11 ELECTRIC CURRENT

Generating Electric Current

OBJECTIVES

At the end of this topic, students should be able to:

- generate a continuous flow of charges;
- explain electric current, electromotive force (e.m.f.) and potential difference (p.d.).

Electricity is the study of charge either at rest or in motion. When charges are at rest, they are said to be **electrostatic;** when they are in motion, they produce electric current. Electrons will not move until a force acts on them. The force or pressure which causes the electrons to move in one direction, is provided by a cell or a battery.

Electric current – electrons in motion

Metals are good conductors of electricity because they have free electrons in them. These electrons move about randomly inside the conductor under normal condition. When a cell or a battery is connected across the ends of the conductor, electric field created by the cell or the battery, causes the electrons to move in one direction. **The drift of the electrons inside the conductor is called electric current.** The electrons move from the negative terminal to the positive terminal of the cell.

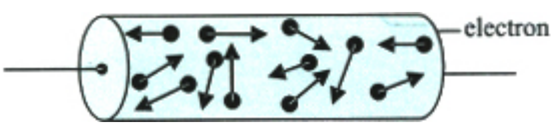


Figure 11.1 Random movement, of electrons in a conductor when no battery is connected

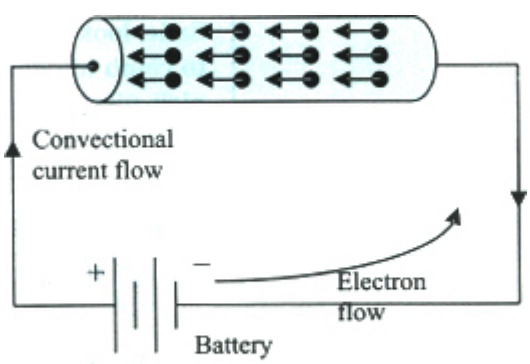


Figure 11.2 Electrons drift in the conductor when battery is connected

Electric current is the time rate at which electrons drift past a given point in a conductor.

Current and quantity of charge

$$\text{Electric current} = \frac{\text{Quantity of charge}}{\text{Time}}$$

$$I = \frac{Q}{t}$$

The quantity of charge or electricity passing a given point in a conductor is given by:

Q = I Ã— t

If a current of 1A flows through a conductor, about 6.25 Ã— 10^{18} electrons drift pass a section of the conductor every second.

Unit of current and quantity of charge

The unit of electric current is ampere (A), named after the famous French physicist Andre-Marie Ampere (1775 – 1836).

An ampere is the magnetising force between two long parallel conductors of negligible cross-sectional area separated by 1m in a vacuum.

Electric current can be measured in other units like milliampere (mA) which is 10^{-3}A and microampere (Ã¬A) 10^{-6}A. The unit of quantity of charge is Coulomb (C).

A coulomb of electricity is the quantity of charge passing a given point of a conductor when a current of 1A is allowed to flow through it.

The electromotive force (emf)

A force is needed to move electrons from the negative terminal of a cell or battery to the positive terminal. The force that drives the electrons from one end of the conductor to another is called the **electromotive force**.

Electromotive force is the work done by the cell in moving one coulomb of charge or electron round a closed circuit

It is the voltage measured across the terminal of the cell when it is not supplying current to an external load. The unit of the electromotive force is volt (V). *A cell of emf 2 V supplies energy at the rate of 2 joules per coulomb. That means 1 V = 1 JC^{-1} or J/C.*

The potential difference (p.d)

Heat flow in a conductor is due to temperature difference between two points in the conductor. In the same way, continuous charge flow (electrons) is maintained by a force or pressure difference called **potential difference** (p.d.).

Potential difference is the workdone by a cell in moving a unit charge from a region of lower potential to a region of higher potential

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge moved}}$$

$$V = \frac{W}{Q} \quad or \quad W = QV$$

The unit of potential difference is volt (V).

The volt is the unit of work done when one coulomb of charge is transferred between two points of a conductor kept at different potentials.

A p.d. of 1 V means that 1 joule of work is done per coulomb between two sections of a conductor. Other units of potential difference are megavolt (MV) or 10^6V, kilovolt (KV) or 10^3V and microvolt (Î¼V) 10^{-6}V.

Generating electric current

Electric current is the continuous flow or drift of electric charges due to potential difference between two points of a conductor. Production of electric current can be done by:

- using **chemical cells.** A chemical cell converts chemical energy to electrical energy.
- using **generators.** Generators are electro-mechanical devices which change mechanical energy to electrical energy.
- using **thermocouples.** A thermocouple uses a thermoelectric effect to transform heat energy to electrical energy.
- using **solar cells.** A solar cell is a device that converts solar or light energy to electrical energy.

Generating electric current from chemical energy

A chemical cell produces continuous flow of electric charge or electric current from chemical energy. Two types of chemical cells are the **primary cells** and the **secondary cells**.

A **primary cell produces electric current through a chemical reaction which is not easily reversed.** Once the chemicals of the cell are used up, the cell is thrown away. There are many types of primary cells; the most popular types are the simple cell, Daniel cell and the Lechlanch cell (dry cell).

The simple cell

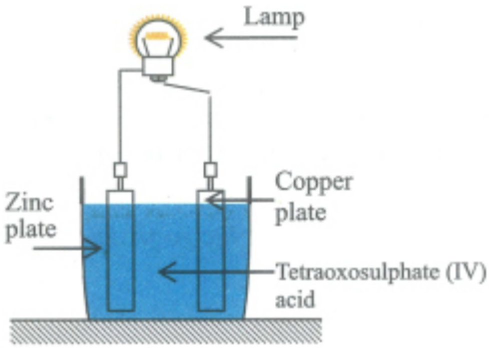


Figure 11.3 A simple cell

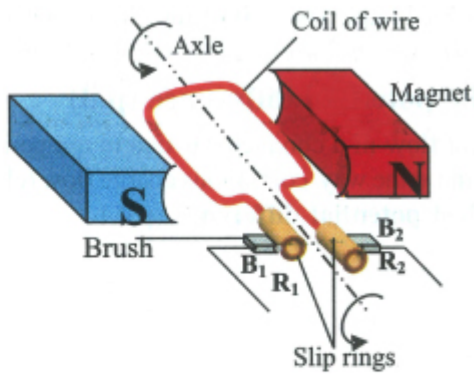


Figure 11.4 A.C. generator

The simple cell consists of a vessel containing dilute tetraoxosulphate (VI) acid solution as an **electrolyte** and two **electrodes** made of two different metals (copper and zinc), dipped into the electrolyte. The **positive electrode or anode** is the copper plate while the **cathode or negative electrode** is the zinc plate.

When the copper plate and the zinc plate dipped in the electrolyte are connected to a lamp, electrons drift from the zinc plate to the copper plate. **The continuous flow of electrons from the zinc to copper is called electric current**.

Generating electric current from mechanical energy

Magnetic force acts on any charge (electrons) moving in a magnetic field. Good conductors like metals contain free electrons moving about randomly inside the metal. If the metal is placed in a strong magnetic field, the free electrons drift in the direction of the force from one end of the conductor to other. **The movement of the electrons in one direction is called an electric current.** Continuous production of electric current can be achieved with a conductor in form of a loop turning in a magnetic field. A practical machine, which produces electric current in this way, is called a **generator.** A generator converts mechanical energy (rotation of the conductor) to electrical energy.

A simple generator consists of the following essent al parts:

- powerful magnets (N and S poles) to produce strong magnetic field.

- a loop of wire (armature) which is free to turn about its axis in the field of a powerful magnet.
- two slip rings and brushes, one each at the ends of the looped wire to remove current from one end of the wire and return it at the other end.

When the wire turns in the magnetic field, current is induced in it. The size of the current induced in the wire depends on the speed at which the wire cuts through the field, the length of the wire and the strength of the magnetic field.

Generating electric current from light energy

The photovoltaic cell or solar cell is used to convert light energy directly to electrical energy.

It consists of two dissimilar materials (semi conductors) joined together to form a junction. Electrons inside these materials are not free to move from one atom to another but when light falls on them, the electrons gain enough energy to move. The electrons drift in one direction only, crossing the junction between the two dissimilar semiconductors. The end of semiconductor with excess electrons will have a negative voltage with respect to the other end. **Continuous flow of electrons or electric current is generated if light is allowed to fall on the two materials constantly**.

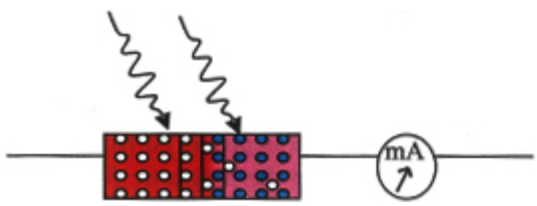


Figure 11.5 A photovoltaic cell

The current or voltage produced by a solar or photovoltaic cell is usually very low therefore, they are used as power source for calculators, watches and other electronic devices. Many solar cells can be connected together to produce a solar battery. Solar batteries generate more electricity and are used in weather and communication satellites.

Generating electric current from heat energy

A **thermocouple** is used to convert heat energy to electrical energy. It has two wires made from different metals (e.g. copper and iron) joined together to form two junctions. When the two junctions are kept at different temperatures, electric current flows from the hot junction to the cold junction. **Continuous flow of current is sustained if the temperature difference between the two junctions is maintained.** The electric current produced by a thermocouple is usually very small, therefore, it is measured with a sensitive meter or galvanometer.

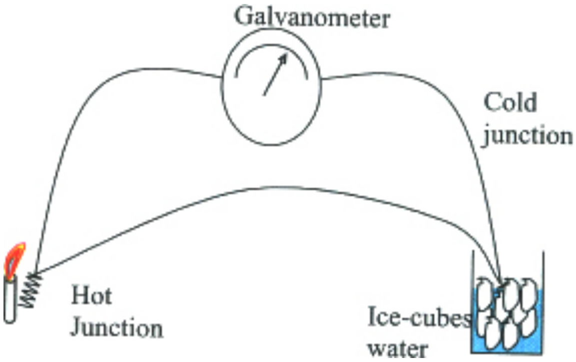


Figure 11.7 Thermocouple

Summary

- Electric current is the time rate at which electrons drift past a given point in a conductor.
- An ampere is the magnetising force between two long parallel wires of negligible cross-sectional area separated by 1m in a vacuum.
- A coulomb of electricity is the quantity of charge passing a given point of a conductor when a current of 1 A is allowed to flow through it.
- Electromotive force is the work done by the cell in moving one coulomb of charge or electron round a closed circuit.
- Potential difference is the work done by a cell in moving one coulomb of charge between two points of a conductor kept at different potentials.
- Electric current is generated from a chemical energy using a chemical cell. A primary cell produces electric current through a chemical reaction, which is not easily reversed.
- Electric current is produced from a mechanical energy by a generator. When the wire is made to turn in the magnetic field, current is induced.
- The photovoltaic cell or solar cell is used to convert light energy directly to electrical energy. Continuous flow of electrons or electric current is generated if light is allowed to fall on the two materials constantly.
- A thermocouple is used to convert heat energy to electrical energy. When the two junctions are kept at different temperatures, electric current flows from the hot junction to the cold junction.

Practice questions 11a

1. (a) Explain what you understand by electric current; state the

unit of electric current.

(b) How is electric current related to the quantity of charge?

(c) Find the quantity of charge which passed through a section of a conductor when a current of 3 A flowed through the conductor for 30 minutes.

2. (a) Define electric current and potential difference applied to the ends of a conductor.

(b) Describe how an electric current is produced from mechanical energy with a diagram.

(c) State three factors which increase the size of current or electromotive force produced.

3. (a) What do you understand by the term electromotive force?

(b) Explain how the electromotive force or current is produced in a solar cell.

(c) State three uses of solar cells and explain why it is not used to operate high energy electronic devices.

4. (a) What is a primary cell?

(b) Describe the structure of a simple primary cell and explain how it produces electric current.

5. (a) Explain briefly the terms: electric current, electromotive force and potential difference.

(b) State four different ways electricity may be generated. What energy transformation takes place in each case?

6. Explain what is meant by the electromotive force (e.m.f.) of a cell is 12 V?

7. State the difference between electromotive force and potential difference.

ELECTRIC CIRCUIT

OBJECTIVES

At the end of this topic, students should be able to:

- set up a simple electric circuit;
- measure electric current and potential difference in a series and parallel circuits;
- state the characteristics of current and voltage in the series and parallel circuits.

The drift or movement of electrons in a conductor is possible if there is a complete path through which they can pass.

Electric circuit is the continuous and complete path through which electrons flow.

Simple electric circuit

A simple electric circuit consists of a cell or battery (a battery is a collection of cells). A cell is made up of a source of energy to move electrons, a load (a lamp or a resistor), a switch and connecting wires which serve as the conducting path for the electrons. A simple electric circuit may be closed or open. Figure 12.7 shows simple closed and simple open circuits.

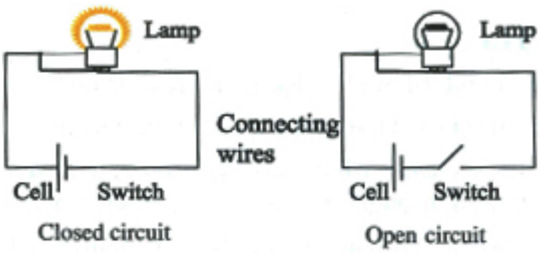


Figure 11.7 Closed and open circuits

The circuit is closed if the switch is closed and there is no break or cut along the connecting wires. The conducting path comprises the cell, the switch, the connecting wire and the lamp. Electric current can move round the circuit since it is complete and continuous. A circuit is open if there is a break along its conducting path or if the switch is open. The conducting path is not continuous; therefore, electric current cannot flow.

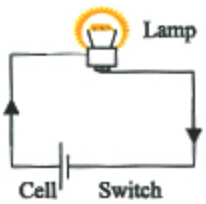


Figure 11.8a Current passes through the lamp

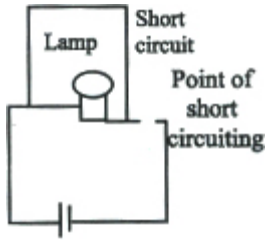


Figure 11.8b No current passes through the lamp

Short circuit

When a conductor of very low resistance is connected across a lamp, electric current flowing through the circuit is diverted away from the lamp through the low resistance wire. We say that the lamp is short-circuited.

The low resistance wire stops the current from passing through the lamp because it gives the easiest path for the current to flow. Short circuit is very dangerous and should be avoided for the following reasons:

- it increases the total current passing through the circuit but reduces the current through the lamp to zero.

- power loss along the connecting wires is increased, although the potential difference across the lamp is zero.

Circuit elements or components

A circuit can be either simple or complex, it may have two or more components. To draw an electric circuit, we use symbols to represent the components. Table 12.1 shows the list of circuit components, their symbols and some of their uses.

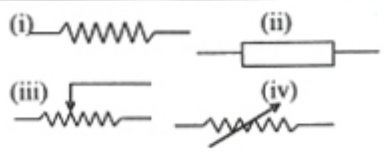
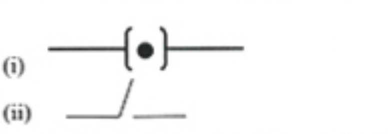
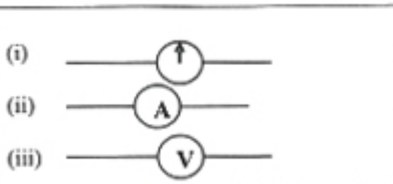
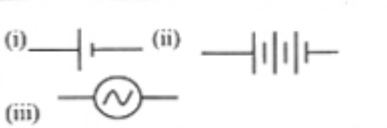
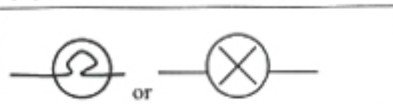
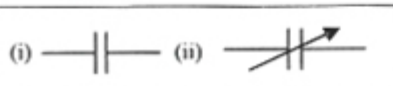
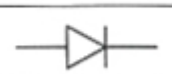
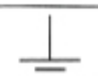
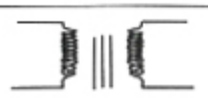
S/N	Circuit component	Symbol	Uses
1.	Resistors (i) Fixed resistor (ii) Resistance box (iii) Rheostat (iv) Variable resistance		Resistors are used to vary the current flowing through an electric circuit.
2.	Switches (i) Plug key (ii) Tap key		Switches are used in an electric circuit to open or close an electric circuit.
3.	Meters (i) Galvanometer (ii) Ammeter (iii) Voltmeter		Meters are used to detect or measure the current in the circuit or to measure the p.d. across a component
4.	Power sources (i) Cell (ii) Battery } d.c.sources (iii) a.c. source		The power is a means of moving the current round the electric circuit.
5.	Lamp		Electric lamps convert electrical energy to light energy.
6.	Capacitor (i) Fixed capacitor (ii) Variable capacitor		Capacitors are used to store electrical charges.
7.	Diode		Diodes allow current to flow in only one direction.
8.	Earth connection		It prevents electrical appliances from electric shock.
9.	Transformer		Transformers are used to increase or decrease the voltage or e.m.f of the power source.

Table 11.1 Circuit components, symbol and uses

Series and parallel circuits

Two or more components are connected in series if they are connected end to end such that they form a complete loop. Along the conducting path, there is no diversion of current passing through a series circuit. A series circuit is shown in Figure 12.9.

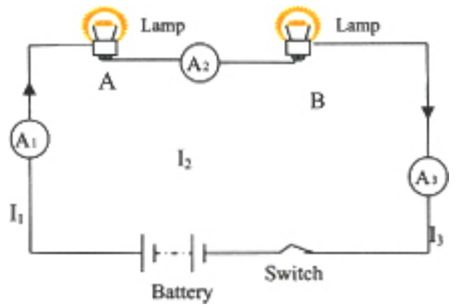


Figure 11.9 Series circuit. Lamps A and B are in series

Measurement of current in a series circuit

An **ammeter** is the instrument used to measure **electric current** passing through a circuit. Ammeters are low resistance moving coil instrument because we do not want their resistance to change the size of current being measured.

When two or more ammeters are connected to different parts of a series circuit, they all indicate the same reading. The ammeters I_1, I_2 and I_3 in Figure 11.9 show the same reading, therefore, **the same current passes through all the components connected in series**.

$$I = I_1 = I_2 = I_3$$

Measurement of potential difference (voltage) in a series circuit

Potential difference and **e.m.f.** are measured with a **voltmeter.** A voltmeter is a high resistance moving coil instrument, therefore, it is connected in parallel to a component to measure the p.d. or voltage across it. A voltmeter is not supposed to draw any current from the circuit; its resistance must be infinitely high to ensure that no current is diverted through the voltmeter.

- The positive terminals of the voltmeters are connected to the positive terminals of the cells.
- The voltmeter V_1 measures the p.d. across the points BC and the voltmeter V_2 measures the p.d. across the points DE. The voltmeter V measures the total p.d. across the lamps.
- The lamps share the total p.d. across AF such that the p.d between A and F is the sum of the p.d. across BC and DE.

$$V = V_1 + V_2$$

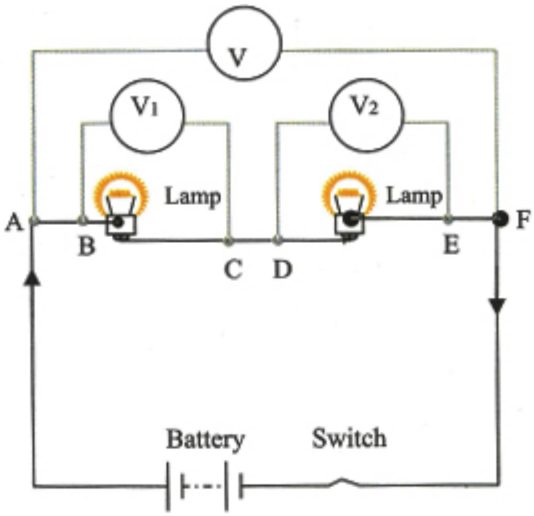


Figure 11.10 Measurement of p.d.

Parallel circuit

Two or more components are connected in parallel if they share a common point with the terminal of the cell or battery. From fig. 11.11, note that the current delivered by the battery splits at one junction **J** such that I_1 passes through the ammeter A_1 and I_2 passes through the ammeter A_2. The currents I_1 and I_2 reunite at the second junction **X**.

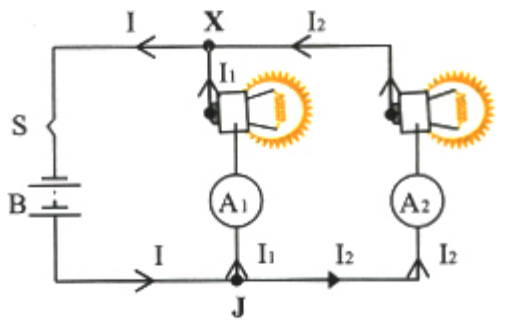


Figure 11.11 Parallel circuit lamps A and B are in parallel.

The sum of current passing through the components connected in parallel is equal to the current delivered by the battery. Kirchorff summarized this as follows: **the sum of currents moving towards a junction is equal to the sum of the currents moving out of the same junction**.

At junction J: $I = I_1 + I_2$, at the junction X: $I_1 + I_2 = I$

Measurement of voltage or p.d. in a parallel circuit

Voltmeter used to measure voltage or p.d. is connected across the components. The positive (red) terminal of the voltmeter and that of the battery are joined together to one terminal of the component. The negative terminal (black) of the voltmeter and that of the battery are joined to the other terminal of the component. See Figure 11.12.

The voltage measured across the components connected in parallel is the same because all the components are connected across the same points with the same p.d.

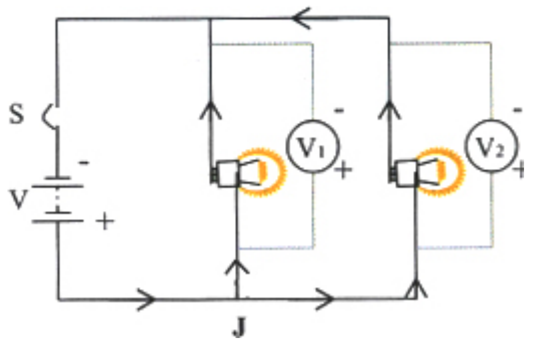


Figure 11.12 Voltage across parallel components are the same

$$\therefore V = V_1 = V_2$$

Summary

- The continuous and complete path through which electrons flow is called electric circuit.
- Series circuit forms a complete loop with no junction where the current is diverted.
- The same current passes through all the components connected in series.
- $I = I_1 = I_2 = I_3$
- The total voltage is the sum of the voltages across each component in a series circuit.
- The total current is shared among the components connected in parallel.
- Kirchorffâ€™s law states that the sum of currents moving towards a junction is equal to the sum of the currents moving out of the same junction.
- The voltage measured across the components connected in parallel is the same and equal to the supplied voltage.

Practice questions 11b

1 What is an electric circuit? Draw a simple electric circuit comprising a battery of three cells in series, two lamps arranged in series, a switch, an ammeter and a voltmeter connected to measure the current and voltage across the lamps.

2 Name two types of an electric circuit. What happens to current and voltage in each type of the circuit?

3 State Kirchorffâ€™s law about current moving towards and away from a junction.

RESISTANCE

OBJECTIVES

At the end of this topic, students should be able to:

- define resistance and use it to distinguish between conductors and insulators;
- state Ohmâ€™s law and use it to solve problems on resistance;
- identify ohmic and non-ohmic conductors;
- explain resistivity, conductivity and temperature coefficient of a material;
- state the factors that determine the resistance of a given conductor;
- identify different types of resistors.

Resistance is ability of a material to resist the flow of electrons (electric current) passing through it. Some materials conduct electric current better than others do if the same voltage or p.d. is applied across them. Metals and other good conductors of electricity have low resistance. Insulators or bad conductors of electricity do not conduct electric current because their resistance is very high.

Ohmâ€™s law

George Simon Ohm (1787 – 1854) showed that the current flowing through a metal wire depends on the voltage applied across its ends. The simple relationship between the voltage and the current flowing through a conductor is known as Ohmâ€™s law.

Ohmâ€™s law states that the current passing through a metalic conductor is directly proportional to the potential difference across its ends provided temperature and other physical properties of the conductor are kept ocnstant.

Mathematically, Ohm’s states that:

$$\text{Voltage} \propto \text{Current}$$

$$\frac{\text{Voltage}}{\text{Current}} = \text{a constant(R)}$$

The constant of proportionality (R) is called the **resistance** of the wire.

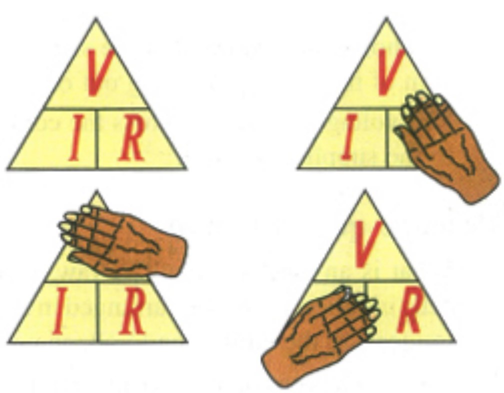


Figure 11.13 Showing relationship between voltage, current and resistance

Resistance is the ratio of voltage to current.

It measures the strength of the opposition of the wire to flow of electric current. The resistance is low if the current passing through the circuit is high. When the current through the circuit is small, the resistance is high.

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

$$R = \frac{V}{I} \text{ or } I = \frac{V}{R} \text{ or } V = IR$$

The unit of resistance is Ohm (Î©).

Ohm is defined as the resistance of a wire which needs a voltage of 1 volt to cause a current of 1 A to flow through it

Ohmic and non-ohmic conductors

The conductors which obey ohmâ€™s law, are called **ohmic conductors.** Metal conductors are good examples of ohmic conductors because their resistance remains constant as current varies at constant temperature. If the temperature of a metal wire is increased, the resistance also increases; Ohmâ€™s law is no longer obeyed.

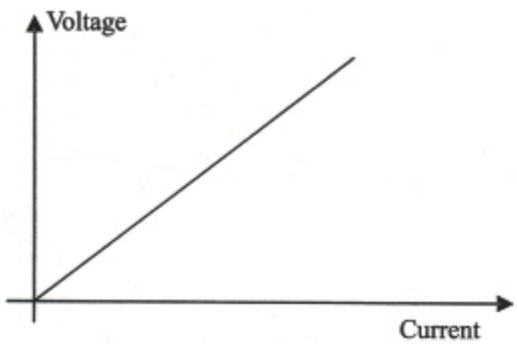


Figure 11.14 Graph of voltage against current for ohmic conductors

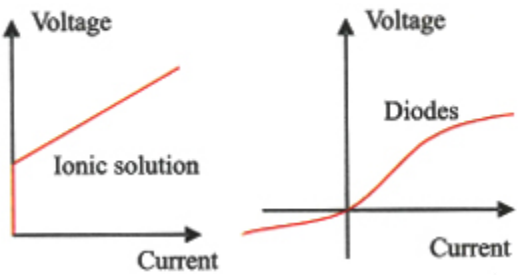


Figure 11.15 Graphs of voltage against current for non-ohmic conductors

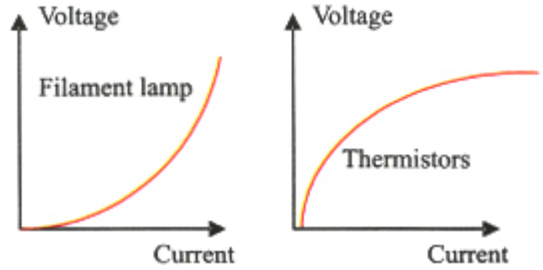
Conductors which do not obey ohmâ€™s law, are called non-ohmic conductors. The resistance of these materials varies as the current changes. Examples of non-ohmic conductors are discussed below.

Filament lamps: the resistance of filament lamps do not obey Ohmâ€™s law because its resistance increases with temperature. The filament wire is coiled, therefore, the temperature rises as current is passed through it.

Thermistors: the resistance of thermistors falls as temperature rises, therefore, thermistors do not obey Ohmâ€™s law.

Chemical solutions or electrolytes: electrolytes are good conductors of electric current but they do not obey Ohmâ€™s law since their resistance varies with current.

Semiconductor diodes: the resistance of diodes decreases as the temperature increases.



Voltage against current for a filament lamp and a thermistor is a curve. Resistance changes with temperature

Worked examples

1. What is the resistance of a lamp, which draws a current of 3 A from a battery whose e.m.f is 12 V?

   Solution

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} = \frac{12}{3} = 4\,\Omega$$

2. A filament lamp of resistance of 12 Î© draws a current of 0.5 A; calculate the voltage applied across the lamp.

   Solution

   Voltage = current Ã— resistance
   = 0.5 Ã— 12 = 6 V

3. What is the value of current that will flow through a resistor of 5 Î© when a potential difference of 3 V is applied across its ends?

   Solution

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} = \frac{3}{5} = 0.6\,A$$

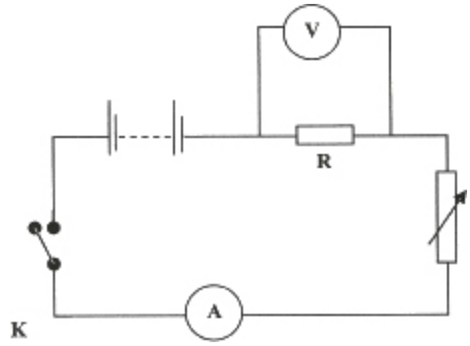


Figure 11.16 Verification of Ohmâ€™s law

VERIFICATION OF OHMâ€™S LAW

Apparatus

Low resistance ammeter, high resistance voltmeter, a resistance wire or a resistor, battery, rheostat, key and seven connecting wires.

Procedure

(i) Connect the key, ammeter, resistor, rheostat and the battery in series and the voltmeter in parallel or to the resistor as shown in Figure 11.16.

(ii) Close the key and adjust the rheostat to set the current passing through the ammeter to a certain value I_1. Read and record the corresponding voltmeter reading V_1.

(iii) Adjust the rheostat again to set the ammeter reading to I_2 and the voltmeter reading V_2. Repeat the experiment four more times.

(iv) Tabulate the values of I and V as shown in the table below.

I/A^{-1}	**V/V^{-1}**	**R/Î©$^{-1}$**
0.1	0.2	2.0
0.2	0.4	2.0
0.3	0.6	2.0
0.4	0.8	2.0
0.5	1.0	2.0
0.6	1.2	2.0

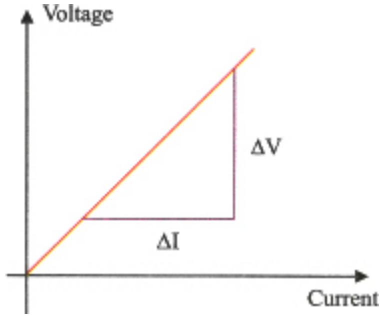
From the above table, the resistance of the wire is 2.0 Î©.

Graph of voltage against current

When the voltage is plotted against current, a straight line passing through the origin is obtained. Voltage is directly proportional to current since the graph is a straight line passing through the origin.

The slope of the graph is the resistance of the wire.

$$\text{Slope}(S) = \frac{\Delta V}{\Delta I} = \text{Resistance}$$



Precautions

- Remove the key immediately after each reading to avoid running down the battery.
- Tightly connect the wire to the terminals to avoid overheating them.
- Avoid parallax error on the voltmeter/ ammeter.
- Avoid zero error on the voltmeter/ammeter.

Resistivity (Ï)

The resistance of a material depends on its length and thickness. The resistance of a given material is:

(i) proportional to its length if the thickness (cross-sectional area) of the material does not change.

$$(R \propto l)$$

(ii) inversely proportional to its cross-sectional area for a fixed length of a material. That is, the resistance of material increases as the area of the cross-section decreases.

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

The two equations above are combined to give: $R \propto \frac{1}{A}$

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

The constant *Ï* (rho) is the **resistivity** of the material at a given temperature. The resistivity of good conductors like silver and copper are low. They are used as electrical cables and connecting wires in electric circuit based on their low resistivity. Copper is widely used as connecting wires because it is cheaper than silver. Poor and bad conductors have high resistivity. They are used to make standard resistors.

The unit of resistivity is ohm-metre (Î© m).

Resistivity is the resistance of a unit length (1 m) and a unit cross-sectional area (1 m^2) of a material.

The resistivities of some materials are shown in the table 12.2.

Material	Resistivity (Î© m) at 20 Â°C
Silver	1.62 Ã— 10^{-8}
Copper	1.72 Ã— 10^{-8}
Aluminium	2.82 Ã— 10^{-8}
Manganium	44.00 Ã— 10^{-8}
Constantan	49.00 Ã— 10^{-8}
Nichrome	111.00 Ã— 10^{-8}

Table 12.2 Resistivity of some materials

Factors that determine the resistance of a material

The resistance of a material depends on:

- the nature or type of **M**aterial or the resistivity of the material. Resistance of different materials varies. The resistance of copper is less than the resistance of constantan under the same condition.
- the **A**rea of the cross-section. The resistance of material is inversely proportional to the area of cross-section. Resistance of thick wires are smaller than the resistance of thin wires.
- the **L**ength of the material. Resistance of a material increases as its length increases.
- the **T**emperature of the material. Resistance of a material increases with rise in temperature. Recall the factors with the acronym **MALT**.

Conductivity (Ïƒ)

Conductivity is the ability of a material to conduct electric current.

It is the reciprocal of resistivity of a material. When the resistivity of material is low, it is a good conductor and the conductivity is high.

$$\text{Conductivity} = \frac{1}{\text{Resistivity}}$$

$$\sigma = \frac{1}{\rho} \quad or\ \sigma = \frac{l}{RA}$$

Worked examples

1. The resistance of a certain material of length 10 m is 7.2 Î©. Calculate the:

a) resistance per metre of the material.
b) length needed to make a 5 Î© resistor.

Solution

(a) Resistance Ã¡ length (R Î± 1)

$\therefore R = kl$

$$\text{Resistance } per\ metre\ k = \frac{R}{l} = \frac{7.2}{10} \qquad k = 0.72\ \Omega\ m^{-1}$$

(b) $R = kl$

5 = 0.72 Ã— l

$$\therefore l = \frac{5}{0.72} = 6.944\ m$$

2. Calculate the resistance of a copper wire 100 m long and 1.5 mm diameter if the resistivity of copper is 1.73 Ã— 10^{-8} Î© m.

Solution

$$Area(A) = \frac{\pi d^2}{4} = \frac{3.142 \times (1.5 \times 10^{-3})^2}{4} \quad = 1.767 \times 10^{-6} m$$

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

R = resistance, Ï = resistivity, L = length and
A = Cross-sectional area of the wire.

$$R = \frac{1.73 \times 10^{-8} \times 100}{1.767 \times 10^{-6}} = 0.98\ \Omega$$

3. A material of resistivity 4.8 Ã— 10^{-5} Î© cm and cross-sectional area 3.0 Ã— 10^{-3} cm^2 is needed to make a resistor of 5 Î©, what length of the material is needed to make to construct the resistor?

Solution

$$l = \frac{RA}{\rho} = \frac{5 \times 3.0 \times 10^{-3}}{4.8 \times 10^{-5}} = 312.5 cm$$

Since the resistivity and the area are given in centimetre, the unit of length is also expressed in centimetre.

4. A resistor of 2 Î© is constructed using 372m length of a material. Calculate:
   a) the resistivity of the material if its cross-sectional area is 3.2 Ã— $10^{-6}m^2$.
   b) the conductivity of the material.

Solution

$$\text{(a)}\ \rho = \frac{RA}{l} = \frac{2 \times 3.2 \times 10^{-6}}{372} = 1.72 \times 10^{-8}\,\Omega\, m.$$

$$\text{(b) Conductivity } (\sigma) = \frac{1}{\rho} = \frac{1}{1.72 \times 10^{-8}}$$

$$= 5.81 \times 10^{7}\,\Omega^{-1}\,m^{-1}.$$

Effect of temperature on resistance

The resistance of a material varies with temperature. The resistance of some materials increases as the temperature rises, while the resistance of some decreases as temperature increases.

Temperature coefficient (Î±) is the amount by which a resistance of 1 Î© increases when its temperature rises by 1 K.

$$\alpha = \frac{R - R_0}{R_0 \Delta \theta}$$

Î± = temperature coefficient, R = resistance at a given temperature, R_0 = resistance at 0Â°C and Î”*Î¸* = change in temperature.

The resistance of a material at a temperature Î¸ is given by:

$$R = R_0\,(1 + \alpha\, \Delta\theta)$$

Using the temperature coefficient (Î±), there are three classes of materials.

- **Materials with positive temperature coefficients.** The resistance of these materials increases equally from 0Â°C as the temperature rises. Most metals fall under these class.
- **Materials with zero temperature coefficients.** The resistance of these materials does not change as their temperature changes. Special alloys like constantan and manganin whose resistance is constant over wide changes in temperature are used in making standard resistors.
- **Materials with negative temperature coefficients.** The resistance of these materials falls as temperature rises. Carbon, semiconductors (e.g. Germanium and Silicon), insulators and electrolytes are good examples of materials whose resistance decreases as temperature increases.

Semiconductors device like integrated circuits (IC), transistors and diodes are used in making electronic equipment like computer. The resistance of these devices falls as their temperature rises; therefore, they are kept in cold rooms to avoid the current passing through them from increasing above the safe value.

Worked example

The resistance of a wire is 10 Î© at 30Â°C. Calculate the resistance of the wire when the temperature is (i) 0 Â°C (ii) 40Â°C. (Î± = 0.006 k^{-1})

Solution

(i) $R = R_o (1+ \alpha\, \Delta\theta)$

$R = 10\ \Omega, R_o =?, \alpha = 0.006\ K^{-1}, \Delta\theta = 30\ ^\circ C.$

$10 = R_o (1+ 0.006\times30)$

$$R_0 = \frac{10}{1+0.006\times30} = \frac{10}{1.18} = 8.47\ \Omega.$$

(ii) $R = R_o (1+ \alpha\Delta\theta)$

$R = 8.47 (1+0.006\times40)$

$R = 8.47\times1.24$

$R = 10.50\ \Omega$

Types of resistors

A resistor is a component of a circuit which opposes the flow of electric current. The two types of resistors are; the **fixed** and the **variable resistors**.

Fixed resistors: Fixed resistors or standard resistors have fixed value of resistance. They are produced by coiling a resistance wire into many turns on an insulating base. Specific length of resistance wire is chosen to make a resistor of a specific resistance.

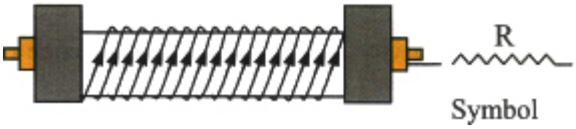


Figure 11.17 Standard resistor

Variable resistors: As the name implies, the value of their resistance varies. They are used in an electric circuit when the current flowing through the circuit is to be altered. Two variable resistors used in the school laboratory are, **rheostat** and **resistance box.**

Rheostat: The rheostat is a variable resistor whose resistance can be varied by moving the slider **S**. The value of the resistance added or removed from the circuit is not known, only the current is adjusted to the desired value. Like the standard resistors, they are made by winding manganin wire on an insulating base. When the slider **S** is moved from **P** towards **T**, the resistance is increased thereby, decreasing the current flowing in the circuit.

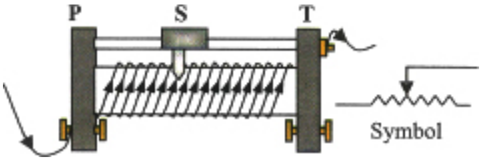


Figure 11.18 Rheostat

Resistance box

Resistance box is a variable resistor used to add known values of resistance at a time to the electric circuit. The resistance box adds to the circuit integral values of resistance ranging from 1 Î© to the maximum value of resistance in the box. When the plug B is removed, a gap is formed between Y and Z, the current passes through the resistance coil from Y to Z. This adds a resistance of 3 Î© to the circuit. The plug A is tightly fitted in the gap between P and N therefore, the 2 Î© resistance is not added to the circuit.

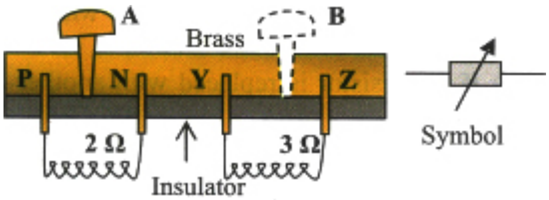


Figure 11.19 Section of a resistance box

Summary

- Resistance is ability of a material to resist the flow of electrons (electric current) passing through it. It is defined as the ratio of voltage to current. The unit of resistance is Ohm(Î©).

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

- Resistance of material depends on its length, area of cross-section, resistivity and temperature.
- Ohmâ€™s law states that the current flowing through a metal wire at constant temperature is directly proportional to the applied voltage.
- Ohm is defined as the resistance of a wire which needs a voltage of 1volt to cause a current of 1 A to flow through it.
- Resistivity is defined as the resistance of a unit length (1 m) and a unit cross-sectional area (1m^2) of a material.
- The ability of a material to conduct electric current is called conductivity.
- The amount by which a resistance of 1 Î© increases when its temperature rises by 1 K is called the temperature coefficient of the resistance (Î±).
- A resistor is a component of a circuit which opposes the flow of electric current.
- Two types of resistors are fixed and variable resistors. Rheostat and resistance box are examples of variable resistors.

Practice questions 11c

1 (a) Define resistance and state its unit.

(b) How does the resistance of a copper wire vary with its (i) length (ii) thickness.

(c) Explain why a good conductor should have a low resistance.

2. (a) State Ohmâ€™s law.

(b) Describe an experiment to determine the resistance of a wire using Ohmâ€™s law.

(c) State two precautions you should observe to ensure good result.

3. (a) What do you understand by the statement,â€ the resistance of a wire is 5 Î©?â€

(b) Calculate the resistance of a resistor which permits a current of 1.2 A to flow when a voltage of 6 V is connected across its ends.

(c) Find the current passing through the circuit if the resistor is replaced with another whose resistance is twice the initial value.

4. (a) Explain the meaning of resistance.

(b) State four factors which determine the resistance of a wire. How does the resistance of the wire depend on these factors?

5. (a) What is meant by the term resistivity?

(b) What is the value of resistance produced when a copper wire of length 85 m, diameter 0.0015 m and resistivity 1.72Ã—10^{-8} Î© m is wound into a resistor?

(c). How will the resistance of the wire be affected if the diameter of the wire is doubled while the length does not change?

6. (a) Explain the meaning of the statement, â€œthe resistivity of an aluminium wire is 2.83Ã—10-^{8} Î© m.â€

(b) What factors influence the resistance of a conductor?

(c) What is the resistivity of a material needed to make a resistor of 10 Î© if the cross-sectional area and the length of the wire are 4.9Ã—l0^{-6}m^{2} and 100 m respectively?

7. (a) Explain the terms ohmic and non-ohmic conductors. Give two examples of each type.

(b) Make a sketch of voltage-current graphs for (i) a metal wire (ii) a lamp filament (iii) an electrolyte.

8. (a) Define the temperature coefficient of a substance.

(b) Explain in terms of the motion of free electrons and the atoms why the resistance of a substance increases with temperature.

(c) The resistance of a tungsten wire at 32 Â°C is 250 Î©. Calculate the value of its resistance when the temperature is

2500Â°C. [Î± = 0.0006 K^{-1}]

9. (a) What is a resistor? Why are standard resistors made from special alloys like constantan?

(b) A steady current of 1.5 A flows through a copper wire of length 10 m and cross-sectional area 3.44 Ã— $10^{-8}m^2$. What is the voltage applied across the wire if the resistivity of copper is 1.72Ã—10^{-8}Î©?

ARRANGEMENT OF RESISTORS

(a) Resistors in series

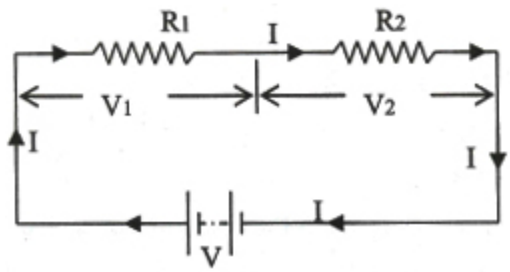


Figure 11.20 Resistors in series

Two or more resistors are connected in series if they are connected end to end, forming a complete loop. Figure 11.20 shows two resistors connected in series.

The same current flows through the resistors.

The supply voltage is shared between the two resistors. The voltage across each resistor is proportional to the size of the resistance of the resistor. $V = V_1 + V_2$

From Ohm's law, $R = \frac{V}{I} \Rightarrow V = IR, V_1 = IR_1$ and $V_2 = IR_2$

$$\therefore IR = IR_1 + IR_2$$

$$\boxed{\therefore R = R_1 + R_2}$$

A single resistance can replace two or more resistances connected in series and still has the same effect as the resistances it replaced. The single resistance which replaces the resistances connected in series, is called the **total** or **effective resistance. The effective resistance of a series is the arithmetic sum of all the resistances. This is true for any number of resistances connected in series**.

Worked examples

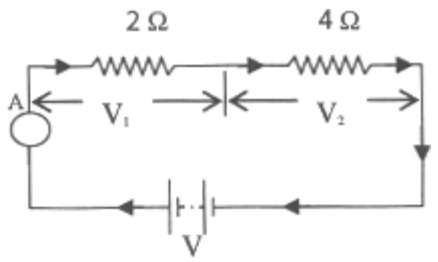
1 Two resistors 2 Î© and 4 Î© are connected in series with an ammeter and a battery. Two voltmeters are connected across the resistors to measure the voltage across the resistors.

(a) Sketch the circuit diagram and calculate the effective resistance of the circuit.

(b) Calculate the voltage across each resistor when a current of 1.5 A is flowing through the circuit.

Solution

(a)



$$R = R_1 + R_2 = 2\ \Omega + 4\ \Omega = 6\ \Omega$$

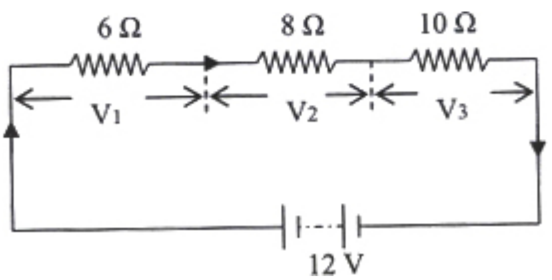
(b) $V_1 = IR_1 \quad 1.5 \times 2 = 3\ V$

$V_2 = IR_2 = 1.5 \times 4 = 6\ V$

Note: The same current passes through the resistors connected in series.

2. Three resistors 6 Î©, 8 Î© and 10 Î© are connected in series to a supply voltage of 12 V. Calculate the:
   (a) effective resistance of the circuit
   (b) total current flowing through the circuit
   (c) voltage across each resistor.

Solution



(a) $R = R_1 + R_2 + R_3 = 6 + 8 + 10 = 24\ \Omega$

(b) $I = \frac{V}{R} = \frac{12}{24} = 0.5\ A$

(c) $V_1 = IR_1 = 0.5 \times 6 = 3\ V$

$V_2 = IR_2 = 0.5 \times 8 = 4\ V$

$V_3 = IR_3 = 0.5 \times 10 = 5\ V$

a) Resistors in parallel

Two or more resistors are connected in parallel if they are connected side by side as shown in Figure 12.21. For resistors connected in parallel:

- the same voltage is applied across the resistors. $V = V_1 = V_2$
- the current from the battery splits at the junction J such that the sum of currents moving towards the junction is equal to the sum of currents moving away from the same junction.
  $I = I_1 + I_2$

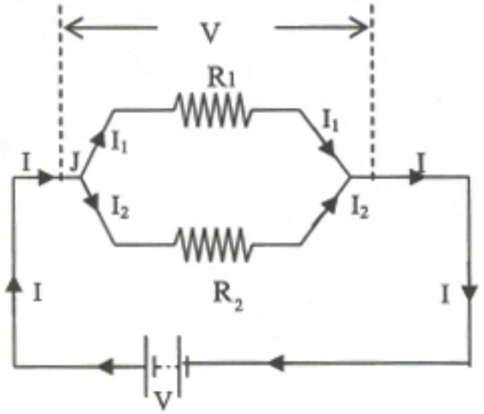


Figure 11.21 Resistances in parallel

From Ohmâ€™s law;

$$I = \frac{V}{R}, I_1 = \frac{V}{R_1} \text{ and } I_2 = \frac{V}{R_2}$$

$$\therefore \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

The effective resistance in parallel is less than the smallest resistance in a parallel circuit. The equation for resistances in parallel can be extended to any number of resistances connected in parallel.

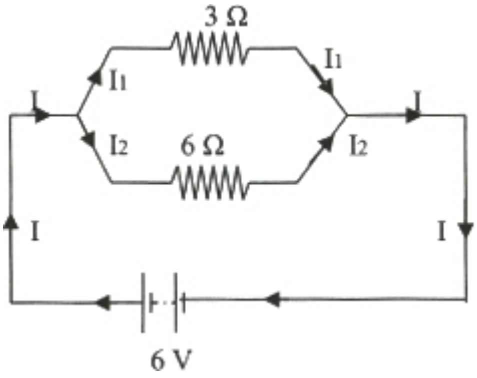
$$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}}$$

$$\Rightarrow \frac{1}{R} = \sum_{n=1}^{n} \frac{1}{R_n}$$

Worked examples

1. A voltage of 6 V is connected across two resistors of 3 Î© and 6 Î© connected in parallel. Calculate the:
   (a) effective resistance of the circuit;
   (b) total current flowing through the circuit;
   (c) current passing through the 3 Î© resistor.

Solution



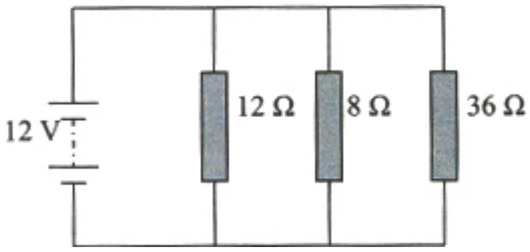
(a) $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{3} + \frac{1}{6} = \frac{1}{2}$

R = 2 Ω

(b) $I = \frac{V}{R} = \frac{6}{2} = 3\ A$

(c) $I_1 = \frac{V}{R_1} = \frac{6}{3} = 2\ A$

2. The circuit diagram below shows a 12 V battery connected across three resistances 12 Î©, 18 Î© and 36 Î© respectively. Use the diagram to calculate the:
   (a) effective resistance of the circuit;
   (b) total current in the circuit;
   (c) current passing through each resistor.



Solution

(a) $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{12} + \frac{1}{18} + \frac{1}{36} = \frac{6}{36}$

R = 6 Ω

(b) $I = \frac{V}{R} = \frac{12}{6} = 2\ A$

(c) $I_1 = \frac{V}{R_1} = \frac{12}{12} = 1\ A$

$I_2 = \frac{V}{R_2} = \frac{12}{18} = 0.67\ A$

$I_3 = \frac{V}{R_3} = \frac{12}{36} = 0.33\ A$

Combining resistors in both series and parallel

In designing electrical and electronic circuits, standard resistors may be combined to get the required value of resistance needed. This may be achieved by connecting the resistors in series, parallel or a combination of series and parallel.

Parallel combination in series with a third resistor

When two or more resistors arranged in parallel are connected in series to another resistor as shown in Figure 11.22,

- the supply voltage is shared between the series resistor and the parallel combination.
- the current through the series resistor is the same as the total current flowing in the circuit.
- the current splits at the junction of the parallel combination such that the total current flowing towards the junction is equal to the total current flowing away from the junction.

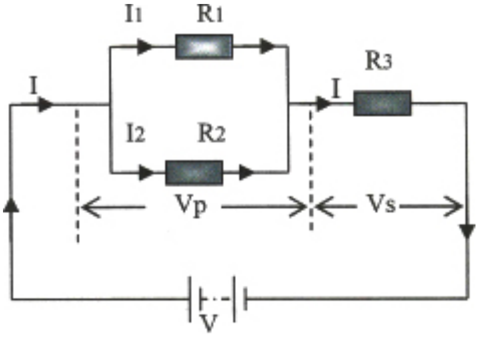


Figure 11.22 Resistors arranged in series parallel

Series combination in parallel with a third resistor

Two or more resistors connected in series can be arranged in parallel with another resistor as shown in Figure 11.23.

- The voltage across R^3 is equal to the supply voltage.
- The supply voltage is shared between R_1 and R_2.
- The same current passes through R_1 and R_2 but the current through R_3 is different. These points must be remembered as we solve problems on electric circuits.

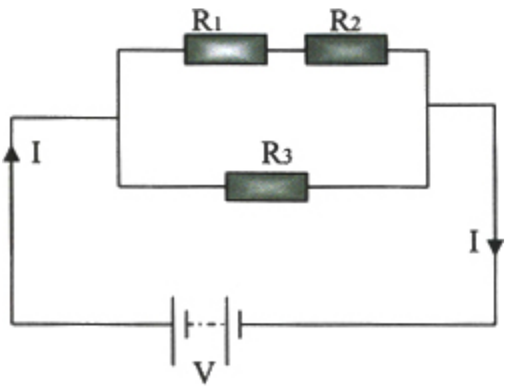
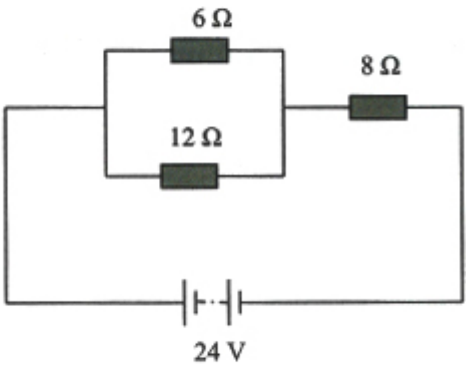


Figure 11.23 Resistors arranged in series and parallel

Worked examples

1. The circuit below shows three resistors arranged in both series and parallel.



Calculate the:

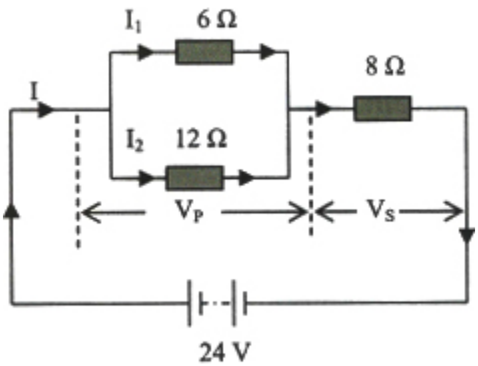
(a) combined resistance of the circuit.

(b) total current flowing through the circuit.

(c) voltage across each resistor.

(d) current passing through each resistor.

Solution

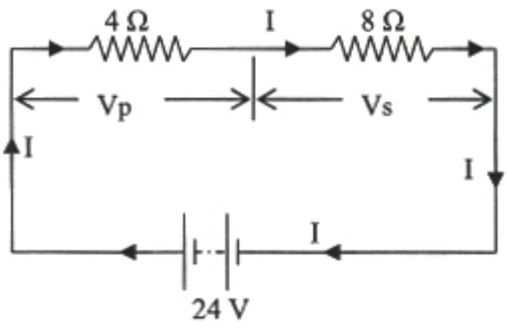


(a)

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{6} + \frac{1}{12} = \frac{3}{12}$$

$$R_p = \frac{12}{3} = 4\,\Omega$$

Therefore, 4 Î© resistor can replace the parallel network of 6 Î© and 12 Î©.



R = Rp + Rs = 4+8 = 12 Ω.

(b) $I = \frac{V}{R} = \frac{24}{12} = 2\ A$

(c) Vp = voltage across the resistors in parallel.

Vp = I × Rp = 2 × 4 = 8 V

$\therefore V_p = V_1 = V_2 = 8\,V$

$\therefore V_S = V_3 = V - V_P = 24\ V - 8\ V = 16\ V$

(d) $\therefore I_S = I_3 = I = 2\ A$

$I_1 = \frac{V_P}{R_1} = \frac{8}{6} = 1.33\ A$

$I_2 = \frac{V_P}{R_2} = \frac{8}{12} = 0.67\ A$

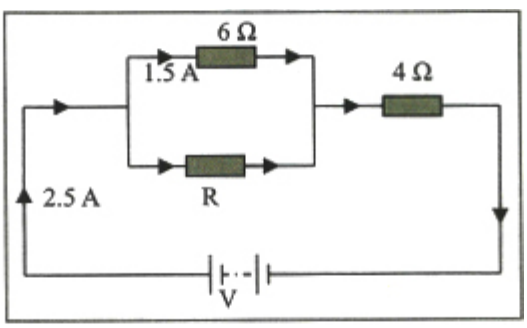
Summary

- When resistors are connected in series the same current flows through the resistors and the supply voltage is shared between the resistors.
  $R = R_1 + R_2 + R_3 +$ â€¦ $+ R_n$
- $R = \sum_{n=1}^{n} R_n$
- For resistors connected in parallel, the same voltage is applied across the resistors and the current from the battery splits at the junction J such that the sum of currents moving towards the junction is equal to the sum of currents moving away from the same junction.

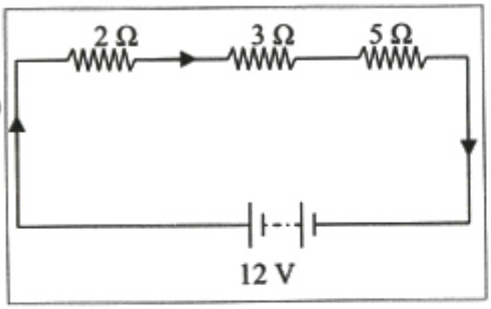
- $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$

Practice questions 11d

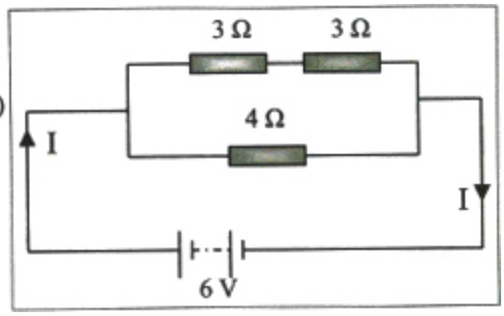
1. (a) State Ohmâ€™s law.
   (b) A resistor of 4 Î© is connected in series to a box speaker of unknown resistance. If a current of 0.6 A flows through the speaker when a voltage of 12 V is applied across the combination, calculate:
   (i) the total resistance of the circuit.
   (ii) the resistance of the speaker.
   (iii) the voltage applied across the speaker.
2. (a) Explain what is meant by the resistance of a material is 10 Î©.
   (b) Two resistors of 2 Î© and 6 Î© respectively are connected in parallel across a voltage of 15 V. Calculate:
   i. the total resistance of the circuit;
   ii. the current passing through the circuit;
   iii. the current passing through the 2 Î© resistor.
3. The circuit on the right shows an arrangement of three resistors. Use the circuit to find:
   (a) the current passing through the resistor R.
   (b) the voltage across each resistor.
   (c) the supply voltage (V).
   (d) the resistance of the resistor R.
   (e) the total resistance of the circuit.
   (f) Calculate for each of the diagram below, the effective resistance and the total current flowing through the circuit.



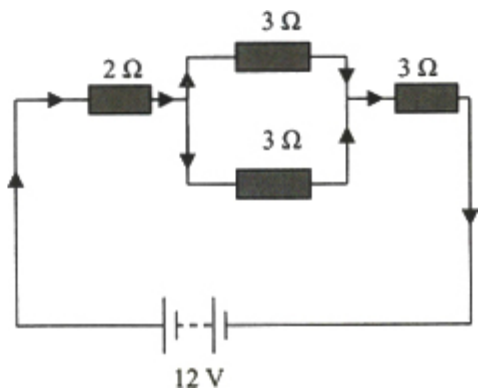
4(a)



(b)

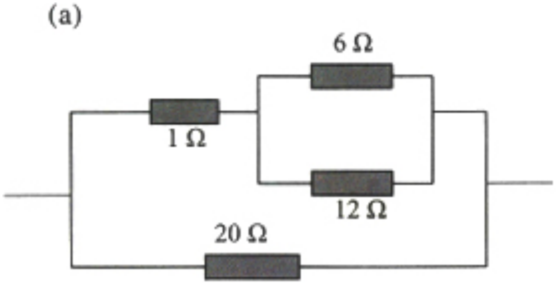


(c)

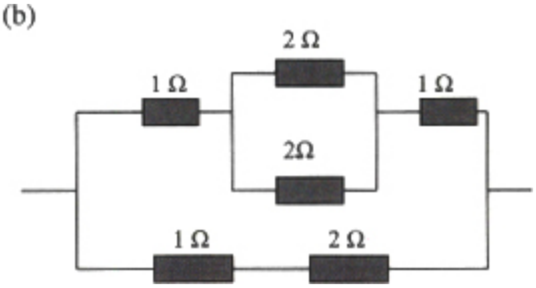


5 Calculate the total resistance in each of the electric circuit shown below.

(a)



(b)



Electrical energy and power

When you pay electricity bill, you are paying for energy transformation from electrical to other forms of energy in your house. Electrical energy supplied to the homes is changed to other useful forms of energy. e.g your heater changes electrical energy to heat energy.

OBJECTIVES

At the end of this topic, students should be able to:

- calculate the electrical work done and power in a given circuit;
- state some heating effect of electric current and its applications.

Electrical energy (W)

Voltage or potential difference between two points in a circuit is the energy transformed in moving one coulomb of charge

between the points.

Or voltage is the work done per unit charge.

$$\boxed{\text{Voltage} = \frac{\text{Energy transformed}}{\text{Charge moved}}}$$

$$\boxed{V = \frac{W}{Q} \quad \Rightarrow \quad W = QV}$$

Electrical energy transformed to heat is the product of charge moved and the voltage applied to the appliance.

But Q = IÃ—t.

$$\boxed{\therefore \quad W = IVt}$$

Energy transformed = current Ã— voltage Ã— time.

From Ohm's law, V = IR, $I = \frac{V}{R}$

$$\boxed{\therefore W = \frac{V^2}{R}t \quad or \quad W = I^2Rt}$$

The unit of electrical energy is joule (J). It is also measured in watt-hour (Wh) and kilowatt-hour (kWh). 1kWh is the energy transformed or dissipated at the rate of 1 kwh every hour.

1 kWh = 1 kW Ã— 1 hr
= 1000 W Ã— 3600 s
= 3 600 000 J

$$\boxed{\therefore 1\,kWh = 3.6\,MJ = one\ unit\ of\ energy}$$

Electrical power

The time rate at which an appliance transforms electrical energy to heat energy is its power.

In a mechanical system, power is given by:

$$\text{Power} = \frac{\text{Energy transformed}}{\text{Time taken}} \Rightarrow P = \frac{W}{t}$$

Electrical power can be expressed in terms voltage and current.

$$P = \frac{W}{t} = \frac{IVt}{t} = IV$$

$$\boxed{P = IV, \quad P = I^2R \ and \ P = \frac{V^2}{R}}$$

The unit of electrical power is watt (W) or joule per second (Js^{-1}).

Power rating

The power rating of an electrical appliance is the energy it dissipates per second in normal use. An appliance rated 1000 W, 240 V transforms energy at the rate of 1000 J s^{-1} in normal use.

Worked examples

1. Calculate the energy dissipated by an electric iron which draws a current of 5 A from a 240V power supply for 25 minutes.

Solution

W = IVt

W = energy dissipated, I = current and

V = Voltage

W = 5 Ã— 240 Ã— 25 Ã— 60

W = 1 800 000 J

2. (a) An electric kettle is rated 2000 W, 250 V; explain the meaning of the statement.

   (b) Calculate; (i) the current taken from the mains. (ii) the resistance of the heating element of the kettle.

Solution

(a) The statement means that the kettle dissipates electrical energy at rate of 2000 J per second when it is connected to a 250 V supply.

(b)

(i) $\text{Current} = \dfrac{\text{Power}}{\text{Voltage}} = \dfrac{2000}{250} = 8A$

(ii) $\text{Resitance} = \dfrac{\text{Voltage}}{\text{Current}} = \dfrac{250}{8} = 31.25\ \Omega$

3. A 2000 W electric oven is used for 10 hours. What is the cost of using the oven if the cost of electrical energy is ₦2.00 per unit of energy?

Solution

$$\begin{aligned}\text{Energy dissipated} &= \text{Power} \times \text{time}\\ &= 2\,000 \times 10 = 20\,000\ \text{Wh}\\ &= 20\ \text{kWh}\end{aligned}$$

1unit of energy = 1 kWh costs ₦2.00

The cost of 20 kWh or 20 units of energy is 20 × ₦2.00 = ₦40.00

4. A homemaker uses the following kitchen appliances for 10 hours each day for a month of 30days.
   (i) An electric kettle rated 1000 watts
   (ii) A deep freezer rated 400 watts
   (iii) A blender rated 200 watts
   (iv) Two light points each rated 100 watts

Calculate the cost of using these appliances if a unit of energy cost ₦5.00.

Solution

Energy dissipated = Power Ã— Time
Total energy dissipated per day = (1000 Ã— 10) + (400 Ã— 10) + (200 Ã— 10) + (2 Ã— 100 Ã— 10)
Total energy dissipated per day = 18 000 Wh
Energy consumption in a month of 30 days
= 30 Ã— 18 000 = 540 000 Wh

= 540kWh
Total cost = 540 Ã— ₦5.00 = ₦2 700.00

The heating effect of current

The flow of current through a wire warms it to increase its temperature. The amount of heat energy (H) produced in a conductor or a resistor depends on:

- **the time (t) the current passes through the resistor.** The longer the time the current flows through the resistor the more the energy dissipated ($H \alpha t$).
- **the square of the current passing through the resistor.** The heat dissipated is proportional to the square of the current passing through the resistor ($H \alpha I^2$).
- **the resistance (R) of the resistor.** The heat energy dissipated is proportional to the resistance of the resistor ($H \alpha R$).

The total heat energy produced by a resistor is given by:

$$\mathbf{H = I^2R\,t}$$

The formula above is called Jouleâ€™s law of electrical heating. **The law states that the heat dissipated in a resistor is proportional to the product of the square of the current, resistance and the time it takes the current to pass through the resistor.**

Applications of heating effect of current

Domestic heating appliances like electric heaters, irons, and kettles have heating elements. Heating elements are made from Nichrome wire. Nichrome wire is used because it has high resistance and does not react with air to form oxide easily when it is red hot.

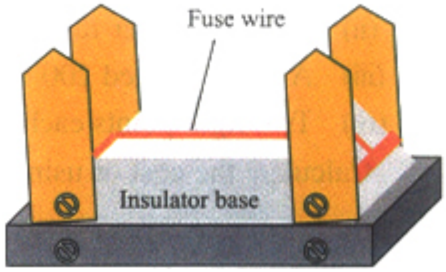


Figure 11.24 Fuse protect circuits from excess current

Electric heater

The electric heater transforms electrical energy to heat energy. The heating element is made of thin wire so it can resist current in order to produce heat energy. The element is insulated to prevent water from touching it and to prevent electric shock.

The electric iron

The electric iron has a heating element of resistance wire made from nichrome. Heating element is a resistance wire wound on a mica and sandwiched between two mica sheets to prevent physical contact with the metal parts of the electric iron.

Fuse

Fuses protect electric circuit and household appliances from excess current. It has a short wire of low melting point which melts when too much current flows through it. A fuse is always connected to the live wire and designed to melt at a particular temperature.

Fuse rating

This states the maximum current that will flow through it without melting the fuse wire. Table 12.3 shows different fuse ratings and their uses.

Fuse rating	**Uses**
5 A Fuse	Lighting points
13 A and 15 A Fuse	Sockets
20 A and above	Power circuits

The electric filament lamp

The electric filament lamp transforms electrical energy to light and heat energies. It consists of a thin coil of tungsten wire as a heating element, which becomes very hot as current flows through it. Tungsten is chosen as the filament element because it has high melting point (3400Â°C) and can stand high temperature. At high temperature, tungsten reacts easily with air to form oxide. Oxides of metals are bad conductors of heat and break easily. To prevent air from coming in contact with the tungsten at this temperature, it is placed inside a glass glove with inert gas to keep the tungsten from evaporating.

Filament lamp

Figure 11.23 Application of heating effect of current

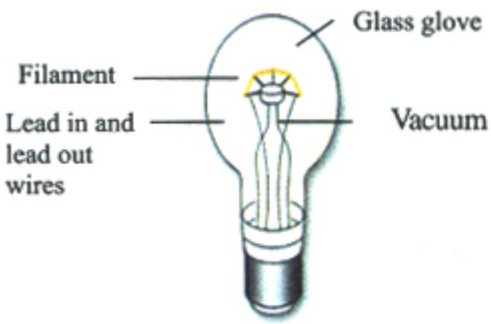


Figure 11.26 Electric filament lamp

Summary

- Voltage is the work done per unit charge.
- $$\text{Voltage} = \frac{\text{Energy transformed}}{\text{Charge moved}}$$

$$W = \frac{V^2}{R}t \quad \text{or} \quad W = I^2Rt$$

- Electrical power is the rate which an appliance transforms electrical energy to heat energy.
- $$P = IV, \quad P = I^2R \text{ and } P = \frac{V^2}{R}$$

- The power rating of an electrical appliance is the energy it dissipates per second in normal use.
- Jouleâ€™s law of electrical heating states that the heat dissipated in a resistor is proportional to the product of the square of the current, resistance and the time it takes the current to pass through the resistor.
- Fuse rating is the maximum current that will flow through it without melting the fuse wire.

Practice questions 11e

1. (a) A radio set is rated 200 W, 240 V; explain the meaning of the statement.
   (b) An electric kettle connected to a 240 V mains supply draws a current of 8 A. Calculate: (i) the power of the kettle.
   (ii) the energy dissipated in 10 minutes.
2. Two lamps rated 60 W; 240 V and 100 W, 240 V respectively are connected in series to a 240 V power source. Calculate;
   (a) the resistance of each lamp.
   (b) the effective resistance of the circuit.
   (c) the current passing the lamps.
3. Find the cost of operating 2 kW heater, 200 W television and two deep freezers each rated 800 W for two weeks. The deep freezers are on for 24 hours while the television and the warmer are on for 10 hours each day. A unit of energy costs ₦5.00.
4 Why is tungsten used to make the filament of a lamp? (b) State the factors that determine the heat produced in a wire. How does the heat produced depend on each factor?

Past questions

1. Which of the following factors does **not** affect the electric resistance of a wire?
   A. Length
   B. Mass
   C. Temperature
   D. Cross sectional area

WASSCE

2. A current of 10 A passes through a conductor for 10 s, calculate the charge flowing the conductor.
   A. 100.0 C
   B. 10.0 C
   C. 1.0 C

D. 0.1 C

WASSCE

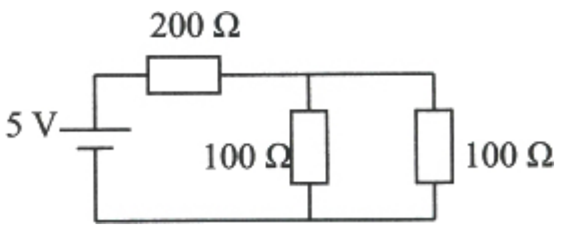
3. A lamp is rated 240 V 60 W, calculate the resistance of its filament.
   A. 240 Î©
   B. 360 Î©
   C. 960 Î©
   D. 1440 Î©

WASSCE

4. The maximum power dissipated by a 100 Î© resistor in a circuit is 4 W; calculate the voltage across the resistor.
   A. 10 V
   B. 20 V
   C. 25 V
   D. 400 V

WASSCE

Use the diagram below to answer 5 to 7.



5. Calculate the current in the circuit.
   A. 0.13 A
   B. 0.05 A
   C. 0.03 A
   D. 0.02 A

WASSCE

6. Calculate the power dissipated in the 200 Î© resistor.
   A. 4.00 W
   B. 2.00 W
   C. 0.08 W
   D. 0.04 W

WASSCE

7. Calculate the potential difference across each of the 100 Î© resistor.
   A. 1 V
   B. 2 V
   C. 4 V
   D. 5 V

WASSCE

8. A wire of length 5m and cross sectional area 4.0 Ã— 10^{-8}m^2 has a

resistance of 10 Î©. Calculate the conductivity of the wire.

A. 1.25 Ã— 10^7Î©$^{-1}$ m^{-1}

B. 2.50 Ã— 10^7Î©$^{-1}$ m^{-1}

C. 5.00 Ã— 10^7Î©$^{-1}$ m^{-1}

D. 8.00 Ã— 10^7Î©$^{-1}$ m^{-1}

WASSCE

9. An electric iron, which draws a current of 5.0 A, is connected to a 240 V_{rms} supply. Calculate the energy consumed if it is used for 6 minutes.

A. 432.0 kJ

B. 375.0 kJ

C. 17.3 kJ

D. 7.2 kJ

WASSCE

10. Three identical lamps each of power 100 W are connected in parallel across a potential difference of 250 V. Calculate the current in the circuit.

A. 7.5 A

B. 2.5 A

C. 1.2 A

D. 0.8 A

WASSCE

11. An electric bulb is rated 60 W, 220 V. Calculate the resistance of its filament when it is operating normally.

A. 296.7 Î©

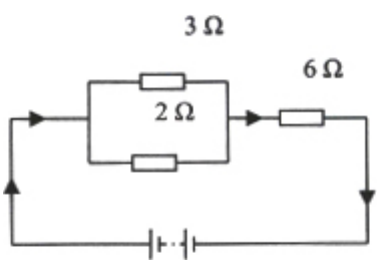
B. 400.0 Î©

C. 512.2 Î©

D. 806.7 Î©

WASSCE

Use the diagram below to answer questions 12 and 13.



12. In the diagram above the current passing through the 6 Î© is 1.5 A. Calculate the current in the 3 Î© resistor.

A. 1.20 A

B. 0.90 A

C. 0.75 A

D. 0.60 A

WASSCE

13. Calculate the terminal p.d. of the battery in the diagram.

A. 7.50 V

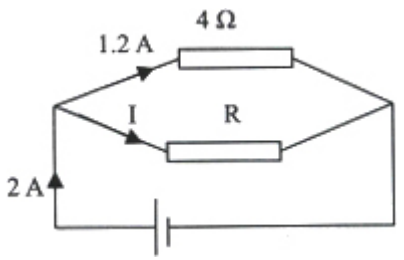
B. 9.00 V

C. 10.80 V

D. 11.25 V

WASSCE

14



Calculate the value of R in the circuit shown above.

A. 6.0 Î©

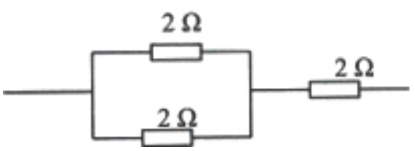
B. 2.7 Î©

C. 1.2 Î©

D. 0.8 Î©

WASSCE

15



In the diagram above, if each of the resistors can dissipate a maximum of 18 W without becoming excessively heated, what is the maximum power the circuit can dissipate?

A. 9W

B. 5W

C. 18W

D. 27W

JAMB

16. A wire of 5 Î© resistance is drawn out so that its new length is twice the original length. If the resistivity of the wire remains the same and the cross-sectional area is halved, the new resistance is

A. 5Î©

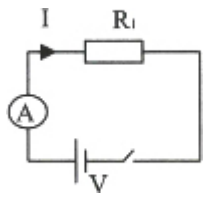
B. 10Î©

C. 40Î©

D. 20Î©

JAMB

17.



In the diagram above, what would happen to the current, I, if another resistor, R_2, is connected in parallel to R_1?

A. It will decrease if R_2 is less than R_1.

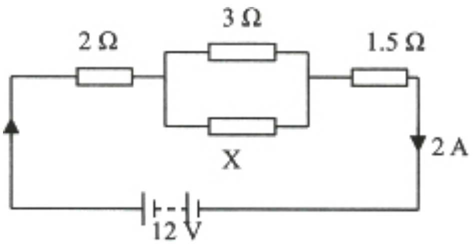
B. It will increase because the effective resistance will decrease.

C. It will increase because the equivalent resistance will increase.

D. It will decrease if R_2 is greater than R_1.

JAMB

18.



From the diagram determine the value of the resistance X.

A. 9Î©

B. 12Î©

C. 15Î©

D. 6Î©

JAMB

19. When connected to 250 V, the fuse rating in the plug of an electric device of 1 kW is

A. 4A

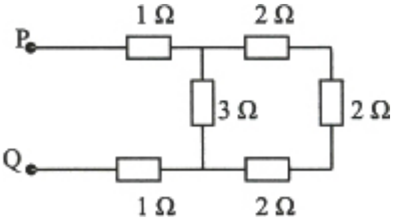
B. 2A

C. 5A

D. 3A

JAMB

20.



The total resistance measured at PQ in the diagram above is

A. 18.0Î©

B. 11.0Î©
C. 4.0Î©
D. 2.0Î©

JAMB

21. Electricity is supplied to a school along a cable of total resistance 0.5 Î© with the maximum current drawn from the mains as 100 A. The maximum energy dissipated as heat for 1hour is

A. 3.6 Ã— 10^3J
B. 5.0 Ã— 10^3J
C. 3.0 Ã— 10^5J
D. 1.8 Ã— 10^7J

JAMB

22. The resistance of 5 m uniform wire of cross sectional area 0.2 Ã— 10^{-6}m^2 is 0.425 Î©. What is the resistivity of the material of the wire?

A. 1.10 Ã— 10^{-6}Î© m
B. 4.25 Ã— 10^{-6}Î© m
C. 2.40 Ã— 10^{-7}Î© m
D. 1.70 Ã— 10^{-8}Î© m

JAMB

23. A wire of length 15m made of a material of resistivity 1.8 Ã— 10^{-6}Î© m has a resistance of 0.27 Î©. Determine the area of the wire.

A. 1.5 Ã— 10^{-4}m^2
B. 1.0 Ã— l0^{-4}m^2
C. 2.7 Ã— 10^{-5}m^2
D. 7.3 Ã— 10^{-6}m^2

JAMB

24. The heat produced in a conductor carrying an electric current is

A. inversely proportional to the current and the resistance.
B. directly proportional to the current, resistance and the time.
C. inversely proportional to the square of resistance, current and the time.
D. directly proportional to the square of the current, the resistance and the time.

JAMB

25. In a domestic circuit, electrical appliances and lamps are arranged in parallel across the mains so as to enable the

A. same current flow through the electrical appliances and the lamps.
B. maximum energy to be consumed at least cost.

C. same fuse to be used in the electrical appliances and the lamps.

D. voltage across the appliances not to be affected when the lamps are switched on and off.

E. Heat losses to be minimized.

JAMB

26. Three resistances of 3, 5 and 6 Ohms are arranged between two points A and B so that their equivalent resistance is 7 Ohms. Draw a sketch of the arrangement, and show that the sketch is correct.

WAEC

27. (a) (i) Describe, with the aid of a circuit diagram, an experiment to measure the resistance of a wire given an ammeter of low resistance, a battery, a key, a rheostat, a high resistance voltmeter and some connecting wires.

(ii) State two precautions necessary to maintain an accurate result.

(b) Using the experimental result and any necessary measurements, explain how the resistivity of the wire may be determined.

WAEC

28. (i). State **two** advantages of a secondary cell over a primary cell.

(ii) State two sources of electromotive force other than the chemical source.

WASSCE