CHAPTER 3

Electricity

How is electric field produced?

What are the factors affecting the resistance of a conducting wire?

What are the advantages of connecting dry cells in series and in parallel?

How can we reduce electrical energy consumption at home?

You will learn:

- **3.1** Current and Potential Difference
- **3.2** Resistance
- **3.3** Electromotive Force (e.m.f.) and Internal Resistance
- **3.4** Energy and Electrical Power

Learning Standards and List of Formulae in Chapter 3

Information Portal

Tenaga Nasional Berhad (TNB) was expected to spend RM1.2 billion from 2018 to 2020 to install new smart meters in residential homes across the country. A smart meter is a device that allows the daily electricity usage to be recorded and converted to data that users can monitor through mobile applications. The device can collect and analyse data of electricity usage hourly. Electricity consumption data is collected and transmitted to the control centre through a radio frequency (RF). It allows users to monitor electricity consumption easily and reduces TNB's manpower in recording electricity consumption. Indirectly, this technology enhances the efficiency of electrical energy consumption in our country.

https://bit.ly/32oAmeA

Importance of the Chapter

Careers in the Fourth Industrial Revolution (IR 4.0) require the need for software engineering skills to develope applications to meet the current market demands through two main platforms, namely Android and IOS. These platforms prioritise artificial intelligence software (AI) that makes decisions based on smart algorithms in electrical and electronic fields.

Futuristic Lens

Power Line Communication (PLC) will become the digital data transmission method of the future between smart meters and the utility control center. This method allows the power consumption data and the usage profile of each home to be monitored online.

https://bit.ly/2EtOII4

3.1 Current and Potential Difference

Observe Photograph 3.1 which shows the lightning phenomenon. How does the phenomenon occur? Recall the chapter on electricity which you studied in Form 2 Science.

Let's Recall

Electricity

https://bit.ly/2YCPNP0

Photograph 3.1 *The lightning phenomenon*

Electric Field

SCAN ME

EduwebTV: Electric field and charge flow

https://bit.ly/2Yzo2ac

When a charged comb is brought near to a fine stream of tap water, the stream of water bends towards the comb. This phenomenon indicates the existence of electric fields in our daily life. Can you list some other examples of the existence of electric fields?

(a) A fine stream of tap water is bent when a charged comb is brought near it

(b) Hair is attracted to a charged balloon

(c) Tiny pieces of paper are attracted to a charged plastic comb

(d) A charged drinking straw moves closer to an approaching finger

Photograph 3.2 *Examples of the existence of electric fields in daily life*

LS 3.1.1

Activity 3.1 Teacher's Demonstration

Aim: To study electric fields by using an electric field kit

Apparatus: Electric field kit and extra high tension (E.H.T.) power supply

Materials: Olive oil and semolina powder

Safety Precaution

- Do not touch any metallic part while using the E.H.T. power supply.
- Ensure that the E.H.T. power supply is switched off when no observation is being recorded.

Instructions:

1. Set up the apparatus as shown in Figure 3.1.

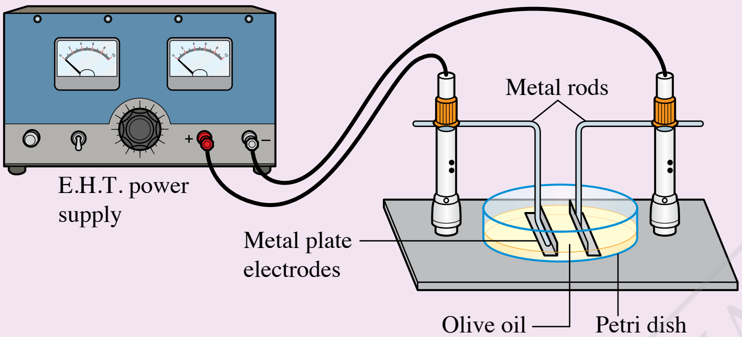


Figure 3.1

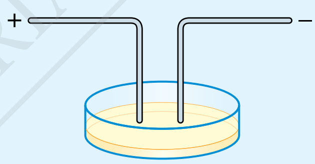
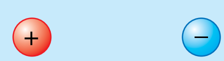
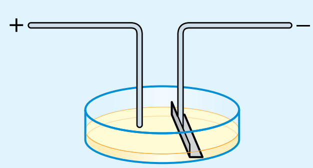
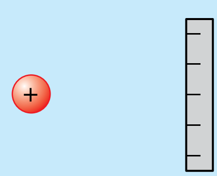
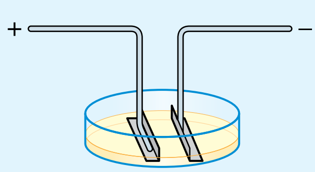
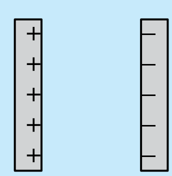
SCAN ME
Demonstration video of an electric field kit
https://bit.ly/2EIDqKb

SCAN ME
Worksheet (Table 3.1)
https://bit.ly/3b7dWT1

2. Scan the QR code and print Table 3.1.
3. Pour olive oil into a petri dish.
4. Sprinkle semolina powder on the surface of the olive oil.
5. Switch on the E.H.T. power supply and observe the movement of the semolina powder.
6. Record your observation in Table 3.1.
7. Repeat steps 3 to 6 with a pair of electrodes of different shapes as shown in Table 3.1.

Results:

Table 3.1

Shape of electrodes	Electrodes	Electric field
Two point electrodes		
A point electrode and a plate electrode		
Two parallel plate electrodes		

Discussion:

1. Why is the E.H.T. power supply used in this activity?
2. What happens to the parallel plate electrodes when the E.H.T. power supply is switched on?
3. Why does the sprinkled semolina powder form a certain pattern when the E.H.T. power supply is switched on?
4. What is the function of olive oil in this activity?
5. Name other materials beside semolina powder that can be used in this activity.

Based on Activity 3.1, when the E.H.T. power supply is switched on, the two electrodes will be at different potentials. An electric field exists between the two electrodes. **An electric field is the region around a charged particle where any electric charge in the region will experience an electric force.** When semolina powder is placed in the electric field, it experiences an electric force. The pattern formed by the semolina powder shows the pattern of the electric field.

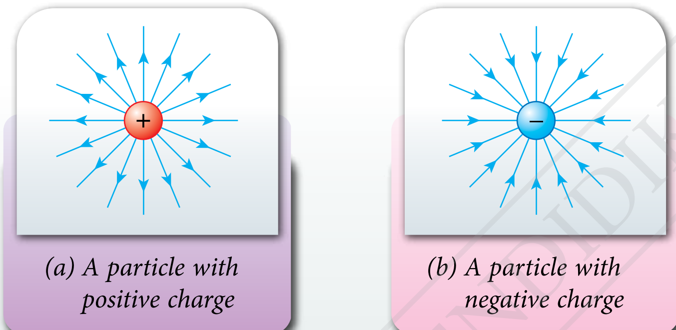


Figure 3.2 *Pattern of an electric field around a positively charged and a negatively charged particle*

Info GALLERY

An electric field line begins on a positive charge and ends on a negative charge. Electric field lines also do not cross each other.

The electric field lines around a positive charge always point outward while the electric field lines around a negative charge always point inward (Figure 3.2). Unlike charges attract each other while like charges repel each other.

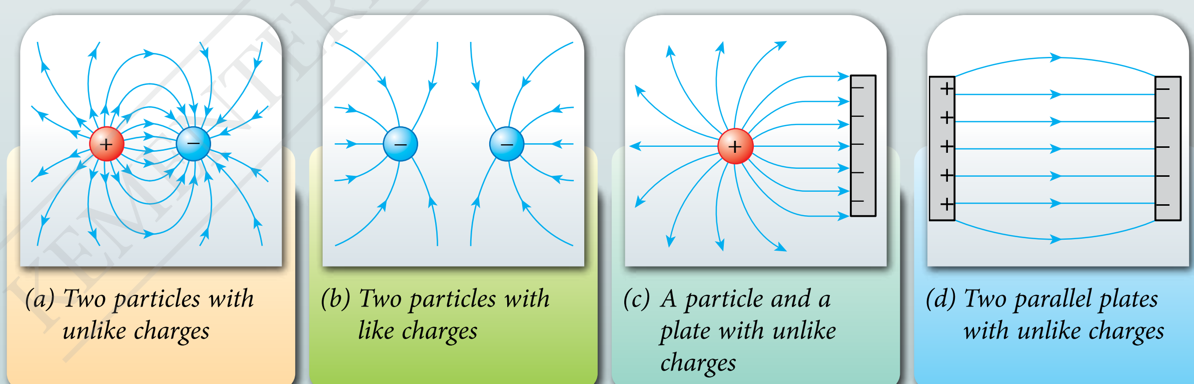


Figure 3.3 *Electric field patterns*

Electric field patterns can be drawn using lines with arrows as shown in Figure 3.3. Every line represents an electric field line.

Electric Field Strength

Assume that a positive test charge, q is placed in an electric field. The test charge will experience an electric force. This force can either be a repulsive or an attractive force depending on the type of a charged particle. Figure 3.4 shows an electric force acting on a positive test charge.

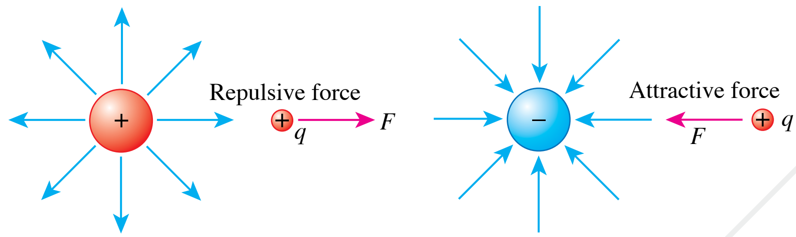


Figure 3.4 *Electric force acting on a positive test charge in an electric field*

The electric field strength, E at a given point in an electric field is defined as **the electric force acting on a unit positive charge placed at the point**.

$$E = \frac{F}{q}$$

where E = electric field strength
F = electric force
q = quantity of electric charge

The S.I. unit for E is newton per coulomb (N C^{-1})

Info GALLERY

The electric field lines follow the direction of the force on a positive test charge that is placed in the electric field.

Let's Recall

The S.I. unit for charge is coulomb (C).

Figure 3.5 shows a uniform electric field between two oppositely charged parallel plates. A uniform electric field is represented by a set of parallel electric field lines.

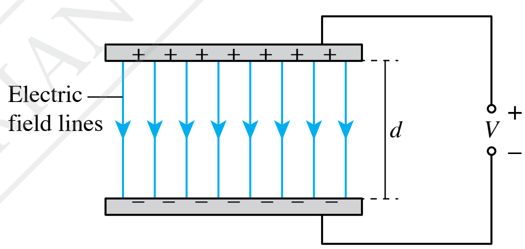


Figure 3.5 *A uniform electric field between two oppositely charged parallel plates*

The electric field strength, E produced by two parallel charged plates is

$$E = \frac{V}{d}$$

where E = electric field strength
V = potential difference between two parallel plates
d = distance between two parallel plates

The S.I. unit for E in this formula is volt per metre (V m^{-1})

BRIGHT Info

V m^{-1} is equivalent to N C^{-1}.

Behaviour of Charged Particles in an Electric Field

In an electric field, there is electric charge which can be positive or negative. Like charges repel each other while unlike charges attract each other. What will happen to charged particles when they are placed in an electric field?

Activity 3.2 Teacher's demonstration

Aim: To show the effects of an electric field on a charged object

Apparatus: Extra high tension (E.H.T.) power supply, metal plates and retort stands

Materials: Polystyrene ball wrapped in aluminium foil, nylon string and candle

Instructions:

1. Set up the apparatus as shown in Figure 3.6.

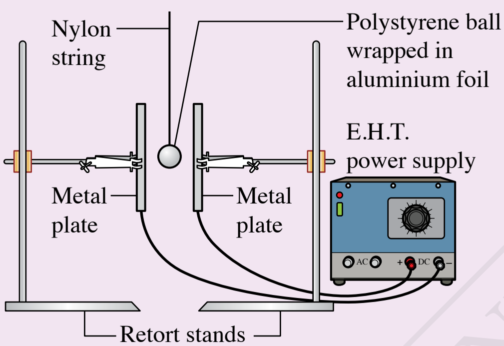


Figure 3.6

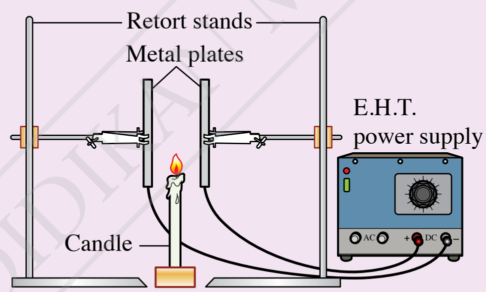


Figure 3.7

2. Switch on the E.H.T. power supply. Displace the polystyrene ball so that it touches one of the metal plates and release the ball. Record your observation.
3. Repeat step 2 by:
   (a) decreasing the distance between the two metal plates.
   (b) increasing the voltage of E.H.T. power supply.
4. Switch off the power supply and replace the polystyrene ball with a lighted candle as shown in Figure 3.7.
5. Switch on the E.H.T. power supply. Observe the effects on the candle flame. Record your observations.
6. Switch off the E.H.T. power supply. Reverse the connection at the power supply terminals and then switch on again. Observe the effects on the candle flame. Record your observations.

Discussion:

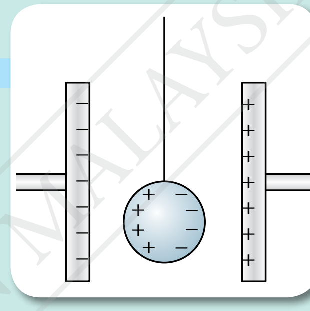
1. Why must the polystyrene ball be wrapped in aluminum foil?
2. What is the function of the nylon string?
3. What will happen to the movement of the polystyrene ball if the distance between the metal plates increases?

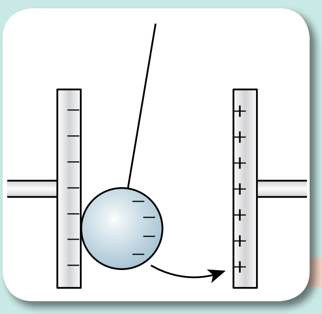
LS 3.1.3

The effect of an electric field on a metal coated polystyrene ball

1. When a polystyrene ball is displaced to touch a positively charged metal plate and released, the polystyrene ball will swing to and fro between the two plates until the power supply is switched off.

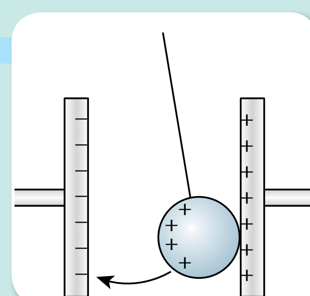
2. When the power supply is switched on, the metal coated polystyrene ball which is in between the two charged metal plates does not move. The polystyrene ball is neutral.





3. When the polystyrene ball is displaced to the negatively charged metal plate, positive charges of the ball will be discharged. The polystyrene ball will become negatively charged. Like charges on the polystyrene ball and the metal plate will produce a repulsive force which pushes the ball away. The negatively charged polystyrene ball will be attracted towards the positive metal plate.

4. At the positive metal plate, the electrons in the polystyrene ball will be transferred to the metal plate until the ball becomes positively charged. Like charges on the polystyrene ball and the metal plate produce a repulsive force which pushes the ball away. The positively charged polystyrene ball will be attracted towards the negative metal plate.



5. The process keeps repeating until the power supply is switched off.

SCAN ME

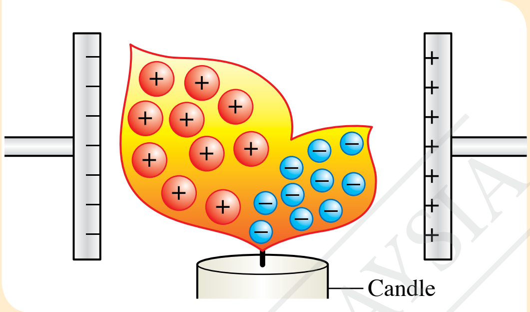
Video on the effect of an electric field on a polystyrene ball

https://bit.ly/3hzg9ZI

Figure 3.8 *The effect of an electric field on the movements of a metal coated polystyrene ball*

The effects of an electric field on a candle flame

1. When the power supply is switched on, the candle flame will spread out between the two metal plates. The spread of the flames towards the negatively charged metal plate is greater than towards the positively charged metal plate.
2. The heat from the candle flame causes the air to ionise to form positive ions and negative ions.
3. The negative ions will be attracted to the positively charged metal plate while the positive ions to the negatively charged metal plate.
4. Positive ions have larger mass and size compared to negative ions. Therefore, the spread of flames towards the negatively charged metal plate is greater than towards the positively charged metal plate.



SCAN ME

Video on the effects of an electric field on a candle flame

https://bit.ly/3jigi4h

Figure 3.9 *The effect of an electric field on a candle flame*

Electric Current

An electrical equipment can only function if current flows in a complete electric circuit. **Current**, I is **the rate of flow of charge, Q in a conductor**.

$$I = \frac{Q}{t} \quad \text{or} \quad Q = It$$

where I = current
Q = total charge
t = time

The S.I. unit for current, I is coulomb per second ($C\ s^{-1}$) or ampere (A).

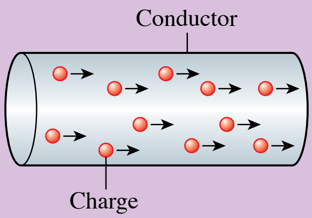


Figure 3.10 *Electric charges flowing in a conductor*

Potential Difference

You have learned that current is the rate of flow of electric charges. What makes the current flow in a circuit? This is related to the electric **potential difference**.

Brain-Teaser

In the electric field of a positively charged particle, why is the electric potential higher at a position nearer to the charge?

Current can flow from one point to another due to a potential difference between the two points in a circuit. **The potential difference**, V between two points in an electric field is **the work done, W in moving one coulomb of charge, Q from one point to another**.

$$V = \frac{W}{Q} \quad \text{or} \quad V = \frac{E}{Q}$$

where V = potential difference
W = work done
E = energy transferred
Q = the amount of charges flowing

The S.I. unit for potential difference, V is joule per coulomb ($J\ C^{-1}$) or volt (V).

The potential difference is 1 V if the work done to move 1 C of charge from one point to another is 1 J.

EAC History

Alessandro Volta was an Italian physicist who invented the voltaic pile, the first chemical battery. The unit of volt was named in his honour to recognise his contribution in the field of electricity.

BRIGHT Info

Charge of an electron,
$e = 1.6 \times 10^{-19}$ C

Therefore,

$$1\text{ C} = \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18} \text{ electrons}$$

Formative Practice 3.1

1. Define current and potential difference.
2. What is an electric field?
3. Figure 3.11 shows an electronic advertisement board. The current flowing is 4.0×10^{-2} A. What is the number of electrons flowing in the circuit when it remains switched on for 3 hours?

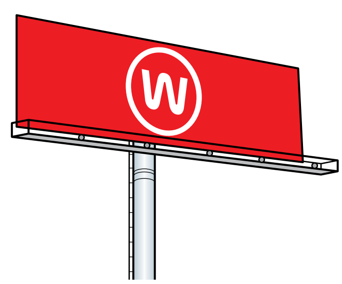


Figure 3.11

4. A bulb labelled 3.0 V, 0.2 A was lit for 1 hour. Calculate:
   (a) the electric charge
   (b) the energy generated
5. An electric charge of 900 C flows through a metallic conductor in 10 minutes. Calculate the current.

3.2 Resistance

Ohmic Conductor and Non-Ohmic Conductor

A conductor which obeys Ohm's Law is called an ohmic conductor whereas a conductor which does not obey Ohm's Law is called a non-ohmic conductor. Do the potential difference and the current vary according to Ohm's Law for conductors such as a constantan wire and a bulb? Carry out Experiment 3.1.

SCAN ME
Ohm's Law
https://bit.ly/31uiGir

SCAN ME
Video on Ohm's Law
https://bit.ly/2QzBPZP

Experiment 3.1

Inference: The potential difference across a conductor depends on the current flowing through it
Hypothesis: The higher the current, the higher the potential difference across the conductor
Aim: To study the relationship between the current and the potential difference of an ohmic conductor and a non-ohmic conductor

A Ohmic conductor (a constantan wire)

Variables:
(a) Manipulated: Current, I
(b) Responding: Potential difference, V
(c) Constant: Temperature, diameter and length of constantan wire

Apparatus: 1.5 V dry cell, cell holder, switch, connecting wires, ammeter, voltmeter, metre rule, rheostat, constantan wire s.w.g 24 (20 cm length)

Procedure:
1. Set up the apparatus as shown in Figure 3.12.

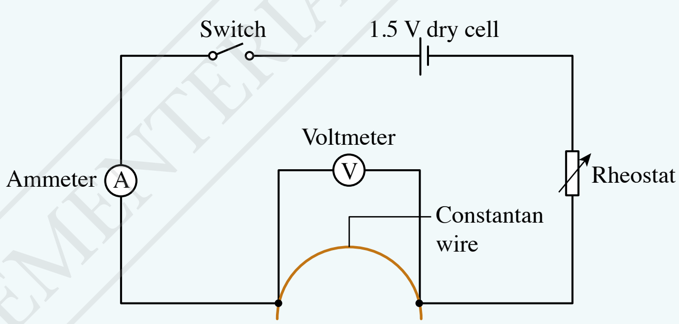


Figure 3.12

2. Close the switch and adjust the rheostat until the ammeter reads I = 0.2 A. Record the voltmeter reading, V in Table 3.2.
3. Repeat step 2 with values of I = 0.3 A, 0.4 A, 0.5 A and 0.6 A.

Info GALLERY

Standard wire gauge (s.w.g.) represents the diameter of a wire. The bigger the value of its s.w.g., the smaller the diameter.

Safety Precaution

- Ensure that the connecting wires are connected tightly.
- Avoid parallax error when taking the ammeter and voltmeter readings.
- Turn off the switch immediately after taking each reading so that the temperature of the constantan wire remains constant throughout the experiment.

LS 3.2.1

Results:

Table 3.2

Current, I / A	Potential difference, V / V
0.2	
0.3	
0.4	
0.5	
0.6	

B Non-ohmic conductor (a filament bulb)

Variables:

(a) Manipulated: Current, I

(b) Responding: Potential difference, V

(c) Constant: Filament length

Apparatus: 1.5 V dry cell, cell holder, switch, connecting wires, ammeter, voltmeter, rheostat and filament bulb (2.5 V, 3 W)

Procedure:

1. Replace the constantan wire in Figure 3.12 with a filament bulb.
2. Close the switch and adjust the rheostat until the ammeter reads I = 0.14 A. Record the voltmeter reading, V in Table 3.3.
3. Repeat step 2 with values of I = 0.16 A, 0.18 A, 0.20 A and 0.22 A.

Results:

Table 3.3

Current, I / A	Potential difference, V / V
0.14	
0.16	
0.18	
0.20	
0.22	

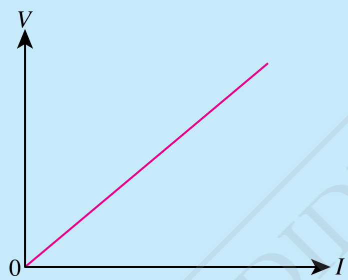
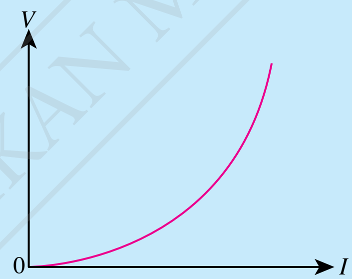
Data analysis:
Plot graphs of potential difference, V against current, I for experiment A and experiment B.

Conclusion:
What conclusions can be drawn from both experiments?

Prepare a complete report of experiment A and experiment B.

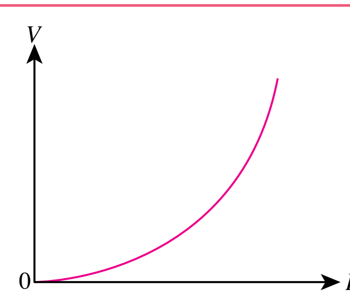
Discussion:
Based on the two graphs of V against I, compare the shapes and gradients of the graphs.

***Table 3.4** Comparison of graphs of V against I for an ohmic conductor and a non-ohmic conductor*

Type of conductor	Ohmic conductor	Non-ohmic conductor
Graph of V against I	A straight-line graph passing through the origin 	A curved graph passing through the origin 
Relationship between V and I	V is directly proportional to I	V increases with I
Rate of increase of voltage	Constant	Increases
Resistance	Constant	Increases

Info GALLERY

The graph on the right shows the relationship between potential difference, V and current, I for a tungsten filament bulb. The bulb filament uses a tungsten coil. The tungsten wire is actually an ohmic conductor. As the current flowing through the coil increases, the temperature of the coil increases and the bulb lights up. At the same time, the resistance of the coil also increases with the temperature. Under this condition where the temperature cannot be kept constant, the tungsten coil in the bulb exhibits a non-ohmic characteristic.

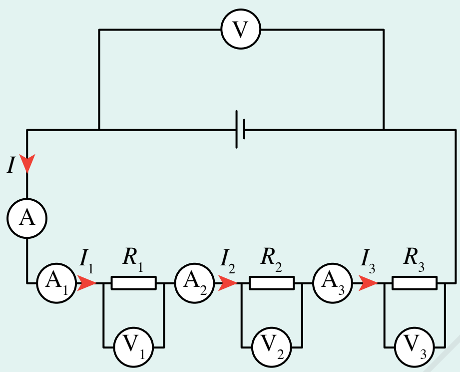
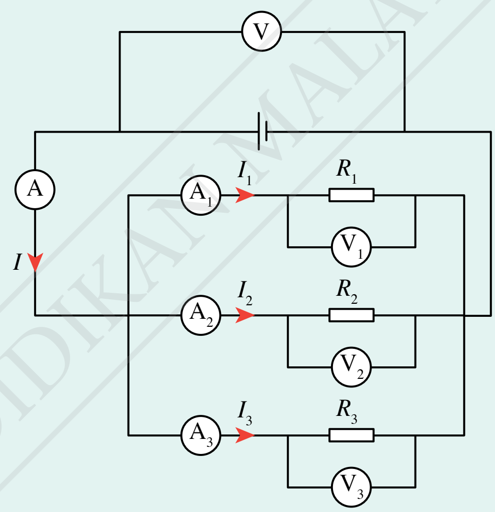


Graph of V against I

Solving Problems Involving Series and Parallel Combination Circuits

Let us recall series circuits and parallel circuits that you have studied in Form 2. The relation of current, potential difference and resistance in a series circuit are different from those in a parallel circuit. Table 3.5 summarises current, potential difference and resistance for series and parallel circuits. Based on the summary, you can determine the current, potential difference and resistance for series, parallel and combination circuits.

Table 3.5 *Summary of current, potential difference and resistance for series and parallel circuits*

<table>
<tr><th>Series circuit</th><th>Parallel circuit</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>The current flowing through each resistor is the same.
$I = I_1 = I_2 = I_3$</td><td>The sum of current leaving a junction is equal to the sum of current entering a junction.
$I = I_1 + I_2 + I_3$</td></tr>
<tr><td>The potential difference across the dry cell is equal to the sum of the potential differences across all the resistors.
$V = V_1 + V_2 + V_3$</td><td>The potential difference across the dry cell is the same as the potential difference across each resistor.
$V = V_1 = V_2 = V_3$</td></tr>
<tr><td>Effective resistance
$R = R_1 + R_2 + R_3$</td><td>Effective resistance
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$</td></tr>
</table>

Example 1

Three resistors are arranged in series and in parallel as shown in Figure 3.13. The resistance for R_1, R_2 and R_3 are 2 Ω, 4 Ω and 12 Ω respectively.

LET'S ANSWER

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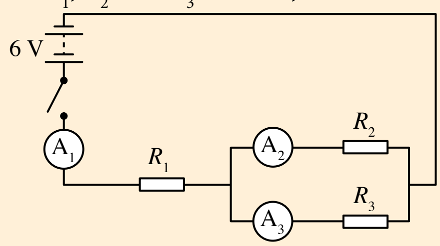
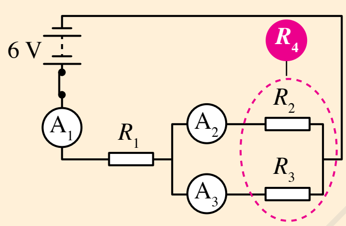


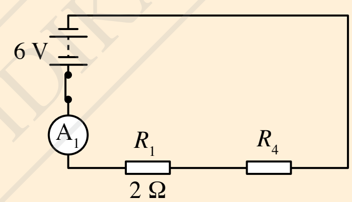
Figure 3.13

When the switch is closed, calculate:
(a) the effective resistance, R
(b) the current flowing through the 2 Ω resistor and the potential difference across it
(c) the current flowing through the 4 Ω and 12 Ω resistors and the potential difference across them respectively

Solution

(a)





Total resistance in the parallel circuit,

$$\frac{1}{R_4} = \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{1}{4} + \frac{1}{12}$$
$$= \frac{4}{12}$$
$$R_4 = \frac{12}{4}$$
$$= 3\ \Omega$$

Thus, the effective resistance in the complete circuit,

$$R = R_1 + R_4$$
$$= 2 + 3$$
$$= 5\ \Omega$$

(b) Total current flowing in the circuit,

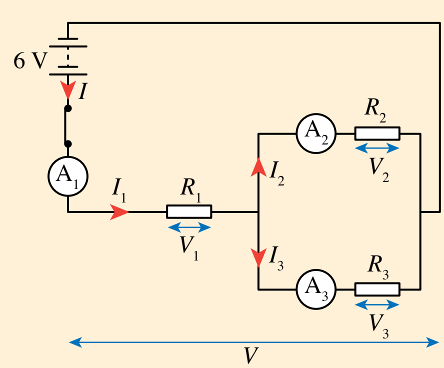
$$I = \frac{V}{R}$$
$$I = \frac{6}{5}$$
$$= 1.2\ \text{A}$$

$I_1 = I$

Thus, the potential difference for $V_1 = I_1R_1$

$V_1 = 1.2\ (2)$

$= 2.4$ V



LS 3.2.2

(c) For the 4 Ω and 12 Ω resistors:

Potential difference, $V = V_1 + V_2$

$V_2 = V - V_1$
$= 6 - 2.4$
$= 3.6$ V

Since R_2 is parallel with R_3,

Then, $V_3 = V_2 = 3.6$ V

So, the current flowing through the 4 Ω resistor,

$I_2 = \dfrac{V_2}{R_2}$
$= \dfrac{3.6}{4}$
$= 0.9$ A

While the current flowing through the 12 Ω resistor,

$I_3 = \dfrac{V_3}{R_3}$
$= \dfrac{3.6}{12}$
$= 0.3$ A

Example 2

Figure 3.14 shows five resistors connected in a combination circuit. Calculate:
(a) the effective resistance, R
(b) the current flowing through the ammeter, I
(c) the potential difference across points A and B, V_{AB}

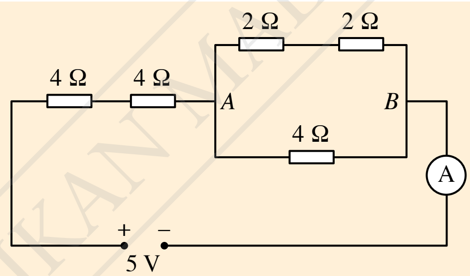
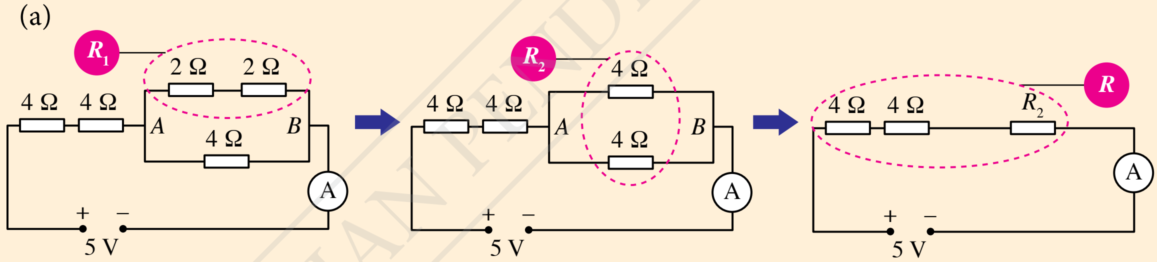


Figure 3.14

Solution

(a)



$R_1 = 2 + 2$
$= 4$ Ω

$\dfrac{1}{R_2} = \dfrac{1}{4} + \dfrac{1}{4}$
$= \dfrac{2}{4}$
$R_2 = \dfrac{4}{2}$
$= 2$ Ω

$R = 4 + 4 + 2$
$= 10$ Ω

(b) Potential difference, $V = 5$ V
Effective resistance, $R = 10$ Ω

Current, $I = \dfrac{V}{R}$
$= \dfrac{5}{10}$
$= 0.5$ A

(c) Resistance, $R_2 = 2$ Ω
Current, $I = 0.5$ A
Potential difference, $V_{AB} = IR_2$
$= (0.5)(2)$
$= 1.0$ V

Factors that Affect the Resistance of a Wire

Factors that affect the resistance of a wire are the length of the wire, l, cross-sectional area of the wire, A and resistivity of the wire, ρ. Conduct Experiments 3.2, 3.3 and 3.4 to study the relationship between these factors and the resistance of the wire.

Experiment 3.2

Inference: The resistance of a wire depends on the length of the wire

Hypothesis: The longer the wire, the higher the resistance of the wire

Aim: To study the relationship between the length and the resistance of a wire

Variables:

(a) Manipulated: Length of wire, l

(b) Responding: Resistance, R

(c) Constant: Diameter, resistivity and temperature of the wire

Apparatus: Two 1.5 V dry cells, cell holder, switch, connecting wires, ammeter, voltmeter, crocodile clips, rheostat and metre rule

Material: 110.0 cm of s.w.g. 24 constantan wire

Procedure:

1. Set up the apparatus as shown in Figure 3.15.

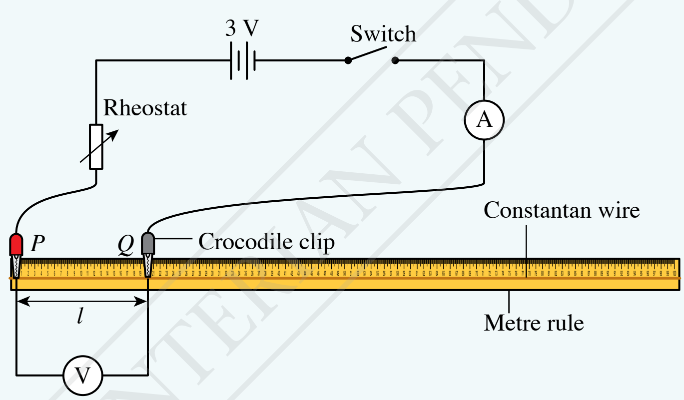


Figure 3.15

Info GALLERY

The resistivity of a wire depends on the wire material.

Note

Ensure the wire temperature is constant throughout the experiment as changes in the temperature will affect the resistance of the wire.

2. Adjust crocodile clips P and Q so that the length of the wire, l = 20.0 cm.
3. Close the switch and adjust the rheostat until the current, I flowing in the circuit is 0.5 A.
4. Record the value of potential difference across the wire in Table 3.6.
5. Repeat steps 2 to 4 for different lengths of the constantan wire, l = 40.0 cm, 60.0 cm, 80.0 cm and 100.0 cm.
6. Calculate the resistance, $R = \frac{V}{I}$.

Results:

Table 3.6

Length of wire, l / cm	Current , I / A	Potential difference, V / V	Resistance, R / Ω
20.0			
40.0			
60.0			
80.0			
100.0			

Data analysis:
Plot a graph of resistance, R against the length of wire, l.

Conclusion:
What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:
State one precaution that needs to be taken to ensure that the wire temperature is constant throughout the experiment.

Experiment 3.3

Inference: The resistance of a wire depends on the cross-sectional area of the wire

Hypothesis: The larger the cross-sectional area of the wire, the smaller the resistance of the wire

Aim: To study the relationship between the cross-sectional area and the resistance of a wire

Variables:
(a) Manipulated: Cross-sectional area of wire, A
(b) Responding: Resistance, R
(c) Constant: Length, resistivity and temperature of the wire

Apparatus: Two 1.5 V dry cells, cell holder, switch, ammeter, voltmeter, connecting wires, crocodile clips, rheostat and metre rule

Materials: 30.0 cm constantan wires of s.w.g. 22, s.w.g. 24, s.w.g. 26, s.w.g. 28 and s.w.g. 30

Procedure:
1. Set up the apparatus as shown in Figure 3.16.

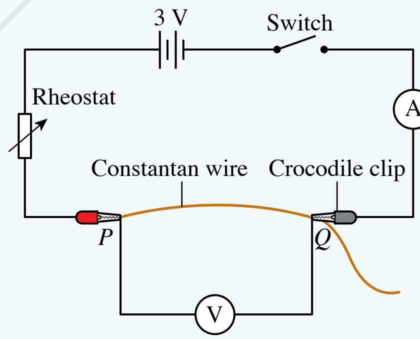


Figure 3.16

Note
Ensure that the wire temperature is constant throughout the experiment as changes in the temperature will affect the resistance of the wire.

2. Connect a 25 cm length of s.w.g. 22 constantan wire between P and Q.
3. Close the switch and adjust the rheostat until the current, I flowing in the circuit is 0.5 A.
4. Record the value of the potential difference across the wire.
5. Repeat steps 2 to 4 using the s.w.g. 24, s.w.g. 26, s.w.g. 28 and s.w.g. 30 constantan wires.
6. Based on the diameters given in Table 3.7, calculate the cross-sectional area of wire, $A = \pi r^2$ and resistance, $R = \frac{V}{I}$ for the five sets of data obtained (r = wire radius).
7. Record all the values for cross-sectional area, A, current, I, potential difference, V and resistance, R in Table 3.7.

Results:

Table 3.7

s.w.g.	Diameter, d / mm	Cross-sectional area, A / mm²	Current, I / A	Potential difference, V / V	Resistance, R / Ω
22	0.711				
24	0.559				
26	0.457				
28	0.376				
30	0.315				

Data analysis:

Plot a graph of resistance, R against cross-sectional area of wire, A.

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:

State the relationship between:
(a) the cross-sectional area and the resistance of a wire.
(b) the value of s.w.g. and the resistance of a wire.

Based on the results of Experiment 3.2, the graph in Figure 3.17 is obtained. The graph of R against l shows that as the length of the wire increases, the resistance of the wire also increases provided that the wire temperature remains constant. This shows that the resistance is directly proportional to the length of the wire.

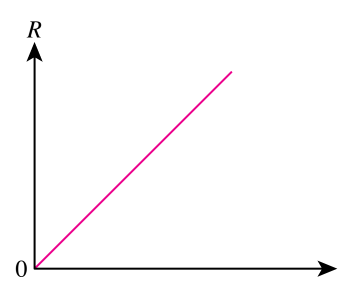


Figure 3.17 *Graph of R against l*

Based on the results of Experiment 3.3, the graph in Figure 3.18 is obtained. The graph of R against A shows that the resistance of the wire decreases as the cross-sectional area of the wire increases provided that the wire temperature remains constant. When R is plotted against $\frac{1}{A}$, a straight-line graph passing through the origin is obtained as shown in Figure 3.19. This shows that the resistance is directly proportional to $\frac{1}{A}$.

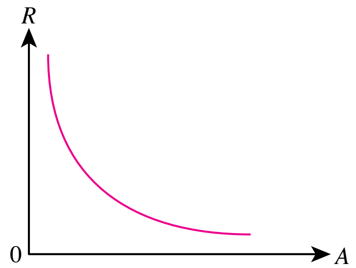


Figure 3.18 *Graph of R against A*

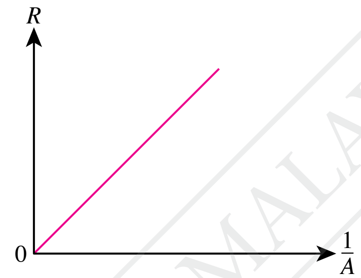


Figure 3.19 *Graph of R against* $\frac{1}{A}$

Resistivity of a Conductor

- The resistivity of a conductor, ρ is **a measure of a conductor's ability to oppose the flow of electric current**.
- The unit of resistivity is ohm-meter (Ω m).
- The value of resistivity depends on the temperature and the nature of the conductor material.

Experiment 3.4

Inference: The resistance of a wire depends on the resistivity of the wire

Hypothesis: The greater the resistivity of a conductor, the greater the resistance of the wire

Aim: To study the relationship between the resistivity and the resistance of a wire

Variables:

(a) Manipulated: Resistivity of the wire, ρ
(b) Responding: Resistance, R
(c) Constant: Length, diameter and temperature of the wire

Apparatus: Two 1.5 V dry cells, cell holder, switch, connecting wires, ammeter, voltmeter, crocodile clips, rheostat and metre rule

Materials: 35.0 cm of s.w.g. 24 constantan wire and 35.0 cm of s.w.g. 24 nichrome wire

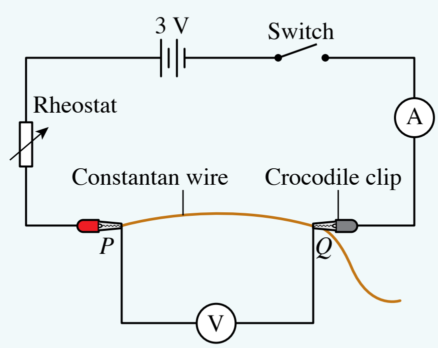


Figure 3.20

Procedure:

1. Set up the apparatus as shown in Figure 3.20.
2. Adjust the length of the constantan wire between P and Q so that its length, l = 30.0 cm.
3. Close the switch and adjust the rheostat until the current, I flowing in the circuit is 0.5 A.
4. Record the value of potential difference across the wire, V.

5. Repeat steps 2 to 4 with the nichrome wire.
6. Calculate the resistance, $R = \frac{V}{I}$ for each type of wire.
7. Record all the values of current, I, potential difference, V and resistance, R in Table 3.8.

Note

Ensure the wire temperature is constant throughout the experiment as changes in the temperature will affect the resistance of the wire.

Results:

Table 3.8

Type of wire	Current, I / A	Potential difference, V / V	Resistance, R / Ω
Constantan			
Nichrome			

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:

The resistivity of different conductors is given in Table 3.9. What can you say about the resistance of copper wire compared to the resistance of constantan and nichrome wires? Explain.

Table 3.9

Material	Resistivity of conductor, ρ / Ω m
Copper	1.68×10^{-8}
Constantan	49×10^{-8}
Nichrome	100×10^{-8}

Based on the results of Experiments 3.2, 3.3 and 3.4, the factors that affect the resistance of a wire can be summarised as shown in Figure 3.21.

$R \propto l$

$R \propto \frac{1}{A}$

$R \propto \frac{l}{A}$

$$R = \frac{\rho l}{A}$$

where ρ = the proportional constant known as the resistivity of the conductor

***Figure 3.21** Summary of the factors affecting the resistance of a wire*

Applications of Resistivity of Conductors in Daily Life

How can you apply your knowledge of resistivity in your daily life?

Activity 3.3

ISS

Aim: To study and elaborate on the applications of resistivity of conductors in daily life

Instructions:

1. Carry out this activity in groups.
2. Gather information to study the applications of resistivity of conductors on:
   (a) heating elements
   (b) electrical wiring at home (fuse and connecting wires)
3. Prepare a short report on the applications of resistivity of conductors.

Figure 3.22 describes the applications of resistivity in an electric rice cooker.

Heating Element

- The heating plate acts as a heating element.
- The conductor material has a high resistivity, melting point and is durable.

Connecting Wire

- The connecting wire consists of fine metal wires.
- Copper wire is used because copper has low resistivity which prevents the wire from heating up too quickly when current flows through it.

***Figure 3.22** Applications of resistivity in an electric rice cooker*

Different conductors have different resistivities. Likewise, non-conductors, semiconductors and superconductors have different resistivities as well.

Activity 3.4

ISS ICS

Aim: To seek information about the resistivity of conductors, non-conductors, semiconductors and superconductors

Instructions:

1. Carry out a Think-Pair-Share activity.
2. Get information from reading resources or search the websites for the resistivity of conductors, non-conductors, semiconductors and superconductors.
3. Present your findings.

SCAN ME

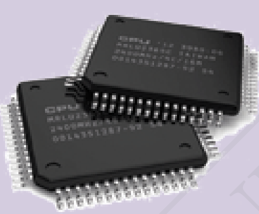
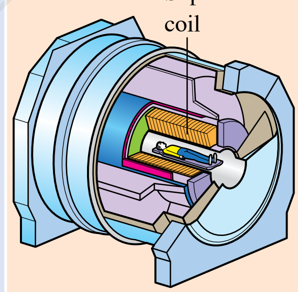
Examples on the resistivity of materials

https://bit.ly/3b0skwd

LS 3.2.5

Table 3.10 shows the comparison between non-conductors, semiconductors, conductors and superconductors.

Table 3.10 *Comparison between non-conductors, semiconductors, conductors and superconductors*

Non-conductor	Semiconductor	Conductor	Superconductor
A material that does not conduct electricity, good insulator.	A material that conducts electricity better than an insulator but not as good as a conductor.	A material that conducts electricity.	A material that conducts electricity without any resistance.
Has the highest resistivity	Has resistivity between a non-conductor and a conductor	Has low resistivity	Has zero resistivity at critical temperature
Examples: plastic and wood.	Examples: silicone and germanium.	Examples: iron and carbon.	Example: caesium at a temperature of 1.5 K or lower
 *Plastic cover of fuse box*	 *Silicon chip*	 *Nichrome coil as a heating element*	 *Superconductor coil in MRI*

Superconductors are **materials that conduct electricity without any resistance**. Therefore, no energy is lost when the current flows through the superconductor. **Critical temperature**, T_c is **the temperature when the resistivity of a superconductor becomes zero**.

Activity 3.5

ISS ICS

Aim: To seek information on previous studies of superconductors

Instructions:

1. Carry out this activity in groups.
2. Browse the website or scan the QR code to obtain information on previous studies of superconductors.
3. Gather information about:
   (a) the critical temperature, T_c
   (b) the graph of resistance against the thermodynamic temperature of superconductors
   (c) recent discoveries and studies of the critical temperature, T_c
4. Present your findings.

SCAN ME
Superconductors
http://bit.ly/2SqGe3v

Solving Problems Involving Wire Resistance

Example 1

The resistivity of constantan is $49 \times 10^{-8}\ \Omega$ m. Calculate the resistance of a constantan wire with a length of 50.0 cm and a diameter of 0.6 mm.

LET'S ANSWER

https://bit.ly/3jgPsJU

Solution

Step 1: Identify the problem

Step 2: Identify the information given

Step 3: Identify the formula that can be used

Step 4: Solve the problem numerically

1. Constantan wire resistance, R

2. Resistivity, $\rho = 49 \times 10^{-8}\ \Omega$ m
   Length of wire, l = 50.0 cm
   = 0.5 m
   Diameter of wire, d = 0.6 mm
   Radius of wire, $r = \dfrac{0.6 \times 10^{-3}\text{ m}}{2}$
   $= 3 \times 10^{-4}$ m

3. Cross-sectional area of wire, $A = \pi r^2$
   Resistance, $R = \dfrac{\rho l}{A}$

4. $A = \pi(3 \times 10^{-4})^2\ \text{m}^2$
   $R = \dfrac{(49 \times 10^{-8})(0.5)}{\pi(3 \times 10^{-4})^2}$
   $= 0.867\ \Omega$

Example 2

Azwan is an electrical wiring contractor in Taman Kota Puteri. He found that a coil of pure copper wire with a length of 500 m and a radius of 0.5 mm has a resistance of 10.8 Ω. What is the resistivity of copper?

Solution

Resistance of wire, $R = 10.8\ \Omega$
Length of wire, l = 500 m
Radius of wire, r = 0.5 mm
$= 0.5 \times 10^{-3}$ m

Resistivity of copper, $\rho = \dfrac{RA}{l}$

$$= \frac{R\pi r^2}{l}$$

$$= \frac{(10.8)\pi(0.5 \times 10^{-3})^2}{500}$$

$$= 1.696 \times 10^{-8}\ \Omega\ \text{m}$$

Formative Practice 3.2

1. List the factors that affect the resistance of a wire.
2. Calculate the total resistance of a coil of copper wire with a length of 50.0 m and a cross-sectional area of 2.5 mm^2, given that the resistivity of copper at a temperature of 20°C is $1.72 \times 10^{-8}\ \Omega$ m.

3.3 Electromotive Force (e.m.f.) and Internal Resistance

Electromotive Force

There are various sources of electromotive force, e.m.f. like electric generators, dynamos, batteries and accumulators. Photograph 3.3 shows several sources of e.m.f.

The electromotive force (e.m.f.), $\mathcal{E}$ is the energy transferred or work done by an electrical source to move one coulomb of charge in a complete circuit.

$$\mathcal{E} = \frac{E}{Q}$$

where $\mathcal{E}$ = electromotive force
E = energy transferred / work done
Q = the amount of charge flowing
The S.I. unit for e.m.f. is volt (V) or J C^{-1}.

Photograph 3.3 *Sources of e.m.f.*

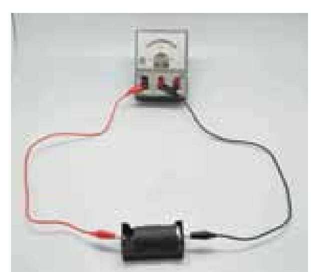
Photograph 3.4 shows a dry cell that can supply 1.5 J of electrical energy for each coulomb of charge in a complete circuit.

e.m.f. of a dry cell = 1.5 V
= 1.5 J C^{-1}

Photograph 3.4 *A dry cell*

SCAN ME
Video of Electromotive Force and Internal Resistance
https://bit.ly/2QJbAR1

Info GALLERY



A voltmeter has a high resistance. Thus, the current from a dry cell through a voltmeter can be neglected. The voltmeter reading is the e.m.f. of the dry cell.

Electromotive force and potential difference have the same S.I. units. However, electromotive force differs from potential difference under different circumstances.

Activity 3.6

Aim: To compare between e.m.f. and potential difference

Apparatus: 1.5 V dry cell, cell holder, switch, bulb, connecting wires and voltmeter

Instructions:

1. Set up the apparatus as shown in Figure 3.23 with the switch *S* open (open circuit).

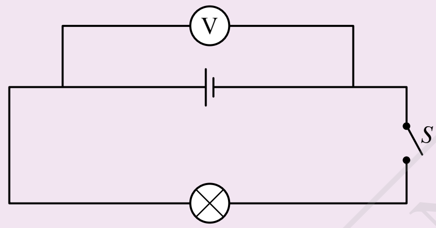


Figure 3.23

2. Observe what happens to the bulb and record the voltmeter reading in Table 3.11.
3. Close the switch *S* (closed circuit). Observe what happens to the bulb and record the voltmeter reading.

Results:

Table 3.11

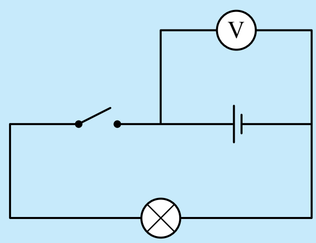
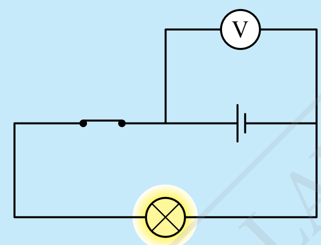
	Open circuit	Closed circuit
State of the bulb		
Voltmeter reading / V		

Discussion:

1. What is the change in energy when the bulb lights up?
2. Based on the results of this activity:
   (a) which circuit measured the potential difference across the bulb?
   (b) what is the quantity of electrical energy released by the bulb for every coulomb of charge that flows through it?
3. What is the e.m.f. of the dry cell?
4. What is the quantity of electrical energy that is supplied to every coulomb of charge flowing through the dry cell?
5. What is the difference in voltmeter readings between the open circuit and the closed circuit? Discuss why this difference occurs.

Based on Activity 3.6, a comparison between electromotive force and potential difference is shown in Table 3.12.

***Table 3.12** Comparison between electromotive force and potential difference*

Electromotive force (e.m.f.), $\mathcal{E}$	Potential difference, V
	
No current flows in the circuit	A current flows in the circuit
The voltmeter reading in an open circuit is the electromotive force, $\mathcal{E}$.	The voltmeter reading in a closed circuit is the potential difference across the bulb, V.
Work done by an electrical source to move one coulomb of charge in a complete circuit.	Work done to move one coulomb of charge between two points.

Internal Resistance

Based on Activity 3.6, the value of potential difference across the bulb, V is smaller than the e.m.f., $\mathcal{E}$ of the dry cell. This indicates that there is a **voltage drop**. What causes the voltage drop in the dry cell?

Activity 3.7

Aim: To study the effect of internal resistance on voltage drop

Apparatus: Two 1.5 V dry cells from two different brands (brands A and B), cell holder, switch, bulb with holder, connecting wires, ammeter and voltmeter

Instructions:

1. Check the dry cells you are using. Make sure both dry cells are new.
2. Set up the apparatus as shown in Figure 3.24 using the brand A dry cell.

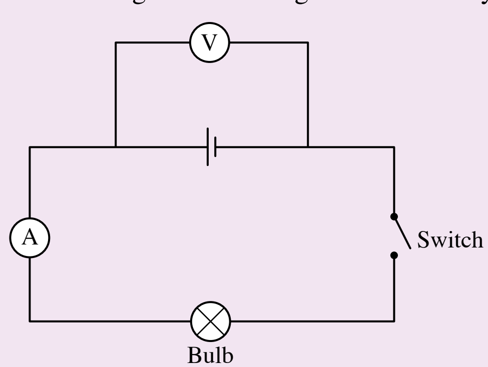


Figure 3.24

LS 3.3.1 3.3.2

3. Record the voltmeter reading as e.m.f., $\mathcal{E}$ in Table 3.13.
4. Close the switch and record the voltmeter reading as potential difference, V.
5. Calculate the difference in voltmeter readings before and after the switch is closed to determine the voltage drop.
6. Repeat steps 2 to 5 using the brand *B* dry cell.

Results:

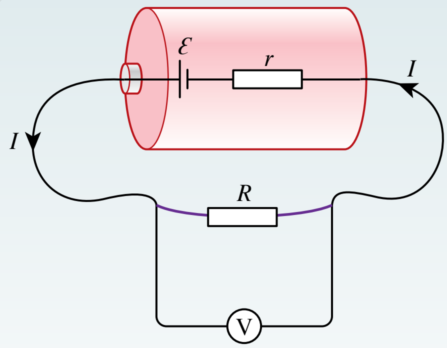
Table 3.13

	Brand *A*	Brand *B*
Voltmeter reading before switch is closed, $\mathcal{E}$ / V		
Voltmeter reading after switch is closed, V / V		
Voltage drop, $Ir = \mathcal{E} - V$		

Discussion:

1. Why should new dry cells be used in this activity?
2. Which brand of dry cell experiences greater voltage drop?
3. Why is there a difference in voltage drop between the two dry cells? Explain.

Internal resistance, r of a dry cell is **the resistance caused by electrolyte in the dry cell**. The S.I. unit for internal resistance, r is ohm (Ω). Internal resistance causes:
- loss of energy (heat) in dry cells as work has to be done to move one coulomb charge against the resistance within the dry cell
- the potential difference across the dry cell terminals to be less than the e.m.f., $\mathcal{E}$ when current flows in a complete circuit



Voltage drop, $Ir = \mathcal{E} - V$

Figure 3.25 *Internal resistance of a dry cell*

Determining the e.m.f. and Internal Resistance of a Dry Cell

Experiment 3.5

Aim: To determine the e.m.f. and internal resistance of a dry cell

Apparatus: 1.5 V dry cell, cell holder, switch, connecting wires, ammeter, voltmeter and rheostat

Procedure:

1. Set up the apparatus as shown in Figure 3.26.
2. Plan steps to:
   - obtain an ammeter reading
   - avoid parallax errors when taking ammeter and voltmeter readings
   - reduce energy loss from the dry cell
   - repeat the experiment to obtain a set of data so that a graph of potential difference, V against current, I can be plotted

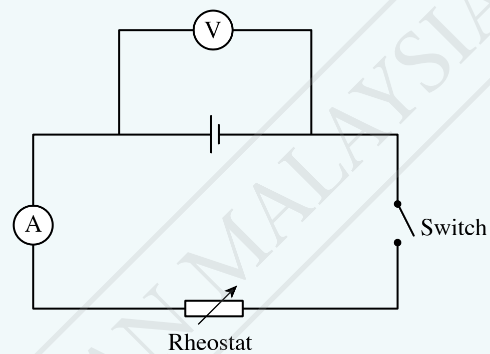


Figure 3.26

3. Carry out the experiment according to plan.
4. Record the results of the experiment and plot the graph of potential difference, V against current, I.
5. Based on the graph plotted, perform the data analysis as follows:
   (a) calculate the gradient of the graph
   (b) write a linear equation of the graph and relate it to the voltage drop, $Ir = \mathcal{E} - V$
   (c) calculate the internal resistance, r
   (d) determine the e.m.f., $\mathcal{E}$

Conclusion:
What conclusion can be drawn from this experiment?

Prepare a complete report of this experiment.

Discussion:
Based on the graph of this experiment, state the relationship between V and I. Explain your answer.

Voltage drop, $Ir = \mathcal{E} - V$

Then, $V = -Ir + \mathcal{E}$

where $\mathcal{E}$ = electromotive force motion (e.m.f.)
V = potential difference across variable resistor (rheostat)
I = current
r = internal resistance of dry cells
R = external resistance

$$\mathcal{E} = V + Ir = IR + Ir = I(R + r)$$

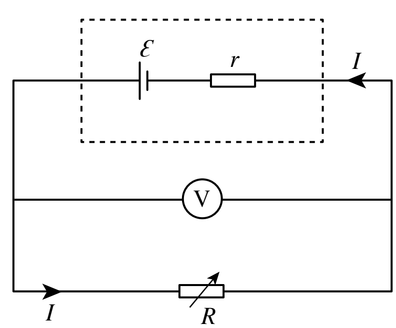


Figure 3.27

When a graph of V against I is plotted, a straight-line graph with a negative gradient is obtained as shown in Figure 3.28.

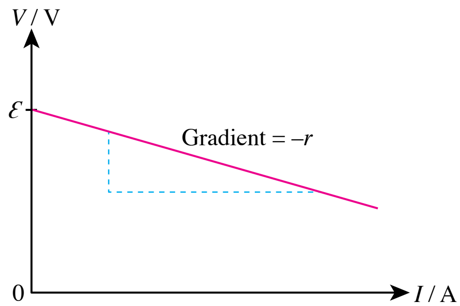


***Figure 3.28** Graph of V against I*

The equation for the linear graph is:

$$y = \boxed{m}\, x + \boxed{c}$$
$$V = \boxed{-r}\, I + \boxed{\mathcal{E}}$$

Intercept at vertical axis, $c = \mathcal{E}$
Gradient, $m = -r$

SCAN ME
A comparison of shapes of graphs of V against I in the experiment to determine the e.m.f. of a dry cell and the experiment to verify Ohm's Law
https://bit.ly/3loBfMY

Activity 3.8

Aim: To study the effects of connecting dry cell in series and parallel arrangements on:
- e.m.f., $\mathcal{E}$
- potential difference, V
- internal resistance, r
- current flows in the circuit

Apparatus: Six 1.5 V dry cells, cell holder, switch, connecting wires, ammeter, voltmeter and 10 Ω resistor

Instructions:

1. Set up the apparatus as shown in Figure 3.29 for dry cells in series and Figure 3.30 for dry cells in parallel.

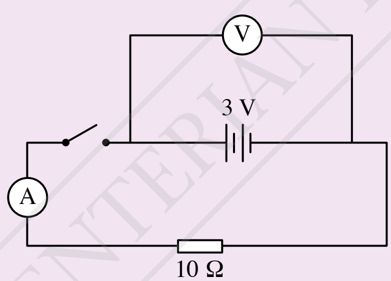


Figure 3.29

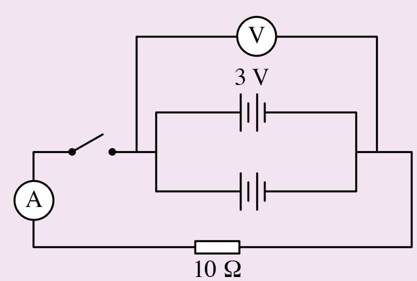


Figure 3.30

2. Record the voltmeter reading (total e.m.f. of dry cells), $\mathcal{E}$ in Table 3.14.
3. Close the switch. Record the ammeter and voltmeter readings (values of potential difference across 10 Ω resistor).
4. Using the voltage drop, $Ir = \mathcal{E} - V$, calculate the effective internal resistance, r_e for dry cells in the series and the parallel arrangements. Complete the table.

Results:

Table 3.14

	Dry cells in series	Dry cells in parallel
e.m.f., $\mathcal{E}$ / V		
Potential difference, V / V		
Current, I / A		
Effective internal resistance, r_e / Ω		

Discussion:

Which arrangement of dry cells produces smaller effective internal resistance? Explain.

Alkaline batteries that use potassium hydroxide electrolyte are twice as durable compared to zinc-carbon batteries that use ammonia chloride. Different electrolyte cause the internal resistance of the two batteries to be different. Apart from the electrolyte used, the arrangements of dry cells also affect the effective internal resistance.

Effects of Dry Cell Connected in Series and Parallel Arrangements

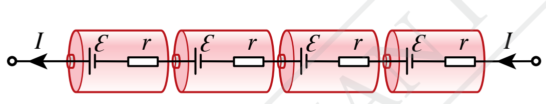
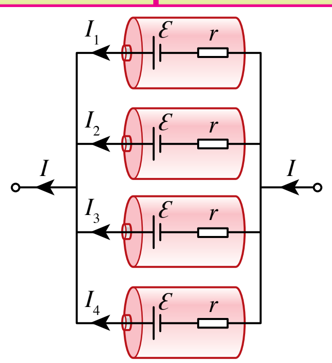
	Dry Cells in Series	Dry Cells in Parallel
Dry cell arrangement		
Effective internal resistance	$r_e = r + r + r + r = 4r$	$\frac{1}{r_e} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \frac{1}{r} = \frac{4}{r}$, $r_e = \frac{r}{4}$
Total e.m.f.	$4\mathcal{E}$	$\mathcal{E}$

***Figure 3.31** Effects of dry cell connected in series and parallel arrangements*

The arrangement of dry cells in series increases the effective e.m.f. while the arrangement of dry cells in parallel reduces the effective internal resistance.

Problem Solving Involving e.m.f. and Internal Resistance of Dry Cells

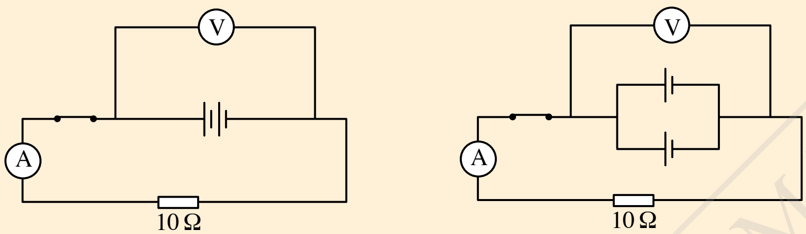
There are many electrical appliances that use dry cells such as radios, flashlights and children's toys. If an electrical appliance uses more than one dry cell, how should the dry cells be arranged so that the device can function with maximum efficiency?

Example 1

Figure 3.32 shows two circuits with dry cells arranged in series and in parallel. It is given that the e.m.f., $\mathcal{E}$ of each dry cell is 1.5 V and the internal resistance, r is 0.5 Ω.

LET'S ANSWER

https://bit.ly/2YFuOv5



(a) Arrangement of two dry cells in series *(b) Arrangement of two dry cells in parallel*

Figure 3.32

(a) (i) Compare the current flow in the two circuits.
(ii) Which arrangement of dry cells gives a greater current? Explain.

(b) If the circuit in Figure 3.32(b) is replaced with three dry cells in parallel:
(i) calculate the current
(ii) compare the current in the arrangements of two dry cells in parallel and three dry cells in parallel
(iii) state the relationship between the number of dry cells arranged in parallel with the current in the circuit and explain your answer.

Solution

(a) (i) Arrangement of two dry cells in series:

$r_e = 0.5 + 0.5$
$= 1.0\ \Omega$

$\mathcal{E} = I(R + r)$

Current, $I = \dfrac{\mathcal{E}}{R + r_e}$
$= \dfrac{3}{10 + 1.0}$
$= 0.27$ A

Arrangement of two dry cells in parallel:

$\dfrac{1}{r_e} = \dfrac{1}{0.5} + \dfrac{1}{0.5}$
$r_e = 0.25\ \Omega$

Current, $I = \dfrac{\mathcal{E}}{R + r_e}$
$= \dfrac{1.5}{10 + 0.25}$
$= 0.1463$ A

(ii) The dry cell connected in series provides a higher current because of a higher effective e.m.f.

(b) (i) Arrangement of three dry cells in parallel:

$\dfrac{1}{r_e} = \dfrac{1}{0.5} + \dfrac{1}{0.5} + \dfrac{1}{0.5}$
$r_e = 0.167\ \Omega$

Current, $I = \dfrac{\mathcal{E}}{R + r_e}$
$= \dfrac{1.5}{10 + 0.167}$
$= 0.1475$ A

(ii) The current for three dry cells arranged in parallel is higher.

(iii) Increasing the number of dry cells that are arranged in parallel will increase the current in the circuit because the effective internal resistance decreases.

Figure 3.33 explains how two types of vehicles are powered by different electrical sources.

Types of Vehicles Using Electric Power

Electric Vehicle (E.V.)

- Electric vehicle uses 100% electric power using rechargeable batteries to supply energy to electric motors. The commonly used batteries are Li-Ion or Ni-MH batteries.
- The battery voltage range required is 300 – 800 V.

Hybrid Car

- 25 – 40% of its power is supplied by rechargeable batteries and the remainder by fossil fuels such as petrol.
- The battery voltage range used is 100 – 200 V.

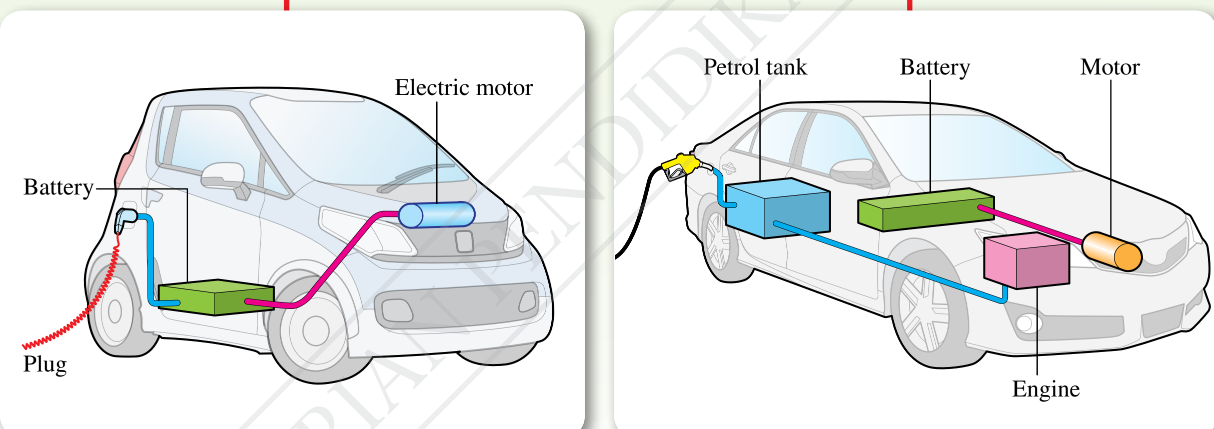


Figure 3.33 *Type of vehicles using electric power*

E.V. and hybrid cars batteries can be charged using domestic electricity supply and at E.V. charging stations or at solar cell charging power stations. Solar cells are components which can convert sunlight into electricity. Solar cells are arranged in series to form a solar panel. Arrangement of solar panels at solar cell charging power station plays a role in providing a suitable voltage and current. The use of E.V. is a good alternative in maintaining environmental sustainability.

SCIENCE, TECHNOLOGY and SOCIETY Gateway

The use of electric vehicle and hybrid cars can reduce the consumption of fossil fuel, increase the efficiency of energy usage and reduce air pollution.

Activity 3.9

CPS / ISS / ICS

Aim: Discuss the connection of solar cells and batteries in an electric vehicle to power the engine that requires high current

Instructions:

1. Carry out this activity in groups.
2. Scan the QR code given or browse the Internet to get information on how solar cells and batteries in electric vehicle are connected to generate high current.

SCAN ME
Video on solar cells and batteries connections
https://bit.ly/2EHtQYk

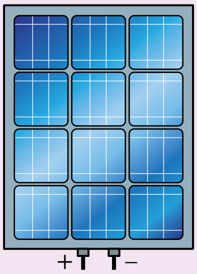
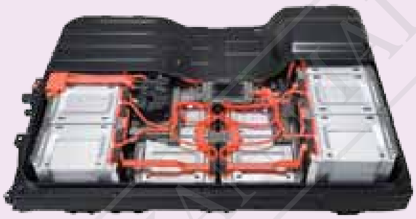


Figure 3.34 *Solar cells*



Photograph 3.5 *Battery packs in electric vehicle*

3. Discuss the connection of solar cell and batteries to start the engine of an electric car that requires high current.
4. Present the results.

Formative Practice 3.3

1. What is meant by electromotive force, e.m.f.?
2. State the difference between e.m.f. and potential difference.
3. What is the effect of internal resistance on current in a complete circuit?
4. If you are supplied with two dry cells, what type of arrangement can reduce the effective internal resistance of the dry cells?

LS 3.3.4

3.4 Electrical Energy and Power

Photograph 3.6 *Various electrical appliances at home*

Photograph 3.6 shows various electrical appliances that are used at home. Electrical appliances convert electrical energy into other forms of energy. For example, lamps produce light and heat energy when supplied with electrical energy. Can you state the form of energy that is generated by the electrical appliances in Photograph 3.6?

The Relationship between Electrical Energy (E), Voltage (V), Current (I) and Time (t)

Based on the formula of potential difference, $V = \frac{E}{Q}$

where V = potential difference
E = electrical energy
Q = the amount of charge flowing

Electrical energy, $E = VQ$ and $Q = It$

Therefore, the relationship between E, V, I and t can be formulated as:

$$E = VIt$$

The S.I. unit for electrical energy, E is joule (J).

Info GALLERY

1 J is the electrical energy that is used when 1 A of current flows through an electrical device with a potential difference of 1 V across it for 1 s.

LS 3.4.1

The Relationship between Power (*P*), Voltage (*V*) and Current (*I*)

Have you ever seen a label as shown in Photograph 3.7? The label displays the voltage and electrical power required to operate the electrical appliance.

Based on the label in Photograph 3.7, the electric rice cooker will use 700 J of electrical energy in one second when a voltage of 240 V is supplied. This information can be used to calculate the amount of electrical energy that is used over a period of time.

Photograph 3.7 *Power rating label on an electric rice cooker*

$$\text{Electrical power} = \frac{\text{Electrical energy used}}{\text{Time taken}}$$

$$P = \frac{E}{t}$$

and electrical energy, $E = VIt$

Therefore, the relationship between P, V and I can be derived as:

$$P = \frac{VIt}{t}$$

$$P = VI$$

From Ohm's Law, $V = IR$, two other equations for electrical power, P can be obtained as follows:

1. $P = V\left(\frac{V}{R}\right)$, then $P = \frac{V^2}{R}$
2. $P = (IR)I$, then $P = I^2R$

The S.I. unit for electrical power, P is watt (W) or J s^{-1}.

Info GALLERY

The voltage labelled on an electrical appliance is the working voltage. The working voltage is the potential difference required for an electrical appliance to operate under normal conditions. When an electrical appliance is operating at the working voltage, the electrical power used is as stated in the label.

LS 3.4.2

Solving Problems Involving Electrical Energy and Power in Daily Life

Example 1

Figure 3.35 shows a circuit that is supplied with a 6 V battery to light up a lamp. If the current is 0.7 A, what is the amount of electrical energy used to light up the lamp for one minute?

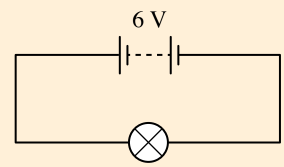


Figure 3.35

LET'S ANSWER

https://bit.ly/3jlXjWq

Solution

Step 1: Identify the problem

Step 2: Identify the information given

Step 3: Identify the formula that can be used

Step 4: Solve the problem numerically

1. Total electrical energy, E
2. Potential difference, $V = 6$ V
   Current, $I = 0.7$ A
   Time, $t = 1 \times 60$ s
   $= 60$ s
3. $E = VQ$
   $Q = It$
   Therefore, $E = VIt$
4. $E = 6 \times 0.7 \times 60$
   $= 252$ J

Example 2

A fluorescent lamp is labelled 240 V, 32 W.
Calculate:
(a) the lamp resistance
(b) the current flowing through the lamp under normal conditions
(c) the electrical energy that is supplied for three hours in kJ

BRIGHT Info

Scan the QR code for tips on how to use formulae to solve problems involving electrical energy and power.

https://bit.ly/3lxmt6G

Solution

(a) Electrical power required, $P = 32$ W
Potential difference across the lamp, $V = 240$ V
Resistance, $R = \dfrac{V^2}{P}$
$= \dfrac{240^2}{32}$
$= 1\ 800\ \Omega$

(b) Electrical power required, $P = 32$ W
Potential difference across the lamp, $V = 240$ V
Current, $I = \dfrac{P}{V}$
$= \dfrac{32}{240}$
$= 0.13$ A

(c) Electrical power required, $P = 32$ W
Time, $t = 3 \times 60 \times 60$
$= 10\ 800$ s
Electrical energy,
$E = Pt$
$= 32 \times 10\ 800$
$= 345\ 600$ J
$= 345.6$ kJ

The Power and Energy Consumption Rate for Various Electrical Devices

Nowadays, a variety of electrical appliances are available in the market. Consumers need to be wise in choosing electrical appliances that provide maximum energy saving.

For example, a 40 W Compact Fluorescent Lamp (CFL) and a 12 W Light Emitting Diode (LED) both produce the same brightness. If they are switched on for 12 hours a day, compare the costs of energy consumption for both lamps for 30 days.

Info GALLERY

The cost of electricity consumption depends on the amount of electrical energy used in a certain duration (usually 30 days). The total electrical energy used is measured in kWh.

1 kWh = 1 unit of electricity

Table 3.15 *Comparison of costs of energy consumption between CFL and LED*

CFL	LED
Energy used, $E = Pt$ $= 0.04 \text{ kW} \times 12 \text{ h}$ $= 0.48$ units Given that the cost of energy consumption is RM0.218 per unit; Cost of energy consumption = 30 days × 0.48 units × RM0.218 = RM3.139 	Energy used, $E = Pt$ $= 0.012 \text{ kW} \times 12 \text{ h}$ $= 0.144$ units Given that the cost of energy consumption is RM0.218 per unit; Cost of energy consumption = 30 days × 0.144 units × RM0.218 = RM0.942 

The energy consumption of LED is lower than CFL. This shows that LED has a higher efficiency and is more energy-saving compared to CFL.

Activity 3.10

ISS

Aim: To calculate electrical energy consumption at home

Instructions:

1. Carry out this activity individually.
2. Scan the QR code and print Table 3.16.
3. List all the electrical appliances that are found in your home such as electric rice cooker, television, lamp, electric oven, fan, air conditioner and so on in the table.
4. Collect information on the consumption of electrical energy based on the power rating of the electrical appliances. For each electrical appliances:
   (a) determine the quantity, power and hours used in a day
   (b) estimate the cost of electrical energy consumption in your home for a month

SCAN ME
Worksheet (Table 3.16)
https://bit.ly/3hxmyF3

Table 3.16

No.	Electrical appliance	Quantity (A)	Power / kW (B)	Hours used in a day / h (C)	Total energy usage / kWh (A × B × C)
1	Electric rice cooker				
2	Television				
3	Lamp				

5. Present the results of your findings.

Discussion:

1. Identify the electrical appliance in your home that consumes the highest electrical energy.

2. Suggest steps to reduce the cost of electricity consumption in your home.

Steps in Reducing Household's Electrical Energy Usage

Prudent use of electricity can help save and reduce the cost of electricity consumption at home. Can you suggest some energy saving measures that you can do at home?

Steps in Reducing Household's Electrical Energy Usage			
Close all windows and doors when using the air conditioner and ensure that the air conditioner filter is kept clean to cool the room down faster and more efficiently.	Switch off electrical appliances when they are not in use to conserve energy.	Use only full loads of laundry when using the washing machine.	Use energy saving lamps to reduce energy consumption.

Figure 3.36 *Steps in reducing household's electrical energy usage*

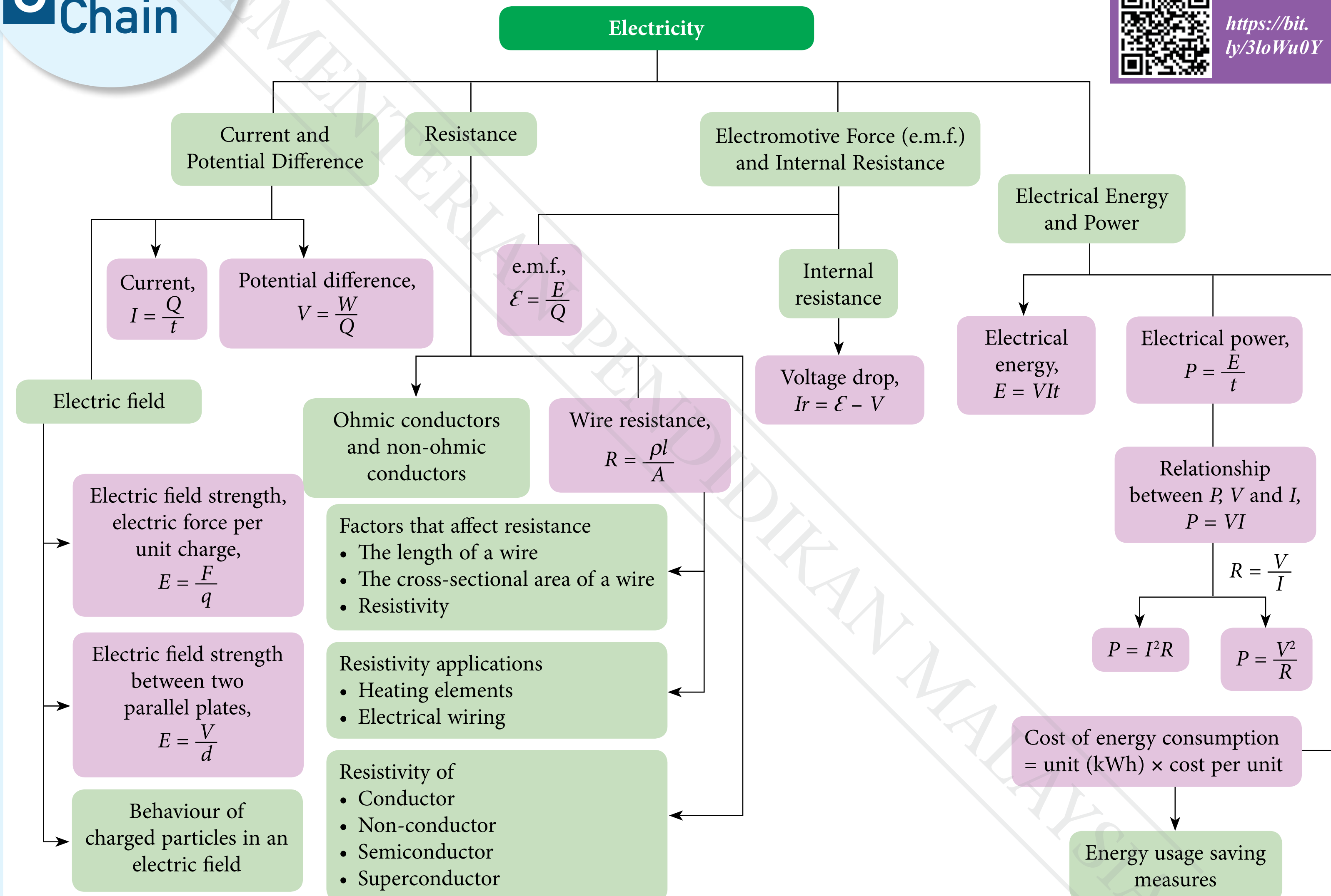
Formative Practice 3.4

1. The output power of a battery is 80 W. Determine the electrical energy that is supplied by the battery in:
(a) 10 seconds
(b) 2 hours

2. If the cost of electricity is 30 sen per unit, calculate the cost of using:
(a) 600 W LED television for 8 hours
(b) 1 kW vacuum cleaner for half an hour

Concept Chain

Interactive Games
https://bit.ly/3loWu0Y



Self-Reflection

SCAN ME
Download and print Self-Reflection
https://bit.ly/3jfv9N1

1. New things I have learnt in the chapter on 'Electricity' are ________.

2. The most interesting thing I have learnt in this chapter is ________.

3. The things I still do not fully understand are ________.

4. My performance in this chapter.

   Poor | 1 | 2 | 3 | 4 | 5 | Very good

5. I need to ________ to improve my performance in this chapter.

QUIZ PORTAL
https://bit.ly/3guA7nn

Summative Practice

1. Figure 1 shows a filament lamp. Why does a coiled filament produce a brighter light?

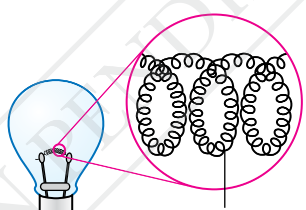


Figure 1

2. Figure 2 shows a circuit with three bulbs, X, Y and Z with a resistance of 3 Ω each.

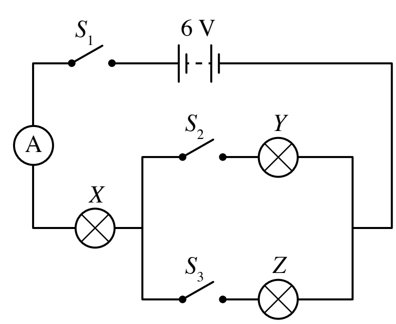


Figure 2

   (a) If switches S_1, S_2 and S_3 are closed, calculate:
      (i) the effective resistance in the circuit
      (ii) the current indicated by the ammeter
      (iii) the potential difference across bulb X

   (b) Compare the brightness of light bulbs X, Y and Z when switches S_1, S_2 and S_3 are closed.

   (c) If only switches S_1 and S_2 are closed, calculate:
      (i) the effective resistance in the circuit
      (ii) the current indicated by the ammeter
      (iii) the potential difference across bulb X

   (d) Compare the brightness of light bulbs X, Y and Z when only switches S_1 and S_2 are closed.

3. An experiment is conducted to study the relationship between electromotive force, $\mathcal{E}$ and internal resistance, r of a dry cell. The electrical circuit for the experiment is shown in Figure 3. The voltmeter readings, V and the corresponding ammeter readings, I are as shown in Table 1.

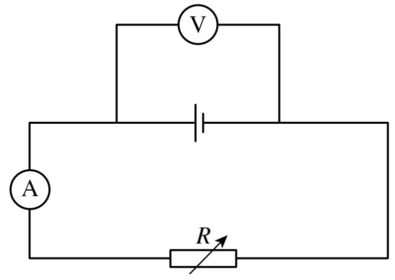


Figure 3

Table 1

V / V	I / A
1.40	0.2
1.35	0.4
1.25	0.6
1.15	0.8
1.10	1.0

(a) What is meant by electromotive force?

(b) Based on the data in Table 1, plot a graph of V against I.

(c) Based on the graph plotted, answer the following questions:

 (i) What happens to V when I increases?

 (ii) Determine the value of the potential difference, V when the current, $I = 0.0$ A. Show on the graph how you determine the value of V.

 (iii) Name the physical quantity that represents the value in 3(c)(ii).

(d) The internal resistance, r of the dry cell is given by $r = -m$, where m is the gradient of the graph. Calculate r.

(e) State two precautions that need to be taken in this experiment.

4. Figure 4 shows a circuit that is used to investigate the relationship between resistance, R and length of wire, l for two different wire conductors with the same diameter, that is 0.508 mm. Figure 5 shows the graph of resistance against length of wire.

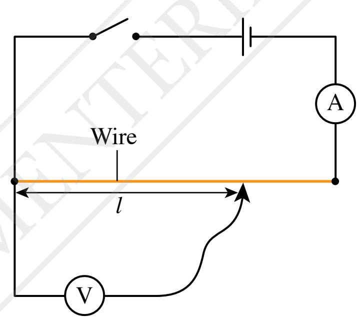


Figure 4

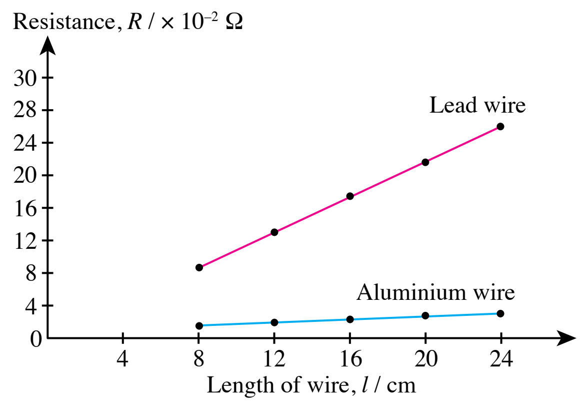


Figure 5

(a) What is meant by resistivity?

(b) Based on the graph in Figure 5, compare:

 (i) the gradients of the graph

 (ii) their resistivities.

(c) Based on your answer in 4(b), state the relationship between the gradient of the graph and the resistivity of the conductor.

5. Figure 6 shows four types of air fryers *A*, *B*, *C* and *D* with different specifications. Study the specifications of the four air fryers based on the following aspects:

- heating element
- coil turns of the heating element
- number of fan blades
- suitability of fuse

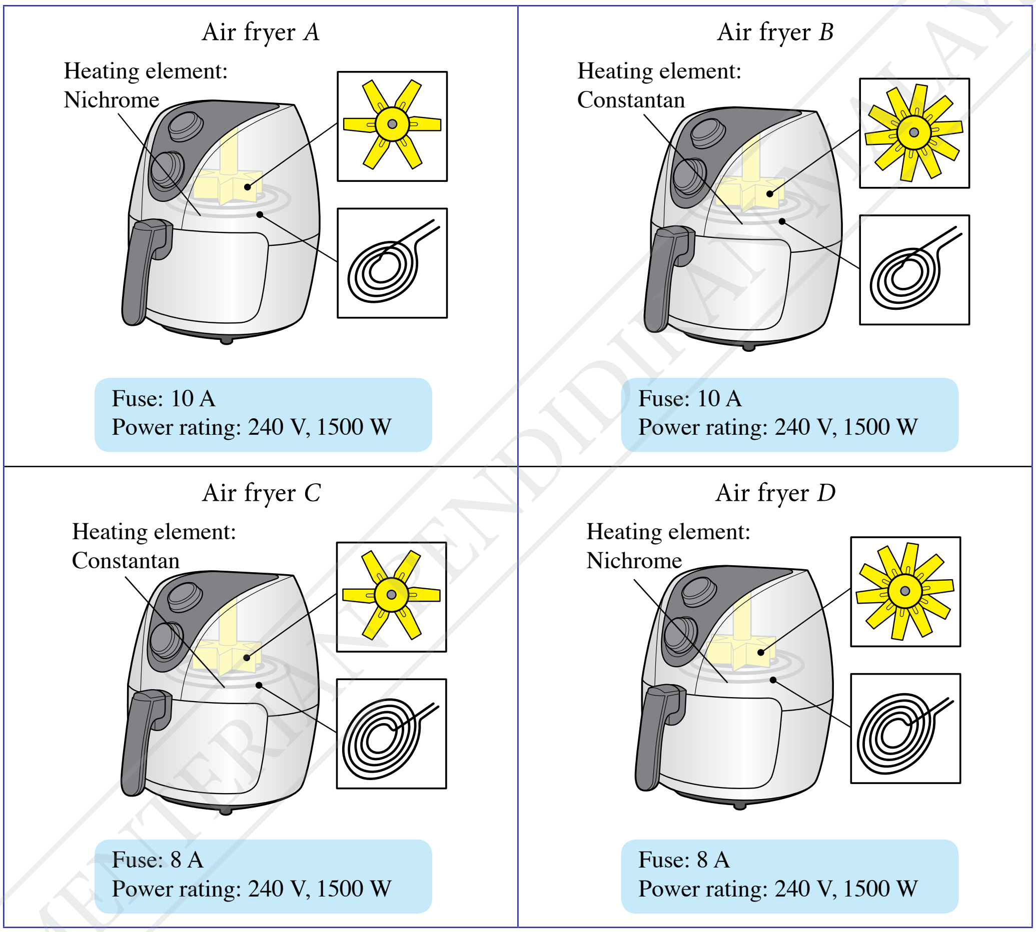


Figure 6

(a) What is the function of a fuse in an air fryer?

(b) What is meant by 240 V, 1500 W on the label of the air fryers?

(c) Discuss the specifications of the four air fryers to cook food quickly and safely.

(d) Determine the most suitable air fryer. Give your reasons.

6. Your mother has just renovated her kitchen with a modern concept. As a final touch, she asked you to buy an electric stove that can heat up food quickly and save electricity. Table 2 shows several electric stoves with its heating element features.

Table 2

Type of electric stove	Metal resistivity at 20°C, ρ / $10^{-6}\ \Omega$ cm	Thermal conductivity	Melting point / °C	Oxidation rate
P	1.7	Low	1 084	High
Q	2.7	High	660	Low
R	6.9	High	1 452	Low
S	20.6	Low	327	High

(a) Discuss the suitability of the four types of electric stoves based on the features given.

(b) Determine the most suitable electric stove. Give your reasons.

21st Century Challenge

7. Figure 7 shows a heating element in an electric kettle. You are required to modify the heating element so that it is portable and can boil water faster and safer.
Explain the modifications based on the following aspects:
- number of coil turns of the heating element
- density of the heating element
- diameter of the heating wire
- type of material used as the heating element

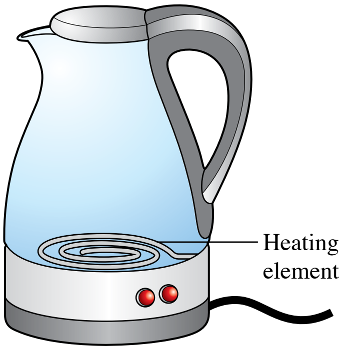


Figure 7