Mastering Chemistry

- Book 2B
- Topic 5 Redox Reactions,
  Chemical Cells and Electrolysis

Content

21.1 Chemical cells with inert electrodes (p.107)

- In situations where reactants and products cannot serve as the electrode material, an **inert electrode (惰性電極)** (for example, carbon or platinum which does not take part in the redox reaction) must be used. The inert electrode provides a surface for the reaction to occur.
- Look at the reaction between acidified permanganate ions and iodide ions:

$$2MnO_4^-(aq) + 16H^+(aq) + 10I^-(aq) \longrightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 5I_2(aq)$$

Half equation for the reduction:

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$$

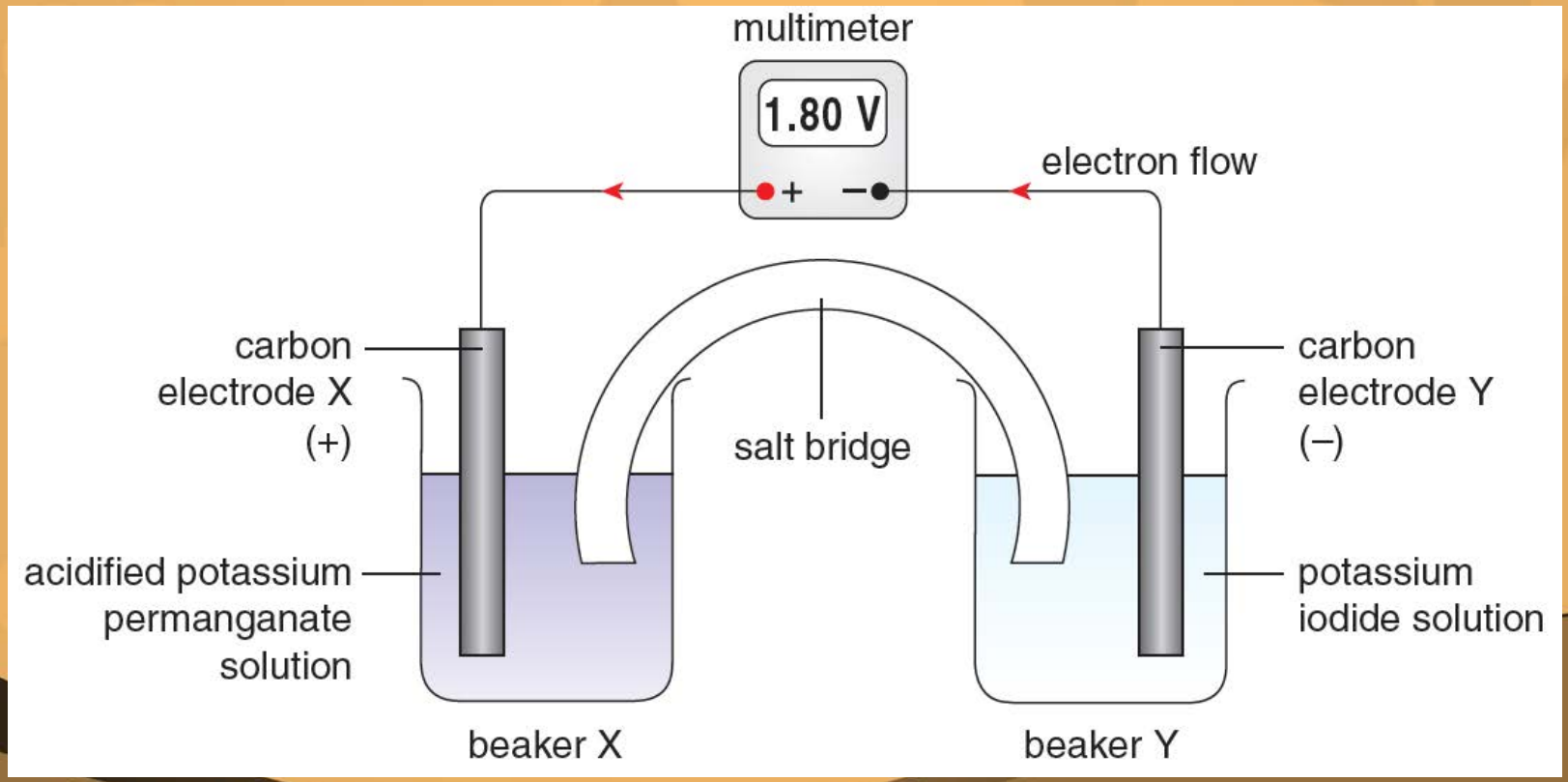
Half equation for the oxidation:

$$2I^-(aq) \longrightarrow I_2(aq) + 2e^-$$

Investigating redox reactions in chemical cells *Ref.*

21.1 Chemical cells with inert electrodes (p.107)

- Neither the reactants nor the products can be used as an electrode material. Therefore, the two half cells are set up with carbon electrodes.



A chemical cell with carbon electrodes

21.1 Chemical cells with inert electrodes (p.107)

The electrode at which oxidation occurs is the anode (陽極).
The electrode at which reduction occurs is the cathode (陰極).

- Electrode Y is the anode as oxidation occurs here. Electrons produced by the oxidation process are transferred to the surface of carbon electrode Y, making the electrode negatively charged.
- Electrode X is the cathode as reduction occurs here. The reduction process removes electrons from the surface of carbon electrode X, making the electrode positively charged.

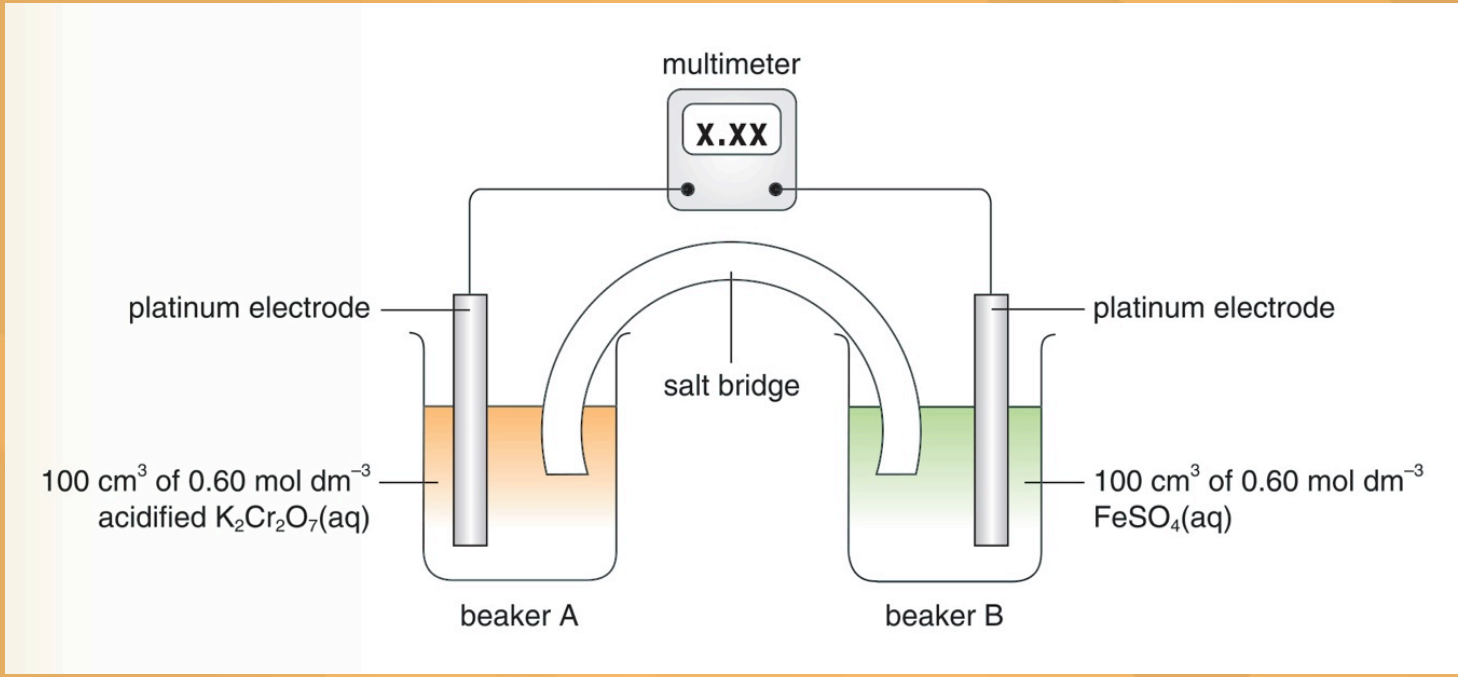
21.1 Chemical cells with inert electrodes (p.107)

- In beaker X, the acidified permanganate ions are reduced to manganese(II) ions. Hence the purple colour of the solution fades.
- In beaker Y, the iodide ions are oxidised to iodine. Hence the colourless solution turns brown.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.1)

Consider the chemical cell shown below.



The colour of the acidified $K_2Cr_2O_7$(aq) in beaker A changes from orange to green gradually.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.1) (continued)

a) Write the half equation for the change that occurs in beaker A. Explain whether the $Cr_2O_7^{2-}(aq)$ ion is oxidised or reduced.

b) What will be observed in beaker B after the cell has operated for some time? Write the half equation for the change that occurs.

c) Identify the direction of electron flow in the external circuit.

d) After the cell has operated for some time, the concentration of $K_2Cr_2O_7(aq)$ drops to 0.56 mol dm^{-3}. What is the concentration of $FeSO_4(aq)$ at this time?

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.1) (continued)

A

a) $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$
The oxidation number of Cr decreases from +6 to +3. Hence the $Cr_2O_7^{2-}(aq)$ ion is reduced.

b) The colour of the $FeSO_4(aq)$ in beaker B changes from pale green to yellow-brown gradually.
$Fe^{2+}(aq) \longrightarrow Fe^{3+}(aq) + e^-$

c) Electrons flow from $FeSO_4(aq)$ to $K_2Cr_2O_7(aq)$ in the external circuit.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.1) (continued)

A

d) Number of moles of $Cr_2O_7^{2-}(aq)$ ions reacted = $(0.60 - 0.56)$ mol $dm^{-3} \times \frac{100}{1\,000}$ dm^3

$= 4.0 \times 10^{-3}$ mol

Number of moles of electrons gained by $Cr_2O_7^{2-}(aq)$ ions

$= 6 \times 4.0 \times 10^{-3}$ mol

$= 2.4 \times 10^{-2}$ mol

= number of moles of electrons lost by $Fe^{2+}(aq)$ ions

= number of moles of $Fe^{2+}(aq)$ ions reacted

$$\text{Concentration of } FeSO_4(aq) \text{ at this time} = \frac{(0.60 \times \frac{100}{1\,000} - 2.4 \times 10^{-2}) \text{ mol}}{\frac{100}{1\,000}\ dm^{-3}}$$

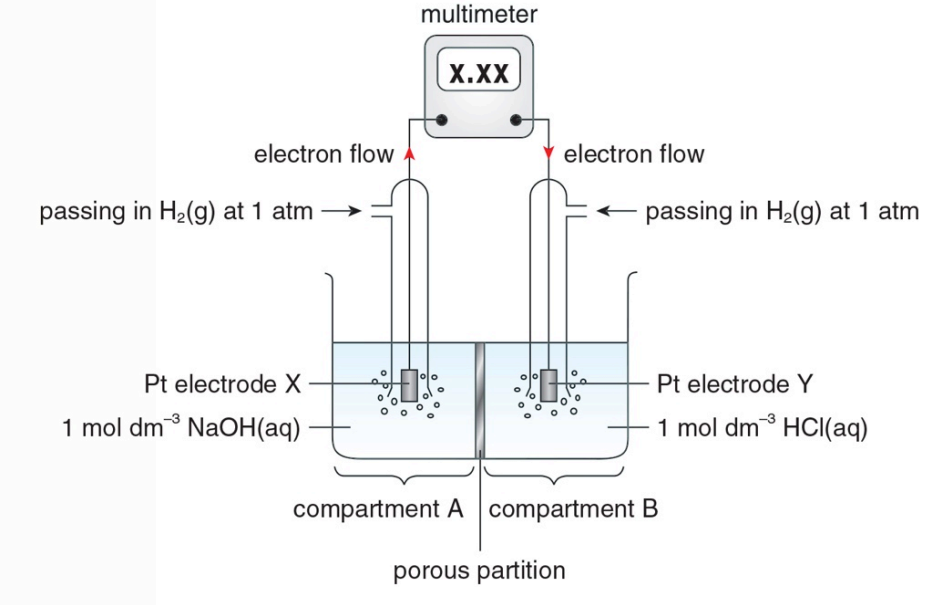
$= 0.36$ mol dm^{-3}

$\therefore$ the concentration of $FeSO_4(aq)$ at this time is 0.36 mol dm^{-3}.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.2)

Consider the chemical cell shown below.



The overall redox equation for the chemical cell is

$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$

Electrons flow from electrode X to electrode Y in the external circuit.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.2) (continued)

a) The pH of the solution in compartment A decreases gradually. Write the half equation for the change that occurs at electrode X.

b) Write the half equation for the change that occurs at electrode Y.

c) Explain whether electrode X or Y is the anode.

d) Explain whether the pH of the solution in compartment B would increase or decrease gradually.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.2) (continued)

A

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

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

c) Electrode X
Oxidation occurs at electrode X.

d) The pH of the solution in compartment B would increase gradually as the concentration of hydrogen ions in the solution decreases.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.3)

When a secondary cell with a cadmium electrode is discharging, the two half reactions that occur are:

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

$$NiO(OH)(s) + H_2O(l) + e^- \longrightarrow Ni(OH)_2(s) + OH^-(aq)$$

a) Write the overall equation for the reaction that occurs when the cell is discharging.

b) Decide whether the cadmium electrode is the positive or negative electrode.

c) Give the half equation for the change that occurs at the cadmium electrode when the cell is being recharged.

21.1 Chemical cells with inert electrodes (p.107)

Q (Example 21.3) (continued)

A

a) Multiply the second equation by 2. Then add the two half equations together:

$$Cd(s) + 2OH^-(aq) \longrightarrow Cd(OH)2(s) + 2e^-$$
$$2NiO(OH)(s) + 2H2O(l) + 2e^- \longrightarrow 2Ni(OH)2(s) + 2OH^-(aq)$$

$$Cd(s) + 2NiO(OH)(s) + 2H_2O(l) \longrightarrow Cd(OH)_2(s) + 2Ni(OH)_2(s)$$

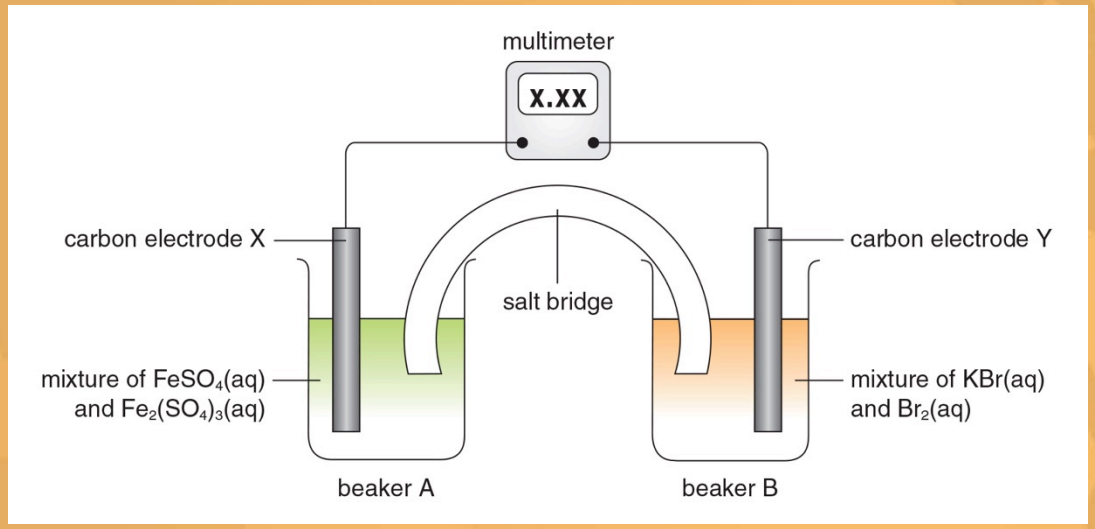
b) The cadmium electrode is the negative electrode.

c) When the cell is being recharged, the reverse change occurs at each electrode.
Hence the half equation for the change that occurs at the cadmium electrode is:
$Cd(OH)_2(s) + 2e^- \longrightarrow Cd(s) + 2OH^-(aq)$

21.1 Chemical cells with inert electrodes (p.107)

Practice 21.1

1 Consider the experimental set-up shown below.



It is known that $Br_2(aq)$ is a stronger oxidising agent than $Fe^{3+}(aq)$ ion.

a) Write the half equation for the change that occurs in beaker A.

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

21.1 Chemical cells with inert electrodes (p.107)

Practice 21.1 (continued)

b) What will be observed in beaker B after the cell has operated for some time? Write the half equation for the change that occurs.

The colour of the mixture of KBr(aq) and $Br_2(aq)$ fades.

The yellow-brown bromine changes to colourless bromide ions.

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

c) Explain whether electrode X or Y is the anode.

Electrode X is the anode.

Oxidation occurs at electrode X.

21.1 Chemical cells with inert electrodes (p.107)

Practice 21.1 (continued)

2 Silver oxide cells are used in hearing aids. The equation below shows the overall reaction that occurs in the cell when the cell is discharging.

$Zn(s) + Ag_2O(s) \longrightarrow ZnO(s) + 2Ag(s)$

a) Deduce, in terms of the change in oxidation number, the oxidising agent in the cell.

Ag_2O is the oxidising agent in the cell.

The oxidation number of Ag decreases from +1 to 0.

b) Complete the half equation for the change that occurs at the anode of the cell.

$Zn(s) + \underline{\ 2\ }OH^-(aq) \longrightarrow ZnO(s) + H_2O(l) + \underline{\ 2\ }e^-$

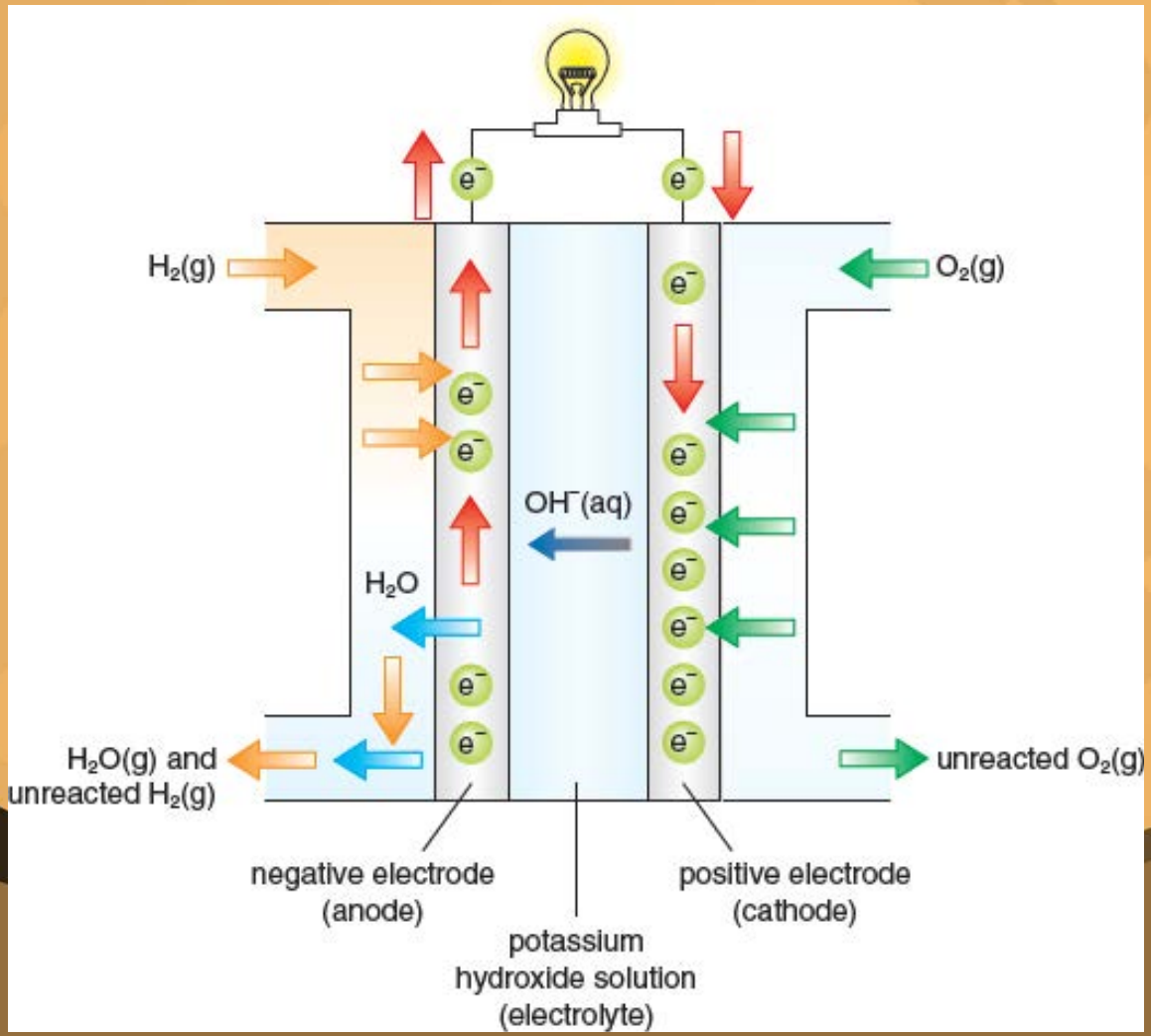
21.2 Hydrogen-oxygen fuel cell (p.114)

- A **fuel cell (燃料電池)** is a chemical cell in which the reactants can be supplied continuously and the products of the cell reaction are continuously removed.
- Like a dry cell, a fuel cell uses a chemical reaction to produce electrical energy. But unlike a dry cell, it can be refueled on an ongoing basis.
- The most common fuel cells are based on the reaction of hydrogen and oxygen to produce water. Most of the energy released in the reaction is converted to electrical energy.

A hydrogen-powered car

21.2 Hydrogen-oxygen fuel cell (p.114)

- A simplified diagram of a **hydrogen-oxygen fuel cell (氫氧燃料電池)** with an alkaline electrolyte.



Fuel cell *Ref.*

21.2 Hydrogen-oxygen fuel cell (p.114)

- The negative electrode is porous graphite coated with nickel. The positive electrode is porous graphite coated with nickel and nickel(II) oxide.
- The nickel and nickel(II) oxide act as catalysts for the reactions that occur on the surfaces of the electrodes. The electrolyte is potassium hydroxide solution.
- Hydrogen (the fuel) is supplied into the negative electrode (or anode) compartment. It diffuses through the porous electrode and reacts with hydroxide ions to form water and a source of electrons to the external circuit:

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

21.2 Hydrogen-oxygen fuel cell (p.114)

- Oxygen (the oxidant) is supplied into the positive electrode (or cathode) compartment. It diffuses through the porous electrode and accepts electrons from the external circuit, forming hydroxide ions:

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

- Combination of the half equations gives the overall redox equation:

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

21.2 Hydrogen-oxygen fuel cell (p.114)

Advantages of hydrogen-oxygen fuel cell

- Only water is formed. No pollutants!
- It is a very efficient way of converting chemical energy into electrical energy. About 70% of the energy is converted compared with only 45% in a power station using fossil fuels.
- It does not need recharging.
- It can have a range of sizes for different uses.

21.2 Hydrogen-oxygen fuel cell (p.114)

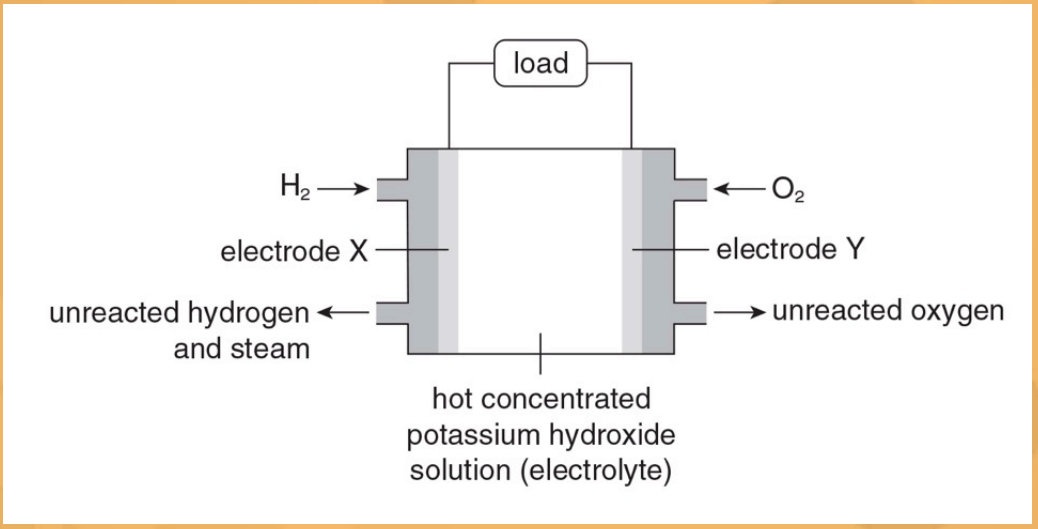
Problems associated with hydrogen-oxygen fuel cell

- It is relatively expensive to produce them.
- Hydrogen is explosive, so great care has to be taken when transporting it.
- Hydrogen is difficult to be stored.
- At the moment most of the hydrogen is produced from methane, which is a finite resource. Hydrogen can also be produced using renewable resources, but this is an expensive process. Integrated wind-to-hydrogen plants, using electrolysis of water, are technologies being explored.
- It does not work well at low temperatures.

21.2 Hydrogen-oxygen fuel cell (p.114)

Practice 21.2

A fuel cell produces electrical energy by the oxidation of a fuel by oxygen. A diagram of a hydrogen-oxygen fuel cell is shown below. The electrolyte is concentrated potassium hydroxide solution.



a) i) Explain whether electrode X is the anode or cathode.

Electrode X is the anode.

Hydrogen reacts with hydroxide ions to form water at electrode X. Oxidation occurs here.

21.2 Hydrogen-oxygen fuel cell (p.114)

Practice 21.2 (continued)

a) ii) Write the half equation for the change that occurs at electrode X.

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

b) Write the half equation for the change that occurs at electrode Y.

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

c) Hydrogen-oxygen fuel cells produce water.
Water is not a pollutant. However, fuel cells still cause pollution. Suggest how fuel cells can cause pollution.

Burning of fossil fuels associated with fuel cell production / manufacture of raw materials causes pollution.
Fuel cells contain poisonous catalyst (which needs to be disposed of).

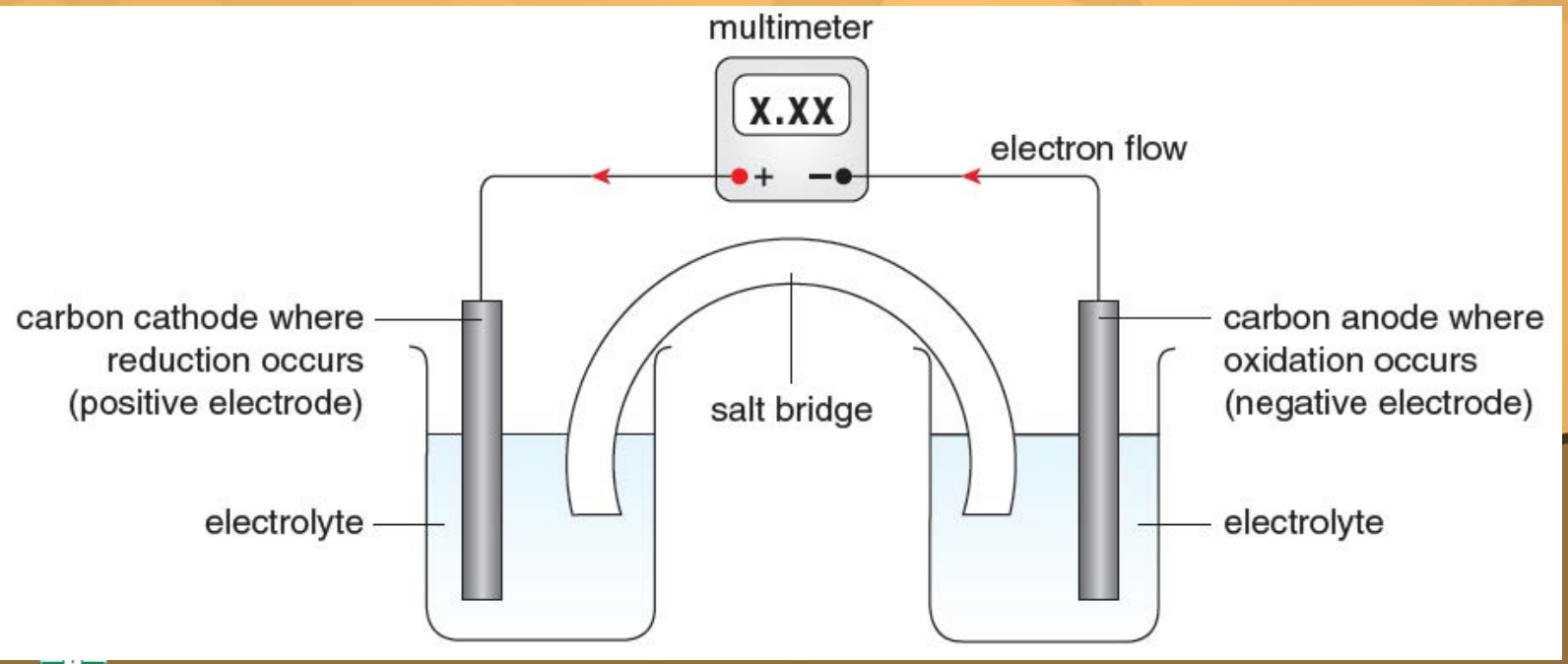
Key terms (p.119)

inert electrode	惰性電極	fuel cell	燃料電池
anode	陽極	hydrogen-oxygen fuel cell	氫氧燃料電池
cathode	陰極		

Summary (p.120)

1 In a chemical cell with inert electrodes,
- the electrode at which oxidation occurs is the anode;
- the electrode at which reduction occurs is the cathode.

2 Electrons are supplied by the chemical species being oxidised; they move from the anode to the cathode in the external circuit.



Summary (p.120)

3 In a hydrogen-oxygen fuel cell, hydrogen and oxygen react to generate electricity.

a) At the negative electrode (or anode) compartment:

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

b) At the positive electrode (or cathode) compartment:

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

c) The overall redox equation is:

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

Unit Exercise (p.121)

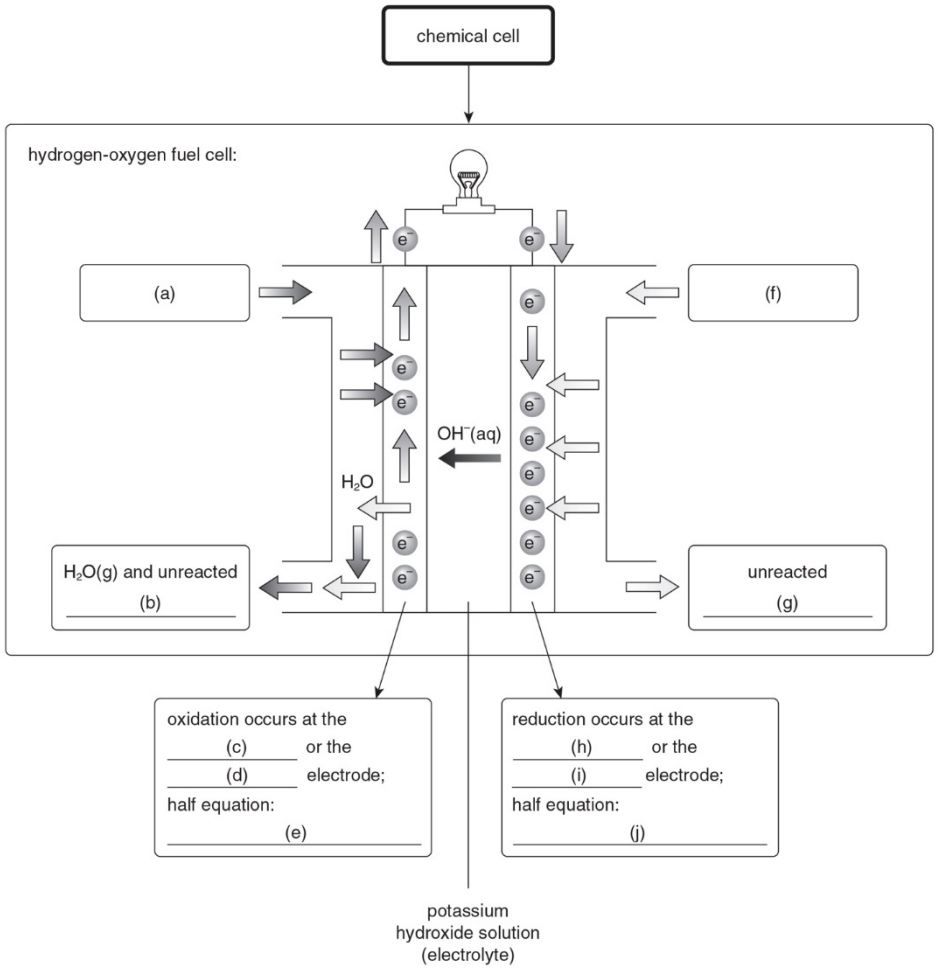
Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**
 **question targeted at level 4 and above;**
 **question targeted at level 5.**
‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.121)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.

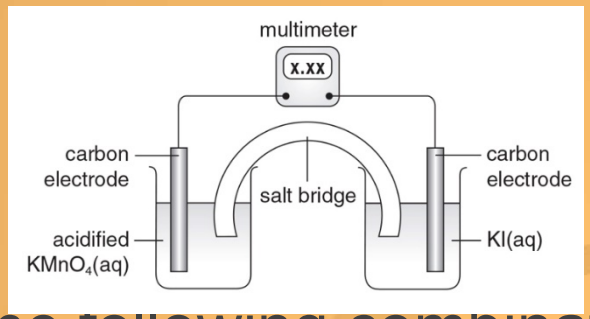


a) hydrogen
b) hydrogen
c) anode
d) negative
e) $H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-$
f) oxygen
g) oxygen
h) cathode
i) positive
j) $O_2(g) + 2H_2O(l) + 4e^- \longrightarrow 4OH^-(aq)$

Unit Exercise (p.121)

PART II MULTIPLE CHOICE QUESTIONS

2 Consider the chemical cell shown below.



Which of the following combinations is correct?

	Anode polarity	Half equation for the change at the anode
A	+	$2I^-(aq) \longrightarrow I_2(aq) + 2e^-$
B	+	$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$
C	–	$2I^-(aq) \longrightarrow I_2(aq) + 2e^-$
D	–	$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$

Answer: C

Unit Exercise (p.121)

2 (continued)

Explanation:

The change that occurs at the electrode in acidified $KMnO_4(aq)$ is:

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$$

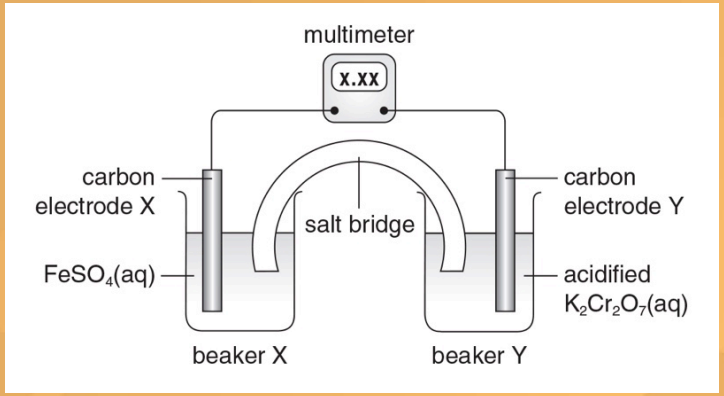
The change that occurs at the electrode in KI(aq) is:

$$2I^-(aq) \longrightarrow (aq) + 2e^-$$

Oxidation occurs at the electrode in KI(aq). This is the anode. Electrons produced by the oxidation process are transferred to the surface of the carbon electrode in acidified $KMnO_4(aq)$. Thus, the anode is negatively charged.

Unit Exercise (p.121)

3 Consider the chemical cell shown below.



Answer: B

Which of the following statements concerning the chemical cell is correct?

A Electrode X is the cathode.

B Electrons flow from electrode X to electrode Y in the external circuit.

C The content of beaker X becomes deep green after some time.

D The content of beaker Y becomes colourless after some time.

Unit Exercise (p.121)

3 (continued)

Explanation:

The change that occurs at electrode X is:

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

The change that occurs at electrode Y is:

$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$

Electrons flow from $FeSO_4(aq)$ to $K_2Cr_2O_7(aq)$ in the external circuit.

Unit Exercise (p.121)

4 Silver oxide button cells are commonly used in hearing aids. The following half equations represent the changes that occur when the cell is discharging.

At electrode X:

$Ag_2O(s) + H_2O(l) + 2e^- \longrightarrow 2Ag(s) + 2OH^-(aq)$

At electrode Y:

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

A Electrode X is the cathode.

B Oxidation occurs at electrode Y.

C Electrode Y is the negative electrode.

D Electrons flow from electrode Y to electrode X in the electrolyte.

Answer: D

Explanation:

Option A — Electrode X is the cathode as reduction occurs here.

Option B — Zinc undergoes oxidation at electrode Y.

Option D — Electrons do NOT flow in the electrolyte.

Unit Exercise (p.121)

5 The following equation shows the reaction when a secondary cell is discharging:

$$2NiO(OH)(s) + Cd(s) + 2H_2O(l) \longrightarrow 2Ni(OH)_2(s) + Cd(OH)_2(s)$$

Which of the following half equations shows the change at the negative electrode when the cell is being recharged?

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

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

C $Ni(OH)_2(s) + OH^-(aq) \longrightarrow NiO(OH)(s) + H_2O(l) + e^-$

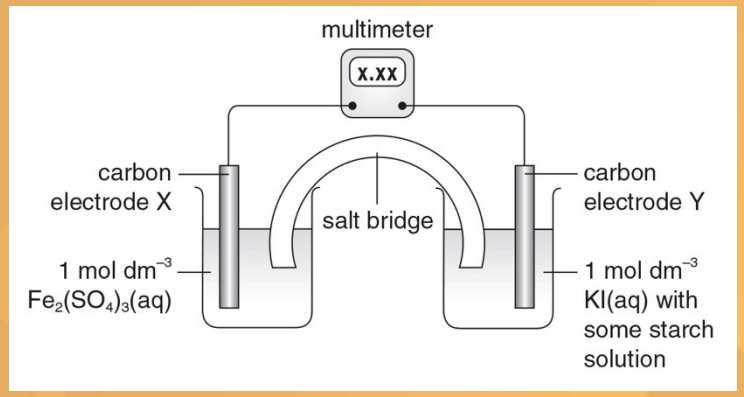
D $NiO(OH)(s) + H_2O(l) + e^- \longrightarrow Ni(OH)_2(s) + OH^-(aq)$

(HKDSE, Paper 1A, 2016, 15)

Answer: B

Unit Exercise (p.121)

6 Consider the chemical cell shown below.



Which of the following statements concerning the chemical cell is correct?

A Electrons flow from electrode X to electrode Y in the external circuit.

B Oxidation occurs at electrode X.

C Electrode Y is the cathode.

D A blue colour appears in the KI(aq) after the cell has operated for some time.

Answer: D

Unit Exercise (p.121)

6 (continued)

Explanation:

The change that occurs at electrode X is:

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

The change that occurs at electrode Y is:

$2I^-(aq) \longrightarrow I_2(aq) + 2e^-$

Option A — Electrons flow from electrode Y to electrode X in the external circuit.

Option B — Reduction occurs at electrode X.

Option C — Oxidation occurs at electrode Y. Hence this is the anode.

Option D — $I_2(aq)$ gives a blue colour with starch.

Unit Exercise (p.121)

7 Which of the following statements concerning hydrogen-oxygen fuel cell is INCORRECT?

A It contains a catalyst.
B Water is formed during discharge.
C Oxygen gas is passed to the anode.
D Hydrogen gas acts as the reducing agent.

(HKDSE, Paper 1A, 2017, 8)

Answer: C

Unit Exercise (p.121)

8 Which of the following changes would take place at the cathode in a chemical cell?

(1) $Zn^{2+}(aq)$ to $Zn(s)$
(2) $Br_2(l)$ to $Br^-(aq)$
(3) $Mg(s)$ to $Mg^{2+}(aq)$

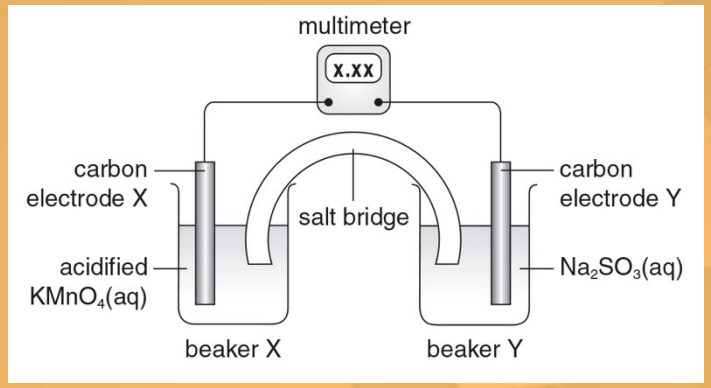
A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Explanation:
Reduction occurs at the cathode in a chemical cell. $Zn^{2+}(aq)$ to $Zn(s)$ and $Br_2(l)$ to Br (aq) are reduction processes.

Answer: A

Unit Exercise (p.121)

9 Consider the chemical cell shown below.



Which of the following statements concerning the chemical cell is / are correct?

(1) Electrode Y is the cathode.
(2) The colour of the solution in beaker X fades gradually.
(3) Electrons flow from electrode X to electrode Y through the salt bridge.

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Answer: B

Unit Exercise (p.121)

9 (continued)

Explanation:

The change that occurs at electrode X is:

$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$

The change that occurs at electrode Y is:

$SO_3^{2-}(aq) + H_2O(l) \longrightarrow SO_4^{2-}(aq) + 2H^+(aq) + 2e^-$

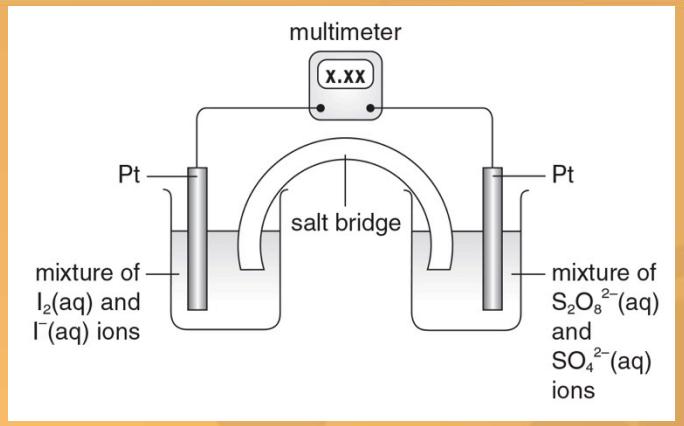
(1) Oxidation occurs at electrode Y. Hence this is the anode.

(2) The purple $MnO_4^-(aq)$ ions in beaker X change to pale pink $Mn^{2+}(aq)$ ions gradually.

(3) Electrons flow through the external circuit, NOT the salt bridge.

Unit Exercise (p.121)

10 Consider the chemical cell shown below.



Given that $S_2O_8^{2-}(aq)$ ion is a stronger oxidising agent than $I_2(aq)$, which of the changes represented by the following half equations would occur if the cell is producing a current?

(1) $S_2O_8^{2-}(aq) + 2e^- \longrightarrow 2SO_4^{2-}(aq)$

(2) $2SO_4^{2-}(aq) \longrightarrow S_2O_8^{2-}(aq) + 2e^-$

(3) $I_2(aq) + 2e^- \longrightarrow 2I^-(aq)$

A (1) only

B (2) only

C (1) and (3) only

D (2) and (3) only

Answer: A

Unit Exercise (p.121)

10 (continued)

Explanation:

The $S_2O_8^{2-}(aq)$ ion acts as the oxidising agent, accepting electrons via the external circuit.

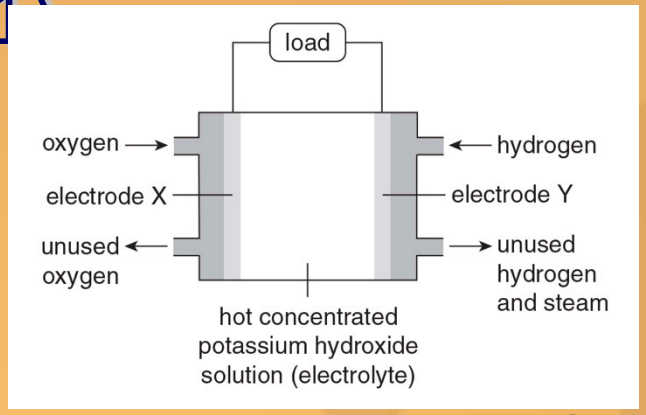
$$S_2O_8^{2-}(aq) + 2e^- \longrightarrow 2SO_4^{2-}(aq)$$

Electrons from $I^-(aq)$ ions flow via the external circuit to the beaker containing $S_2O_8^{2-}(aq)$ and $SO_4^{2-}(aq)$ ions.

$$2I^-(aq) \longrightarrow I_2(aq) + 2e^-$$

Unit Exercise (p.121)

11 Consider the fuel cell shown below.



Which of the following statements about the fuel cell is / are correct?

(1) Electrons flow from electrode Y to electrode X in the external circuit.

(2) $OH^-(aq)$ ions move towards electrode X.

(3) Both $H_2(g)$ and $O_2(g)$ function as fuels in the cell.

A (1) only

B (2) only

C (1) and (3) only

D (2) and (3) only

Answer: A

Unit Exercise (p.121)

11 (continued)

Explanation:

The change that occurs at electrode X is:

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

The change that occurs at electrode Y is:

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

(2) $OH^-(aq)$ ions move towards electrode Y.

(3) $H_2(g)$ functions as a fuel while $O_2(g)$ functions as an oxidant.

Unit Exercise (p.121)

PART III STRUCTURED QUESTIONS

12 Zinc-carbon cells are used in the above experiment. The equation below shows the reaction that occurs in the zinc-carbon cells when the bulb lights up.

$$2MnO_2(s) + 2NH_4Cl(aq) + Zn(s) \longrightarrow Mn_2O_3(s) + 2NH_3(aq) + H_2O(l) + ZnCl_2(aq)$$

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

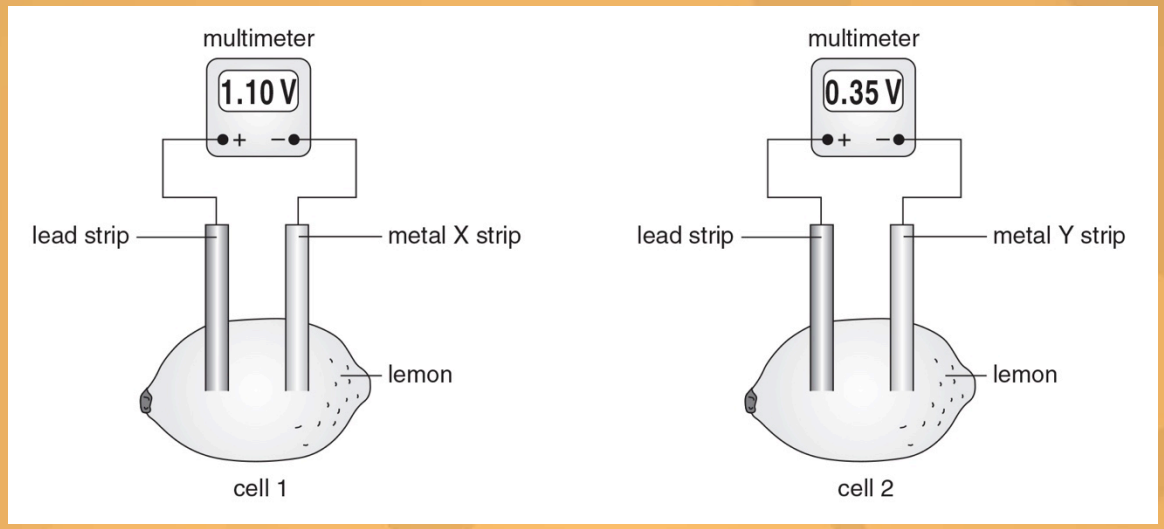
a) Deduce, in terms of change in oxidation number, the oxidising agent in a zinc-carbon cell.

b) Write a half equation for the change that occurs at the cathode in a zinc-carbon cell.

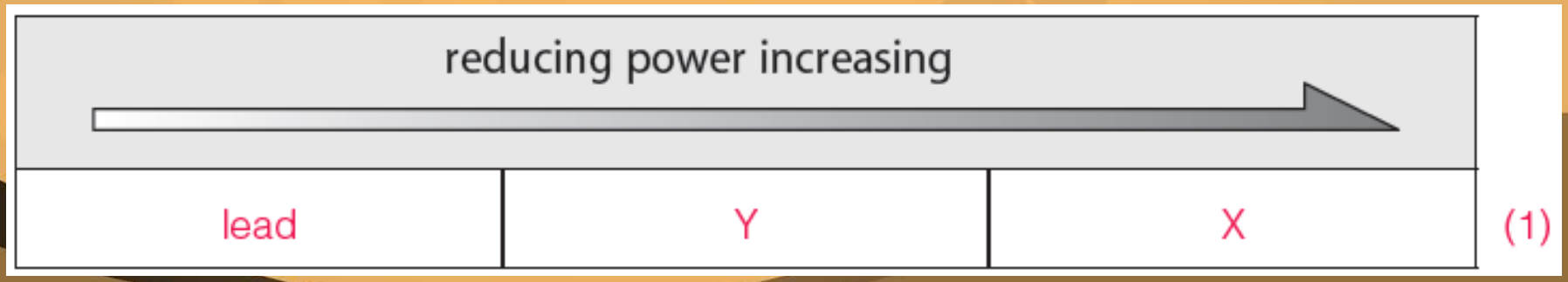
(HKDSE, Paper 1B, 2016, 8(c))

Unit Exercise (p.121)

13 The diagram below shows two lemon cells.



a) Arrange metal X, metal Y and lead in increasing order of reducing power. Explain your answer.



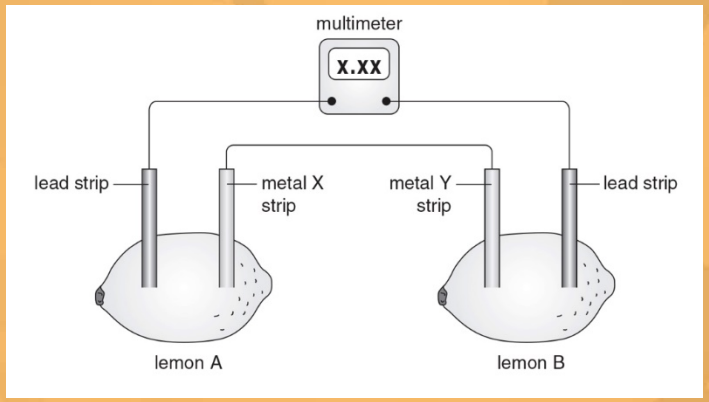
Unit Exercise (p.121)

13 (continued)

b) Explain whether the lead strip or the metal X strip is the anode of cell 1.

Metal X strip is the anode. Oxidation occurs here. (1)

c) Metal strips and lemons are used to build the following set-up.

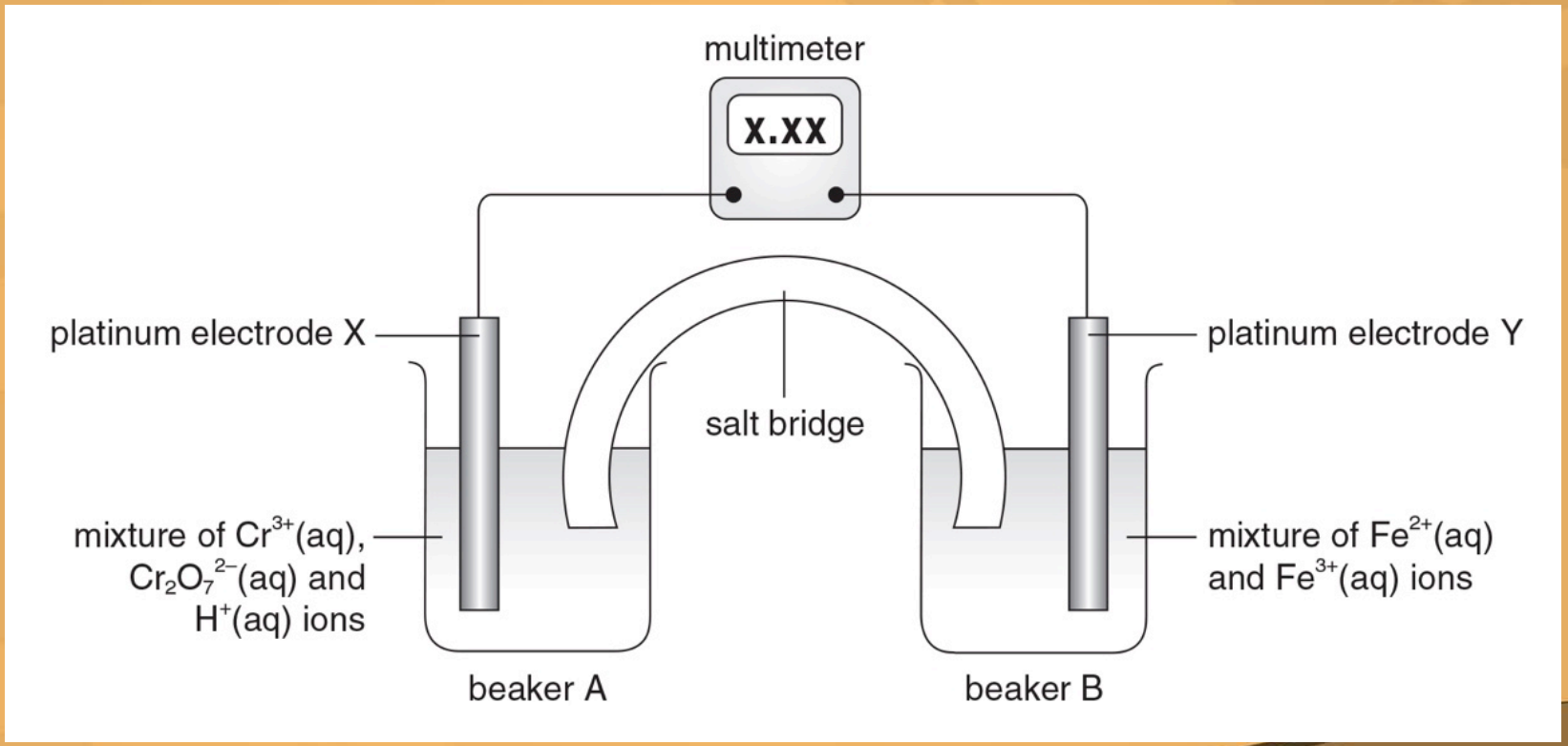


State, with explanation, the direction of electron flow across the connecting wire between the metal X strip and the metal Y strip.

Electrons flow from metal X strip to metal Y strip because the reducing power of X is stronger than that of Y. (1)

Unit Exercise (p.121)

14 Consider the chemical cell shown below. Electrons flow from electrode Y to electrode X in the external circuit.



Unit Exercise (p.121)

14 (continued)

b) What will be observed in each beaker after the cell has operated for some time? Write a half equation for the change that occurs in each beaker.

The green colour of the mixture in beaker A becomes more intense. (1)

The yellow-brown colour of the mixture in beaker B becomes more intense.(1)

Beaker A: $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$ (1)

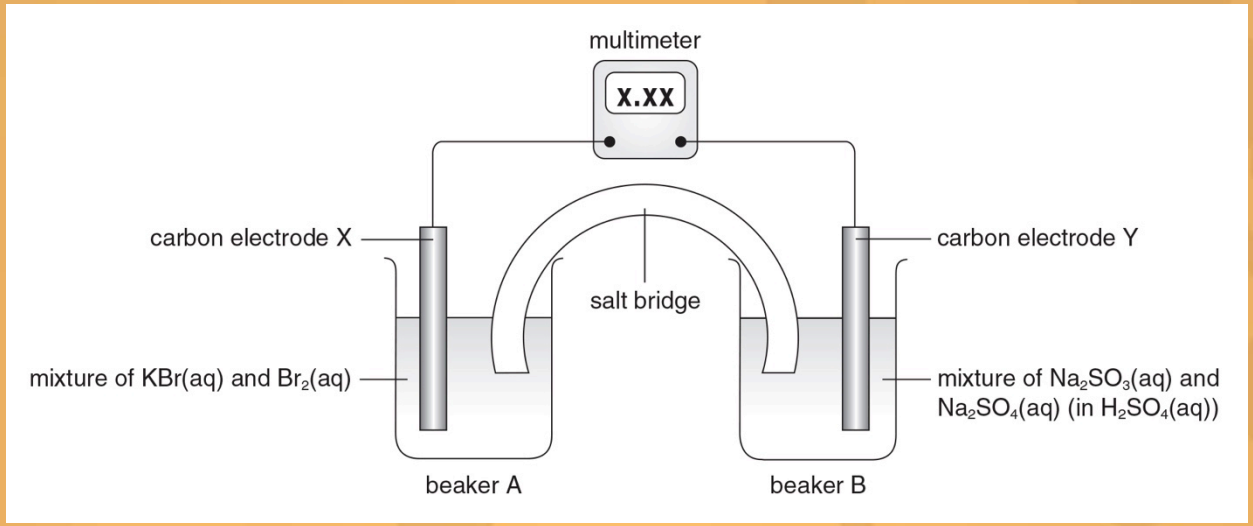
Beaker B: $Fe^{2+}(aq) \longrightarrow Fe^{3+}(aq) + e^-$ (1)

b) Explain whether electrode X or Y is the cathode.

Electrode X is the cathode as reduction occurs here. (1)

Unit Exercise (p.121)

15 Consider the chemical cell shown below.



After the chemical cell has operated for some time, the colour of the mixture in beaker A becomes less intense.

a) Write a half equation for the change that occurs in each beaker.

$Br_2(aq) + 2e^- \longrightarrow 2Br^-(aq)$ (1)

$SO_3^{2-}(aq) + H_2O(l) \longrightarrow SO_4^{2-}(aq) + 2H^+(aq) + 2e^-$ (1)

Unit Exercise (p.121)

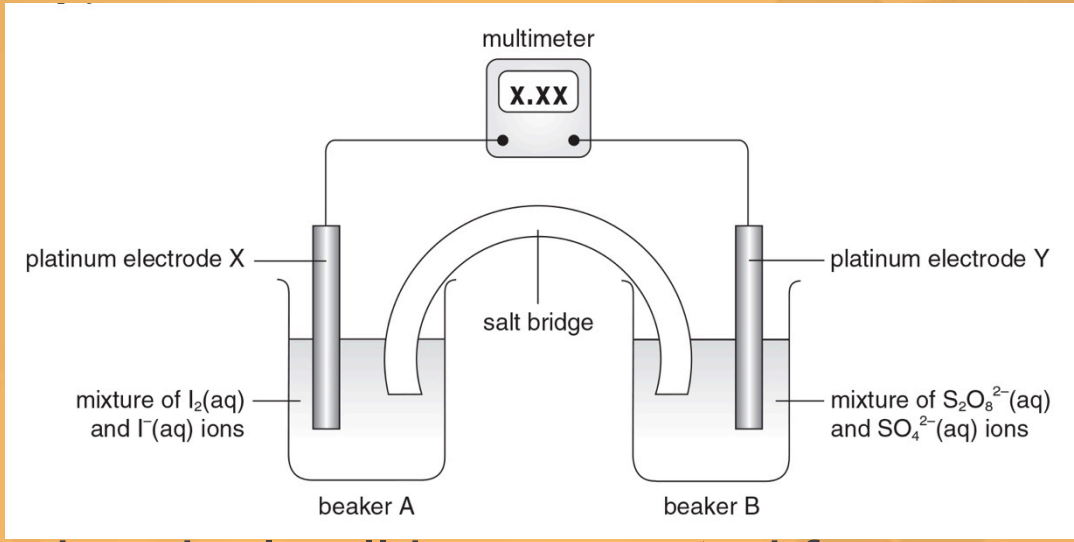
15 (continued)

b) Explain whether electrode X or Y is the anode.
Electrode Y is the anode as oxidation occurs here. (1)

c) Identify the direction of electron flow in the external circuit.
From electrode Y to electrode X (1)

Unit Exercise (p.121)

16 Potassium peroxodisulphate is a white crystalline compound of chemical formula $K_2S_2O_8$. The chemical cell shown below uses $S_2O_8^{2-}$ ions in solution.



After the chemical cell has operated for some time, the brown colour of the mixture in beaker A becomes more intense.

Unit Exercise (p.121)

16 (continued)

a) State the role of the platinum electrodes in this cell.

An inert electrode that is used to carry the charge / current / electron flow. (1)

b) Write a half equation for the change that occurs in each beaker.

Beaker A: $2I^-(aq) \longrightarrow I_2(aq) + 2e^-$ (1)

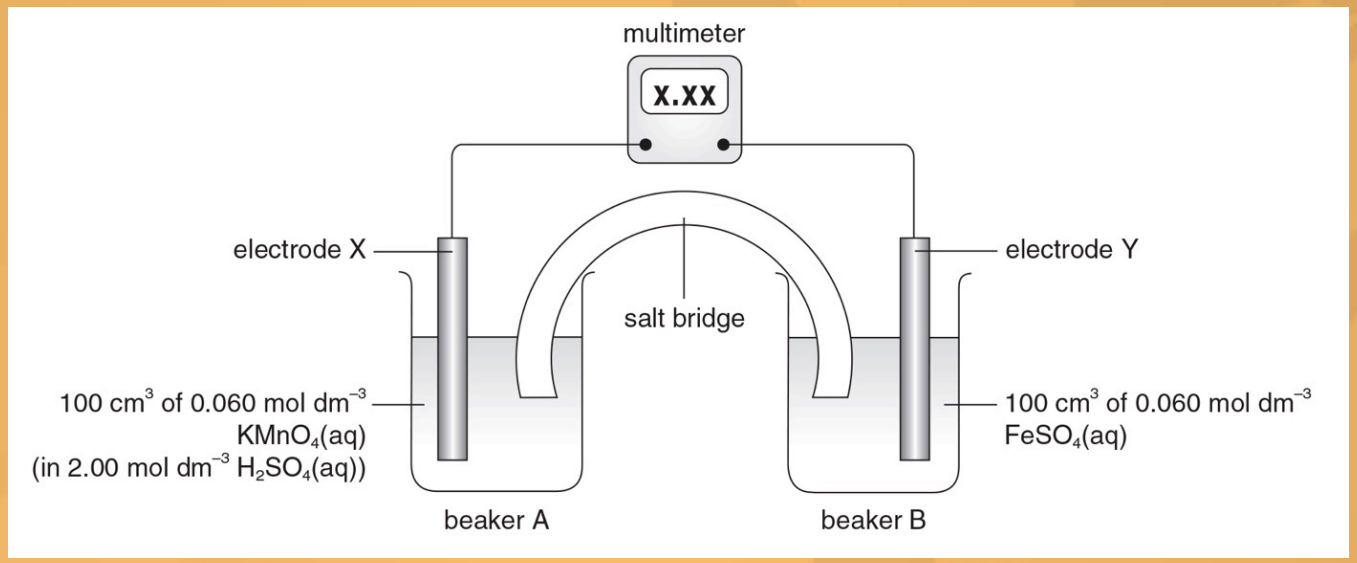
Beaker B: $S_2O_8^{2-}(aq) + 2e^- \longrightarrow 2SO_4^{2-}(aq)$ (1)

c) Decide which electrode is the cathode. Explain your answer.

Electrode Y is the cathode as reduction occurs here. (1)

Unit Exercise (p.121)

17 Consider the following chemical cell at the start of an experiment:



a) Suggest a material commonly used for making electrodes X and Y.

Carbon / graphite (1)

Unit Exercise (p.121)

17 (continued)

b) After the chemical cell has operated for some time, the purple colour of $KMnO_4(aq)$ in beaker A becomes less intense.
Write a half equation for the change that occurs in each beaker.
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \longrightarrow Mn^{2+}(aq) + 4H_2O(l)$ (1)
$Fe^{2+}(aq) \longrightarrow Fe^{3+}(aq) + e^-$ (1)

c) Identify the direction of electron flow in the external circuit.
From electrode Y to electrode X (1)

d) Decide which electrode is the cathode. Explain your answer.
Electrode X is the cathode as reduction occurs here. (1)

Unit Exercise (p.121)

17 (continued)

e) After a period of time, the concentration of $KMnO_4(aq)$ drops to 0.056 mol dm^{-3}. What is the concentration of $FeSO_4(aq)$ at this time?

Number of moles of $MnO_4^-(aq)$ ions reacted = $(0.060 - 0.056)$ mol $dm^{-3} \times \frac{100}{1\,000}$ dm^3

$= 4.0 \times 10^{-4}$ mol (1)

Number of moles of electrons gained by $MnO_4^-(aq)$ ions = $5 \times 4.0 \times 10^{-4}$ mol

$= 0.0020$ mol (1)

= number of moles of $Fe^{2+}(aq)$ ions reacted

$$\text{Concentration of } FeSO_4(aq) \text{ at that time} = \frac{(0.060 \times \frac{100}{1\,000} - 0.0020) \text{ mol}}{\frac{100}{1\,000} \text{ dm}^3}$$

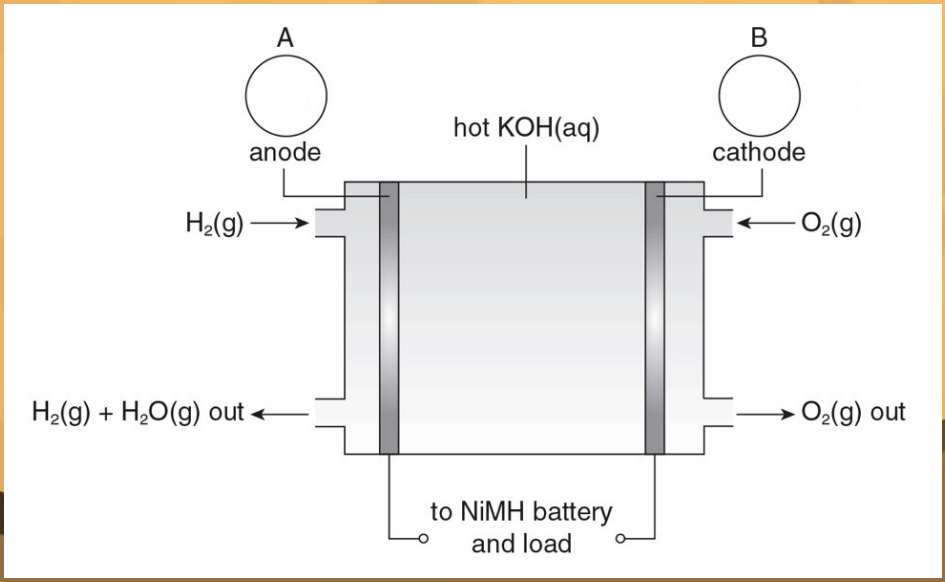
$= 0.040$ mol dm^{-3} (1)

$\therefore$ the concentration of $FeSO_4(aq)$ at that time is 0.040 mol dm^{-3}.

Unit Exercise (p.121)

18 A car manufacturer is designing a conceptual electric vehicle with dual electricity sources. The vehicle is powered by a hydrogen fuel cell and a nickel metal hydride (NiMH) battery. Air, which contains oxygen, and hydrogen are fed into the fuel cell to produce electricity. The NiMH battery is rechargeable using an external electricity source. The fuel cell and the NiMH battery provide electricity to drive the motor of the vehicle (load).

A circuit showing the fuel cell, the NiMH battery and the load is shown below.



Unit Exercise (p.121)

18 (continued)

The overall reaction of the fuel cell is:

$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$

a) Consider the hydrogen fuel cell.

i) On the diagram above, indicate the polarity (+ or –) of the anode and cathode of the fuel cell in circles A and B.

A: – ; B: + (1)

ii) Write half equations for the changes that occur at the anode and cathode of the fuel cell.

Anode: $H_2(g) + 2OH^-(aq) \longrightarrow 2H_2O(l) + 2e^-$ (1)

Cathode: $O_2(g) + 2H_2O(l) + 4e^- \longrightarrow 4OH^-(aq)$ (1)

Unit Exercise (p.121)

18 (continued)

b) The battery to be used in the car is comprised of a series of nickel metal hydride (NiMH) cells.
The half equations for the changes that occur at the electrodes of the cell are listed below.

At electrode X:

$NiO(OH)(s) + H_2O(l) + e^- \longrightarrow Ni(OH)_2(s) + OH^-(aq)$

At electrode Y:

$MH(s) + OH^-(aq) \longrightarrow M(s) + H_2O(l) + e^-$

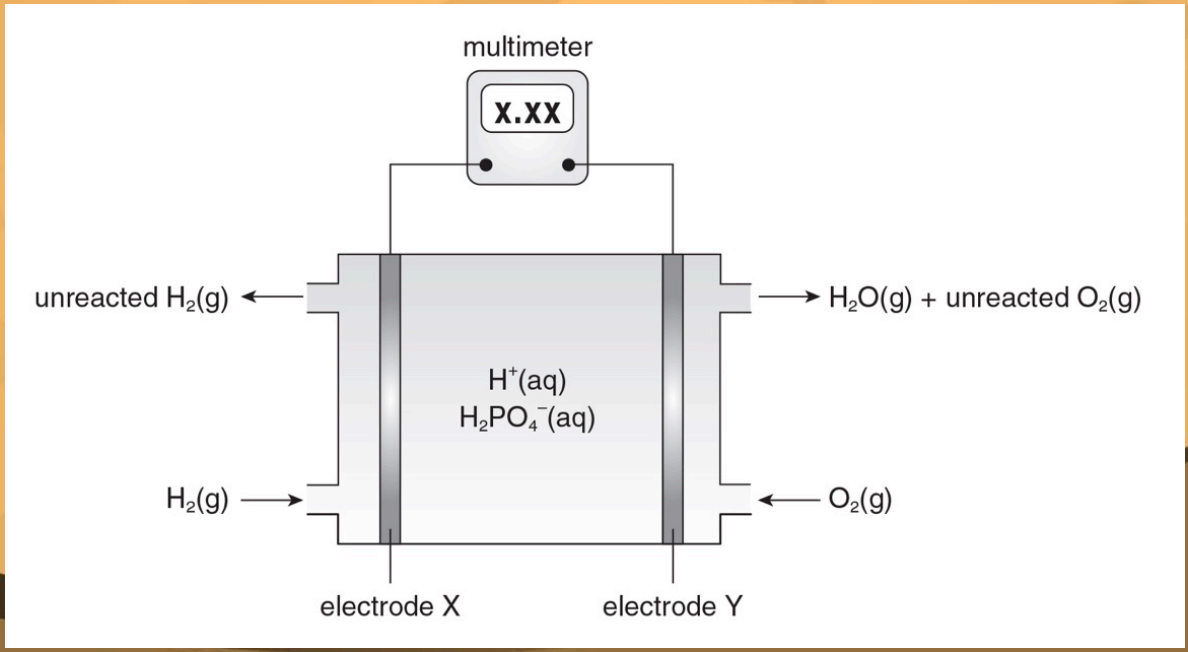
Identify the anode. Explain your choice.

Electode Y is the anode as oxidation occurs here. (1)

Unit Exercise (p.121)

19 A fuel cell that can provide power for buses is the phosphoric acid fuel cell. The reactants are hydrogen and oxygen gases. The electrolyte is concentrated phosphoric acid.

A simplified sketch of a phosphoric acid fuel cell is shown below.



Unit Exercise (p.121)

19 (continued)

The half equation for the change that occurs at electrode Y is:

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

a) Write the half equation for the change that occurs at electrode X.

$H_2(g) \longrightarrow 2H^+(aq) + 2e^-$ (1)

b) Explain whether electrode Y is the anode or cathode.

Electode Y is the cathode as reduction occurs here. (1)

Unit Exercise (p.121)

19 (continued)

c) Describe ONE advantage and ONE disadvantage of such a fuel cell compared with a petrol-driven car engine.

Any one of the following advantages:

- Less energy is lost as heat (1)
- Less noisy (1)
- More efficient energy conversion compared to a petro engine (1)
- NO carbon dioxide, carbon monoxide, unburnt hydrocarbons, oxides of nitrogen, sulphur dioxide and particulates produced (1)

Any one of the following disadvantages:

- Difficulty in accessing and storing hydrogen (1)
- Risk of leaking hydrogen that reacts explosively (1)
- More expensive (1)