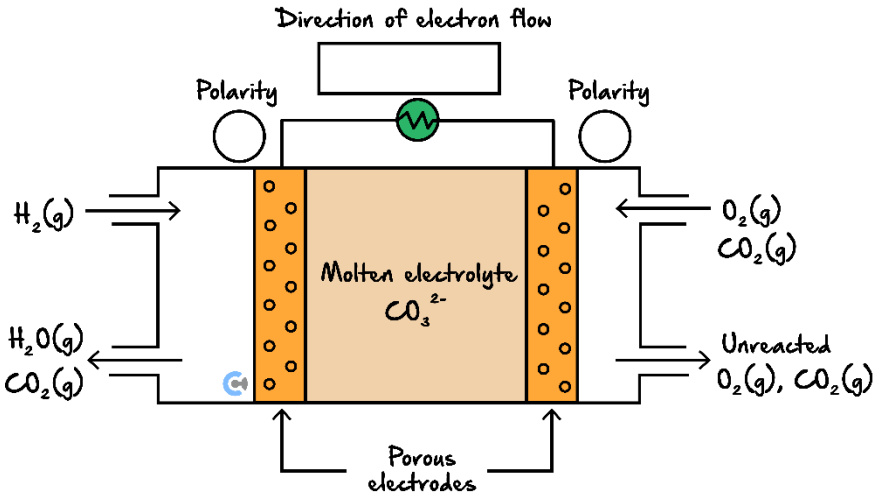
iii. The half-reaction occurring at the anode.

_____

Your Turn!

Question 4

Molten carbonate fuel cells (MCFCs) can be used as a stationary energy source. They operate at temperatures between 600°C and 700°C. The electrolyte in an MCFC is typically a molten mixture of lithium, sodium or potassium carbonates. A simplified diagram of an MCFC is shown below.



At one electrode of the MCFC, carbon dioxide, CO_2, gas reacts with oxygen, O_2, gas to form carbonate ions. At the other electrode, hydrogen, H_2, gas reacts with molten carbonate ions to form steam and CO_2 gas.

a. On the diagram above:

i. Label the polarity of the electrodes in the circles provided.

ii. Show the direction of electron flow in the external circuit by drawing an arrow in the box above the cell.

b.

i. Write a balanced half-equation for the production of carbonate ions from CO_2 and O_2.

_____

_____

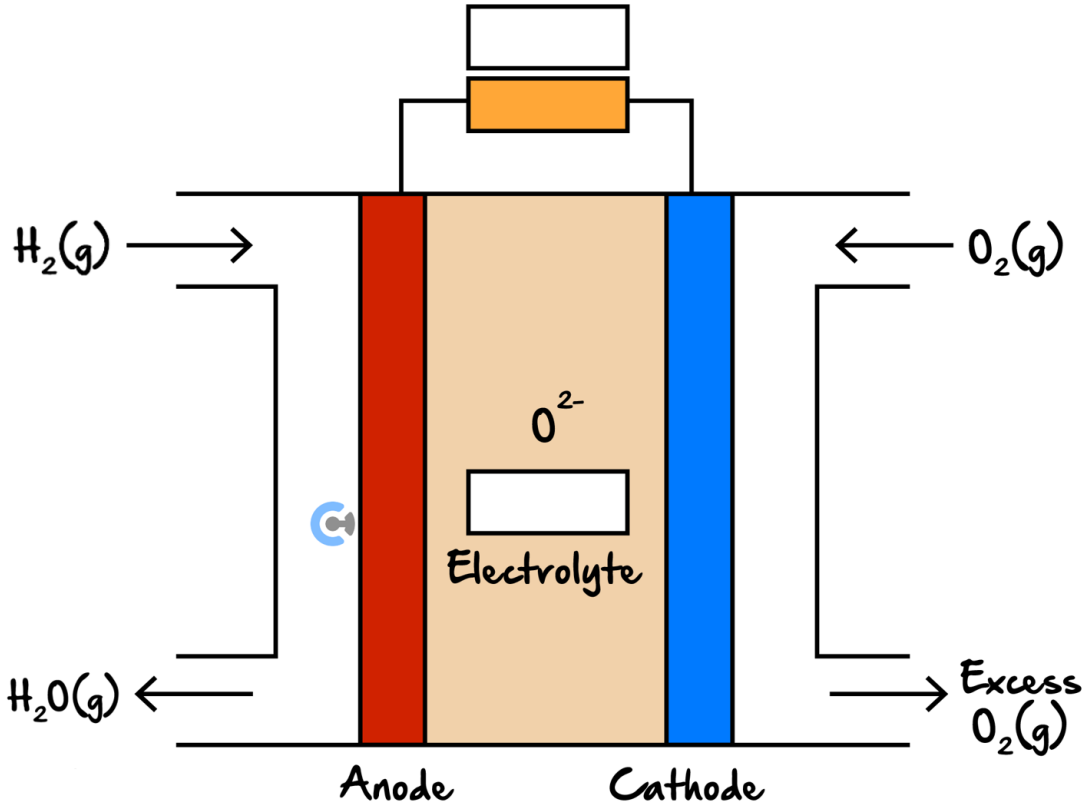
ii. Write the balanced half-equation occurring at the other electrode.

_____

_____

Question 5

Sometimes, hydrogen gas, H_2, are used in solid oxide fuel cells (SOFCs) to produce electricity. The diagram below depicts the fuel cell in operation.



a. In the diagram above, label the direction for the movement of the electrolyte and the electrons in the external circuit.

b. Write the balanced redox equation for:

i. The overall reaction.

_____

ii. The half-reaction occurring at the cathode.

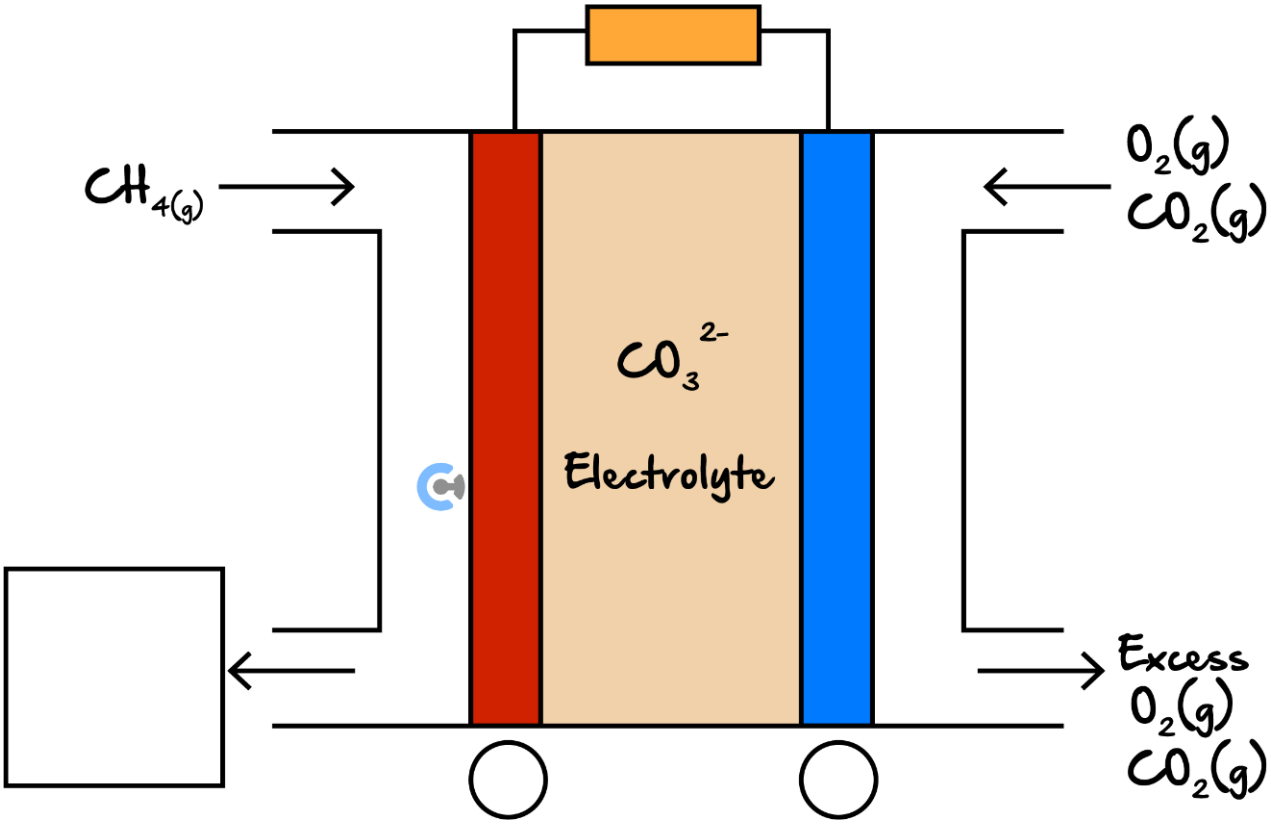
_____

iii. The half-reaction occurring at the anode.

_____

Question 6

Methane gas, CH_4, can also be used in molten carbonate fuel cells (MCFCs) to produce electricity. The diagram below depicts the fuel cell in operation.



a. In the diagram above, label the polarities of the electrodes in the boxes provided.

b. Write the balanced redox equation for:

i. The overall reaction.

_____

ii. The half-reaction occurring at the cathode.

_____

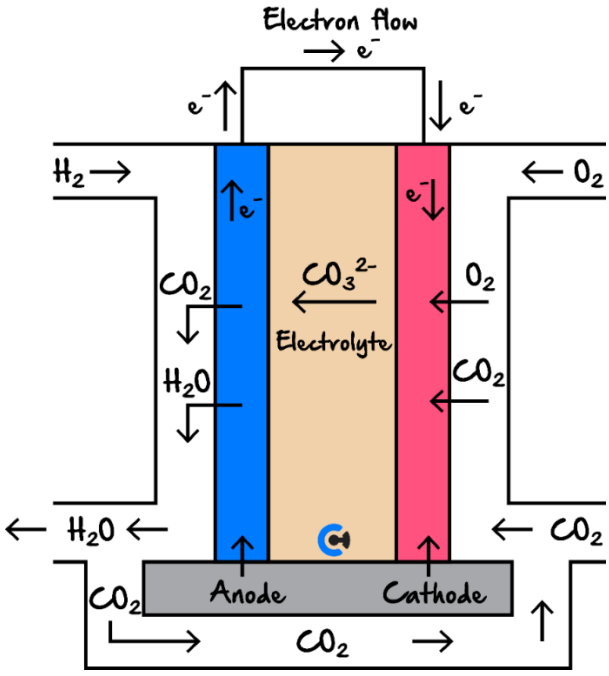
iii. The half-reaction occurring at the anode.

_____

c. In the box in the diagram above, label the expected product(s) from the left electrode.

The following information applies to the two questions that follow.

Scientists have developed a new type of hydrogen fuel cell for use on a large scale in factories and manufacturing plants, as shown in the diagram below. The fuel cell operates at 600°C.



Question 7 Additional Question.

The equation for the half-cell reaction occurring at the positive electrode in the diagram above is:

A. $2CO_2 + 4H_2O + 4e^- \rightarrow O_2 + 2{CO_3}^{2-} + 8H^+$

B. $H_2 + {CO_3}^{2-} \rightarrow CO_2 + H_2O + 2e^-$

C. $H_2O + CO_2 + 2e^- \rightarrow {CO_3}^{2-} + H_2$

D. $O_2 + 2CO_2 + 4e^- \rightarrow 2{CO_3}^{2-}$

Question 8 Additional Question.

Which one of the following statements is accurate for this type of hydrogen fuel cell?

A. Heat is a by-product of this hydrogen fuel cell.

B. O_2 is oxidised to produce CO_2.

C. The enthalpy of the reactants is less than the enthalpy of the products.

D. CO_2 is released into the environment.

Section C: Warmup Questions (13 Marks)

INSTRUCTION: 13 Marks. 8 Minutes Writing.

Question 9 (1 mark)

In a hydrogen fuel cell:

A. A current is supplied and water is the only product.

B. The electrodes are often porous and act as catalysts.

C. The percentage energy conversion is greater than in an internal combustion engine so energy is produced at a faster rate.

D. It is difficult to store the hydrogen and oxygen gas as they are costly to compress.

Question 10 (1 mark)

In an oxygen/methanol fuel cell:

A. The oxidant is methanol and it is oxidised at the anode.

B. The oxidant is methanol and it is reduced at the cathode.

C. The reductant is methanol and it is oxidised at the anode.

D. The reductant is methanol and it is reduced at the cathode.

Space for Personal Notes

Question 11 (2 marks)

Practice balancing the following half-equations in an **acidic** environment. You can assume any carbon-containing reactants fully oxidise into carbon dioxide unless otherwise specified. **Include states.**

a. C_2H_6. (1 mark)

b. C_3H_7OH. (1 mark)

Question 12 (3 marks)

Practice balancing the following half-equations in an **alkaline** environment. You can assume any carbon-containing reactants fully oxidise into carbon dioxide unless otherwise specified. **Include states.**

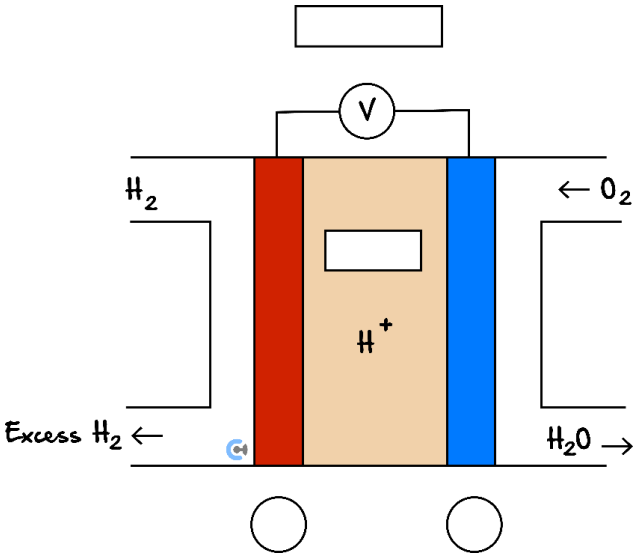
a. C_3H_7OH. (1.5 marks)

b. $O_2 \rightarrow H_2O$. (1.5 marks)

Space for Personal Notes

Question 13 (6 marks)

Use the diagram of the hydrogen fuel cell below for the following questions.



a.

i. Label the polarity of the electrodes in the circles provided above. (1 mark)

ii. Draw arrows in the boxes provided to indicate the direction of the electrolyte ion flow and electron flow. (1 mark)

b. Write the overall equation for this fuel cell. (1 mark)

_____

c. Without using the electrochemical series, write the two half-equations occurring:

i. At the cathode. (1 mark)

_____

ii. At the anode. (1 mark)

_____

d. State the maximum theoretical EMF produced by this cell. (1 mark)

_____

Section D: Ramping Up (10 Marks)

INSTRUCTION: 10 Marks. 8 Minutes Writing.

Question 14 (1 mark)

The advantage of using methane in a fuel cell rather than direct combustion is:

A. Methane is able to react more quickly in a fuel cell and therefore provides more power.

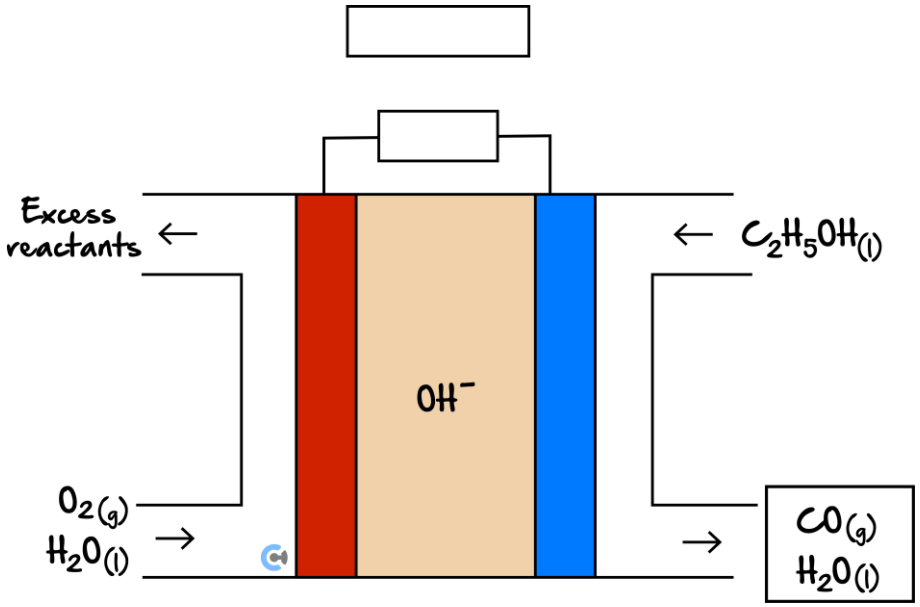
B. Less fuel is needed to obtain the same amount of energy output.

C. Fuel cells are cheaper to produce than an internal combustion engine.

D. It is easier to store methane for a fuel cell than to store methane for an internal combustion engine.

Question 15 (9 marks)

An ethanol fuel cell operating in **basic** conditions is shown below. The ethanol is known to oxidise into carbon monoxide, as shown below.



a. Label the direction of electron flow in the external circuit in the box provided. (1 mark)

b. Write the overall reaction taking place. (1 mark)

_____

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

_____

_____

_____

d. Write the balanced cathode half-equation. (1 mark)

_____

e. State one disadvantage of a fuel cell. Justify your answer. (1 mark)

_____

_____

_____

f. One green chemistry principle that is relevant to this fuel cell is 'design for energy efficiency'. State one other green chemistry principle which applies to the operation of this fuel cell. Justify your answer, and include any relevant equation(s). Use item 26.ii. of the Data Book. (3 marks)

_____

_____

_____

_____

_____

Space for Personal Notes

Section E: Getting Trickier (6 Marks)

INSTRUCTION: 6 Marks. 5 Minutes Writing.

Question 16 (2 marks)

The overall equation for the methane–oxygen fuel cell, operating in acid conditions, is:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

a. The half equation for the reaction occurring at the cathode will be: (1 mark)

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

B. $CO_2(g) + 2H_2O(l) \rightarrow CH_4(g) + 2O_2(g)$

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

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

b. This cell will require: (1 mark)

A. Porous electrodes and potassium hydroxide as the electrolyte.

B. Hydrogen gas at one electrode and oxygen at the other.

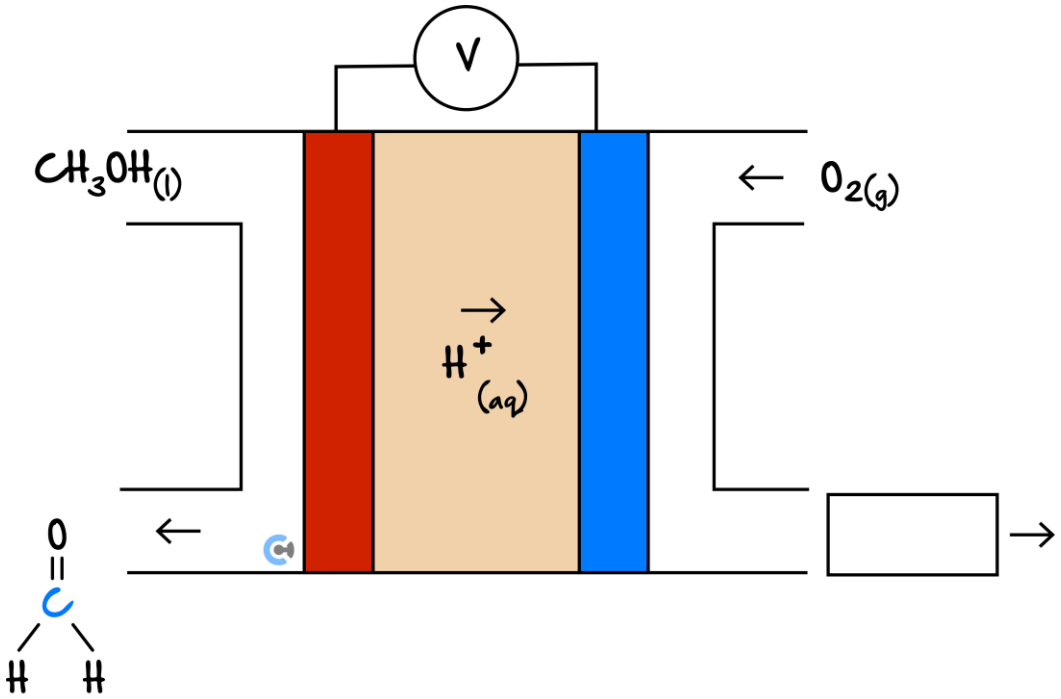
C. Porous electrodes and a continuous supply of reactants.

D. Non-reactive and non-porous electrodes.

Space for Personal Notes

Question 17 (4 marks)

A methanol fuel cell operating in **acidic** conditions is shown below. The methanol is known to oxidise into methanal, which is shown below.



a. Write the half-equation occurring in the half-cell in which the oxidant is present. (1 mark)

_____

b. Write the balanced half-equation for the other species. (1 mark)

_____

c. Fill in the box provided by stating the product(s) formed in the relevant half-cell. (1 mark)

d. Hence, or otherwise, write the equation for the overall reaction taking place in this cell. (1 mark)

_____

_____

Let's take a BREAK!

Section F: VCAA-Level Questions I (11 Marks)

INSTRUCTION: 11 Marks. 30 Seconds Reading. 10 Minutes Writing.

Question 18 (11 marks)

Inspired from VCAA Chemistry Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/2021chem-w.pdf#page=22

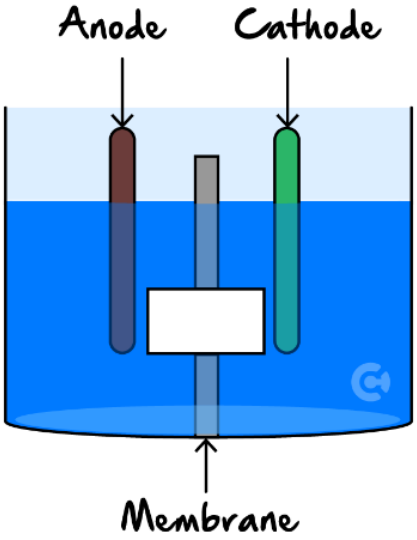
a. What is a fuel cell? (2 marks)

_____

_____

_____

The diagram below shows part of an ethanol fuel cell, which produces carbon dioxide and uses an acidic electrolyte.



b.

i. Name the species that crosses the membrane to enable fuel cell operation. (1 mark)

_____

ii. In the box provided on the diagram above, indicate the direction of flow of the species named in **part b.i.** (1 mark)

c. Write the equation for the reaction that occurs at the anode of an ethanol fuel cell, which produces carbon dioxide and uses an acidic electrolyte. (1 mark)

_____

d. If an ethanol fuel cell was operating at 25°C and at 100% efficiency, how much electrical energy could be produced from 1.0 g of ethanol? (1 mark)

_____

_____

e. Identify two aspects of electrode design that can improve the efficiency of a fuel cell. (2 marks)

_____

_____

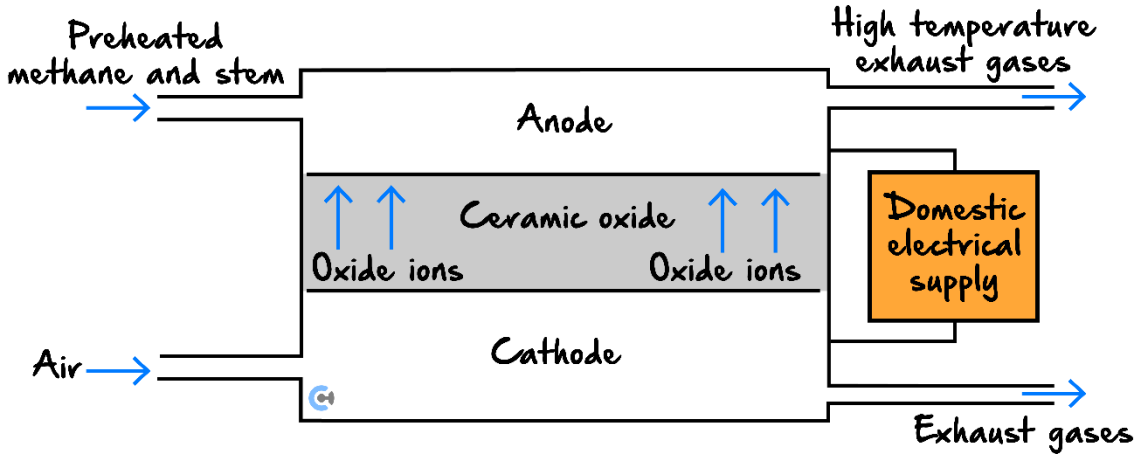
_____

f. State how the environmental impact of using an ethanol fuel cell operating at 100% efficiency can be minimised. (1 mark)

_____

_____

g. A Victorian company produces solid oxide fuel cells for use in the home. These fuel cells use natural gas to produce electricity through an electrochemical process summarised in the diagram below.



i. Write an equation for the reaction at the cathode where atmospheric oxygen is converted to oxide ions. (1 mark)

_____

_____

ii. A complex series of reactions takes place at the anode. These may be summarised by the half-equation:

$$4O^{2-}(g) + CH_4(g) \rightarrow CO_2(g) + 2H_2O(g) + 8e^-$$

Write an equation that represents the overall reaction that takes place in this fuel cell. (1 mark)

_____

_____

_____

Space for Personal Notes

Section G: Multiple Choice Questions (9 Marks)

INSTRUCTION: 9 Marks. 9 Minutes Writing.

Question 19 (1 mark)

The cathode reaction for a particular **alkaline** fuel cell is given below.

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The only product of the overall fuel cell reaction is water, H_2O.

The half-equation that represents the anode reaction is:

A. $H_2 \rightarrow 2H^+ + 2e^-$

B. $H_2 + O^{2-} \rightarrow H_2O + 2e^-$

C. $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

D. $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$

Question 20 (1 mark)

Consider an alkaline hydrogen fuel cell.

Which one of the following will reduce the amount of usable energy produced per kilogram of fuel entering the fuel cell?

A. Supplying oxygen in excess.

B. Increasing the porosity of the cathode.

C. Reducing the operating temperature from 40°C to 20°C.

D. Reducing the rate at which oxide ions move through the electrolyte.

Space for Personal Notes

Question 21 (1 mark)

The reactions occurring in an experimental methanol fuel cell are shown below.

$$CH_3OH(g) + 5OH^-(aq) \rightarrow HCOO^-(aq) + 4H_2O(l) + 4e^-$$

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

During the operation of the cell, the pH of the solution near the positive electrode would initially:

A. Increase.

B. Decrease.

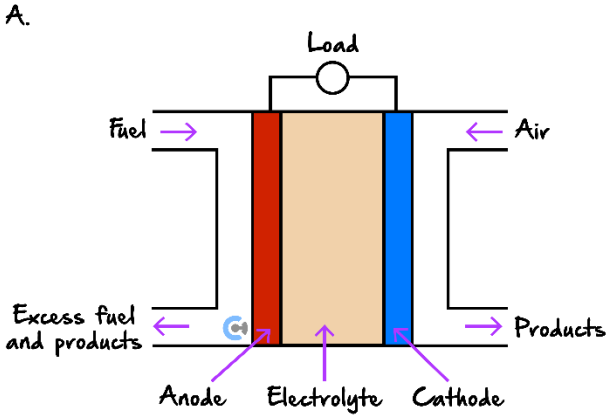
C. Remain unchanged.

D. Decrease then increase steadily as diffusion occurs.

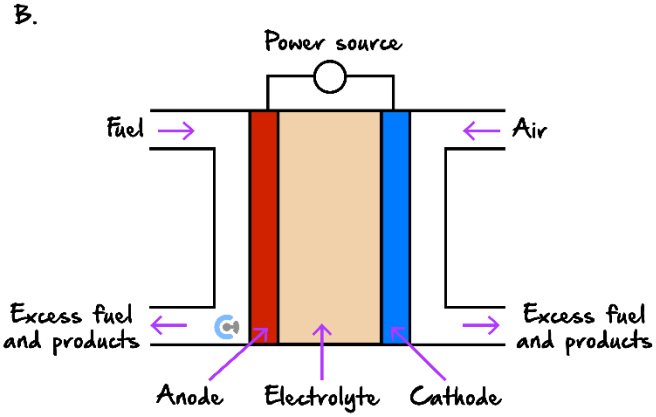
Question 22 (1 mark)

Which one of the following diagrams shows the common design features of a fuel cell?

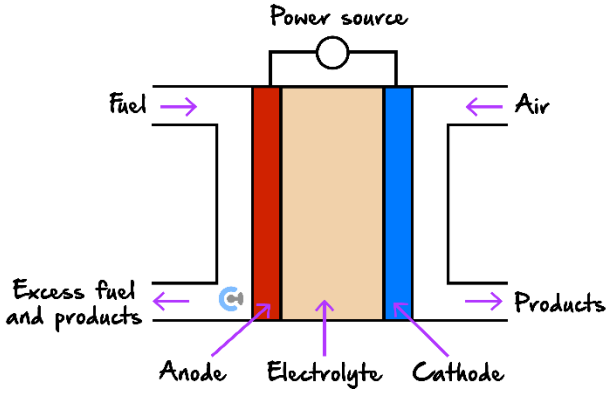
A.



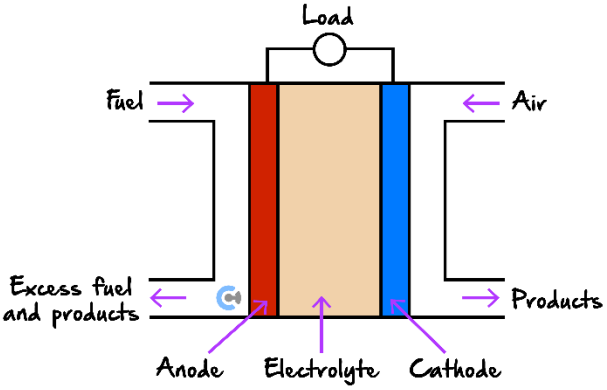
B.



C.



D.



Question 23 (1 mark)

Which of the following is a disadvantage of fuel cells compared to conventional batteries?

A. Higher energy efficiency.

B. Lower greenhouse gas emissions.

C. Requirement for a continuous supply of fuel.

D. Ability to operate silently.

Question 24 (1 mark)

Which statement best describes an advantage of fuel cells over traditional galvanic cells?

A. Fuel cells have a finite lifespan due to electrode degradation.

B. Fuel cells can operate indefinitely as long as fuel and oxidant are supplied.

C. Fuel cells generate more waste products.

D. Fuel cells are less efficient at converting chemical energy to electrical energy.

Question 25 (1 mark)

Fuel cells do not store energy; they convert energy directly and continuously to electrical energy. A fuel cell may be constructed using methanol and oxygen contained in an alkaline electrolyte. The overall reaction for the methanol/oxygen fuel cell is:

$$2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l)$$

If the reaction at the cathode is $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ then the reaction at the anode would be:

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

B. $CH_3OH(l) + 6OH^-(aq) \rightarrow 2CO_2(g) + 5H_2O(aq) + 6e^-$

C. $CH_3OH(l) + 3O_2(g) \rightarrow CO_2(g) + 3H_2O(l)$

D. $CH_3OH(l) \rightarrow CO(g) + 4H^+(aq) + 4e^-$

Question 26 (1 mark)

What is a common challenge associated with the widespread adoption of hydrogen fuel cells for vehicles?

A. The high availability of hydrogen gas as a fuel source.

B. The ease of storing and transporting hydrogen gas.

C. The low cost of producing hydrogen in an environmentally friendly manner.

D. The difficulty of storing and transporting hydrogen due to its low density.

Question 27 (1 mark)

Compared to conventional galvanic cells, fuel cells:

A. Have lower efficiency due to internal resistance.

B. Can only generate electricity when the fuel is a solid material.

C. Do not require an external circuit to complete the flow of electrons.

D. Produce water as a byproduct when hydrogen is used as the fuel.

Space for Personal Notes

Section H: VCAA-Level Questions II (9 Marks)

INSTRUCTION: 9 Marks. 30 Seconds Reading. 8 Minutes Writing.

Question 28 (9 marks)

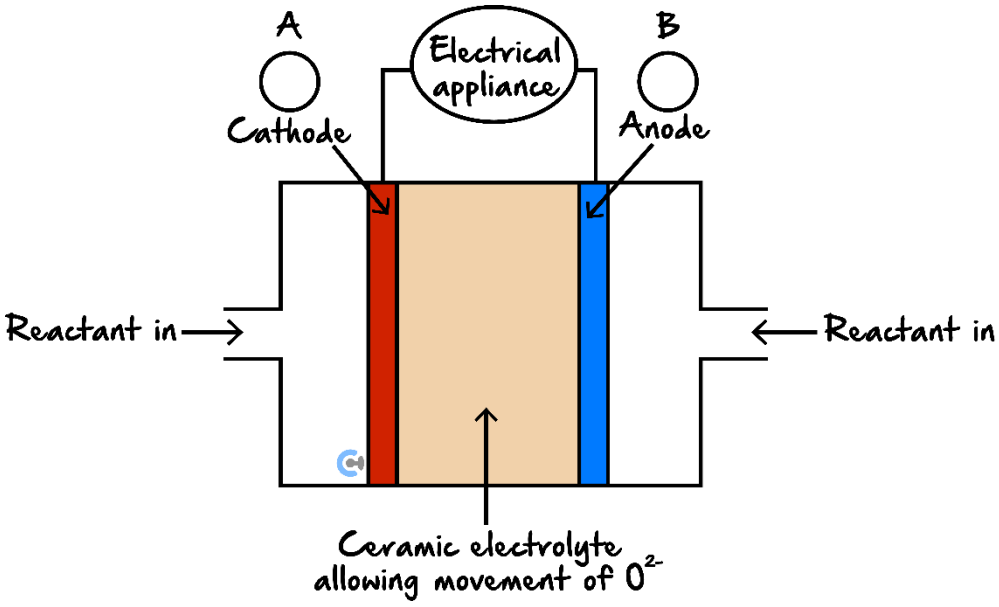
Inspired from VCAA Chemistry Exam 2006
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2006chem2-w.pdf#page=14

An Internet site reporting the latest developments in fuel cell technology describes a cell that uses a solid ceramic material as the electrolyte, hydrogen gas, and oxygen gas as the reactants.

Key features of this cell are:

- Water is the only product from the cell reaction.
- The ceramic material allows the movement of oxide ions (O^{2-}).
- The reaction at the anode is $H_2(g) + O^{2-}(\text{in ceramic}) \rightarrow H_2O(l) + 2e^-$.
- Operation at very high temperatures of over $1000°C$ means that precious metal catalysts are not required.

A representation of the cell providing electricity for an appliance is shown in the diagram below.



a. What distinguishes a fuel cell from a galvanic cell such as a dry cell or lead-acid battery? (1 mark)

_____

_____

b. On the diagram above:

i. In circles *A* and *B*, indicate the polarity of the cathode and anode. (1 mark)

ii. Show, by using an arrow, the direction of electron flow in the external circuit. (1 mark)

c. Write an equation for each of the following reactions. You are not required to show states in these two equations.

i. The overall cell reaction. (1 mark)

_____

ii. The reaction at the cathode. (1 mark)

_____

d. State and explain the **two** differences between fuel cell electrodes and galvanic cell electrodes. (2 marks)

_____

_____

_____

_____

e. Describe two dangers of the reactants used in this fuel cell. (2 marks)

_____

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