Mastering Chemistry

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

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Content

18.1 Chemical cells and you (p.2)

A chemical cell (化學電池) is a device that converts the chemical energy stored in it into electrical energy.

- A battery is a package of two or more chemical cells.

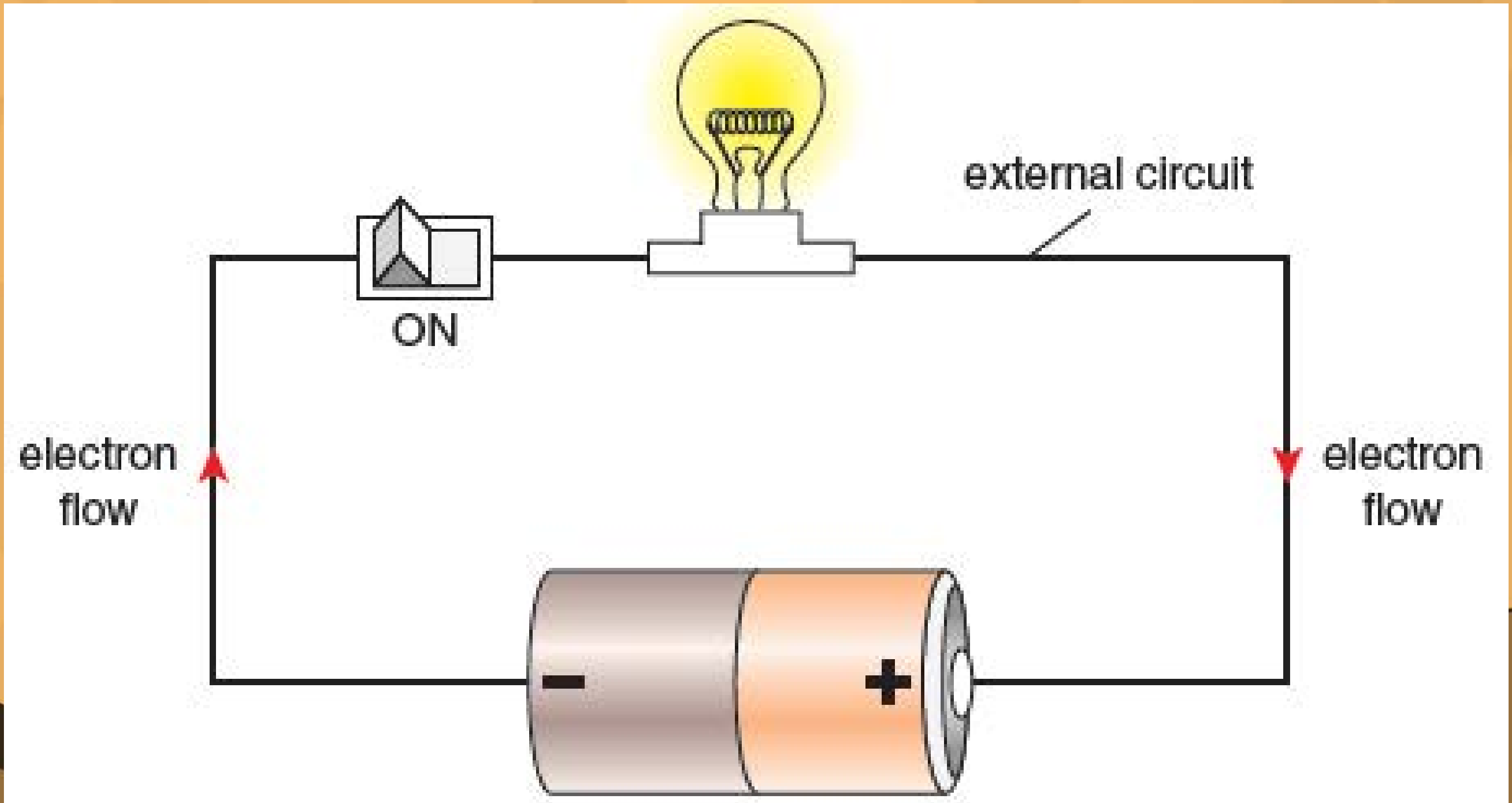
A 9 V battery consists of six 1.5 V chemical cells connected in series

18.1 Chemical cells and you (p.2)

- A chemical cell consists of three basic components:
  - a **negative electrode (負電極)** — the electrode from which electrons flow into the external circuit;
  - a **positive electrode (正電極)** — the electrode into which electrons flow from the external circuit;
  - an **electrolyte (電解質)** — the medium which allows ions to flow between the two electrodes.
- A chemical cell converts its chemical energy into electrical energy as a result of reactions occurring at its electrodes.

18.1 Chemical cells and you (p.2)

- When you connect a light bulb to a chemical cell, electrons flow from the negative electrode to the positive electrode in the external circuit.



18.1 Chemical cells and you (p.2)

Measuring the voltage of a chemical cell

- The voltage of a chemical cell by using a voltmeter or a digital multimeter.

A voltmeter (left) and a digital multimeter (right)

18.1 Chemical cells and you (p.2)

- The multimeter gives a positive voltage when the positive electrode of the chemical cell is connected to its positive terminal and the negative electrode of the chemical cell is connected to its negative terminal.
- Reversing the electrodes of a chemical cell with respect to the multimeter changes the sign on the measured voltage.

Reversing the electrodes of a chemical cell with respect to the multimeter changes the sign on the measured voltage

18.2 Types of chemical cell (p.4)

- There are two types of chemical cell: **primary cell (原電池)** which cannot be recharged, and **secondary cell (二級電池)** which can be recharged.

- Common primary cells include:
  - zinc-carbon cells;
  - alkaline manganese cells;
  - silver oxide cells.

- Primary cells provide electricity until the reactants have reacted to such an extent that the voltage drops to a certain level. The cell is then 'flat' and has to be discarded.

18.2 Types of chemical cell (p.4)

- Common secondary cells include:
  - lead-acid accumulators;
  - nickel metal hydride (NiMH) cells;
  - lithium ion cells.
- Secondary cells can be recharged by applying an electric current which reverses the reactions that occur during their discharge. Products of the cell reactions are converted back into the original reactants. The electrical energy supplied is converted into chemical energy in the cell.
- Devices to supply the charging current are called chargers.

A charger recharges secondary cells by supplying an electric current

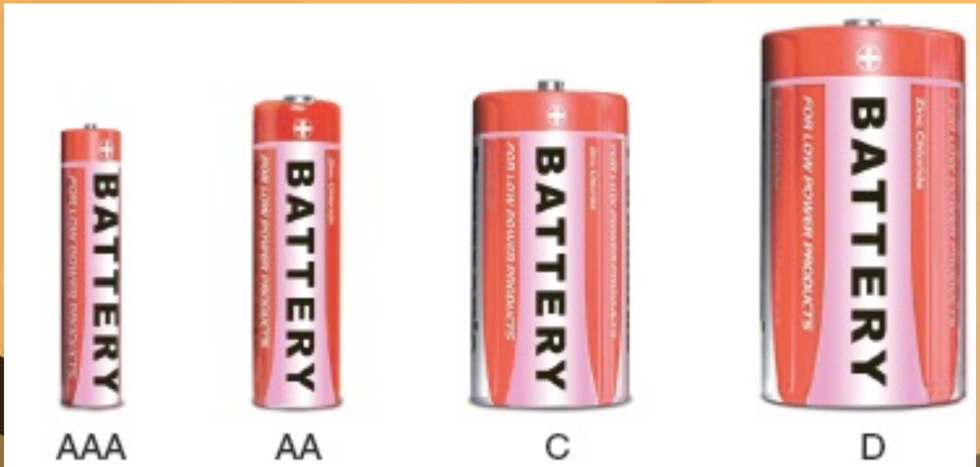
18.2 Types of chemical cell (p.4)

Terms related to chemical cells

- The following terms are related to chemical cells:
  - **Cell capacity (電池容量)** is measured in ampere-hours, which is the number of hours a cell can supply a particular amount of electric current.
  - **Energy density (能量密度)** is the amount of energy that can be derived per unit volume of the cell.
  - **Service life (有效壽命)** is the length of time that a cell can remain in use before its voltage drops to a certain value (usually 0.8 V).
  - **Cycle life (循環壽命)** is the number of charge-discharge cycles that a secondary cell can undergo before its capacity falls to 80% of its original value.
  - **Shelf life (存放期)** is the length of time that a cell can be stored inactive before its capacity falls to 90% of its original value.

18.3 Zinc-carbon cell (p.6)

- **Zinc-carbon cells (鋅碳電池)** have been around for more than 100 years. They are low-cost and are available in different sizes.
- The maximum voltage of these cells is 1.5 V, regardless of the size.
- These cells are commonly used in low drain devices like clocks, small radios and remote control units.



Zinc-carbon cells of different sizes

18.3 Zinc-carbon cell (p.6)

- The zinc negative electrode is in the form of a metal can which acts as a container for the other cell components. There is a central carbon rod which serves as the positive electrode.
- The electrolyte is a moist paste of ammonium chloride.
- Zinc-carbon cells are in declining use today. Although zinc-carbon cells are cheap to purchase, they suffer from a number of limitations:
  - low energy density;
  - cannot perform efficiently in high drain devices;
  - the voltage falls steadily over discharge;
  - chemicals may leak out of the cells after using for a long time.

18.4 Alkaline manganese cell (p.7)

- In the early 1960s, alkaline manganese cells were introduced and became immediately preferable to zinc-carbon cells because of several benefits:
  - higher energy density;
  - good performance at all drain rates;
  - a steadier voltage over discharge;
  - excellent leakage resistance;
  - longer shelf life.

Alkaline manganese cells

18.4 Alkaline manganese cell (p.7)

- The price of the cell is higher than that of a zinc-carbon cell. However, its service life is longer. If the cost-per-hour of usage is considered, the cell becomes cheaper.
- Alkaline manganese cells are suitable for moderate drain devices like motorised toys, smoke detectors and flashlights which you use a lot when camping.
- The negative electrode of the cell is zinc powder while the positive electrode is manganese(IV) oxide, with potassium hydroxide as the electrolyte.
- The maximum voltage of this cell is 1.5 V.

18.5 Silver oxide cell (p.8)

- Silver oxide button cells were introduced in the early 1960s as a power source for electronic watches.
- The negative electrode is zinc powder while the positive electrode is silver oxide, with potassium hydroxide as the electrolyte.
- The maximum voltage of this cell is 1.5 V.
- The **silver oxide cell (氧化銀電池)** is known for its high energy density and constant voltage over discharge. It is widely used in watches, calculators and hearing aids. Because of the silver content, it is somewhat more expensive.

Silver oxide button cells

18.5 Silver oxide cell (p.8)

- Some characteristics of the three types of primary cell.

	Zinc-carbon cell	Alkaline manganese cell	Silver oxide cell
Material of negative electrode	zinc	zinc	zinc
Material of positive electrode	carbon	manganese(IV) oxide	silver oxide
Material of electrolyte	ammonium chloride	potassium hydroxide	potassium hydroxide
Maximum voltage (V)	1.5	1.5	1.5
Shelf life (years)	2–3	5–7	7
Characteristic(s)	• low cost	• good performance at all drain rates • steadier voltage over discharge	• high energy density • constant voltage over discharge
Common uses	low drain devices (e.g. clocks, small radios)	moderate drain devices (e.g. motorised toys, smoke detectors)	watches, calculators, hearing aids

18.6 Lead-acid accumulator (p.9)

- Up until the late 1980s, the two main types of secondary cell available on the market were **lead-acid accumulator (鉛酸蓄電池)** and nickel-cadmium cell.
- Lead-acid accumulators are commonly used in cars.
- A 12 V accumulator normally consists of six cells joined in series. The maximum voltage of each cell is 2 V.
- The negative electrode of each cell is made of lead plates while the positive electrode is made of lead plates coated with lead(IV) oxide, with sulphuric acid as the electrolyte.

Lead-acid accumulator
Ref.

A lead-acid accumulator

18.6 Lead-acid accumulator (p.9)

- These accumulators are still used for automotive SLI (Starting, Lighting and Ignition) applications because they can deliver very large currents and they are low-cost. They can also be found in electric wheelchairs and golf carts.

- Lead-acid accumulators suffer from a number of limitations:
  - heavy and bulky;
  - low energy density;
  - it is possible for the electrolyte to freeze in the winter, making the accumulators useless;
  - environmental and health concerns (e.g. lead is toxic and sulphuric acid is highly corrosive).

18.7 Nickel metal hydride (NiMH) cell (p.10)

- In the early 1990s, with the growth of the market for portable electronic devices, two new types of chemical cell emerged — **nickel metal hydride cell (鎳金屬氫化物電池)** and lithium ion cell.

Nickel metal hydride (NiMH) cells

18.7 Nickel metal hydride (NiMH) cell (p.10)

- The negative electrode of the cell is a hydrogen-absorbing alloy while the positive electrode is nickel oxyhydroxide NiO(OH), with potassium hydroxide as the electrolyte.
- The maximum voltage of this cell is 1.2 V.
- Advantages of nickel metal hydride cells include:
  - high energy density;
  - long cycle life;
  - can withstand to both overcharge and discharge;
  - environmentally friendly (no cadmium, mercury or lead);
  - much safer than lithium based cells in case of an accident.
- Nickel metal hydride cells still find their uses in hybrid electric vehicles. Examples of other industrial applications include standby power systems, aircraft and satellites.

18.8 Lithium ion cell (p.11)

- At present, most commercial **lithium ion cells (鋰離子電池)** have lithium atoms lying between graphite sheets as the negative electrode and lithium cobalt oxide as the positive electrode, with a lithium salt dissolved in an organic solvent as the electrolyte.
- The maximum voltage is 3.7 V.

Lithium ion cells are widely used in mobile phones

18.8 Lithium ion cell (p.11)

- Some advantages of lithium ion cells are listed below:
  - high voltage (3.7 V) meaning fewer cells are needed for high voltage applications;
  - very high energy density;
  - much lighter than other secondary cells of the same size;
  - long cycle life.

- Lithium ion cells are more expensive than most other cells. There are also safety concerns:
  - the cell will be quickly damaged and may burst into flames if overcharged;
  - the cell may be damaged if operated at a high pulse current for more than a few seconds.

18.8 Lithium ion cell (p.11)

- Some characteristics of the three types of secondary cell.

	Lead-acid accumulator	Nickel metal hydride cell	Lithium ion cell
Material of negative electrode	lead plates	hydrogen-absorbing alloys	lithium atoms lying between graphite sheets
Material of positive electrode	lead plates coated with lead(IV) oxide	nickel oxyhydroxide	lithium cobalt oxide
Material of electrolyte	sulphuric acid	potassium hydroxide	a lithium salt dissolved in an organic solvent
Maximum voltage (V)	2	1.2	3.7
Cycle life	200–300	300–500	500–1 000
Energy density	low	high	very high
Toxicity	very high	low	low
Cost	low	moderate	high
Common uses	automotive SLI applications	hybrid electric vehicles	portable electronic devices

18.9 Choosing a chemical cell for a particular purpose (p.12)

- When selecting a cell for a particular purpose, you need to consider
  - the cost of the cell;
  - the voltage of the cell;
  - whether or not the cell can be recharged;
  - the size and mass of the cell;
  - how long the cell can deliver its maximum voltage;
  - whether the cell is able to supply a steady current;
  - whether a large or a small current is required;
  - whether the cell is used continuously or intermittently;
  - the shelf life of the cell.

18.10 Environmental impacts of using chemical cells (p.13)

- Each year consumers dispose of billions of chemical cells that may contain toxic or corrosive materials. When taken to landfills, some chemical cells release toxic metals such as mercury, lead and cadmium into the environment, causing soil contamination and water pollution.
- Secondary cells are less harmful to the environment. The more secondary cells are used, the less is the number of discarded cells entering landfills.

18.10 Environmental impacts of using chemical cells (p.13)

- Manufacturers are working continuously to reduce the environmental impacts of chemical cells by producing cells that contain less toxic materials. For example, small amounts of mercury were formerly used as an additive in zinc-carbon cells and alkaline manganese cells.
- In response to environmental concerns, manufacturers developed new technologies that eliminated the need for mercury in these cells.

An alkaline manganese cell without mercury and cadmium

Key terms (p.14)

chemical cell	化學電池	cycle life	循環壽命
negative electrode	負電極	shelf life	存放期
positive electrode	正電極	zinc-carbon cell	鋅碳電池
electrolyte	電解質	alkaline manganese cell	鹼性錳電池
primary cell	原電池	silver oxide cell	氧化銀電池
secondary cell	二級電池	lead-acid accumulator	鉛酸蓄電池
cell capacity	電池容量	nickel metal hydride cell	鎳金屬氫化物電池
energy density	能量密度	lithium ion cell	鋰離子電池
service life	有效壽命		

Summary (p.14)

1 A chemical cell is a device that converts the chemical energy stored in it into electrical energy. It consists of a negative electrode, a positive electrode and an electrolyte.

2 There are two types of chemical cell: primary cell which cannot be recharged, and secondary cell which can be recharged.

Summary (p.14)

3 The following table summarises some characteristics of three types of primary cell.

	Zinc-carbon cell	Alkaline manganese cell	Silver oxide cell
Negative electrode	zinc	zinc	zinc
Positive electrode	carbon	manganese(IV) oxide	silver oxide
Electrolyte	ammonium chloride	potassium hydroxide	potassium hydroxide
Maximum voltage (V)	1.5	1.5	1.5
Shelf life (years)	2–3	5–7	7
Characteristic(s)	• low cost	• good performance at all drain rates • steadier voltage over discharge	• high energy density • constant voltage over discharge
Common uses	low drain devices (e.g. clocks, small radios)	moderate drain devices (e.g. motorised toys, smoke detectors)	watches, calculators, hearing aids

Summary (p.14)

4 The following table summarises some characteristics of three types of secondary cell.

	Lead-acid accumulator	Nickel metal hydride cell	Lithium ion cell
Negative electrode	lead plates	hydrogen-absorbing alloys	lithium atoms lying between graphite sheets
Positive electrode	lead plates coated with lead(IV) oxide	nickel oxyhydroxide	lithium cobalt oxide
Electrolyte	sulphuric acid	potassium hydroxide	a lithium salt dissolved in an organic solvent
Maximum voltage (V)	2	1.2	3.7
Cycle life	200–300	300–500	500–1 000
Energy density	low	high	very high
Toxicity	very high	low	low
Cost	low	moderate	high
Common uses	automotive SLI applications	hybrid electric vehicles	portable electronic devices

Summary (p.14)

5 Disposal of chemical cells may cause environmental problems. When taken to landfills, some chemical cells release toxic metals such as mercury, lead and cadmium into the environment, causing soil contamination and water pollution.

Unit Exercise (p.16)

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;**

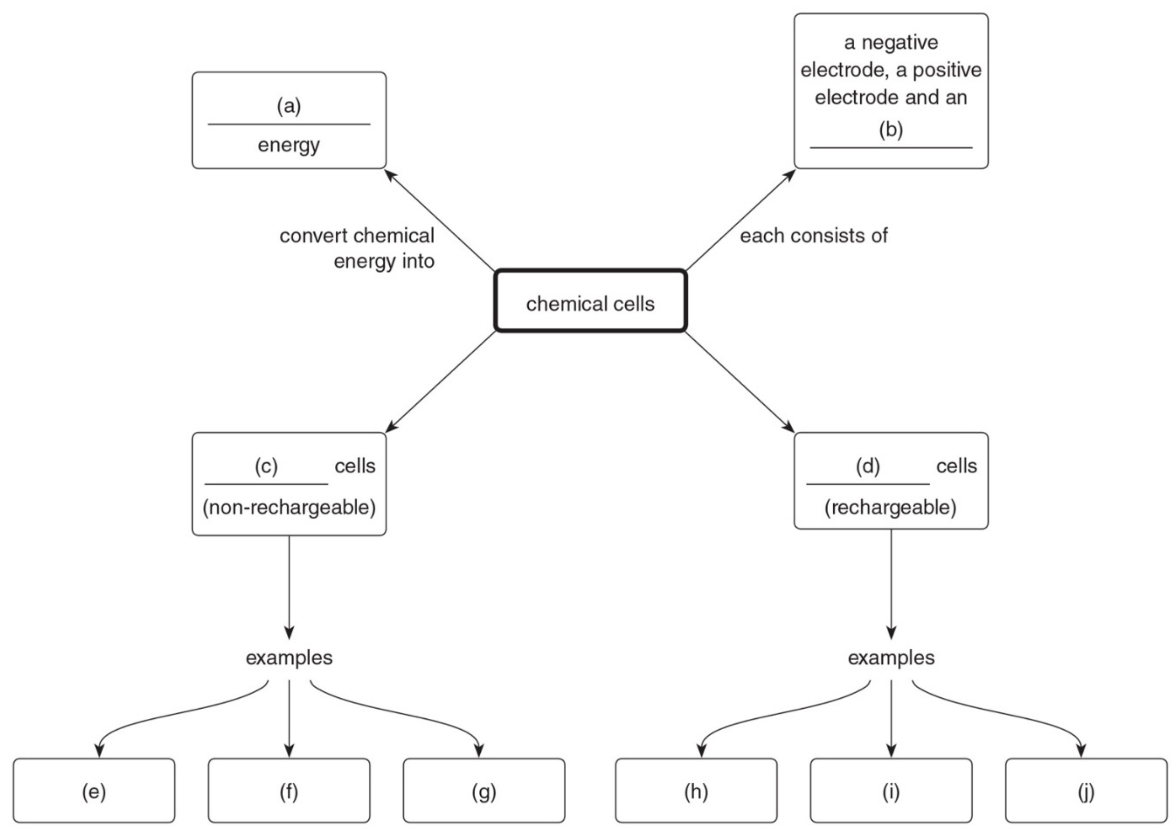
 **question targeted at level 5.**

‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.16)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



(a) electrical
(b) electrolyte
(c) primary
(d) secondary
(e) zinc-carbon cell / alkaline manganese cell / silver oxide cell
(f) zinc-carbon cell / alkaline manganese cell / silver oxide cell
(g) zinc-carbon cell / alkaline manganese cell / silver oxide cell
(h) lead-acid accumulator / nickel metal hydride cell / lithium ion cell
(i) lead-acid accumulator / nickel metal hydride cell / lithium ion cell
(j) lead-acid accumulator / nickel metal hydride cell / lithium ion cell

Unit Exercise (p.16)

PART II MULTIPLE CHOICE QUESTIONS

2 Which of the following statements concerning a zinc- carbon cell is correct?

A Manganese(IV) oxide acts as the electrolyte.
B Zinc-carbon cell is rechargeable.
C A zinc-carbon cell of larger size produces a higher voltage than a smaller one.
D In a circuit using a zinc-carbon cell to supply electricity, electrons in the external circuit flow to the carbon electrode of the cell.

Answer: D

Unit Exercise (p.16)

3 Which of the following statements concerning an alkaline manganese cell is correct?

A Its negative electrode is manganese.
B Its electrolyte is potassium hydroxide.
C Its maximum voltage is 3.7 V.
D It is a secondary cell.

Answer: B

Unit Exercise (p.16)

4 Which of the following statements concerning a silver oxide button cell is INCORRECT?

A Its negative electrode is silver oxide.
B Its maximum voltage is 1.5 V.
C Its voltage remains constant during discharge.
D Its electrolyte is potassium hydroxide.

Explanation:
The negative electrode of a silver oxide button cell is zinc.

Answer: A

Unit Exercise (p.16)

5 A lead-acid accumulator is made up of a series of secondary cells.

Which of the following energy transformations occurs when the accumulator is being recharged?

A chemical → electrical + light
B chemical → kinetic + heat
C electrical → chemical + heat
D electrical → light + kinetic

Answer: C

Unit Exercise (p.16)

6 Which of the following combinations is correct for a nickel metal hydride cell?

	Negative electrode	Positive electrode	Electrolyte
A	hydrogen-absorbing alloy	nickel oxyhydroxide	potassium hydroxide
B	hydrogen-absorbing alloy	potassium hydroxide	nickel oxyhydroxide
C	zinc	potassium hydroxide	nickel oxyhydroxide
D	zinc	nickel oxyhydroxide	potassium hydroxide

Answer: A

Unit Exercise (p.16)

7 Which of the following is / are secondary cell(s)?

(1) Alkaline manganese cell
(2) Lithium ion cell
(3) Nickel metal hydride cell

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

(HKDSE, Paper 1A, 2013, 21)

Answer: D

Unit Exercise (p.16)

8 Which of the following are related to the use of silver oxide cells in watches?

(1) Silver oxide cells are primary cells.
(2) Silver oxide cells are small in size.
(3) Silver oxide cells have a high energy density.

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

Answer: D

Unit Exercise (p.16)

9 Which of the following are advantages of using alkaline manganese cells over zinc-carbon cells in flashlights?

(1) Alkaline manganese cells have a longer service life.
(2) Alkaline manganese cells give a steadier voltage over discharge.
(3) Alkaline manganese cells have a higher maximum voltage.

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

Answer: A

Explanation:
(3) Both alkaline manganese cell and zinc-carbon cell have a maximum voltage of 1.5 V.

Unit Exercise (p.16)

10 Which of the following statements concerning lithium ion cells is / are correct?

(1) The electrolyte is an aqueous solution of a lithium salt.
(2) These cells are secondary cells.
(3) These cells are commonly used in portable electronic devices.

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

Explanation:
(1) Lithium CANNOT be used with an aqueous electrolyte as it is highly reactive towards water.

Answer: D

Unit Exercise (p.16)

11 Which of the following statements concerning nickel metal hydride cells are correct?

(1) These cells are rechargeable.
(2) These cells are commonly used in electric vehicles.
(3) The disposal of these cells causes less harm to the environment than the disposal of nickel- cadimum cells.

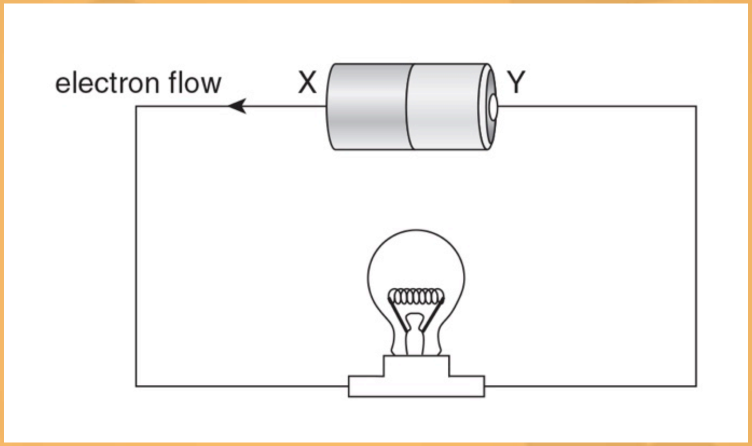
A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Answer: D

Unit Exercise (p.16)

PART III STRUCTURED QUESTIONS

12 A zinc-carbon cell is connected to a light bulb as shown below. Electrons flow from electrode X to electrode Y in the external circuit.



a) What is a chemical cell?

A chemical cell is a device that converts the chemical energy stored in it into electrical energy. (1)

Unit Exercise (p.16)

12 (continued)

b) Identify whether X or Y is the negative electrode of the zinc-carbon cell.

X (1)

c) Ammonium chloride is used as an electrolyte in the zinc-carbon cell.

What is the function of the electrolyte?

The electrolyte is the medium which allows ions to flow between the two electrodes. (1)

Unit Exercise (p.16)

13 Both zinc-carbon cells and silver oxide cells are primary cells.

a) Why are they classified as ‘primary cells’?
They CANNOT be recharged. (1)

b) Complete the following information about the two types of cell.

	Zinc-carbon cell	Silver oxide cell
Material of negative electrode	zinc (1)	zinc (1)
Material of positive electrode	carbon (1)	silver oxide (1)
Material of electrolyte	ammonium chloride (1)	potassium hydroxide (1)

Unit Exercise (p.16)

13 (continued)

c) Suggest TWO characteristics of silver oxide button cells that make them suitable for use in hearing aids.

- High energy density (1)
- Constant voltage over discharge (1)

Unit Exercise (p.16)

14 Alkaline manganese cell was introduced in the early 1960s and became immediately preferable to zinc-carbon cell.

a) Decide whether alkaline manganese cell is a primary or secondary cell.

Primary cell (1)

b) State the material used to make

i) the negative electrode;

Zinc (1)

ii) the positive electrode;

Manganese(IV) oxide (1)

iii) the electrolyte.

Potassium hydroxide (1)

Unit Exercise (p.16)

14 (continued)

c) Suggest TWO advantages of using alkaline manganese cells over zinc-carbon cells in motorised toys.

Any two of the following:

- Higher energy density (1)
- Good performance at all drain rates (1)
- A steadier voltage over discharge (1)
- Excellent leakage resistance (1)
- Longer shelf life (1)

Unit Exercise (p.16)

15 Lead-acid accumulator is a secondary cell containing sulphuric acid. It is commonly used in starting up motor vehicle engines.

a) What is meant by the term 'secondary cell'?

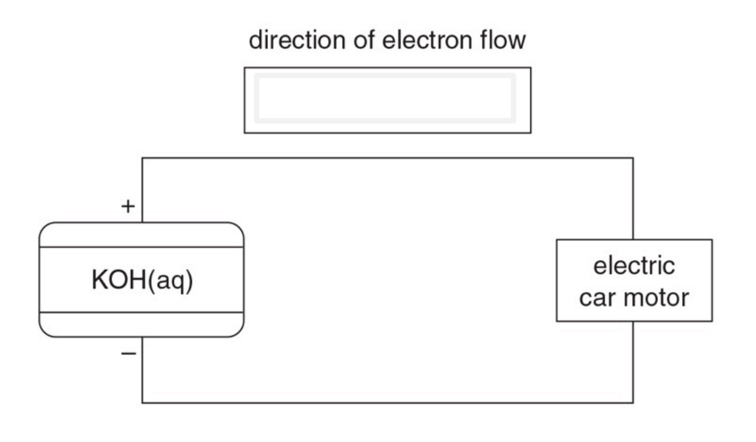
b) Suggest why a lead-acid accumulator is suitable for starting up motor vehicle engines.

c) State ONE environmental impact that would be imposed from the disposal of lead-acid accumulators.

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable). *(HKDSE, Paper 1B, 2015, 4(a)–(c))*

Unit Exercise (p.16)

16 The battery used in hybrid electric cars is comprised of a series of nickel metal hydride (NiMH) cells. MH represents a hydrogen-absorbing alloy that is used as one electrode. The other electrode is nickel oxyhydroxide, NiO(OH). The electrolyte is potassium hydroxide solution.



a) State the material used to make

i) the positive electrode;

Nickel oxyhydroxide (1)

Unit Exercise (p.16)

16 (continued)

a) ii) the negative electrode.

Hydrogen-absorbing alloys (1)

b) In the box provided on the diagram, use an arrow (⟶ or ⟵) to indicate the direction of electron flow as the cell is discharging.

⟵ (1)

c) Suggest ONE advantage of using nickel metal hydride cells over lithium ion cells in vehicles.

Safer (1)

Unit Exercise (p.16)

17 Consider lithium ion secondary cells.

a) State the material used to make

i) the negative electrode;

Lithium atoms lying between graphite sheets (1)

ii) the positive electrode;

Lithium cobalt oxide (1)

iii) the electrolyte.

A lithium salt dissolved in an organic solvent (1)

Unit Exercise (p.16)

17 (continued)

b) Suggest why lithium ion cells have replaced nickel metal hydride cells in portable electronic devices.

- Higher voltage (1)
- Higher energy density (1)

c) State ONE safety concern of lithium ion cells.

The cell will be quickly damaged and may burst into flames if overcharged. (1)