



DEPARTMENT OF EDUCATION

GRADE 11

PHYSICS

MODULE 5



ELECTRICITY PRINCIPLES



PUBLISHED BY FLEXIBLE OPEN AND DISTANCE EDUCATION
PRIVATE MAIL BAG, P.O. WAIGANI, NCD
FOR DEPARTMENT OF EDUCATION
PAPUA NEW GUINEA
2017

Writer

Giles Waken

Content Editors

Science Department

Subject Review Committee

Language Editor

Dr. Mirzi. L. Betasolo

Course Format Editor

Elizabeth. W. Aimundi



GRADE 11

PHYSICS

MODULE 5

ELECTRICITY PRINCIPLES

IN THIS MODULE, YOU WILL LEARN ABOUT:

11.5.1: ELECTROSTATICS

11.5.2: CURRENT ELECTRICITY

11.5.3: RESISTANCE

11.5.4: ALTERNATING CURRENT (AC) CIRCUITS



Acknowledgement

We acknowledge the contribution of all Lower and Upper Secondary teachers who in one way or another helped to develop this Course.

Our profound gratitude goes to the former Principal of FODE, Mr. Demas Tongogo for leading FODE towards this great achievement.

Special thanks are given to the staff of the Science Department of FODE who played active roles in coordinating writing workshops, outsourcing of module writing and editing processes involving selected teachers of Central Province and NCD.

We also acknowledge the professional guidance and services provided through-out the processes of writing by the members of:

Science Subject Review Committee-FODE
Academic Advisory Committee-FODE
Science Department- CDAD

This book was developed with the invaluable support and co-funding of the GO-PNG and World Bank.

DIANA TEIT AKIS
Principal-FODE



Flexible Open and Distance Education
Papua New Guinea

Published in 2017

©Copyright 2017, Department of Education
Papua New Guinea

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means electronic, mechanical, photocopying, recording or any other form of reproduction by any process is allowed without the prior permission of the publisher.

Printed by the Flexible, Open and Distance Education
ISBN 978-9980-89-549-3
National Library Services of Papua New Guinea



TABLE OF CONTENTS

	Page
Title.....	1
Acknowledgement & ISBN.....	2
Contents.....	3
Secretary's Message.....	4
 MODULE 11.5: ELECTRICITY PRINCIPLES	 5 - 72
Course Introduction.....	5
Learning Outcomes.....	6
Time Frame.....	7
 11.5.1: Electrostatics	 8 - 30
☐ Electric Charges.....	8 - 13
☐ Electrostatic Force.....	14 - 19
☐ Electric Fields.....	19 - 25
☐ Electric Potential.....	25 - 30
 11.5.2: Current Electricity	 30 - 49
☐ Basic Electrical Quantities.....	30 - 32
☐ Series and Parallel Circuits.....	32 - 46
☐ Electromotive Force and Internal Resistance.....	47 - 49
 11.5.3: Resistance	 50 - 76
☐ Ohm's Law.....	50 - 53
☐ Resistivity and Factors that Affect Resistance.....	53 - 57
☐ Electrical Energy and Power.....	57 - 63
☐ Kirchhoff's Rules.....	63 - 71
☐ Wheatstone Bridge and Potentiometer Circuits.....	71 - 76
 11.5.4: Alternating Current (AC) Circuits	 77 - 103
☐ Alternating Currents (AC).....	77 - 85
☐ AC Circuits.....	86 - 99
☐ Power Transmission.....	99 - 103
 Summary.....	 104 - 108
Answers to Learning Activities.....	109 - 114
References.....	115



SECRETARY'S MESSAGE

Achieving a better future by individual students, their families, communities or the nation as a whole, depends on the kind of curriculum and the way it is delivered.

This course is part of the new Flexible, Open and Distance Education curriculum. The learning outcomes are student-centred and allows for them to be demonstrated and assessed.

It maintains the rationale, goals, aims and principles of the National Curriculum and identifies the knowledge, skills, attitudes and values that students should achieve.

This is a provision by Flexible, Open and Distance Education as an alternative pathway of formal education.

The Course promotes Papua New Guinea values and beliefs which are found in our constitution, Government policies and reports. It is developed in line with the National Education Plan (2005 – 2014) and addresses an increase in the number of school leavers affected by lack of access into secondary and higher educational institutions.

Flexible, Open and Distance Education is guided by the Department of Education's Mission which is fivefold;

- To develop and encourage an education system which satisfies the requirements of Papua New Guinea and its people
- To establish, preserve, and improve standards of education throughout Papua New Guinea
- To make the benefits of such education available as widely as possible to all of the people
- To make education accessible to the physically, mentally and socially handicapped as well as to those who are educationally disadvantaged

The College is enhanced to provide alternative and comparable path ways for students and adults to complete their education, through one system, two path ways and same learning outcomes.

It is our vision that Papua New Guineans harness all appropriate and affordable technologies to pursue this program.

I commend all those teachers, curriculum writers, university lecturers and many others who have contributed so much in developing this course.

UKE KOMBRA, PhD
Secretary for Education



MODULE 11. 5: ELECTRICITY PRINCIPLES

Introduction

Electricity plays a very important role in sustaining our lives in the modern age. Although electricity has been around for millions of years, it has only been recognised, harnessed and used on a large scale for the best part of the last 200 years. We must appreciate that the human race has advanced very quickly over this time and electricity has been one of the main factors behind this rapid advance.

This module covers the basic aspects of electricity. It includes the causes of electricity and the applications of electricity in supplying energy to meet our needs. It builds on what was learnt in the Grade 9 Electricity unit.

The module begins with electrostatics. In this part of the module, we will investigate electric charges which cause electricity and what happens when electric charges are stationary.

In the second part of this module we will look at the movement of electric charges through conductors and the effects that occur when electric charges are moving. We will also look at electric circuits, their design and applications.

The third part of this module focuses on resistance and its applications.

The fourth and final part of this module introduces us to alternating current (AC) and its uses.



Figure 1 Lightning is a natural phenomenon that proves the existence of electric charges.



Learning Outcomes

After going through this module, you are expected to:

- explain the nature and types of charges including the law of magnetism for the two main types of charge
- explain and describe the three main methods of charging objects
- explain and apply Coulomb's Law to calculate force between charges and solve simple problems
- explain electric field concept of charges and apply formulae to calculate electric field strength
- explain electric potential concept and apply formula to calculate electric potential
- demonstrate an understanding of concepts in current, voltage and resistance for simple circuits
- interpret circuit symbols and apply them to practical and theoretical construction of circuits
- explain the differences between series and parallel circuits
- use voltmeters and ammeters to measure voltage and current in simple circuits
- explain the relative merits of combining cells to produce electricity
- calculate total resistance in series and parallel circuits using the total resistance formulae
- apply resistance formulae to solve simple problems
- explain Ohm's law and use it to solve simple problems
- explain the factors affecting resistance and use the formula to solve simple problems
- explain the concepts of energy and power in an electrical circuit and apply the concepts to solve simple problems
- explain and apply Kirchhoff's rules in solving simple current and voltage problems
- differentiate between AC and DC and discuss their advantages and disadvantages
- explain the concepts and calculate instantaneous, RMS and peak values of voltage and current in AC circuits using correct formulae
- explain the effects of capacitance and inductance on voltage and current in AC circuits



Time Frame

Suggested allotment time: **10 weeks**

This module should be completed within 10 weeks.

If you set an average of 3 hours per day, you should be able to complete the module comfortably by the end of the assigned week.

Try to do all the learning activities and compare your answers with the ones provided at the end of the unit. If you do not get a particular exercise right in the first attempt, you should not get discouraged but instead, go back and attempt it again. If you still do not get it right after several attempts then you should seek help from your friend or even your tutor.

DO NOT LEAVE ANY QUESTION UNANSWERED.



11.5.1 Electrostatics

The study of electrostatics is the beginning of the detailed study into electricity and all the phenomenon that is related to electricity. This deals with the idea of electric charges when they are stationary (i.e. not moving). The aim of this study is to allow us to simplify and observe the behaviour of charges in its most simple terms. The study of charges that are moving is a lot more complex.

Electric charges are mostly responsible for the forces that hold the atom together and that cause chemical reactions to occur. Some of the ideas presented in this unit will assist you in your understanding of chemistry especially with ions and the formation of ionic compounds.

In the first sub-topic of electrostatics we will look at the nature and types of electric charges. We also look at the simple rules of the interactions of charges as well as terms associated with electric charges.

In the second sub-topic, we will look at the force between charges as it is explained by the mathematical relationship of Coulomb's law. This mathematical relationship helps us to predict the size and type of force that charges can exert and also allows us to manipulate charges so that we can get the strength and direction of the forces that we desire.

The third sub-topic looks at the concept of an electric field. It is also related to the idea of the force between charges.

Finally we will look at the electric potential which is basically all about energy. It would have seemed to you that wherever there is a force, there has to be energy involved. If this is the idea that you already have from the previous units that you have studied, then you are definitely on the right track in your study of physics.

Electric Charges

There are two types of electric charges; positive (denoted with + sign) and negative (denoted with – sign).

The relationship between these two types of electric charges is responsible for many phenomenon including elasticity and chemical bonding. The main interaction between charges is the forces that occur when charged objects are together. This interaction is as follows;

LIKE CHARGES REPEL, WHILE UNLIKE CHARGES ATTRACT



Nature and type of charge

The atom contains these two charges in the form of protons (carry positive charge) and electrons (which carry negative charge).

In general, any object that contains an equal amount of positive and negative charge is said to be electrically **NEUTRAL**. An atom is electrically neutral. This means that every atom contain equal amounts of both types of charge.

An object becomes **CHARGED** when there is an imbalance in the amount of one type of charge.

In general, a charged body has an excess of one type of charge.

- Positively charged bodies have more positive charge than negative charge.
- Negatively charged bodies have more negative charge than positive charge.

**An atom becomes a positively charged ion when it loses electrons.
It becomes a negatively charged ion when it gains extra electrons.**

Methods of Charging

A body can become charged in three ways.

1. Charging by rubbing or by friction

When two objects rub against each other there is a possibility that some electrons on one of the objects get transferred to the other. As a result, the object that loses electrons becomes positively charged while the object that gains electrons becomes negatively charged. A simple demonstration of this method of charging can be done by using a plastic comb and some small pieces of paper. Rub a dry plastic comb to your hair very quickly for 30 seconds. As quickly as you can bring the comb to the pieces of paper and observe what happens. If all of this is done in dry conditions, you will be able to see that the paper will be attracted to the dry plastic comb.

When the plastic comb is rubbed through hair, it loses electrons to the hair. The plastic comb becomes positively charged while the hair becomes negatively charged. Charging by friction can also be observed when a dry silk shirt rubs against your skin. Sometimes you might even hear cracks of static electricity such as when you wear sports jerseys that are made of silky materials and the jersey rubs against your skin (which must be dry of course!).

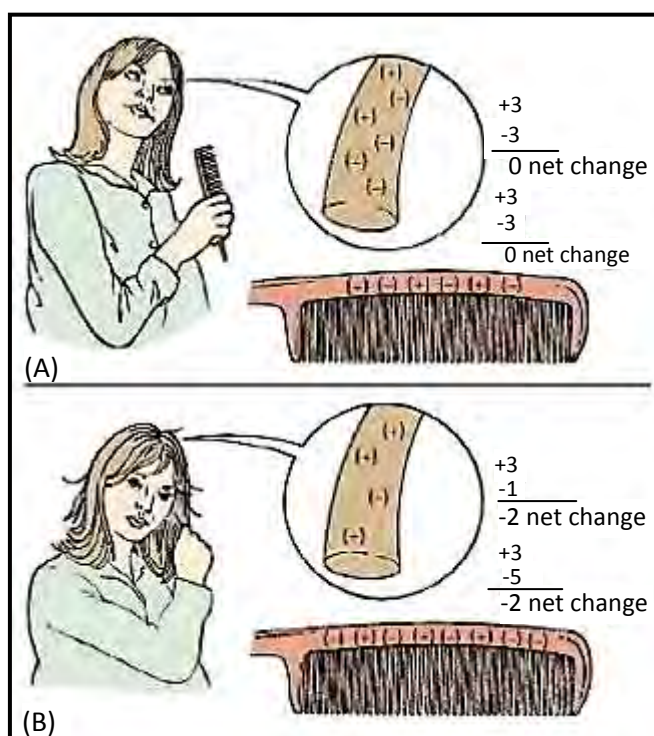


Figure 2 While combing your hair, your plastic comb may become charged (A) before combing and (B) after combing.

2. Charging by conduction

Charge can also be transferred by providing a pathway to another object. The word conduction simply describes the process where a path is provided that allows charges to transfer from one object to another. Objects that provide a pathway for charges are called **conductors** while those that do not are called **insulators**.

The diagrams below illustrate charging by conduction.

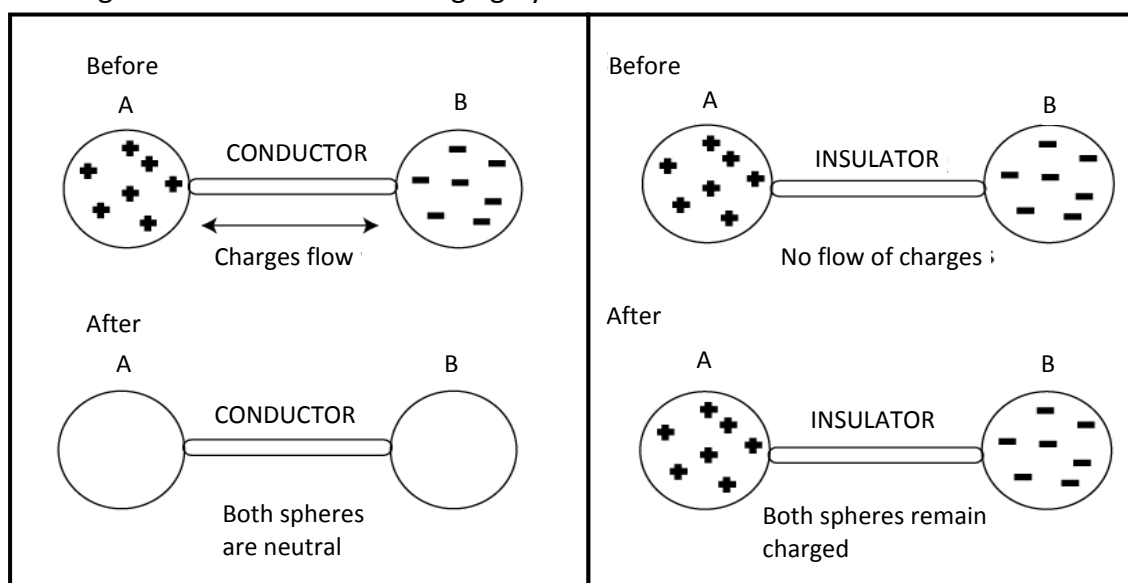


Figure 3 Charged spheres joined by a conductor

Figure 4 Charged spheres joined by an insulator.



Suppose we start with two spheres A and B which contain the same amount of positive and negative charge respectively.

When a conductor is brought between A and B such as in Figure 3, it acts like a bridge that allows the charges from both sides to be evenly distributed until both the spheres become neutral.

When an insulator is used, no charges distribute between the spheres because unlike a conductor, the charges are not allowed to move through the insulator. Both spheres will remain charged as shown in Figure 4.

Conductors are substances which allow charges to pass through them.
Insulators are substances that do not allow charges to pass through them.

All conductors have atomic structures that allow for the conduction of charges. Metals can conduct charges in solid and molten phases. Liquid solutions made from ionic salts and molten ionic compounds can also conduct charges. Some covalent substances such as graphite (carbon) are also capable of conducting charges.

Insulators do not contain atomic structures that allow for the conduction of charges. When an insulator is in physical contact with a charged object, only the part that is in contact with the charge object becomes charged. The charge is not distributed in the insulator due to the absence of atomic structures that allow for this. This is why the two charged spheres in Figure 3 remain charged when they are kept in contact by an insulator. Gases and most covalent liquid substances fall in this category. Most solid covalent substances such as wood, rubber and plastics are also classified as insulators.

3. Charging by induction

The first two methods of charging involve the physical contact of materials in order to transfer charges. The method of induction involves no physical contact. To illustrate this method let us look at an example.

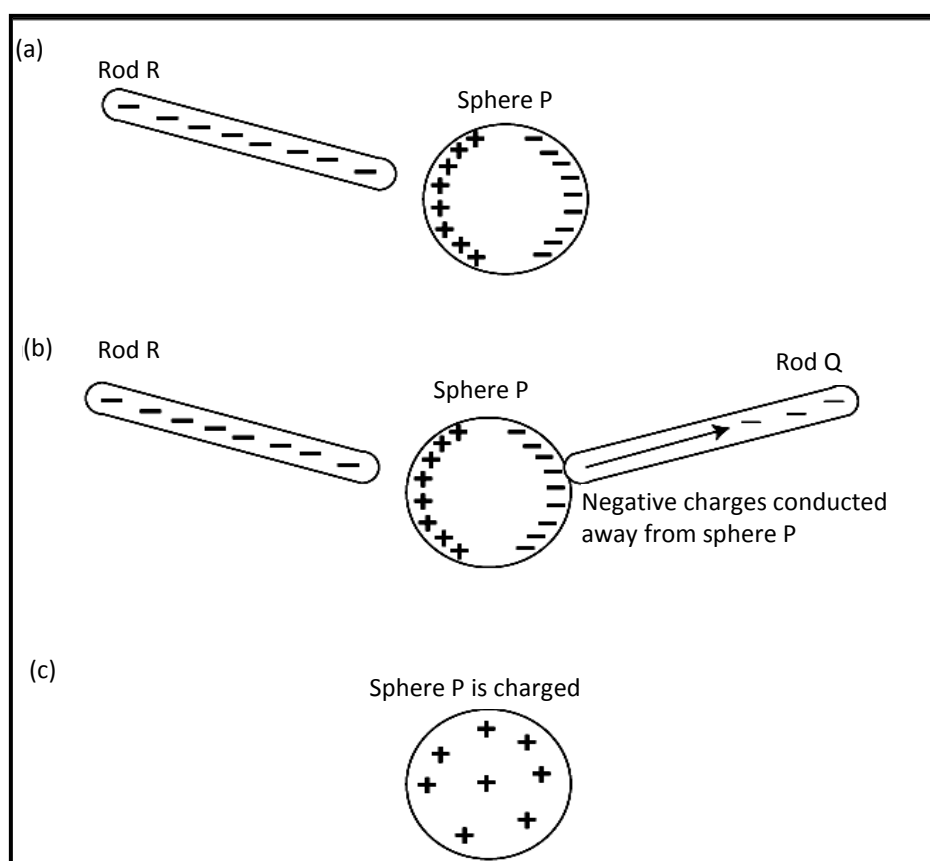


Figure 5 Charging by induction: at (a) a negatively charged rod R is brought close to sphere P. It separates the charges in sphere P. Once separated, a conducting rod Q is used to conduct excess negative charges from one side of sphere P as shown in (b). Finally, both rods R and Q are removed and the excess charge at on sphere P is now positive as shown in (c).

Suppose a negatively charged rod R is brought close to (but not touching) the left side of an isolated neutral metallic sphere P (Figure 5.(a)). The charges on the metallic sphere would separate with negative charges moving away from the region closest to rod R (to the right) and positive charges moving to the region closest to rod R (to the left). **This separation occurs because of the attraction of unlike charges and repulsion of like charges.** Note that although the charges have separated, the sphere P is still neutral since the amount of positive charge is equal to the amount of negative charge.

If the rod R is moved away from the sphere P, the charges would evenly distribute themselves over the sphere and the sphere would again be neutral.

But what would happen if we keep the negatively charged rod R close to sphere P, and use another rod Q as a conductor to remove the negative charges on the left side of sphere P as in Figure 5. (b). This would result in excess positive charge on the sphere making it positively charged! If we also remove the rod R away from sphere P, the positive charges will distribute evenly over the sphere, and the sphere would have a net positive charge as in Figure 5. (c) on the previous page.

The separation of charges explained is important in explaining some occurrences that happen due to charges. For instance, you can make your hair on your arm stand by charging a comb as was discussed earlier. The fact that your hair stands is due to the fact that charge is **induced** on the hair strands by the charged comb. The charges in your hair simply separate and depending on the type of charge on the comb distribute themselves by attraction and repulsion. Charges do not leave your hair strand. When you remove the charged comb, the charges in your hair redistribute again so that your hair falls back to where it was initially.

In the same way a charged plastic object can also pick up bits of paper. The paper itself remains neutral but again there is a separation of charges on the bits of paper which are induced by the plastic. Printers and photocopiers use the induction to pick up paper for printing and copying.

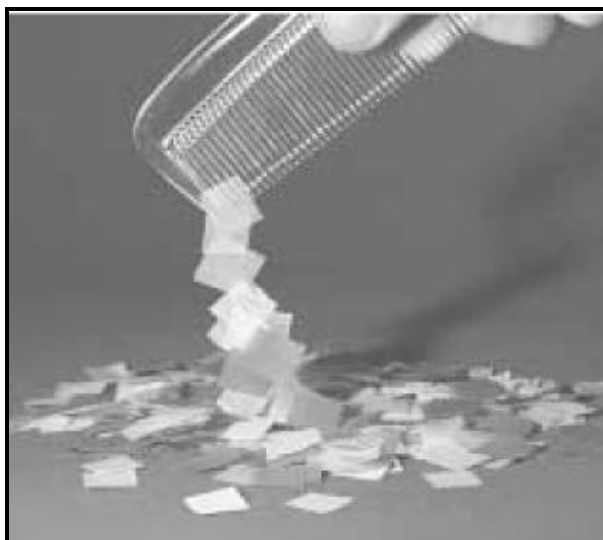


Figure 6 Picking up bits of paper with a charged plastic object

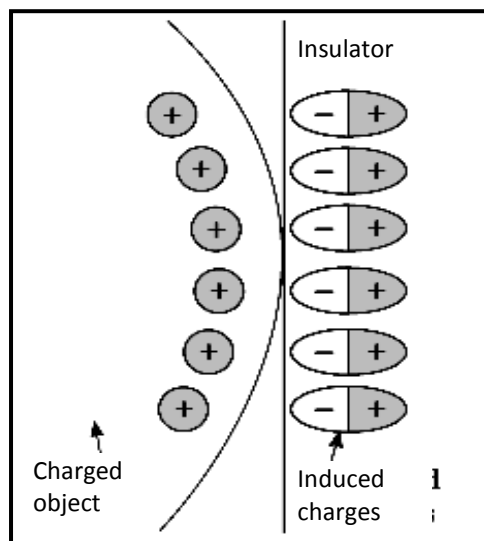


Figure 7 Induced charges on a neutral object caused by the nearby presence of another charged object.

Electric charge as a quantity

Electric charge is a physical quantity measuring the amount of excess charge that an object possesses. The SI unit for electric charge is the **Coulomb (C)**. Throughout this unit charge may be represented using the following prefixes:

$$\begin{aligned} \text{mC} &= \text{milli-coulomb} = 10^{-3}\text{C} \\ \mu\text{C} &= \text{micro-coulomb} = 10^{-6}\text{C} \\ \text{nC} &= \text{nano-coulomb} = 10^{-9}\text{C} \\ \text{pC} &= \text{pico-coulomb} = 10^{-12}\text{C} \end{aligned}$$

$$\text{For instance, } 5.23\mu\text{C} = 5.23 \times 10^{-6}\text{C} = 0.000\,00523\text{C}$$

One coulomb is the amount of charge carried by 6.25×10^{18} electrons. This means that **each electron has a charge of $-1.6 \times 10^{-19}\text{C}$ while each proton has an equal but opposite charge of $+1.6 \times 10^{-19}\text{C}$**



Electrostatic Force

Force between charges

Electrostatic force is the **attraction (pull)** and **repulsion (push)** forces that exist between charged bodies. The electrostatic force is a **field force**. (Other examples of field forces are gravitational force and magnetic force). Field forces are those forces that exert a push or a pull on an object without actually touching it. This is unlike contact forces which exert a push or a pull on an object only when they touch the object.

One significant characteristic of the electrostatic force is that it only exists between charged objects.

Factors that determine the force between charges

Forces between charged objects depend on the following factors;

1. The amount and type of charge on the objects.
2. The distance between the charged objects.
3. The type of medium that the charged objects are in. For simplicity we consider only air or a vacuum as the medium throughout this unit.

Coulomb's Law states that "the force on two charges is proportional to the amount of charge on the two bodies and inversely proportional to the square of the distance between them."

The direction of the force is along the line through the centers of the charges.

Mathematically this is written as;

$$F = \frac{kQ_1Q_2}{d^2}$$

- Where **F** = force in Newton (N) between the charges. Can be an attractive force (for unlike charges) or a repulsive force (for like charges)
- **Q₁** and **Q₂** are the size of the charges in Coulomb (C). Negative charges have – sign; Positive charges have + sign
- **d** is the distance in metres (m) between the charges
- **k** is a constant of proportionality depending on the medium. For air and a vacuum which are approximately equal $k = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$

Remember the following relationships;

- Increase in distance means decrease in force and vice versa (Inverse Square Law)
- Increase in charge means increase in force and vice versa (Proportionality)
- The type of force that occurs depends on what types of charges are interacting
 - A **force of attraction occurs when unlike charges interact**
 - A **force of repulsion occurs when like charges interact**
- Each charge exerts an equal and opposite force on the other (from NEWTON'S THIRD LAW)

**Example 1**

Determine the force between:

- (a) two charges of $+20\mu\text{C}$ and $+30\mu\text{C}$ separated by 10cm in air.
- (b) $+20\mu\text{C}$ and $-10\mu\text{C}$ separated by 20cm in air. Indicate whether the force is one of attraction or repulsion in each case.

(Remember to convert from micro-coulomb to coulomb when working out the answers.)

Solution

(a) $F = \frac{kQ_1Q_2}{d^2}$

$F = \frac{9 \times 10^9 \times 20 \times 10^{-6} \times 30 \times 10^{-6}}{(0.1)^2}$

$Q_1 = 20\mu\text{C} = 20 \times 10^{-6}\text{C} = 2 \times 10^{-5}\text{C}$

$Q_2 = 30\mu\text{C} = 30 \times 10^{-6}\text{C} = 3 \times 10^{-5}\text{C}$

10cm is converted to 0.1m.

$F = \frac{5400 \times 10^{-3}}{1 \times 10^{-2}}$

$F = 540\text{N}$

This force is a repulsive force since the charges are like charges.

(b) $F = \frac{kQ_1Q_2}{d^2}$

$F = \frac{9 \times 10^9 \times 20 \times 10^{-6} \times 10 \times 10^{-6}}{(0.2)^2}$

$Q_1 = 20\mu\text{C} = 20 \times 10^{-6}\text{C} = 2 \times 10^{-5}\text{C}$

$Q_2 = 10\mu\text{C} = 10 \times 10^{-6}\text{C} = 1 \times 10^{-5}\text{C}$

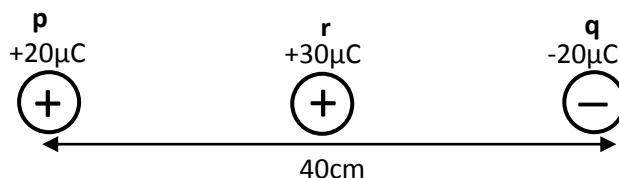
20cm is converted to 0.2m.

$F = \frac{1800 \times 10^{-3}}{4 \times 10^{-2}} = 45\text{N}$

This force is an attractive force since the charges are unlike.

**Example 2**

Calculate the net force on a charge **r** of $+30\mu\text{C}$ midway between charge **p** of $+20\mu\text{C}$ and charge **q** of $-20\mu\text{C}$ separated by a distance of 40cm.

**Solution**

First we calculate the force on **r** due to **p** (F_{rp})

$$F_{rp} = \frac{kQ_r Q_p}{(d_{rp})^2}$$
$$F_{rp} = \frac{9 \times 10^9 \times 30 \times 10^{-6} \times 20 \times 10^{-6}}{(20 \times 10^{-2})^2}$$
$$F_{rp} = \frac{5400 \times 10^{-3}}{400 \times 10^{-4}} = 125\text{N}$$

Next we calculate the force on **r** due to **q**. (F_{rq})

$$F_{rq} = \frac{kQ_r Q_q}{(d_{rq})^2}$$
$$F_{rq} = \frac{9 \times 10^9 \times 30 \times 10^{-6} \times 20 \times 10^{-6}}{(20 \times 10^{-2})^2}$$
$$F_{rq} = \frac{5400 \times 10^{-3}}{400 \times 10^{-4}} = 125\text{N}$$

Because **r** is a positive charge, we can conclude that the direction of the net force is towards **q**. Thus we simply add the magnitudes of F_{rp} and F_{rq} to get our net force.

$$F_{\text{net}} = F_{rp} + F_{rq}$$
$$F_{\text{net}} = 125\text{N} + 125\text{N}$$
$$F_{\text{net}} = 250\text{N}$$

NOTE: according to the diagram, F_{rp} is a repulsive force because **r** and **p** are like charges while F_{rq} is an attractive force because **r** and **q** are unlike charges. Therefore we add both forces since they are linear and in the same direction. If they were in opposite directions we would have to subtract one from the other.

**Example 3**

What is the force exerted on an electron by a point charge of $+0.2\mu\text{C}$ when they are 3 mm apart?

Solution

$$F = \frac{kQ_1Q_2}{d^2}$$
$$F = \frac{9 \times 10^9 \times 0.2 \times 10^{-6} \times 1.6 \times 10^{-19}}{(3 \times 10^{-3})^2}$$
$$F = \frac{2.88 \times 10^{-16}}{9 \times 10^{-6}}$$
$$F = 3.2 \times 10^{-11}\text{N}$$

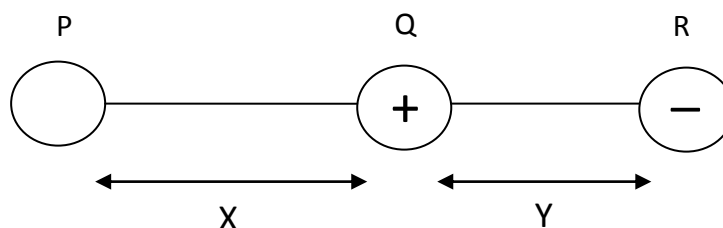
Thus the force exerted on the electron is an attractive force of magnitude $3.2 \times 10^{-11}\text{N}$.

Now check what you have just learnt by trying out the learning activity below!

**Learning Activity 1****30 minutes**

Answer the following questions on the spaces provided.

1. The diagram below shows three charges P, Q and R all lying on a straight line. P and R have the same amount of charge, which is the same as half that of Q. The distance between P and Q is labeled X. Y is the distance between Q and R.



- a) Charge P is attracted to R but repelled by Q. What type of charge is P?
- _____
- b) According to the diagram which of the following forces is stronger;
- i) Force between P and Q
- ii) Force between Q and R



- iii) Force between P and R
(choose one option)

- c) Briefly explain your answer to b.

- d) If the force between Q and R is to be increase by a factor of 4. What changes to the charges and distances could occur for this to happen?

- e) Suppose the distance X is doubled. What then happens to the magnitude of force between P and Q?

-
2. Use Coulomb's law to find the magnitude of force exerted by the following pairs of charges. Also state whether the force is attractive or repulsive.

- (a) $+5\mu\text{C}$ and $+6\mu\text{C}$ separated by a distance of 30cm.

- (b) -80nC and $+70\text{nC}$ separated by a distance of 6cm.

- (c) $-0.4\mu\text{C}$ and -200nC separated by a distance of 0.12m.

-
3. An attractive force of 14kN is experienced by two charges of magnitude 0.004C and 0.007C. At what distance must these two charges be to experience this force?



4. A repulsive force of 40N is experienced by two charges of the same magnitude. This occurs when the charges are 75cm apart. What is the magnitude of the charges?

Thank you for completing learning activity 1. Now check your work. Answers are at the end of the module.

Electric Fields

All charged bodies exert force that has an influence on the surrounding region called an **electric field**. An electric field always exists around a charged object. This field is the reason why all charged objects can exert a push or pull on other charged objects.

It is also important to note that only charged objects are influenced by an electric field. Any neutral object that enters an electric field does not experience force. Only charged objects can exert and experience equal forces due to other charged objects (Newton's Third Law). The electric field exerted by a charged object is invisible. However, we know it exists because we can see its effects when other charged objects are introduced to the field.

The direction of an electric field is taken by convention to be **outward (forward) from the center of a positive charge** and **inward (toward) from the center of a negative charge**.

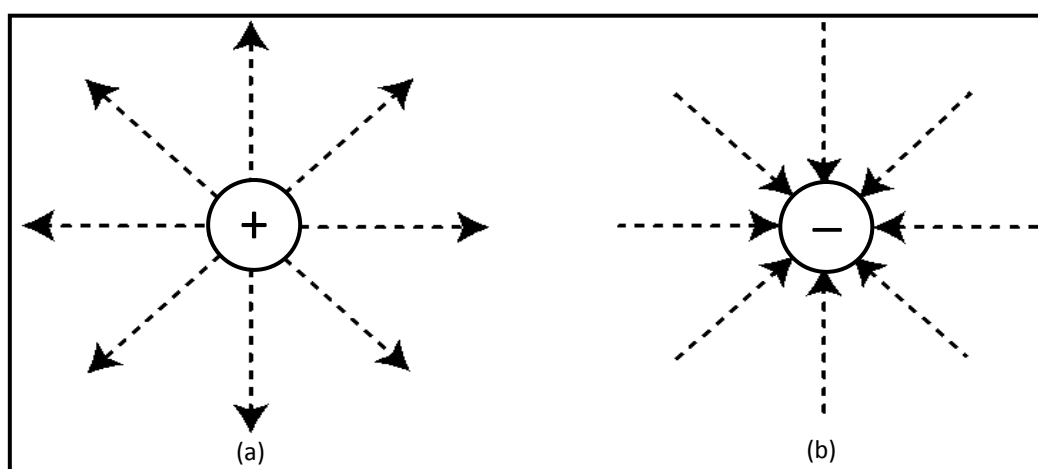


Figure 8 (a) The conventional direction of the electric field lines (dashed) around a positive charge is taken to be outward. (b) The conventional direction of the electric field lines (dashed) around a negative charge is taken to be inward.



When two unlike charges of equal magnitude come together, the electric field lines appear as shown below.

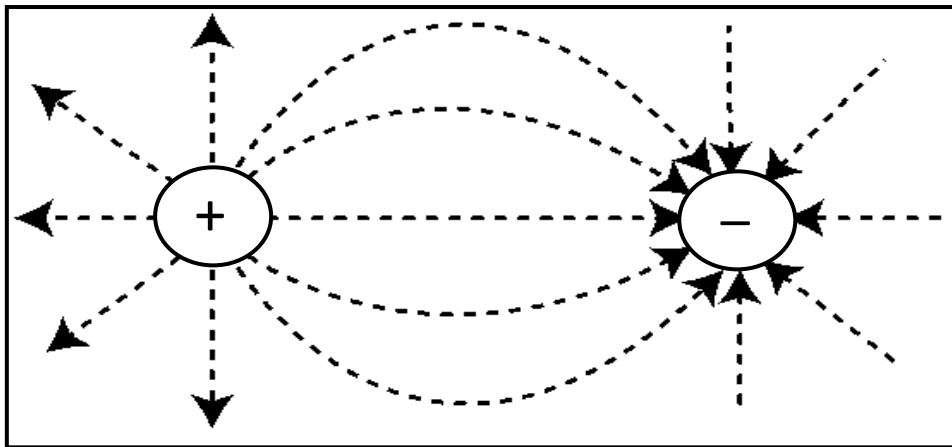


Figure 9 Electric field lines of two equal but opposite spherical charges.

The electric field lines between two positive charges of equal magnitude are shown below.

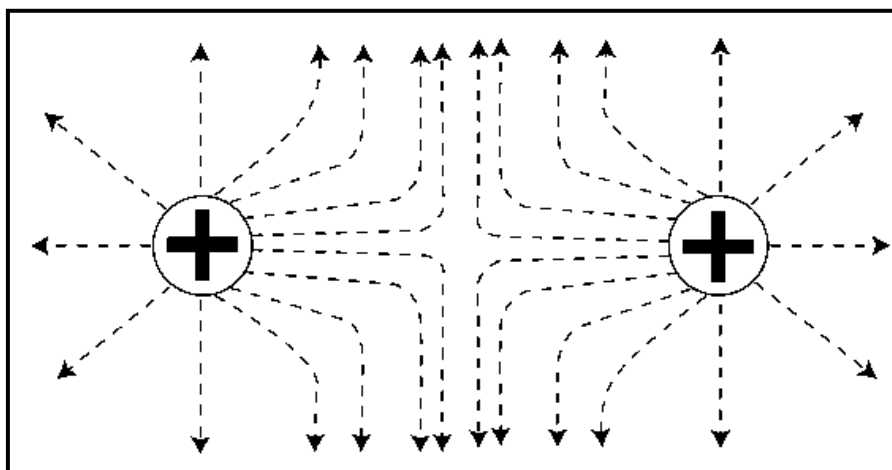


Figure 10 Electric field lines between two like (positive) spherical charges.

The electric field between a pair of oppositely charged parallel plates is uniform at all points between the plates.

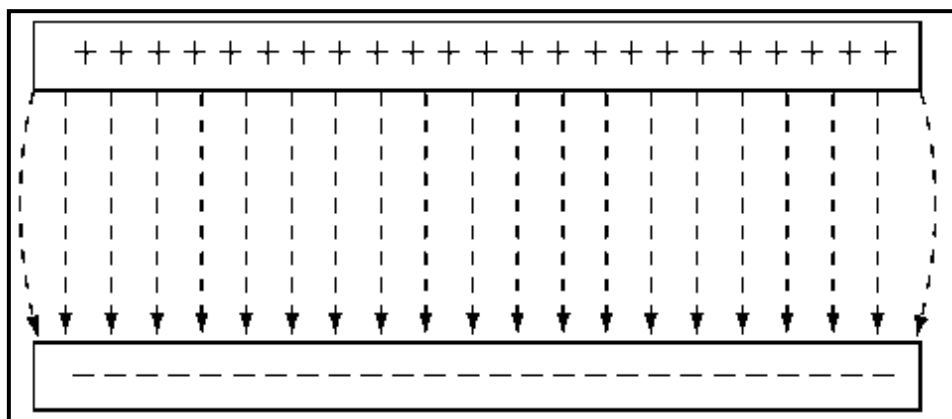


Figure 11 Uniform Electric Field between two parallel and oppositely charged plates.

**Electric field strength**

Electric field strength (E) is a quantity defined as the force per unit positive charge placed in the electric field.

Mathematically;

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

Electric field strength (E) and **force (F)** are vector quantities while **charge (Q)** is a scalar quantity. The SI unit for electric field is **newton per coulomb (N/C)**.

The above definition of electric field strength implies that we can only measure the strength of an electric field by observing the amount of force any 1 C charge experiences when it is within an electric field.

We can calculate the electric field strength surrounding a charged object. This is explained below.

Suppose a charge **Q₁** exists in a space, to determine the field strength due to **Q₁** we introduce a **test charge** in the electric field caused by **Q₁**. Let us call this test charge **Q₂**.

The force on **Q₂** is the force caused by the electric field exerted by **Q₁**. The electric field strength around **Q₁** can be measured by the force it exerts on **Q₂**. Let us call this force **F₂₁**. The electric field caused by **Q₁** is;

$$E = \frac{F_{21}}{Q_2}$$

$$E = \frac{1}{Q_2} \times \frac{kQ_1Q_2}{d^2}$$

$$E = \frac{kQ_1}{d^2}$$

Similarly the electric field caused by **Q₂** exerts a force on **Q₁**. Let us call this force **F₁₂**. The electric field caused by **Q₂** is;

$$E = \frac{F_{12}}{Q_1}$$

$$E = \frac{1}{Q_1} \times \frac{kQ_1Q_2}{d^2}$$

$$E = \frac{kQ_2}{d^2}$$



The **electric field strength (E) due to a point charge** some distance **d** metres from the charge of **Q** Coulombs is;

$$E = \frac{kQ}{d^2}$$

where **k** is a constant of proportionality depending on the medium. For air and a vacuum which are approximately equal **k = $9 \times 10^9 \text{Nm}^2\text{C}^{-2}$**

Example 4

A charge of +3mC is situated at a point in an electric field where it experiences a 0.03N force vertically upward. What is the electric field strength and direction at that point? (Take UP as positive direction)

Solution

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

$$E = \frac{0.03\text{N}}{3 \times 10^{-3}\text{C}}$$

$$E = 10\text{N/C upward}$$

Example 5

A point charge of -6C placed at a point in an electric field experiences a force of 480N vertically downward. What is the electric field strength and direction at that point? (Take DOWN as negative direction)

Solution

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

$$E = \frac{-480\text{N}}{6\text{C}}$$

$$E = -80\text{N/C}$$

Example 6

At what distance in air from a charge of +10μC would the magnitude of electric field strength be 10000N/C?

Solution

$$E = \frac{kQ}{d^2}$$



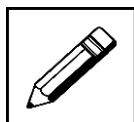
Rearranging this equation in terms of **d** we get;

$$d = \sqrt{\frac{kQ}{E}}$$

$$d = \sqrt{\frac{9 \times 10^9 \times 10 \times 10^{-6} \text{ C}}{10^4}} = 3\text{m}$$

At a distance of 3m from a charge of $+10\mu\text{C}$, the magnitude of the electric field is $10,000\text{N/C}$.

Now check what you have just learnt by trying out the learning activity on the next page!



Learning Activity 2

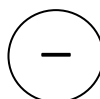
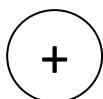
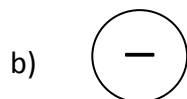
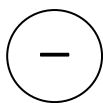
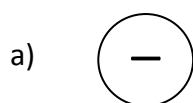


20 minutes

Answer the following questions on the spaces provided.

1. In your own words explain what an electric field is.

2. Draw the electric field lines around the following electric charges.





3. A force of 0.12N is experienced by a charge of 0.005C at a point in an electric field. What is the strength of the electric field at that point?

-
4. What force does a charge of $6\mu\text{C}$ experience when it enters an electric field of strength 200kN/C ?

-
5. Calculate the strength of the electric field at the following distances from the given source charges.

a) 5cm from a charge of $5\mu\text{C}$.

b) 3cm from a charge of 20mC

c) 25mm from a charge 60nC



6. How far must a charge of $9\mu\text{C}$ be to experience an electric field strength of 900000N/C ?

Thank you for completing learning activity 2. Now check your work. Answers are at the end of the module.

Electric Potential

The **electric potential (V)** is the energy that a charge possesses because of the work done to bring a charge to a certain position in an electric field and to maintain it there.

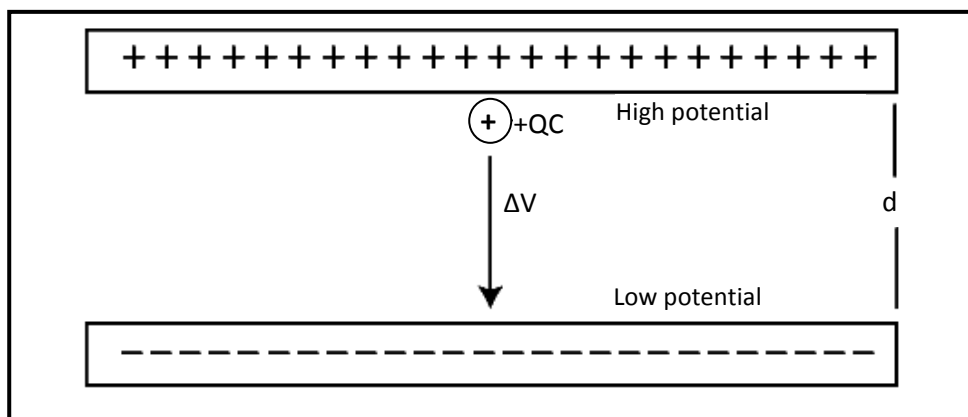


Figure 12 Change in potential as a charge $+QC$ is moved from high potential to low potential.

In figure 12 we have a pair of parallel oppositely charged plates held a distance **d** apart. A small charge of **+QC** held on the positive plate and then released; will move toward the negative plate. Before it is released, it has high electrical potential energy (ability to move from the positive plate to the negative plate). As it starts moving its potential energy changes to kinetic energy (loses potential energy and gains kinetic energy). The change in electrical potential energy (ΔV), is equal to the work done on the charge during the transformation of potential to kinetic energy.



Electric potential (V) is defined generally as the work done (W) per unit charge (Q) to move or maintain the charge's position in an electric field.

Mathematically:

$$V = \frac{W}{Q}$$

The SI unit for electric potential is the **volt (V)**.

A charge in an electric field experiences a force according to Coulomb's law.

If the charge moves in response to this force, work is done by the electric field which results in a decrease in electric potential. If the charge is moved by some other force against the direction of the electric field, work is done against the electric field which results in an increase in electric potential.

When two like charges come closer together, they gain potential. This gain in energy comes about because for each of these charges is moving against an electric field.

When two unlike charges come together they lose potential. This loss in potential occurs because each of these charges is moving in the direction of an electric field.

The potential of a point charge

Any point in space around a fixed charge has an electric potential regardless of whether there is a second charge at that point or not since work had to have been done to put it there.

The potential of point (d) metres from a given charge is;

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

Potential difference (p.d.)

If work has to be done to move a charge from one point to another, the two points are at different potentials. The **change in potential** is called the **potential difference** abbreviated as **p.d.** Potential difference is also known as **voltage**.

$$V = \frac{\text{Work done to change the potential}}{\text{charge}} = \frac{\Delta W}{Q}$$

A **positive p.d.** occurs when a charge is moved **from a point of lower potential to one of higher potential**.

A **negative p.d.** occurs when a charge is moved **from a point of higher potential to one of lower potential**.



The **magnitude of potential near a positive point charge** is **high and decreases as we move away** from the positive charge.

The **magnitude of potential near a negative point charge** is **low and increases as we move away** from the negative charge.

Earth potential is the reference point and is taken as zero. For a point at a potential of 1 Volt, 1 Joule of work per Coulomb is done to move the charge from earth potential to that point.

Electric potential and electric field

Therefore;

$$V = \frac{W}{Q}$$

From previous study you know that work done (W) is the product of force (F) and distance (d)

$$V = \frac{Fd}{Q}$$

If we divide distance d on both sides of this equation, we get the result below.

$$\frac{V}{d} = \frac{F}{Q}$$

Remember that $\frac{F}{Q}$ gives us the electric field strength (E). This result directly relates electric field strength to electric potential.

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

Using the above equation, an alternative unit for electric field is volt per metre (V/m).

The equation above tells us that the magnitude of the potential of a point in an electric field depends very much on the magnitude of the electric field strength at that point.

**Example 7**

To move a charge of $3.2 \times 10^{-19} \text{C}$ between two points A and B, $1.6 \times 10^{-17} \text{J}$ of work is done. What is the potential between A and B?

Solution

$$\begin{aligned} V &= \frac{W}{Q} \\ V &= \frac{1.6 \times 10^{-17} \text{J}}{3.2 \times 10^{-19} \text{C}} \\ V &= 50 \text{JC}^{-1} \\ &= 50 \text{V} \end{aligned}$$

Example 8

Two charged parallel plates with a potential difference of 100V are located 5.0cm apart.

- (a) What is the magnitude of the electric field between the plates?

Solution

$$\begin{aligned} E &= \frac{V}{d} \\ E &= \frac{100 \text{V}}{5.0 \times 10^{-2} \text{m}} \\ E &= 2000 \text{NC}^{-1} \end{aligned}$$

- (b) How much energy is gained by a 2mC charge moving between the plates?

Solution

$$\begin{aligned} W &= QV \\ W &= 2 \times 10^{-3} \text{C} \times 100 \text{V} \\ W &= 0.2 \text{J} \end{aligned}$$

Example 9

- a) What is the potential at a point 20cm from a charge of $+1.8 \times 10^{-10} \text{C}$?
b) What is the potential 10cm away?
c) What is the potential difference between these two points?

**Solution**

$$(a) \quad V_0 = \frac{kQ}{r}$$

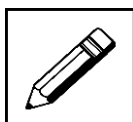
$$V_0 = \frac{9.0 \times 10^9 \times 1.8 \times 10^{-10}}{20 \times 10^{-2}} \\ = 8.1V$$

$$(b) \quad V_1 = \frac{kQ}{r}$$

$$V_1 = \frac{9.0 \times 10^9 \times 1.8 \times 10^{-10}}{10 \times 10^{-2}} \\ = 16.2V$$

$$c) \quad \text{p.d.} = V_1 - V_0 \\ = 16.2V - 8.1V \\ = 8.1V$$

Now check what you have just learnt by trying out the learning activity below!

**Learning Activity 3****20 minutes**

Answer the following questions on the spaces provided.

1. Explain in your own words what electric potential is.

2. A positive charge is brought closer to another positive charge. Explain what happens to the electric potential as both charges are brought closer together.



3. What is the difference between electric potential and potential difference?

4. The potential difference between two parallel plates is 40V. How much work is done to move a charge of 120 μ C in the direction of the electric field?

Thank you for completing learning activity 3. Now check your work. Answers are at the end of the module.

11.5.2 Current Electricity

This part of electricity seems very familiar to us all when we first begin to look at electricity. In the previous topic, we looked at electrostatics which was mainly about electric charges, their nature, type and interactions that result in forces, electric fields and electric potential.

The ideas of electric field and potential are further elaborated in this section, with the slight difference that instead of studying single point charges, we will now deal with many charges and all moving together as a quantity we know as electric current. This is the first basic idea covered in this sub-unit along with definitions of other quantities involved in electric circuits as well as electric devices.

We will also take a look at the behaviour of electric current and voltage in the two (2) main types of electrical circuits.

Basic Electrical Quantities

Electric current

Electric current is defined as the rate of movement of positive charge.

Mathematically:

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



Where **Q** is the amount of electric charge in coulombs (C), **t** is the amount of time in seconds (s) and **I** is the amount of electric current in coulombs per second (C/s) in amperes (A) or amps.

One coulomb of positive charge passes any point in a circuit when a steady current of 1 ampere flows for one second.

Example 10

If 500mC pass a given point in 5 seconds, what is the electric current?

Solution

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

$$= \frac{500\text{mC}}{5\text{s}}$$

$$= \frac{0.500\text{C}}{5\text{s}}$$

$$= 0.1\text{C/s} = 0.1\text{A}$$

Conventional current

Electric charges in current can be either negative or positive so it is often important to distinguish between them when discussing current.

Conventional current flows from high potential to low potential. In a circuit it is from the positive terminal, around the circuit to the negative terminal of the power source. **Electron flow** is the opposite.

Conventional current can be thought of as the movement of positive charges, while electron flow can be thought of as the movement of negative charges (see figure 13. below).

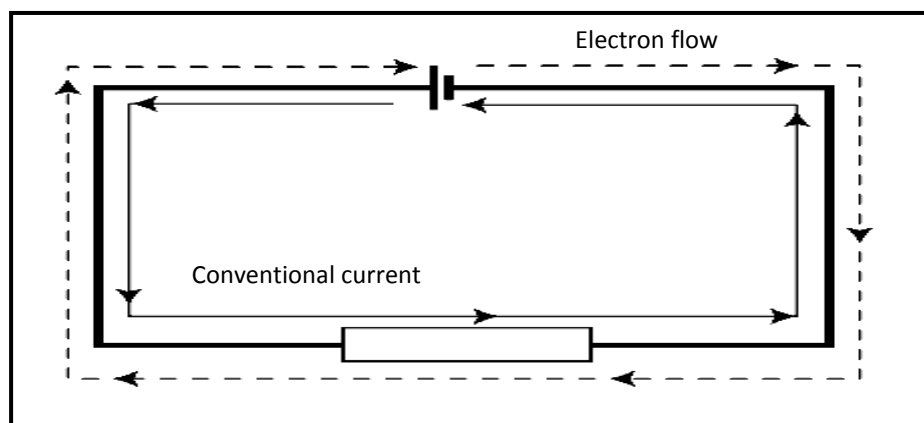


Figure 13. Arrows in the anticlockwise direction indicate the direction of conventional current. Electron flow is in the opposite direction shown by the dashed line.



From this point forward, whenever the word current is mentioned it means we are talking about conventional current.

Direct current and alternating current

In producing electricity, there are two main categories of electric current.

- i. **Direct Current (DC)** where charges are moving in one direction only.
- ii. **Alternating Current (AC)** where charges are changing direction over time. The graphs of both types are shown in figure 14.

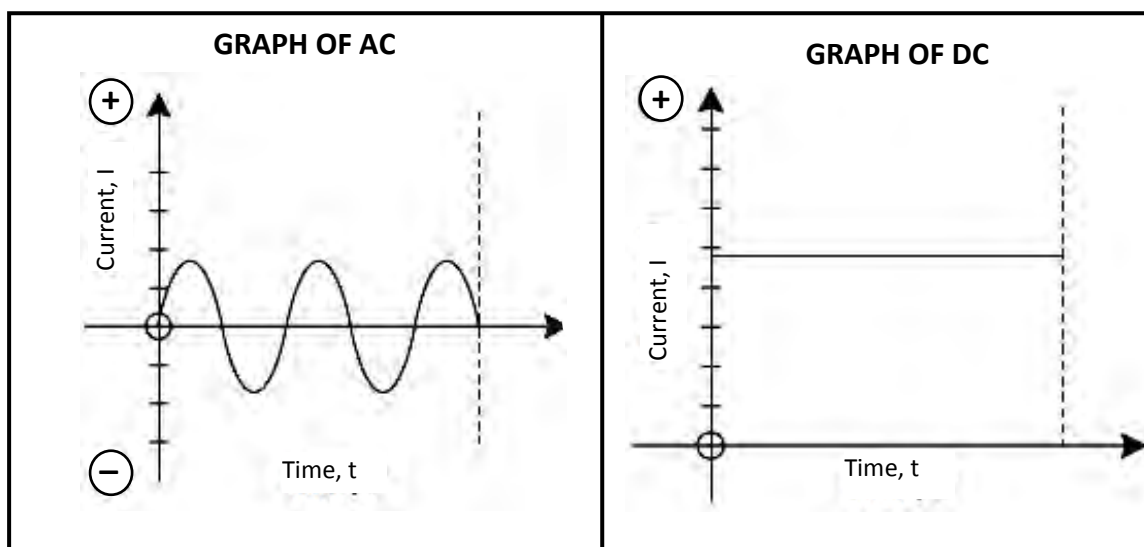


Figure 14 Graphs of AC and DC. The wave shape of AC will be explained later in this module.

In this section we will discuss direct current (DC), alternating current (AC) will be covered later in this unit.

Voltage and resistance

Other quantities that we will meet while studying electric circuits are voltage and resistance.

Voltage is also known as potential difference and is the amount of work done to move a charge from one point to another. It is measured in **Volts (V)**.

Resistance is defined as any opposition to current. Almost all materials regardless of whether they are conductors or insulators offer some resistance to current. Resistance is measured in **ohms (Ω)**.



Series & Parallel Circuits

The two main types of electrical circuits are series and parallel circuits. Circuits can be constructed in a variety of ways but almost all are represented using circuit diagrams. These diagrams use certain symbols to represent the different devices that are commonly used in circuits. Figure 15 below shows a list of symbols and their names.

BASIC CIRCUIT SYMBOLS

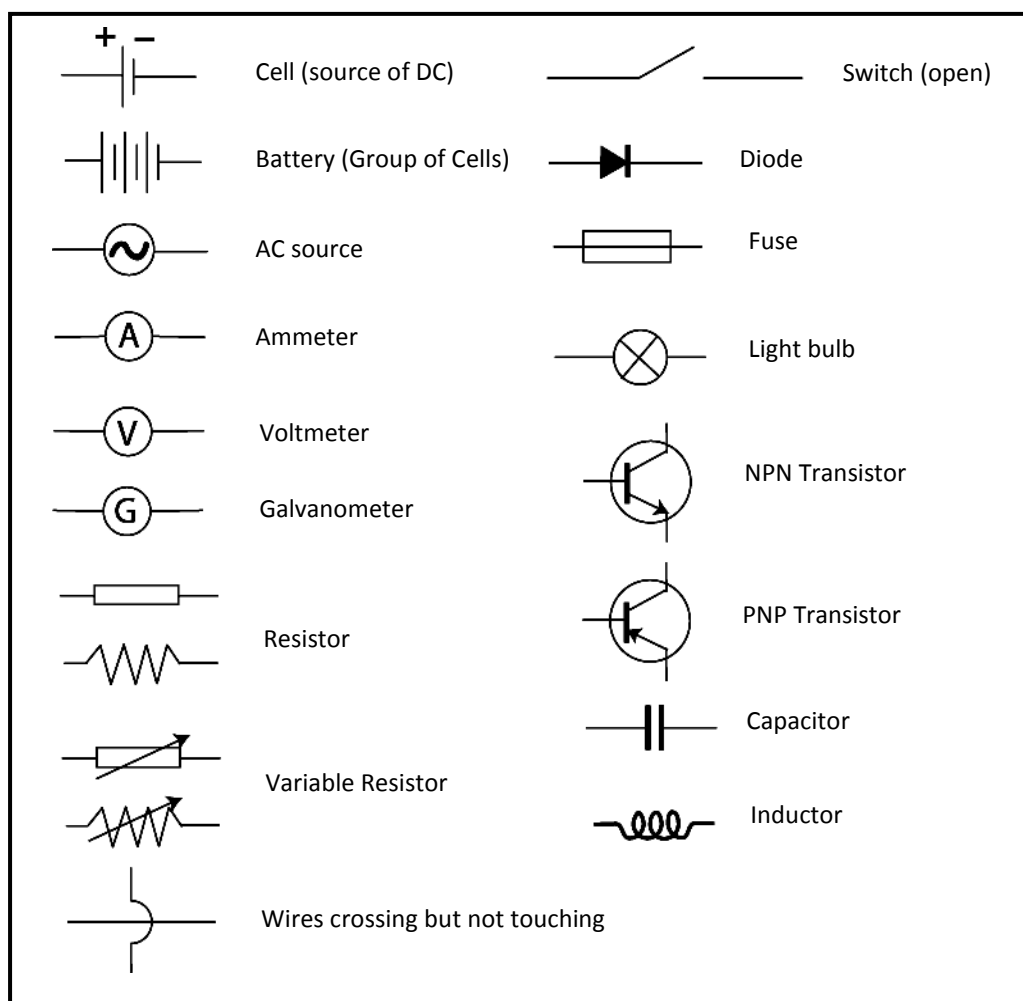


Figure 15 Some basic circuit symbols used in electrical circuit diagrams

Measuring current and voltage in a circuit

In simple electric circuits, electric current is measured using an ammeter.

Ammeters are always connected in series to the circuit components to measure the amount of current through the component. When inserting an ammeter into a circuit, we “break” the circuit.



In simple electric circuits, voltage (or p.d.) is measured using a voltmeter.

Voltmeters are always connected parallel to a circuit component to measure the voltage across the component. Voltmeters are connected across the component.

Figure 16 below shows how we insert ammeter to measure the current through a resistor and how we insert a voltmeter to measure the voltage across a resistor.

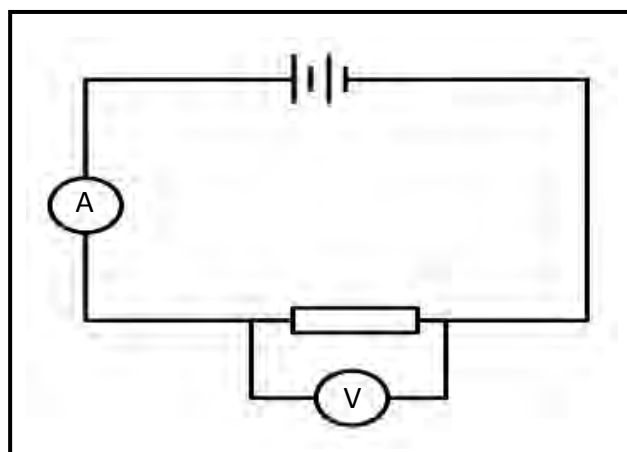


Figure 16 The correct way of connecting an ammeter and a voltmeter in a circuit.

The main difference between series and parallel circuits is that a series circuit provides only one pathway for electric current to flow, whereas a parallel circuit can offer one or more paths for current.

Compare the two circuits in figure 17 below. Suppose the same source of voltage V is used to supply a current I in both circuits, what would we observe?

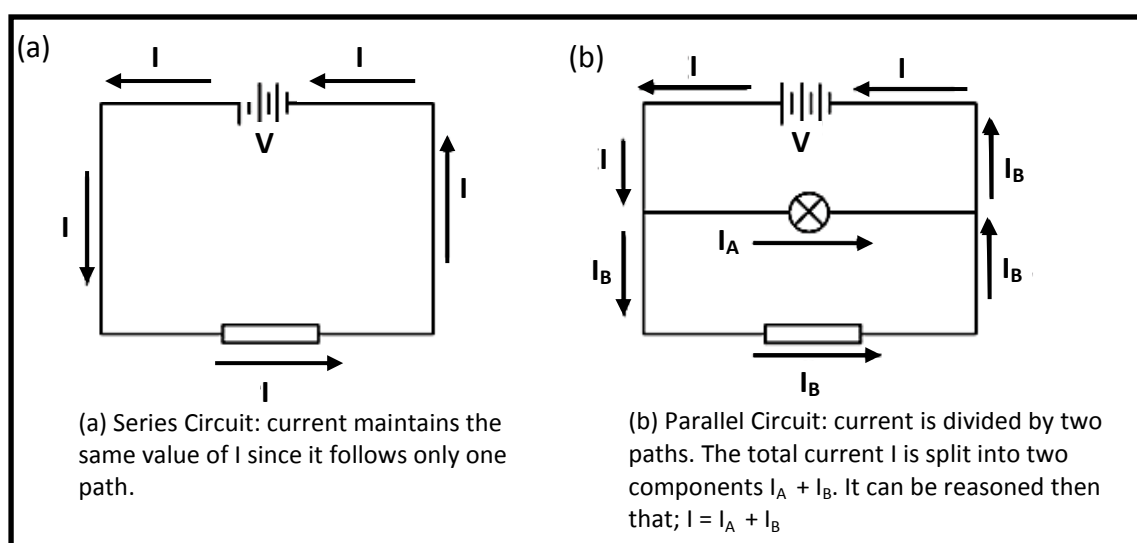


Figure 17 The behaviour of electric current in series and parallel circuits



In the series circuit, the current I will be constant at all points of the circuit. The parallel circuit however offers two pathways for I . Thus we will see that current I will divide into two components I_A and I_B .

Calculating total resistance in a series circuit

In a series circuit, **the total current is the same through all components** (resistors) which are in series. This is due to the fact that there is only one path for the current. The **potential difference is shared across each resistor**. For potential difference, the higher the resistance the higher the potential drop. We can determine the total resistance in a simple series circuit such as in figure 18 below.

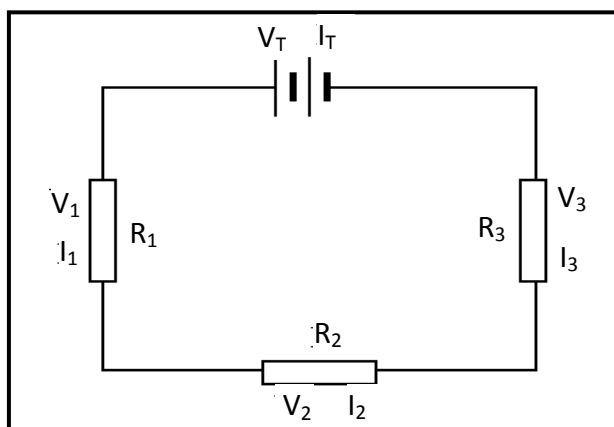


Figure 18 A simple series circuit with three (3) resistors and a source of voltage and current

If we ignore internal resistance and the resistance of the connecting wires, the following will be observed when the circuit in figure 18 is closed.

1. Total current is equal to the current passing through all resistors. That is;

$$I_T = I_1 = I_2 = I_3$$

2. Total potential difference is divided among all the resistors. That is;

$$V_T = V_1 + V_2 + V_3$$

Using this, the total resistance in the circuit is determined as follows using Ohm's Law;

$$V_T = I_1 R_1 + I_2 R_2 + I_3 R_3$$

Since the amount of current flowing in each resistor is the same as the total current in the circuit, we can replace I_1 , I_2 and I_3 in the equation above with I_T and divide both left and right hand side of the equation by I_T leaving only the resistance values on the right hand side.

$$V_T = I_T R_1 + I_T R_2 + I_T R_3$$

$$V_T = I_T (R_1 + R_2 + R_3)$$



$$\frac{V_T}{I_T} = R_1 + R_2 + R_3$$

Using Ohm's Law we know that $R = \frac{V}{I}$ thus the total resistance in a series circuit is calculated as follows;

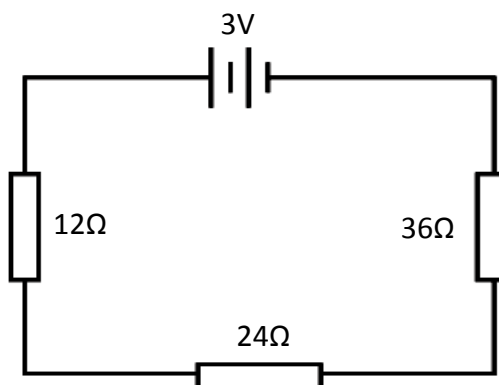
$$R_T = R_1 + R_2 + R_3$$

This equation gives us the total resistance in a circuit that consists of three resistors in series.

In general the total resistance in a circuit with n resistors in series is
 $R_T = R_1 + R_2 + R_3 \dots + R_n$

Example 11

Study the circuit on the below and answer the following questions.



- (a) What is the total resistance in this circuit?

Solution

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ R_T &= 12\Omega + 24\Omega + 36\Omega \\ R_T &= 72\Omega \end{aligned}$$

- (b) What is the total current in this circuit?

Solution

$$\begin{aligned} I_T &= \frac{V_T}{R_T} \\ I_T &= \frac{3V}{72\Omega} \\ I_T &= 0.042A \end{aligned}$$

- (c) What is the p.d. across the 12Ω resistor?

**Solution**

$$V_3 = I_3 R_3$$

$$V_3 = 0.042\text{A} \times 12\Omega = 0.5\text{V}$$

Calculating total resistance in a parallel circuit

In a parallel circuit, the total potential difference is the same through all components in parallel, while the current is shared according to resistance. In a parallel branch a lower current will be expected where there is a higher resistance.

The total resistance in a parallel circuit can be determined in a simple parallel circuit such as that shown in figure 19 below.

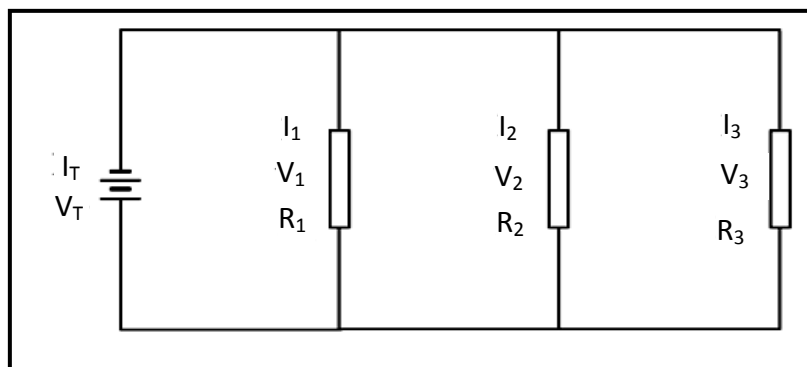


Figure 19 A simple parallel circuit with three (3) resistors and a supply of current and voltage.

If we ignore internal resistance and the resistance of the connecting wires, the following will be observed when the circuit in figure 16 is closed;

1. Total current is divided among the resistors in parallel. That is;

$$I_T = I_1 + I_2 + I_3$$

2. Total potential difference is equal to the potential difference across each parallel resistor. That is;

$$V_T = V_1 = V_2 = V_3$$

Using the fact that current is divided, the total resistance for resistors in parallel is;

$$I_T = \frac{V_T}{R_T}$$

$$I_T = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

Since voltage is the same in all resistors $V_T = V_1 = V_2 = V_3$, this gives us



$$I_T = \frac{V_T}{R_1} + \frac{V_T}{R_2} + \frac{V_T}{R_3}$$

$$I_T = V_T \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

Getting V_T as a common factor, we then divide both sides of the equation by V_T to get

$$\frac{I_T}{V_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Note that $\frac{I_T}{V_T}$ is the same as the **reciprocal** of R_T , therefore;

$$\frac{I}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

In a circuit where three (3) resistors R_1 , R_2 and R_3 are parallel, the total resistance can be determined from the reciprocal of the sum below.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

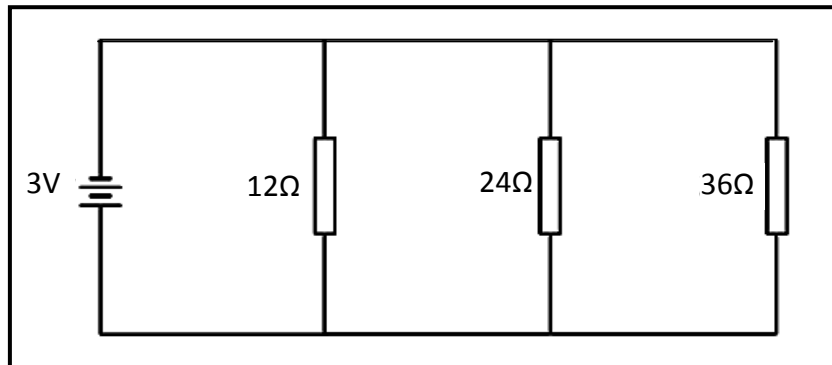
In general, for an electric circuit where there are n resistors parallel to each other

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

Example 12



Study the following circuit and answer the questions that follow.



- (a) What is the total resistance in this circuit?

Solution

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{12} + \frac{1}{24} + \frac{1}{36}$$

$$\frac{1}{R_T} = \frac{6 + 3 + 2}{72}$$

$$\frac{1}{R_T} = \frac{11}{72}$$

$$\therefore R_T = \frac{72}{11} \Omega = 6.55 \Omega$$

NOTE: When calculating total resistance in a parallel circuit using the formula, never forget to take the reciprocal of your answer as the total resistance!

- (b) What is the total current in this circuit?

**Solution**

$$I_T = \frac{V_T}{R_T}$$

$$I_T = 3V \div \frac{72}{11}$$

$$I_T = \frac{11}{24} A = 0.46A$$

- (c) How much current passes through the 12Ω resistor?

Solution

$$I_1 = \frac{V_1}{R_1}$$

$$I_1 = \frac{3V}{12\Omega}$$

$$I_1 = 0.25A$$

Potential drop and potential dividers

Potential drop across a resistor is simply a phrase that describes the use of p.d. in a series circuit by a resistor. P.d. can be thought of as energy that a charge possesses. This energy is used as the charge passes through the resistor. Kirchhoff's junction rule which will be explained in the next section will add further clarity.

Since resistors use up p.d., we can also use resistors in series to manage the amount of p.d. in the circuit. Resistors used in this way are called **potential dividers**.

As we learned earlier, the p.d. in a series circuit is shared among the resistors in a circuit. Suppose we have a circuit which has a voltage source of 6V and we wish to use a device in the circuit that will require 3V. Of course we could replace the 6V voltage source with one that is 3V, but in the case that we don't have one of those, then what?

We could insert a resistor in series such that it uses 3V and leaves the other 3V for our device. Have a look at the example on the next page.

**Example 13**

An electric circuit contains a supply voltage of 16V. A device is to be inserted into the circuit which uses 4V of p.d. and 0.5A of current. What is the value of the resistor that should be inserted in series so as to ensure that the right voltage is supplied across the device?

Solution

Since the circuit is series, the total current and voltage are as follows;

$$V_T = 16V, I_T = 0.5A$$

We can find the total resistance using Ohm's Law and the information above.

$$R_T = \frac{V_T}{I_T}$$

$$R_T = \frac{16V}{0.5A} = 32\Omega$$

The resistance of the device R_D can also be found using Ohm's Law.

$$R_D = \frac{V_D}{I_D}$$

$$R_D = \frac{4V}{0.5A} = 8\Omega$$

It follows here that the total resistance can be determined using the following equation;

$$R_T = R_D + R_x$$

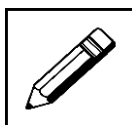
Where R_x is the unknown resistance. Thus;

$$R_x = R_T - R_D$$

$$R_x = 32\Omega - 8\Omega = 24\Omega$$

Therefore, to ensure that a p.d. of 4V is supplied to the device, a resistor of 24Ω should be inserted in series.

Now check what you have just learnt by trying out the learning activity on the next page!

**Learning Activity 4****40 minutes**

Answer the following questions on the spaces provided.

1. How much current flows through a conductor if the amount of charge that passes every 0.25 seconds is

- a) 3C? _____
- b) 1.5C? _____
- c) 250mC? _____
- d) 20mC? _____

2. For a current of 500mA that flows through a conductor, how much charge passes each point after

- a) 1s? _____
- b) 16s? _____
- c) 0.25s? _____
- d) 1.8s? _____

3. 16J of work is required to move a charge of 0.4C through a circuit device. Calculate the p.d. across the device.

4. The p.d. across a circuit is 12V.

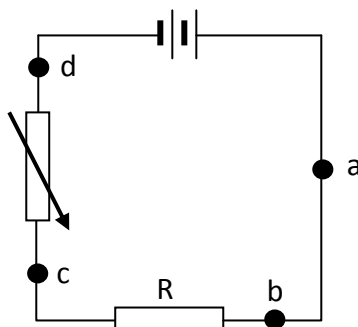
- a) How much work would need to be done to move 0.05C of charge around the circuit?
- b) What is the electric current if this is done in 0.25 seconds?



5. What is an ammeter used for? How can it be connected to make a measurement for a circuit component?

6. What is a voltmeter used for? How can it be connected to make a measurement for a circuit component?

Study the circuit below to answer Question 7.



7. The circuit above contains a voltage source, a variable resistor and a resistor. Four (4) points a, b, c and d are marked in the circuit.

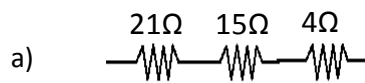
- a) Which points a, b, c or d could an ammeter be placed to measure the current through R?

- b) At which two pairs of points could the terminals of a voltmeter be placed to measure voltage across R?

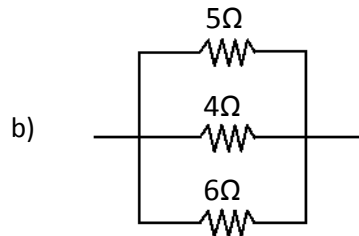
- c) The variable resistor that is used in this circuit is called a **potential divider**. Based on this name, explain its purpose in this circuit.



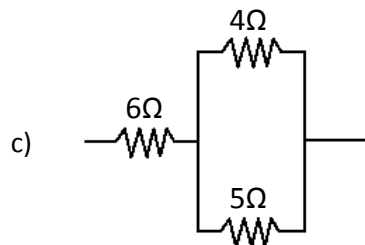
8. Calculate the total resistance for the following combinations of resistors.



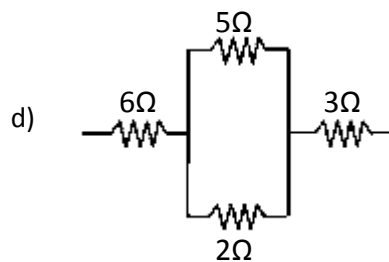
a) _____



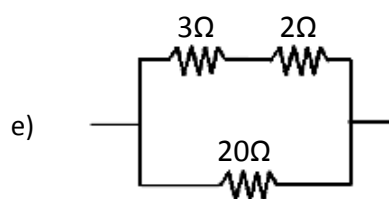
b) _____



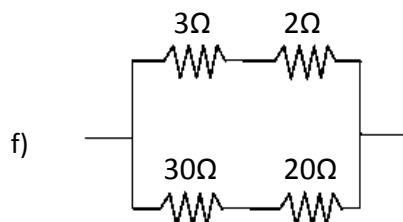
c) _____



d) _____



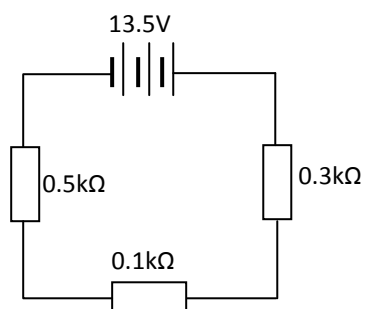
e) _____



f) _____



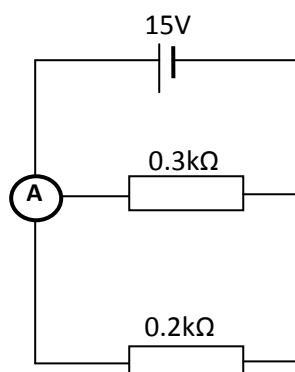
9. Study the following series circuit below and answer the questions that follow.



- a) Find the total resistance.
- b) Find the total current.
- c) Find the current and the p.d. across each of the resistors.



10. Study the parallel circuit below and answer the questions that follow.



- a) Find the total resistance.

- b) What would be the current reading on the ammeter?

- c) Find the p.d. and current across each of the resistors.

Thank you for completing learning activity 4. Now check your work. Answers are at the end of the module.



Electromotive Force and Internal Resistance

Voltage (V) is the potential difference between two ends of a conductor. It is defined as work done (**W**) per unit charge (**Q**).

$$V = \frac{W}{Q}$$

Electromotive force (emf) denoted by ϵ is the potential difference across the terminals of a cell when it is not supplying a current.

A **cell** provides an emf by chemical reaction. The term **battery**, refers to the set of two or more cells connected together in a circuit.

Internal resistance of emf sources

When a cell is connected across a voltmeter, the reading that appears is the emf (ϵ) of the cell. If we add a resistance into the circuit, we find that the voltmeter reading decreases from ϵ to **V**. **When the circuit is closed the total p.d. across the circuit is almost always less than the emf due to internal resistance r .** This is due to the fact that the internal resistance is a property of the cells providing voltage in the circuit. The internal resistance always causes a potential drop as charges move through a cell. This decrease in potential is due to the fact that a potential difference is needed to drive the current through the cell itself.

$$V = \epsilon - Ir$$

In the equation above **V** is known as the **terminal voltage** and is defined as the highest p.d. that can be reached in a circuit with internal resistance **r**. When the circuit is open, **V** is equal to the **emf (ϵ)** of the cell.

Note: In most cases that we will deal with, the internal resistance will be neglected unless stated otherwise.

Example 14

Before being connected in a circuit, the emf of a certain dry cell is measured and found to be 4.5V. When it is connected to the circuit, it supplies a current of 0.75A, but the voltage reading across the dry cells terminals read 4.25V.

Using this information determine; (a) the terminal voltage and (b) the internal resistance of the dry cell when it is supplying current in this circuit.

Solution

- (a) the terminal voltage is 4.25V when the circuit is switched on.
- (b) the internal resistance of the dry cell can be determined by rearranging the equation above.



$$r = \frac{\epsilon - V}{I}$$

$$r = \frac{4.5V - 4.25V}{0.75A} = 0.33\Omega$$

Combinations of cells

When cells are connected together so that the positive terminals are directly connected to negative terminals, it is called a **series connection**. The total emf in a series connection is the sum of the emfs of each cell. Such a connection leads to a higher internal resistance because resistance in series accumulates. Figure 20 below shows such an arrangement.

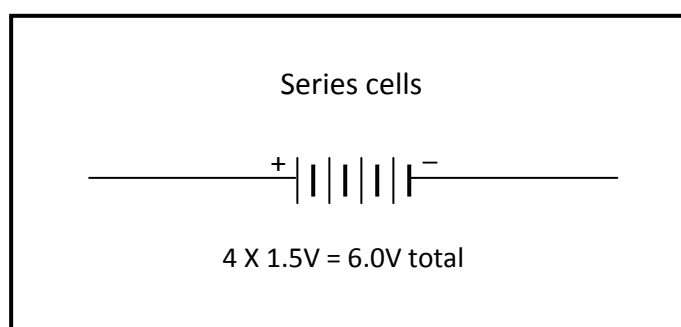


Figure 20 Three (3) cells with 1.5V each when combined in series supply a total of 6V but with a low current due to the increase of internal resistance.

Individual cells may also be connected together so that all positive electrodes are connected together and all negative electrodes are also connected together. This is called a **parallel connection**. In such a connection, the total emf is the same as each individual cell. In this connection the battery cannot supply more energy to each electron, but reduces the overall internal resistance which results in a greater current flow in any external circuit.

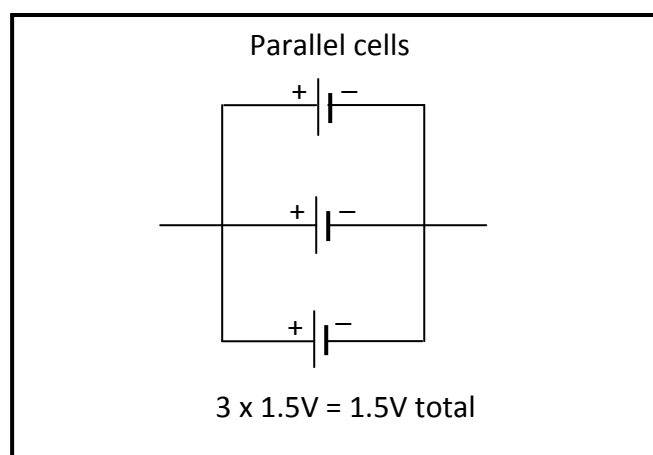
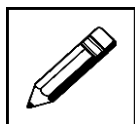


Figure 21 Three (3) cells each with an emf of 1.5V when combined in parallel supply 1.5V with a higher current due to the reduction of internal resistance.

Now check what you have just learnt by trying out the learning activity on the next page!

**Learning Activity 5****20 minutes**

Answer the following questions on the spaces provided.

1. Explain the difference between emf and terminal voltage.

2. What is the difference between a cell and a battery?

3. A 12V battery (i.e. collection of cells) has a terminal voltage of 11.64V when supplying a current of 1.2A. Find the internal resistance of the battery.

4. A 6.0V dry cell with an internal resistance of 0.16Ω is used in a circuit. When the circuit is closed the terminal voltage supplied is 5.8V. How much current does the circuit require?

Thank you for completing learning activity 5. Now check your work. Answers are at the end of the module.



11.5.3 Resistance

We had a brief look at the resistance as a physical quantity in the previous topic along with its unit the ohm (Ω). In this section we look at resistance in a bit more detail.

We begin by revisiting Ohm's law which is familiar to most of you since it was introduced in unit 9.6 in Grade 9 Science. The main emphasis of Ohm's law in grade 9 was for calculating resistance, voltage and current. Here we have a more specific look at the relationship between these three quantities and most especially with the view of manipulating the quantities. For instance, you will find that we can control the amount of current and voltage by using different resistances especially in cases where an exact amount of current or voltage is required for the operation of a device. Ohm's law is one of the basic laws of electricity that must be mastered.

We will also look at the Resistance itself as a quantity. Although voltage and current can be used to determine resistance, it can also be determined by other factors as we will see in this sub-topic.

Electrical energy and power are also discussed in this unit. These quantities are closely related to resistance. We shall see how these quantities also relate to current and voltage and especially their applications in the use of electrical devices.

The final part of this topic is reserved for Kirchhoff's rules which is the best way to account for the voltage and current rules in series and parallel circuits. This topic will also help explain the ideas of electric current and potential difference in series and parallel circuits.

Ohm's Law

Ohm's law gives us a relationship between voltage (potential difference, **V**), current (**I**) and resistance (**R**). It states that the current passing through a metallic conductor is directly proportional to the potential difference across its ends, provided the physical conditions (such as temperature) are constant. Mathematically it is written as follows;

$$R = \frac{V}{I}$$

Suppose we get two different types of resistors and measure the amount of current through them at different potential differences, we obtain a table as shown below.

Potential Difference (V)	0	2	4	6	8
Current (A) in P	0	0.3	0.6	0.9	1.2
Current (A) in Q	0	0.1	0.5	1.6	2.5

Table 1 Current measurements for two different resistors at various voltages.

When a graph of voltage against current is plotted (such as in figure 22), we can see the relationship between voltage and current.

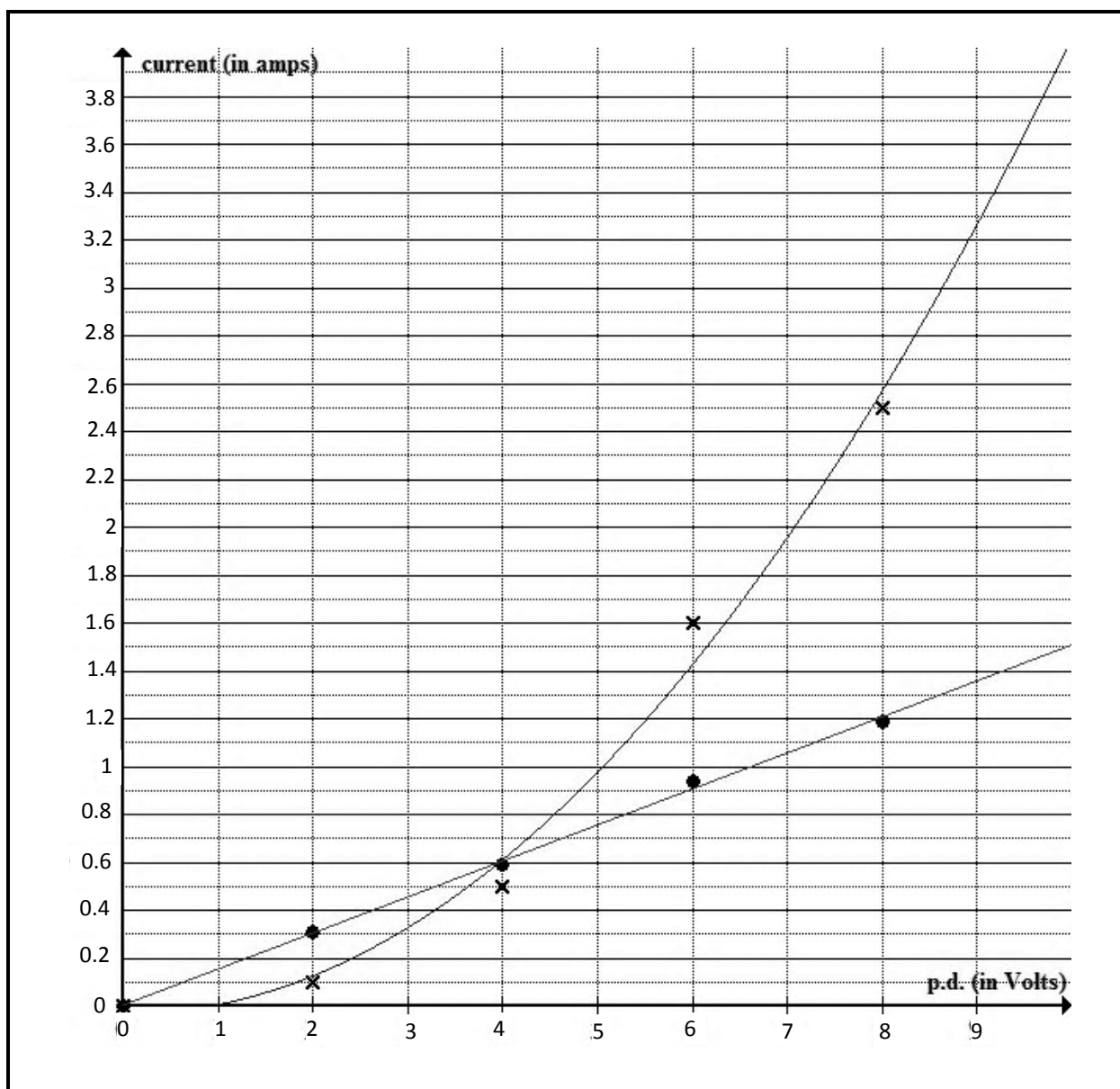


Figure 22 Graph of voltage versus current. The curved line represents the resistance of a resistor that does not follow Ohm's law. The straight line indicates a typical result from a resistor that follows Ohm's law.

All materials whether they are conductors or insulators have some resistance. We classify materials into two groups according to how they follow Ohm's law.

Any material that follows ohm's law is called an **ohmic resistor**. The graph of an ohmic resistor will look similar to the graph shown as a straight line. The resistance in an ohmic resistor can be calculated by plotting points on a voltage-current graph and calculating the gradient of the straight line that is obtained.

Any material that does not follow ohm's law is called a **non-ohmic resistor**. The voltage-current graph of a non-ohmic conductor will look like that of the curved line.

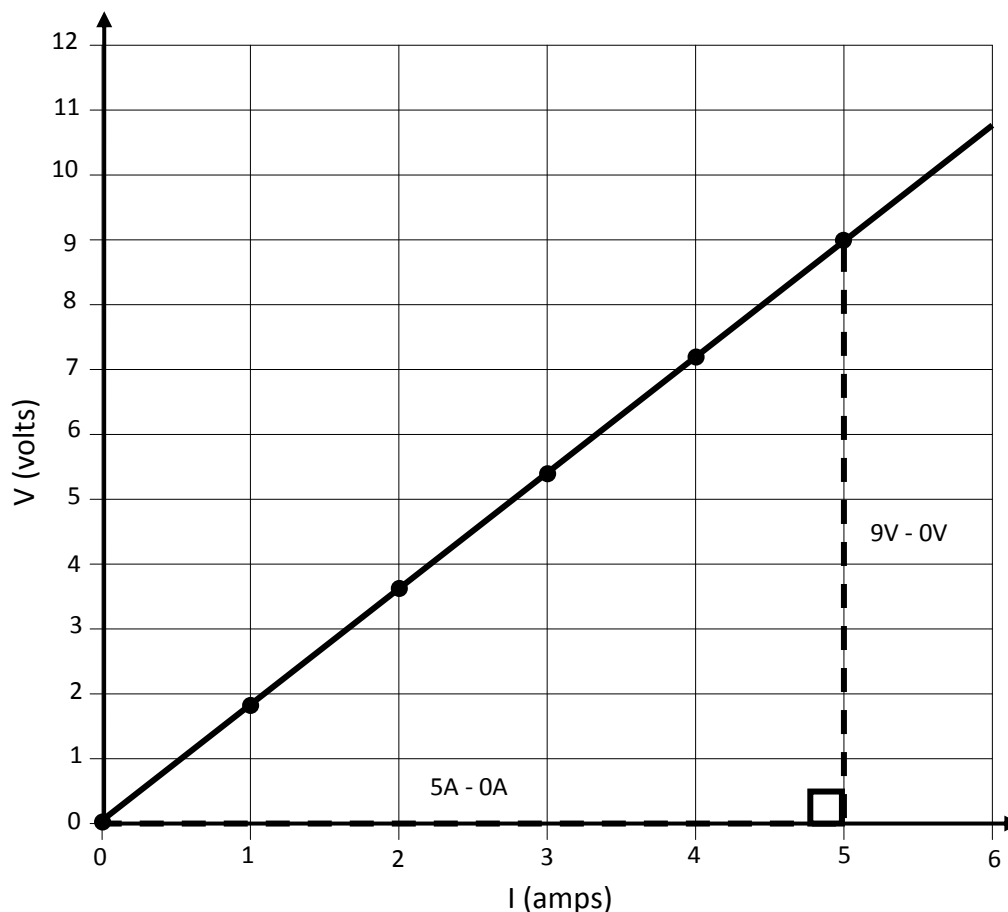


We can use Ohm's law to determine current, voltage or resistance as shown in the examples below.

Example 15

The graph below shows the V-I relationship of an ohmic conductor at a constant temperature. Calculate the resistance of the conductor.

GRAPH SHOWING V-I RELATIONSHIP OF AN OHMIC CONDUCTOR

**Solution**

Choose any two points on the graph. It is always best to choose points which can allow us to read values directly from the axes. In this case we should choose (0,0) and (5,9).

To find the resistance, let's calculate the gradient using these two points.

$$\text{Gradient} = \frac{\text{rise}}{\text{run}} = \frac{V_2 - V_1}{I_2 - I_1} = \frac{9 - 0}{5 - 0} = \frac{9}{5} = 1.8\Omega$$

Therefore the resistance of the ohmic conductor is 1.8Ω .

**Example 16**

A resistor has p.d. of 5V across it and a current of 8mA passing through it. What is its resistance?

Solution

$$R = \frac{V}{I}$$

$$R = \frac{5V}{0.008A} = 625\Omega$$

Example 17

Calculate the p.d. across a resistor of 1.2k Ω when current of 30mA passes through it.

Solution

$$V = IR$$

$$V = 0.030A \times 1200\Omega = 36V$$

Resistivity and Factors That Affect Resistance

Although all conductors offer some resistance to a flow of current, there are several factors that cause the resistance of a conductor to vary in value. These factors are;

Length of the conductor

In general, the longer a wire is, the more resistance it offers to electric current.

This can be explained as follows; a longer wire means that charges have to travel a long distance. In doing so, they require and use more energy to do this.

The thickness or cross-sectional area of the conductor

Generally, thin wires provide more resistance than thick wires. In thin wires, the flow of charges is restricted due to limited space causing frequent collisions between charges and other atoms.

The type of substance the conductor is made of

Some substances naturally offer less resistance than others. Silver is most possibly the best conductor of electricity but is too expensive and rare to be used extensively in electric circuits. On the other hand, aluminium and copper are relatively more abundant but are not as efficient as silver at conducting electricity.

The temperature of the conductor

For metallic substances, resistance increases as temperature increases. At higher temperatures, atoms and charges tend to move more randomly and more quickly. As this happens more collisions occur within the metal at the atomic level. This causes little chance for charges to be conducted.



The resistance, R (in ohms), of a conductor varies proportionally with the length, L , and is inversely proportional to the cross-sectional area, A (in square metres), of the conductor. For a conductor of length L (in metres) with a cross-sectional area A (in square metres) at a constant temperature, the resistance R (in ohms) is given by the mathematical relationship below.

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

The Greek letter ρ (pronounced “rho”) stands for a constant called **resistivity**. The resistivity of a substance is unique for each substance. The SI unit for resistivity is Ohm-metre ($\Omega \cdot \text{m}$).

The Table below shows the resistivities of some common metals at 20°C.

Metal	Resistivity ($\Omega \cdot \text{m}$)	Metal	Resistivity ($\Omega \cdot \text{m}$)
Silver	1.59×10^{-8}	Aluminium	2.8×10^{-8}
Copper	1.7×10^{-8}	Tungsten	5.6×10^{-8}
Iron	10×10^{-8}	Nichrome	1.5×10^{-6}

Table 1 Resistivity of some common metals at 20 degrees celsius

We can use this relationship to determine the resistance of a conductor when the temperature is constant such as in the example below.

Example 18

What is the resistance of a 20m length of nichrome wire with a cross-sectional area of 0.01 cm^2 ? ($\rho = 1.5 \times 10^{-6} \Omega \cdot \text{m}$)

Solution

$$\begin{aligned} R &= \rho \frac{L}{A} \\ R &= 1.5 \times 10^{-6} \Omega \cdot \text{m} \times \frac{20 \text{ m}}{0.01 \times 10^{-4} \text{ m}^2} \\ R &= 30 \Omega \end{aligned}$$

**Example 19**

A length of copper wire has a resistance of 0.8Ω at 20°C . If the length is determined to be 1.64m and the wire is cylindrical, what is its approximate diameter of the wire in millimeters (mm)? ($\rho = 1.7 \times 10^{-8} \Omega\cdot\text{m}$)

Solution

Note: A cylinder has a circle as its cross-sectional area, we can use the formula for area of a circle to determine the diameter of the wire.

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

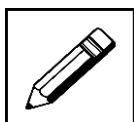
$$A = 1.7 \times 10^{-8} \Omega\cdot\text{m} \times \frac{1.64\text{m}}{0.8\Omega}$$

Now we use the area **A** to find the diameter **d** of the wire.

$$A = \frac{\pi d^2}{4}$$

$$d = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 0.0349\text{mm}^2}{3.14}} = 0.21\text{mm}$$

Now check what you have just learnt by trying out the learning activity on the next page!

**Learning Activity 6****20 minutes**

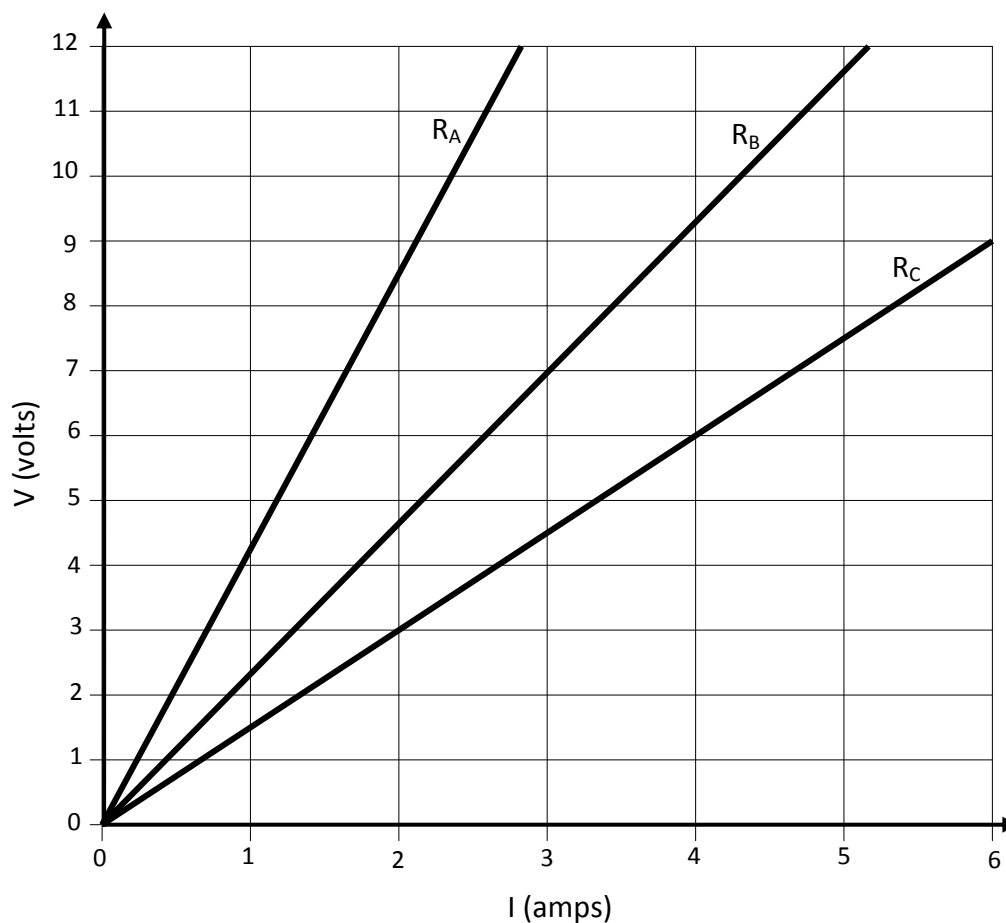
Answer the following questions on the spaces provided.

1. What is the main difference between ohmic and non-ohmic resistors?



2. Jacob experimented with three different resistors R_A , R_B and R_C . For each resistor, he used an ammeter to measure the voltage at various values of current and plotted the results on the graph that is shown below.

GRAPH SHOWING V-I RELATIONSHIP OF AN OMIC CONDUCTOR



- (a) Rank the three resistors in terms of resistance from the smallest to the largest.
- _____
- (b) Without doing any calculations explain your answer to (a).
- _____
- _____
- (c) Calculate the resistance of each of the three resistors.



3. At a constant temperature, the current measured through a resistor is 0.085A. If the p.d. across the resistor is 17V, what is the resistance in $k\Omega$?

-
4. For a resistor of $150k\Omega$, how much current would pass through it when a p.d. of 12V is applied across its ends?

Thank you for completing learning activity 6. Now check your work. Answers are at the end of the module.

Electrical Energy and Power

Electrical Energy

When a source of emf such as a dry cell is placed in a closed circuit, it sets up an electric field in the connecting wires, where one end (positive terminal) has a high electrical potential and the other end (negative terminal) has a low electrical potential. It is the existence of the different potentials that cause electric charges to move in the form of current.



As we saw earlier in electric potential, any movement of a charge in an electric field requires work to be done. So in order for charges to form an electric current, they must possess some energy. This energy is given by the equation;

$$W = QV$$

Where **W** is the energy in joules (J), **Q** is the amount of charge in coulombs (C) and **V** is the electric potential volts (V).

This equation can also give us the amount of energy used in a circuit if we also include the fact that electric charge is related to current and time in the equation;

$$Q = It$$

Where **Q** is the electric charge in coulombs (C), **I** is the current in amperes (A) and **t** is the time in seconds (s). Substituting this into the first equation gives the following;

$$W = VIt$$

This equation gives us the amount of energy used by the operation of a circuit with a voltage **V**, current **I** after some time **t**. See the example below.

Example 20

A certain electric circuit uses 0.75A and has a total voltage supply of 12V. Calculate the amount of energy used in the operation of this circuit for 300s.

Solution

$$W = VIt$$

$$W = 12V \times 0.75A \times 300s$$

$$W = 2700J$$

Note: The symbol for energy used here is W. We can also use E as the symbol for energy.

**Power**

Rearranging the equation for energy we can also come up with another useful quantity in electricity called **power**. You may recall power from unit 11.4 as the rate at which work is done or the rate at which energy is used. This concept is useful in electricity because it gives us a way of measuring how energy is used in a circuit. The SI unit used for power is the **Watt (W)**.

The electrical power (**P**) of a circuit device is related to current (**I**) and voltage (**V**) by the equation below.

$$\text{Power (P)} = \frac{W}{t} = VI$$

Most electrical devices and components use electrical energy or change electrical energy into other forms of energy. They are always given a power rating in watts (and often in kilowatts) to indicate the amount of energy used for each second of operation.

We can also use power ratings to calculate voltage, current and resistance in a circuit. This can be achieved by combining the equation for power with Ohm's Law.

The equations that result are as follows;

If we substitute $V = IR$ into $P = VI$, we eliminate V and get an equation of power in terms of current and resistance. That is;

$$P = I^2R$$

If we substitute $I = \frac{V}{R}$ into $P = VI$, we eliminate I and get an equation of power in terms of voltage and resistance. That is;

$$P = \frac{V^2}{R}$$

Below are some examples of calculations involving power.

Example 21

A light bulb has a power rating of 60W. If it is connected to a 240V source of electricity, how much current does it draw?

Solution

$$I = \frac{P}{V}$$

$$I = \frac{60W}{240V} = 0.25A$$

**Example 22**

A 150Ω resistor draws a current of 0.4A . How much energy does it consume every second?

Solution

Power is the amount of energy consumed per second.

$$P = I^2 R$$

$$P = (0.4\text{A})^2 \times 150\Omega$$

$$P = 24\text{W}$$

Example 23

A small radio has a power rating of 50W . If it operates from a 12V , find the:

- (a) amount of current that it draws at full power.
- (b) total resistance of the radio.
- (c) amount of energy it uses after 4 hours of continuous use at full power.

Solution

$$(a) \quad I = \frac{P}{V} = \frac{50\text{W}}{12\text{V}} = 4.17\text{A}$$

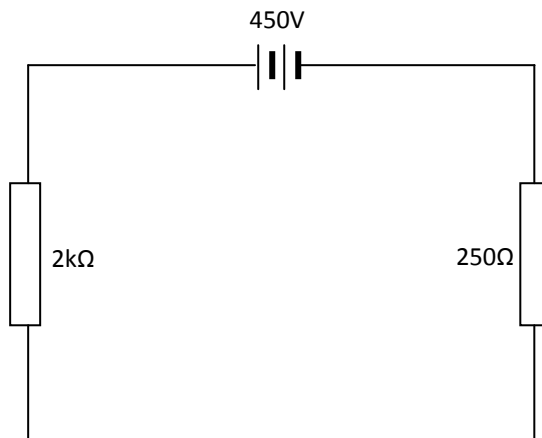
$$(b) \quad R = \frac{P}{I^2} = \frac{50}{(4.17\text{A})^2} = 2.88\Omega$$

$$(c) \quad 4 \text{ hours} = 4\text{hr} \times \frac{3600\text{s}}{\text{hr}} = 14400\text{s}$$

$$\begin{aligned} \text{Energy used is } W &= Pt \\ &= 50\text{W} \times 14400\text{s} \\ &= 720000\text{J} \\ &= 720\text{kJ} \end{aligned}$$

**Example 24**

In the circuit below, determine (a) the current through each resistor, (b) the power dissipated by each resistor and (c) the total power dissipated by the circuit.

**Solution**

- (a) Since this is a series circuit, we must find the total current since each resistor will receive the same amount of current.

Total resistance in this circuit:

$$R_T = 2\text{k}\Omega + 250\Omega$$
$$R_T = 2000\Omega + 250\Omega = 2250\Omega$$

Total current in this circuit is

$$I_T = \frac{V_T}{R_T}$$
$$I_T = \frac{450\text{V}}{2250\Omega} = 0.2\text{A}$$

- (b) We can now work out the power dissipated by each resistor.
In the $2\text{k}\Omega$ resistor, the power dissipated is

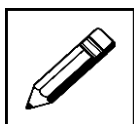
$$P = I^2 R$$
$$P = 0.2^2 \times 2000\Omega = 80\text{W}$$

In the 250Ω resistor, the power dissipated is

$$P = I^2 R$$
$$P = 0.2^2 \times 250\Omega = 10\text{W}$$

- (c) The total power dissipated is $80\text{W} + 10\text{W} = 90\text{W}$

Now check what you have just learnt by trying out the learning activity on the next page!

**Learning Activity 7****20 minutes**

Answer the following questions on the spaces provided.

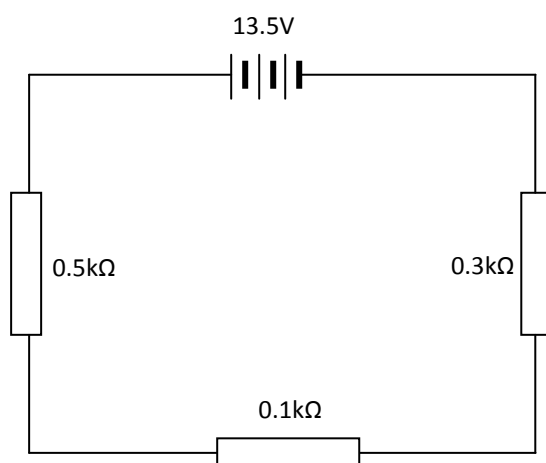
1. An electric kettle is rated at 1.44kW. It uses a voltage of 240V to boil water.

(a) How much energy does the kettle use in one minute of operation?

(b) How much current does the kettle draw when at full power?

(c) What is the resistance of the kettle?

2. Study the following electric circuit and answer the questions that follow.



(a) What is the amount of current passing through each resistor?



(b) Calculate the power dissipated by each of the resistors.

(c) Calculate the total power dissipated by the circuit.

Thank you for completing learning activity 7. Now check your work. Answers are at the end of the module.

Kirchhoff's Rules

Kirchhoff's rules are simple but powerful statements that can help us to mathematically analyse all types of electrical circuits from simple to complex. Let us look at each rule in turn and what they mean.

Kirchhoff's Junction Rule

The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction.

Kirchhoff's first rule is a statement of conservation of electric charge. It tells us that all current that enters a given point in a circuit must leave that point because charge cannot build up at a point.

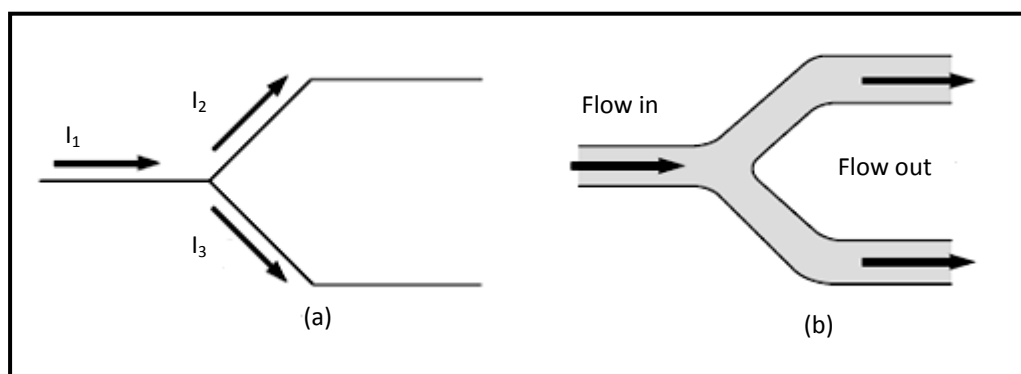


Figure 23 (a) the splitting of electric current as it enters a junction. (b) A similar idea applies when water flows into a junction. For both cases (a) and (b) the amount of current and water entering the junction is equal that the amount that is leaving the junction.

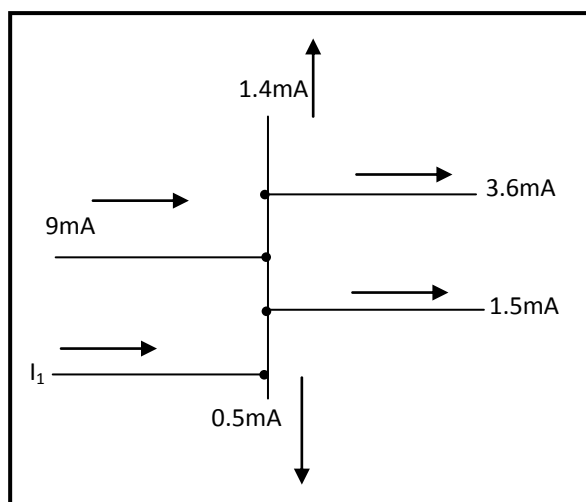


In figure 23(a), I_1 is flowing into the junction, while I_2 and I_3 are leaving the junction. Therefore according to Kirchhoff's junction rule $I_1 = I_2 + I_3$

The following example further illustrates Kirchhoff's junction rule. It is important to know that we will be using a few mathematical techniques especially algebra to help us describe the physics of Kirchhoff's junction rule.

Example 25

Find the current I_1 in the diagram below.



Solution

We use the junction rule to determine I_1 . As the diagram shows, there are two currents entering and 4 currents leaving. Thus the junction equation is;

Current entering the junction = Current leaving the junction

$$9\text{mA} + I_1 = 1.4\text{mA} + 3.6\text{mA} + 1.5\text{mA} + 0.5\text{mA}$$

$$\therefore I_1 = 6.9\text{mA} - 9\text{mA}$$

$$= -2.1\text{mA}$$

The negative sign tells us that the current shown is moving in the opposite direction to that shown. Thus I_1 is actually leaving, not entering!

Kirchhoff's Loop Rule

Kirchhoff's second rule follows from the law of conservation of energy. It is called the loop rule and is stated as follows;

The sum of the potential differences across all elements around any closed circuit loop must be zero.

This rule can be best explained using the circuit shown in figure 24. The circuit consist of a single loop **abcde**.

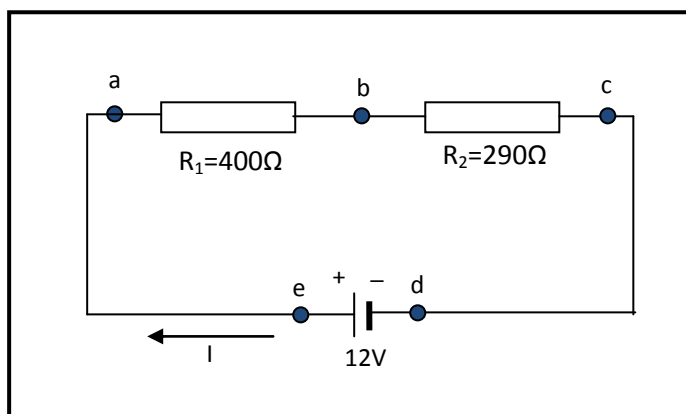


Figure 24 A simple series circuit with a supply emf of 12V and two resistors. Kirchhoff's loop rule is used to describe how energy is consumed in such a circuit.

If we plot a graph to illustrate the electric potential energy changes around the circuit at the different points it would look something like this;

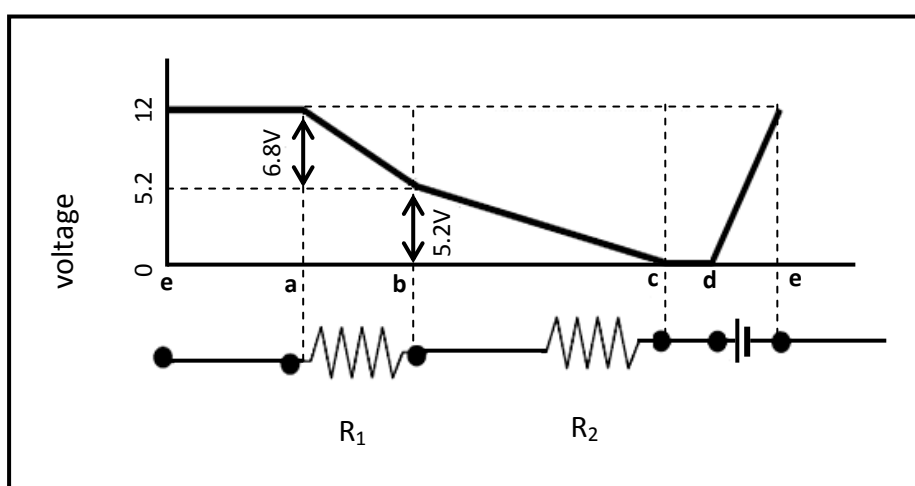


Figure 25. A graph showing the changes in potential difference at different points in the circuit

A graph showing the changes in potential difference at different points in the circuit such as the one shown on the previous page are sometimes called "**hill diagrams**".

If we follow the direction of conventional current (clockwise) as shown, the graph in figure 25 could be explained as follows;

From **e** to **a**, each coulomb of charge in this circuit has 12J of energy. Between points **a** and **b**, 6.8J of energy is used by each coulomb of charge as it passes through the 400Ω resistor. Between **b** and **c**, 5.2J of energy is used by each coulomb of charge as it moves through the 290Ω resistor. Between **c** and **d**, each coulomb of charge has 0J of energy. As the charges pass through the cell from **d** to **e**, each coulomb of charge gains 12J of energy. This cycle repeats as charges move through the circuit.



This is in line with what Kirchhoff's loop rule says. If 12J of energy is gained by each coulomb of charge as it passes through the cell, then 12 J of energy per coulomb must be used by the charges by the time they return to the cell. That is the sum of all energy (p.d.) given is equal to zero.

If follow the charges in the clockwise direction, the equation using Kirchhoff's loop rule to describe what happens is as follows;

$$12 - IR_1 - IR_2 = 0 \text{ or } IR_1 + IR_2 = 12$$

Suppose we go in the anticlockwise direction, then the loop rule equation will look like this;

$$-12 + IR_1 + IR_2 = 0 \text{ or } IR_1 + IR_2 = 12$$

As you can see, it does not depend on our choice of direction in the circuit. The loop rule still gives us the same equation.

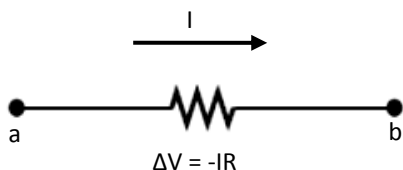
Sign conventions to observe when applying Kirchhoff's rules

As we get to more complex equations we may need to adhere to some rules that can help us to derive equations using the loop rule. The most important skill is to recognize when and where to assign positive (+) signs and negative (-) signs.

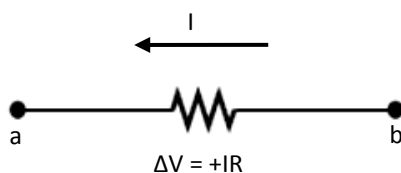
Below are the rules for sign conventions that we must observe in order to obtain the correct equations using Kirchhoff's loop rule.

When using the loop rule in a circuit, the direction of the current can be chosen randomly. Note the following sign conventions when using the loop rule:

1. Because charges move from the high-potential end of a resistor to the low potential end, if a resistor is traversed in the direction of the current, the change in potential ΔV across the resistor is $-IR$. (high potential at a, low potential at b)

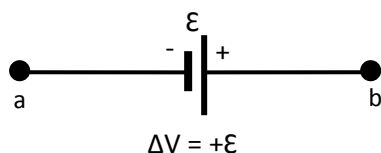


2. If a resistor is traversed in the direction opposite the current, the change in potential ΔV across the resistor is $+IR$.

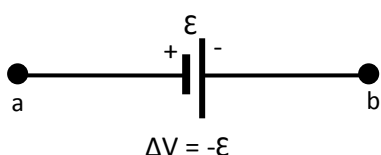




3. If a source of emf (assumed to have zero internal resistance) is traversed in the direction of the emf (from - to +), the change in potential ΔV is $+\mathcal{E}$. The emf of the battery increases the electric potential as we move through it in this direction.



4. If a source of emf (assumed to have zero internal resistance) is traversed in the direction opposite the emf (from + to -), the change in potential ΔV is $-\mathcal{E}$. In this case the emf of the battery reduces the electric potential as we move through it.

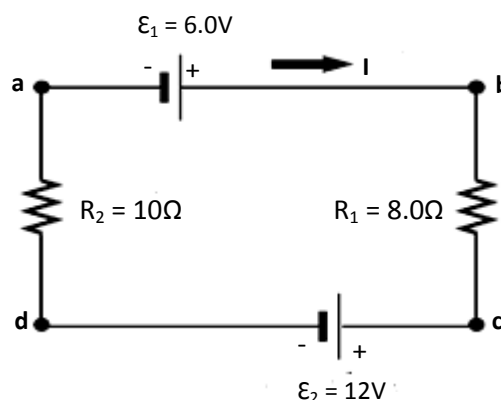


Using these rules will help you to solve any circuit problem by applying Kirchhoff's rules. Let's look at a few examples of using both of Kirchhoff's rules and how the sign conventions help us to solve problems.

These problems can be solved using either the substitution or elimination methods. In the following example, we will use the elimination method.

Example 26

A single-loop circuit contains two resistors and two batteries, as shown in Figure below (Neglect the internal resistances of the batteries.).



- (a) Find the current in the circuit.
- (b) What power is delivered to each resistor?
- (c) What power is delivered by the 12V battery?

**Solution**

- (a) There is only one loop. So we follow the direction of I in a clockwise direction from point **a**.

$$\begin{aligned} 6 - 8I - 12 - 10I &= 0 \\ -18I &= 6 \\ I &= -0.33\text{A} \end{aligned}$$

The negative sign tells us that the direction of the current is opposite that which is shown.

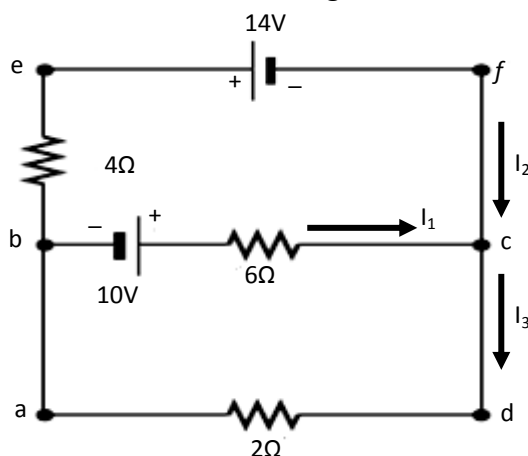
- (b) The power delivered to each resistor is

$$\begin{aligned} 8\Omega \rightarrow P &= I^2 R = \frac{8}{9} \text{W} = 0.89\text{W} \\ 10\Omega \rightarrow P &= I^2 R = \frac{10}{9} \text{W} = 1.11\text{W} \end{aligned}$$

- (c) $P_{\text{Total}} = IV = 4\text{W}$ half of this is going to the resistors while the other half is charging the 6V battery.

Example 27

Find the currents I_1 , I_2 , and I_3 in the circuit shown in figure below.



Junction Equation: $I_1 + I_2 = I_3$

Following the top loop in an anticlockwise direction (febcbf), the loop equation is;

$$\begin{aligned} 14 + 4I_2 + 10 - 6I_1 &= 0 \\ 4I_2 + 6I_1 + 24 &= 0 \end{aligned} \quad \text{..... [1]}$$

Following the bottom loop in an anticlockwise direction, (cbadc), the loop equation is;

$$\begin{aligned} 6I_1 - 10 + 2I_3 &= 0 \\ 6I_1 + 2I_3 - 10 &= 0 \end{aligned} \quad \text{..... [2]}$$



Eliminate I_3 by substituting the junction equation into equation (2)

$$6I_1 + 2(I_1 + I_2) - 10 = 0$$

$$8I_1 + 2I_2 - 10 = 0 \quad \dots [3]$$

Eliminate I_1 by multiplying equation (1) by 4 and equation (3) by 3 and adding both equations.

$$16I_2 - 24I_1 + 96 = 0 \quad \dots [1] \times 4$$

$$6I_2 + 24I_1 - 30 = 0 \quad \dots [3] \times 3$$

$$22I_2 + 66 = 0 \quad \dots [1] \times 4 + [3] \times 3$$

$$I_2 = -3A$$

Substitute I_2 into the equation [1] to find I_1 .

$$4(-3) - 6I_1 + 24 = 0$$

$$I_1 = 2A$$

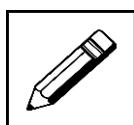
Find I_3 using the junction equation; $I_3 = 2 + (-3) = -1A$

Note that the negative signs tell us that the current is moving in the opposite direction to that which is shown.

The currents are;

$$I_1 = 2A, I_2 = 3A \text{ and } I_3 = 1A$$

Now check what you have just learnt by trying out the learning activity below!



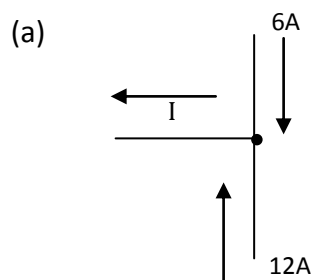
Learning Activity 8



20 minutes

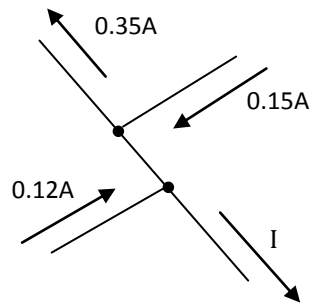
Answer the following questions on the spaces provided.

- Find the values of the currents labelled I in the following diagrams using Kirchhoff's junction rule.

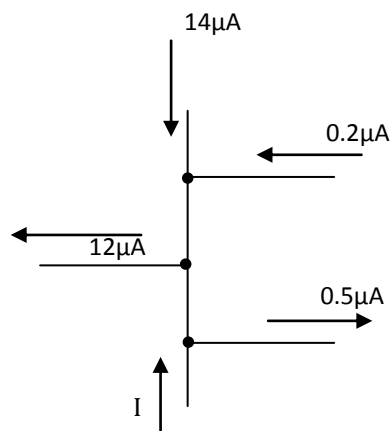




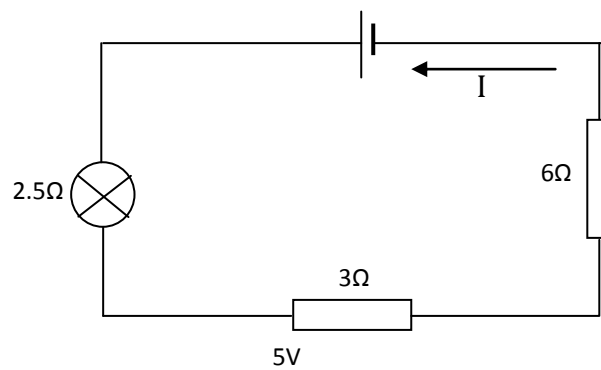
(b)



(c)

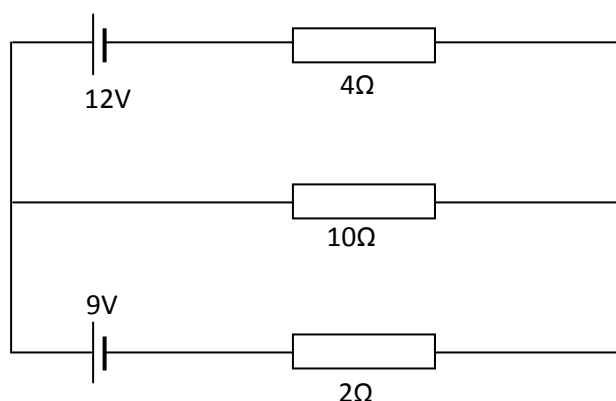


2. Find the current and the potential drop across each resistor and the light bulb in the circuit shown below using Kirchhoff's rules.





3. Find the current through and voltage drop across each of the resistors using Kirchhoff's rules.



Thank you for completing learning activity 8. Now check your work. Answers are at the end of the module.

Wheatstone Bridge & Potentiometer

Wheatstone bridge circuit

The Wheatstone bridge circuit is used to measure unknown resistances. The circuit in figure 26 below shows the layout of the circuit.

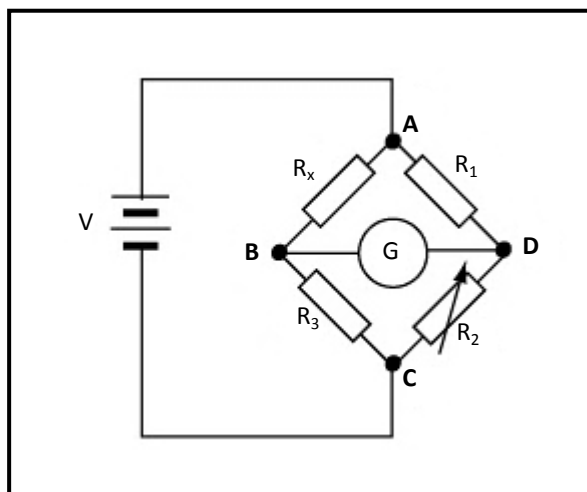


Figure 26 A Wheatstone bridge circuit.



The galvanometer serves as a way of measuring the p.d. between the branches. When the galvanometer reads zero, the bridge is said to be **balanced**. The balanced state occurs when the ratio of the resistors is equal.

In the diagram above, R_1 , R_3 and R_x are fixed value resistors while R_2 is a variable resistor. To determine the value of R_x , R_2 is adjusted until, the galvanometer reads zero. At this instant, there is no p.d. across the galvanometer, which implies that the potential at B is equal to the potential at D.

We can use Kirchhoff's rules to determine that;

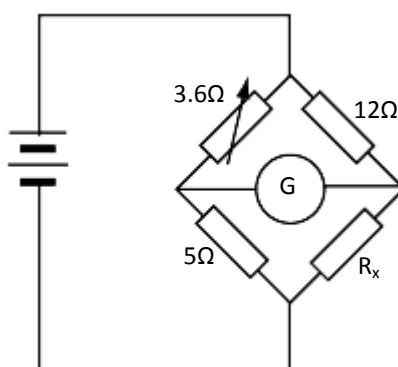
$$\frac{R_x}{R_3} = \frac{R_1}{R_2}$$

Solving this equation we can find R_x

$$R_x = \frac{R_1}{R_2} \times R_3$$

Example 28

Calculate the value of the unknown resistor, R_x in the balanced Wheatstone bridge circuit shown below.



Solution

In a balanced Wheatstone bridge circuit, the ratio of resistance in one branch is equal to that in the other.

$$\frac{3.6\Omega}{5\Omega} = \frac{12\Omega}{R_x}$$

$$R_x = 12\Omega \times \frac{5\Omega}{3.6\Omega}$$

$$R_x = 16.7\Omega$$



Potentiometer circuit

The potentiometer circuit is used to measure an unknown emf by comparing to a known emf. The potentiometer is the most accurate method of measuring an unknown emf. A common type of potentiometer circuit is called the sliding wire potentiometer. A circuit diagram of this is shown in figure 27 below.

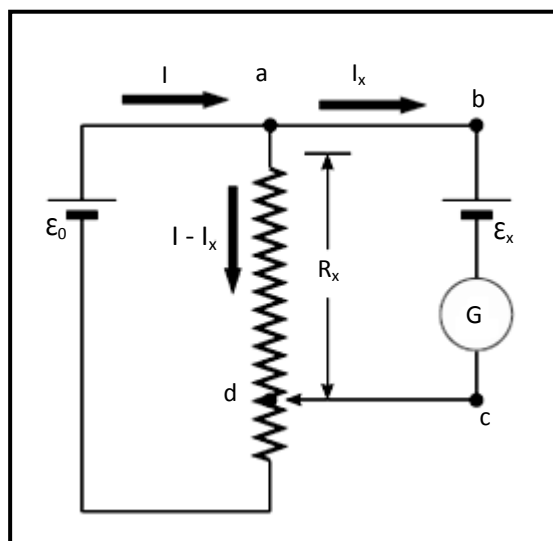


Figure 27 A sliding wire potentiometer.

In figure 27 a sliding contact is used to vary the resistance R_x (and hence the potential difference) between points **a** and **d**. The other required components are a galvanometer, a battery of known emf ϵ_0 , and a battery of unknown emf ϵ_x .

We see that I is the total current entering the junction at **a**. It splits into two components I_x and $I - I_x$ and ϵ_0 is a cell that supplies I . If we follow the current I_x shown and use Kirchhoff's loop rule in the loop **abcda**, the following equation will be obtained to represent the potential of the circuit when the galvanometer reading is non-zero.

$$-\epsilon_x + R_x (I - I_x) = 0$$

If we adjust the sliding contact **d** until the galvanometer reads zero (i.e. it is balanced) the loop equation at this point will be;

$$\epsilon_x = IR_x$$

We can note the length of the slide wire and label it as L_x . The next thing to do is to replace the unknown emf ϵ_x with a known emf ϵ_s and to repeat the procedure until the galvanometer is balanced. This time the equation will be;

$$\epsilon_s = IR_s$$

We also note the length of the slide wire and label it as L_s .

If we assume that the current I is the same, then we can combine these two equations and get;



$$\frac{\mathcal{E}_x}{\mathcal{E}_s} = \frac{R_x}{R_s}$$

We can then solve for $\mathcal{E}_s$ since it is the only unknown.

If the slide wire has a resistivity of ρ then we can also note that $R_x \propto L_x$ and $R_s \propto L_s$. In this way, the unknown emf $\mathcal{E}_x$ can also be determined using the two lengths L_x and L_s instead of the two resistances using the equation below.

$$\mathcal{E}_x = \mathcal{E}_s \frac{L_x}{L_s}$$

NOTE: $R_x \propto L_x$ means that the resistance of x is proportional to the length of x.

Let's look at an example of using a potentiometer to calculate an unknown emf.

Example 29

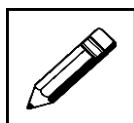
A slide wire potentiometer circuit is set up to find an unknown emf V_x . The slide wire is made of 15cm of copper wire. When V_x is placed in the circuit, it is adjusted to a length of 10cm, the galvanometer reads zero. A known emf of 2.5V is then introduced into the circuit and the slide wire is adjusted to a length of 8cm when the galvanometer reads zero.

Find the unknown emf V_x .

Solution

$$V_x = V_s \frac{L_x}{L_s} = 2.5V \times \frac{10\text{cm}}{8\text{cm}} = 3.125V$$

Now check what you have just learnt by trying out the learning activity below!



Learning Activity 9



20 minutes

Answer the following questions on the spaces provided.

1. What is a Galvanometer? How is it used in a Wheatstone bridge circuit?



2. What does having a balanced Wheatstone bridge circuit mean? Explain how this happens.

3. Below are some statements concerning balanced Wheatstone bridge circuits. Identify which statements are TRUE and which are FALSE and explain the reason for your answer.

- (i) The current through each of the four resistors is always the same.

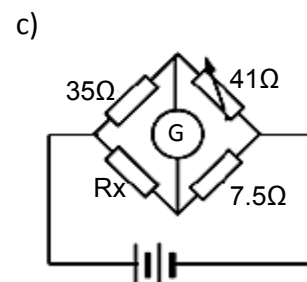
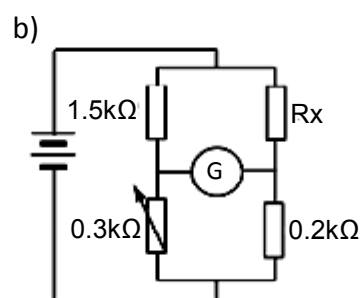
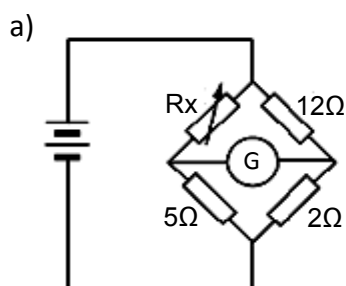
- (ii) The current through resistors in each branch is always the same.

- (iii) The total resistance of each branch is the same.

- (iv) The p.d. across each of the four resistors is the same.

- (v) The p.d across each branch is the same.

4. For each of the Wheatstone bridge circuits below, find the value of the resistance labelled R_x that would make each circuit balanced.





5. What is a potentiometer used for?

6. Referring to the potentiometer circuit diagram in figure 24, explain the purpose of the sliding contact.

7. A potentiometer circuit is set up to measure the emf of a cell which is unknown. When a standard cell of 6V is used, the sliding contact is varied until at a length of 48cm, the galvanometer reads zero. When an unknown cell is used, the galvanometer reads zero when the sliding contact reaches a length of 65cm.

What is the unknown emf?

-
8. If a standard cell with an emf of 1.0186 V is used in a potentiometer circuit and the resistance between the ends of the sliding contact is 36.0Ω , the galvanometer reads zero.

If the standard cell is replaced by another cell X with an unknown emf, the galvanometer reads zero when the resistance is adjusted to 48.0Ω .

What is the emf of the cell X?

Thank you for completing learning activity 9. Now check your work. Answers are at the end of the module.



11.5.4 Alternating Current (AC) Circuits

This topic extends the idea of moving electric charges. In the previous topic we were mostly concerned with resistance and the type of electric current known as the Direct current or DC.

Direct current refers to the motion of electric charges in one direction. That is from the positive terminal of a source (high potential region) to the negative terminal of a source (low potential). In this sense the direction of electric current is only in one direction.

In the case of alternating current or AC, we have a situation where the potential of the source is changing or alternating between positive and negative terminals at regular intervals. This results in an electric current that changes direction at regular intervals.

Although this type of electric current is different from DC, a lot of the concepts do remain the same. The quantities of current, voltage and resistance are the same, but we also introduce some new ones such as frequency, capacitance, inductance and impedance. We also see power and electrical energy in a different way due to the changing current and voltage that is characteristic of AC.

A little is introduced on the production of AC, however it is covered in more detail in Unit 12.4 Electromagnetism.

Alternating Current (AC)

Alternating current is a form of electricity where charges move back and forth (vibrate) along a conductor. This means that electric current in this form is one that changes its value over time. An alternating current voltage also changes value over time.

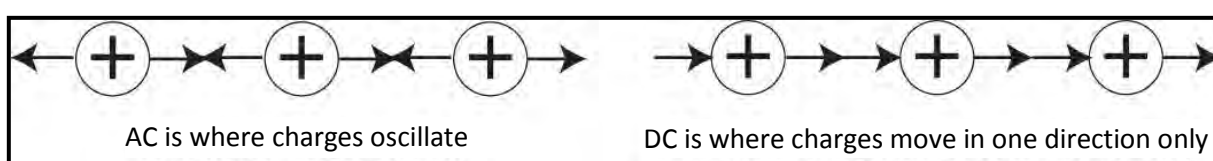


Figure 28. Charges in AC oscillate (or have a to-and-fro motion). This happens because, electric potential in AC sources reverses positions (alternates) over time. In DC charges tend to generally move in one direction from

Direct Current is the form of electricity we have been learning about. Unlike AC, charges in DC move in one direction only. The graphs of AC and DC are shown in figure 29.

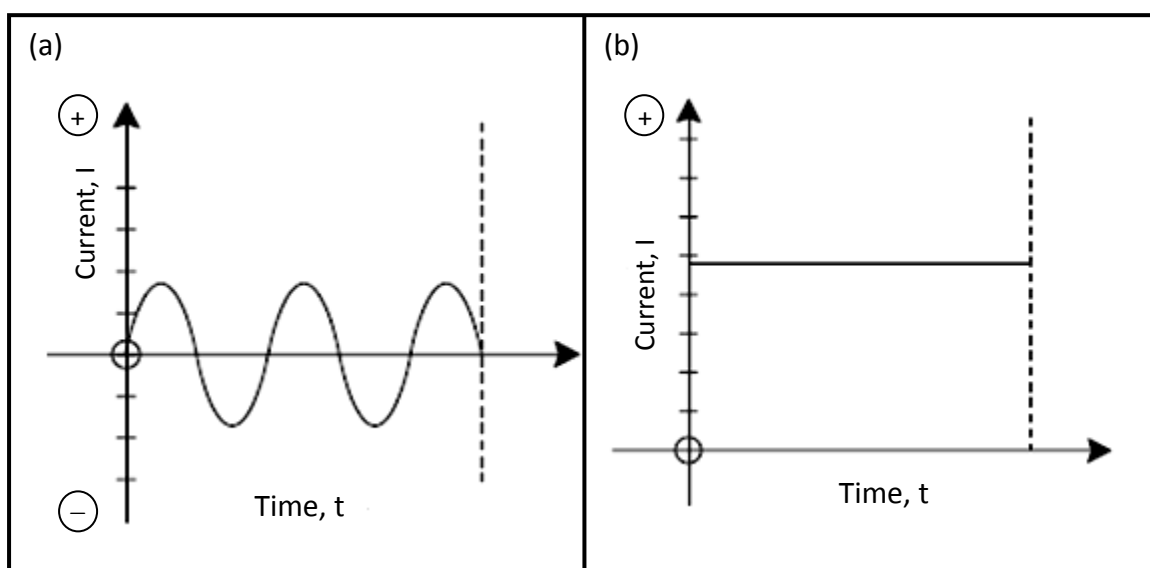


Figure 29. (a) Graph of alternating current over time. (b) Graph of direct current over time.

AC is studied here because of its usefulness in transmitting power from power stations to homes and industries. AC is used instead of DC for two main reasons;

1. AC generators are cheaper and more reliable than DC generators or sources of DC such as cells.
2. AC voltage can be increased or decreased using transformers whereas DC cannot. Transmitting power over long distances using high voltages is necessary to minimize power loss due to the resistance of transmission lines.

**Instantaneous values of AC**

The graph of AC voltage and current is called a sinusoidal graph. This graph is in the form of a **wave** and is sometimes referred to as an **AC waveform**.

At any instant of time, the instantaneous voltage and current are given by the following equations;

Instantaneous current $I_i = I_p \sin(\omega t) = I_p \sin(2\pi ft)$

Instantaneous voltage $V_i = V_p \sin(\omega t) = V_p \sin(2\pi ft)$

Where:

- I_p and V_p stand for peak current and peak voltage respectively
- ω stands for angular velocity of generator coil in radians per second (rad/s)
- f stands for frequency of the generator coil in Hertz (Hz). The typical AC frequency is between 50Hz and 60Hz.
- $\pi = 3.14$
- t stands for an instant of time in seconds (s)

NOTE: When calculating instantaneous voltage and current, you must set your calculator to RADIAN MODE since all the angular velocities are given in radian per second (rad/s).

At any instant in time AC voltage and current will either have a positive value or a negative value. This difference in sign indicates changes in general current direction and electric potential. It is important to remember that $I_{\max}$ (maximum current) and $V_{\max}$ (maximum voltage) represent the highest positive values of AC. While $I_{\min}$ (minimum current) and $V_{\min}$ (minimum voltage) represent the lowest negative values of AC.

The peak value of AC voltage and current is equal to the magnitude of these maximum and minimum values.

$$I_p = |I_{\max}| = |I_{\min}|$$
$$V_p = |V_{\max}| = |V_{\min}|$$



Below are two diagrams (Figures 30 and 31) that show how the sinusoidal appearance of the alternating current and voltage is related to the rotations of a coil of wire in a magnetic field. (This is covered in more detail in 12.4 Electromagnetism).

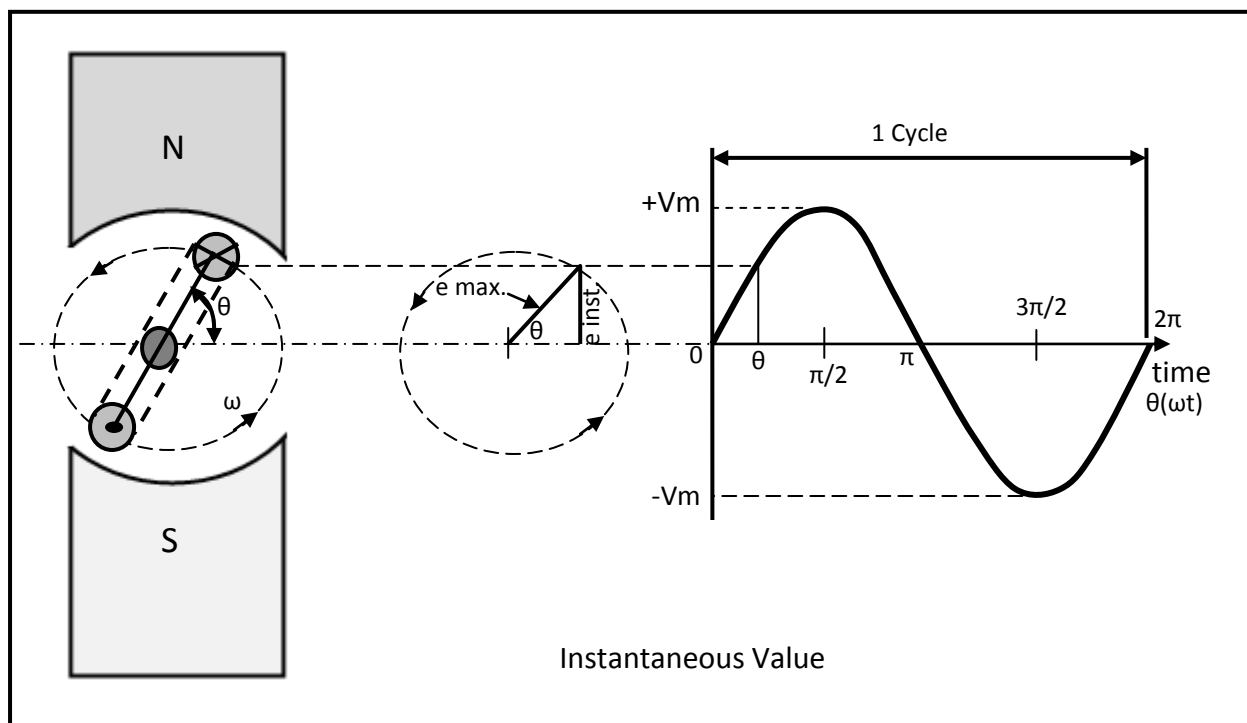


Figure 30. Rotation of a coil of wire in a magnetic field causing AC. The value of voltage and current varies at different values of θ .

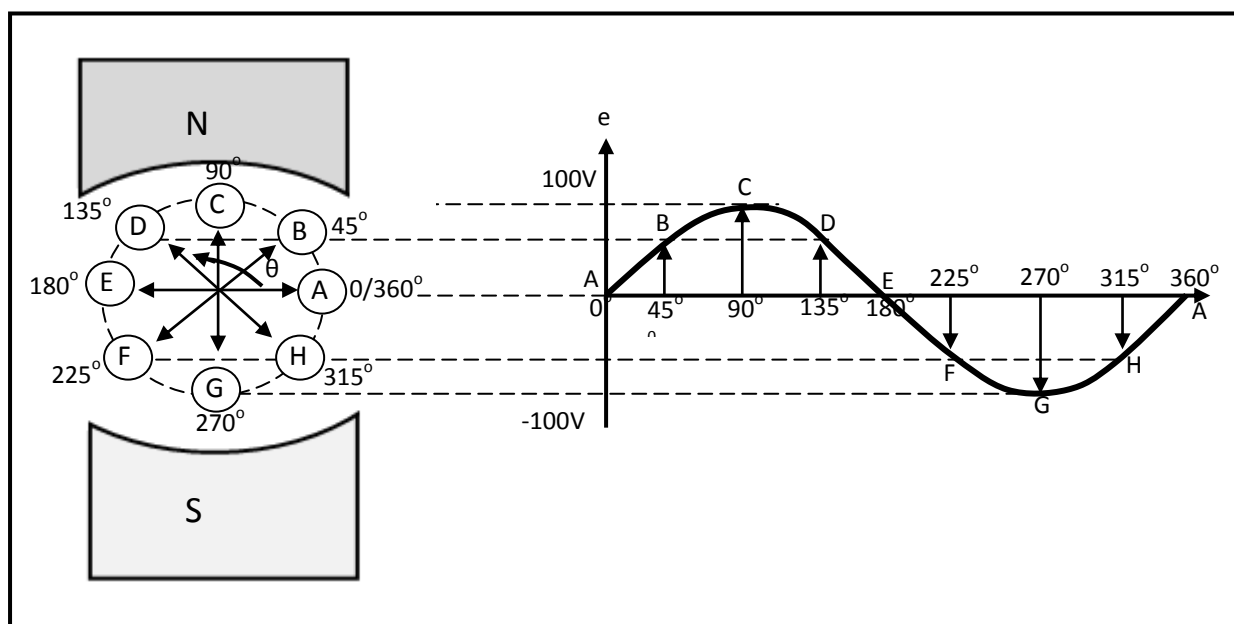


Figure 31. The relationship between different values of AC voltage and current at different values of θ . Ω is the angular velocity of the coil of wire and is related to θ by the equation; $\theta = \omega t$.

NOTE: When calculating instantaneous voltage and current, you must set your calculator to RADIAN MODE since all the angular velocities are given in radian per second (rad/s).

**Example 30**

An electric generator produces an AC peak voltage of 120V. If the generator has a frequency of 50Hz;

- (a) What is the angular speed of the coil in radians per second?
Remember from circular motion (11.2) that the angular velocity is related to frequency and period by the equation;

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$\omega = 2\pi f$$

$$\omega = 100\pi \text{ rad/s}$$

$$\omega = 314.16 \text{ rad/s}$$

- (b) What is the period of revolution of the generator coil?
Period is related to frequency by the following equation;

$$T = \frac{1}{f}$$

$$T = \frac{1}{50} = 0.02 \text{ sec}$$

- (c) What are the instantaneous voltage values at; (i) 0.005s, (ii) 0.01s, (iii) 0.015s?
Simply substitute the peak values of voltage along with either frequency or angular velocity and time in seconds.

(i) $V_{0.005s} = 120 \times \sin(100\pi \times 0.005s)$
 $V_{0.005s} = 120 \sin(0.5\pi)$
 $V_{0.005s} = 120V$

(ii) $V_{0.01s} = 120 \times \sin(100\pi \times 0.01s)$
 $V_{0.01s} = 120 \sin(\pi)$
 $V_{0.01s} = 0V$

(iii) $V_{0.015s} = 120 \times \sin(100\pi \times 0.015s)$
 $V_{0.015s} = 120 \sin(1.5\pi)$
 $V_{0.015s} = 120V$

NOTE: When calculating instantaneous voltage and current, you must set your calculator to **RADIAN MODE** since all the angular velocities are given in radian per second (rad/s).

Phases

For voltage and current produced in an AC generator, both current and voltage reach their maximum and minimum values simultaneously. We therefore say that AC voltage and current are **in phase**. Figure 32 below shows a graph of AC voltage and current over time in phase.

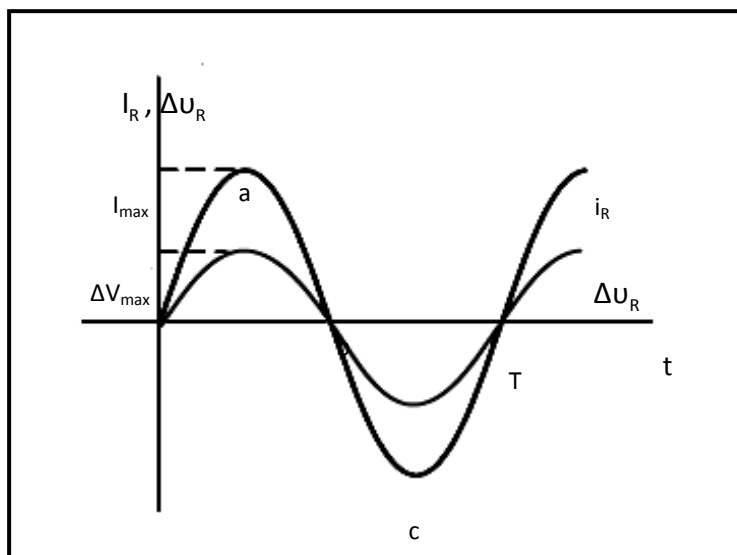


Figure 32. Graph showing voltage and current that are in phase. Being in phase means that voltage and current reach peak values simultaneously.

Domestic electricity supply is called a 3 phase AC since there are three phases of Alternating voltage and current together. This fact relates to the rotating of three sets of coils in a magnetic field. A graph showing three phase AC voltage (current has the same type of appearance) is shown in figure 33.

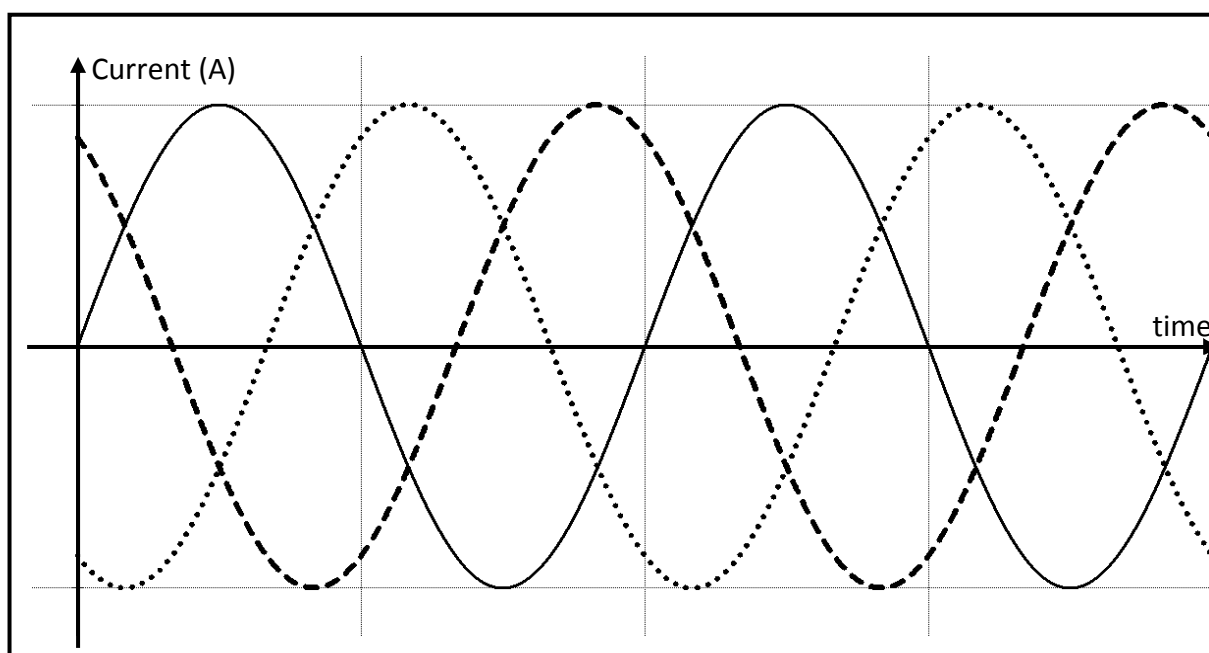


Figure 33. Plot of three-phase AC current. Peak current is reached by each of the three waveforms after equal intervals of time.

**RMS Values**

Potential Difference and Current from AC sources are mostly stated in RMS (Root Mean Square) values.

In a practical sense, the RMS values are AC voltage and current values that supply the same average power to an electrical device as corresponding DC values.

For instance a device that runs on 240V RMS and 150mA RMS dissipates the same amount of energy as 240V DC and 150mA DC.

Mathematically the RMS value is the square root of the mean of the squares of all instantaneous voltage (or current) over one cycle. For electric currents that follow sinusoidal waveform we use the values given below.

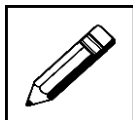
RMS values are related to peak values by the following formulae (for sinusoidal values only);

$$I_{\text{RMS}} = \frac{I_{\text{P}}}{\sqrt{2}}$$

$$V_{\text{RMS}} = \frac{V_{\text{P}}}{\sqrt{2}}$$

There are other types of AC waveforms and they have their own formulae for calculating RMS values. At this stage we will focus our attention of sinusoidal waveforms only.

Now check what you have just learnt by trying out the learning activity below!

**Learning Activity 10****20 minutes**

Answer the following questions in the spaces provided.

1. In terms of the motion of charges, describe how AC is different from DC.

2. What are the two main reasons for using AC instead of DC for transmission of power over long distances?



3. For a generator which produces a 60V peak voltage and 5A peak current at a frequency of 40Hz, find the;
- a. angular speed of the coil in the generator.
 - b. period of the generator coil.
 - c. times in the first period where the instantaneous voltage and current are in phase and;
 - (i) maximum?
 - (ii) minimum?
-
4. A generator produces Alternating current with a peak value of 10A and peak voltage of 240V. Find the instantaneous value of current and voltage to 2 decimal places given that the AC frequency is 25Hz at the following times;
- (a) 0.009s



(b) 0.017s

(c) 0.025s

(d) 0.038s

5. Explain the practical definition of RMS current and RMS voltage.

6. Copy and complete the following tables for missing RMS values and Peak values (to 2 decimal places) from sinusoidal AC voltages & currents.

	V_{RMS}	V_{Peak}	I_{RMS}	I_{Peak}
(a)	520V		0.6A	
(b)		3V		7.4A
(c)	36mV		500mA	
(d)		68 μ V		50mA
(e)	2.40V		65 μ A	

Thank you for completing learning activity 10. Now check your work. Answers are at the end of the module.



AC Circuits

AC Resistance & Power

All resistance calculations can be done for AC circuits with resistors using RMS values (V_{RMS} , I_{RMS}). RMS values can be used to determine peak voltage (V_p) and peak current (I_p) values as well as average power dissipated in an AC circuit.

RESISTANCE (R)	AVERAGE POWER ($\bar{P}$)
$R = \frac{V_{\text{RMS}}}{I_{\text{RMS}}}$	$\bar{P} = I_{\text{RMS}} V_{\text{RMS}}$
$R = \frac{\frac{V_p}{\sqrt{2}}}{\frac{I_p}{\sqrt{2}}} = \frac{V_p}{\sqrt{2}} \div \frac{I_p}{\sqrt{2}}$	$\bar{P} = (I_{\text{RMS}})^2 R$
$R = \frac{V_p}{I_p}$	$\bar{P} = \frac{(V_{\text{RMS}})^2}{R}$

Apart from these we can also continue to apply the circuit rules applied with DC. That is Kirchhoff's rules, resistors in series and in parallel.

Example 31

A 2kW electric jug operates directly from a power main with an operating voltage of 240V RMS.

- (a) What is the peak current that passes through the jug's element?

This question has to be done in two parts. First calculate I_{RMS} then use it to find I_{PEAK} .

$$I_{\text{RMS}} = \frac{\bar{P}}{V_{\text{RMS}}}$$
$$I_{\text{RMS}} = \frac{2000\text{W}}{240\text{V}} = 8.3\text{ A}$$

Now that we know the RMS current, we can find the peak value using the RMS-Peak relationship.

$$I_{\text{PEAK}} = I_{\text{RMS}} \times \sqrt{2}$$
$$I_{\text{PEAK}} = 8.3 \times \sqrt{2} \cong 11.785\text{A}$$



(b) What is the resistance of the jug's element?

We could determine the resistance by using either ohm's Law or the power equations. All should yield the same answer.

$$R = \frac{V_{\text{RMS}}}{I_{\text{RMS}}}$$

$$R = \frac{240\text{V}}{8.3\text{A}} = 28.8\Omega$$

Pure AC resistive circuits

Consider the AC resistive circuit shown in figure 34 below. At any instant, the instantaneous voltage across the resistor is;

$$V_i = V_0 \sin 2\pi ft$$

The instantaneous current can be determined as follows;

$$I_i = \frac{V_i}{R} = \frac{V_0 \sin 2\pi ft}{R}$$

$$I_i = I_0 \sin 2\pi ft$$

Both V_0 and I_0 are multiplied by $\sin 2\pi ft$; this tells us that both the current and voltage alternate simultaneously. We say that both the current and voltage are in phase in a pure AC resistive circuit.

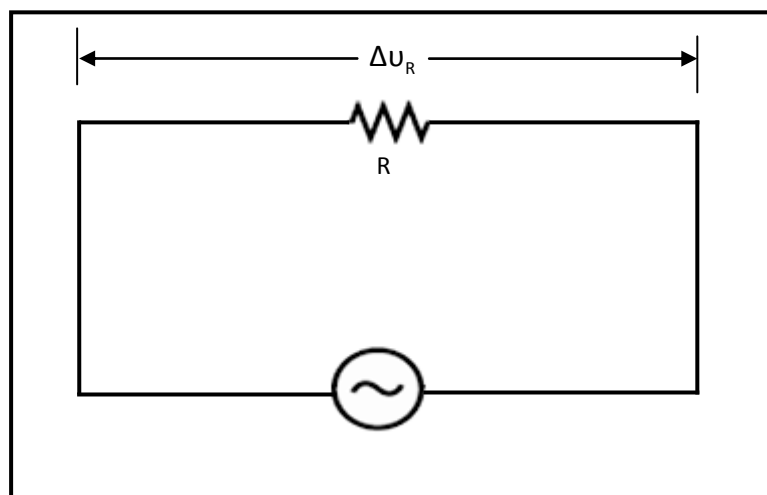


Figure 34. A purely resistive AC circuit is a circuit where there is only one resistor in series with an AC source.



In figure 35 below, the graphs of instantaneous current and voltage against time are shown (left). As you can see, the graphs of current (i_R) and p.d. (Δv_R) are in phase.

A **phasor diagram** can be used instead of a graph to summarise the properties of AC voltage and current. The phasor diagram (in figure 35 on the right) illustrates the current and voltage in a sinusoidal graph as a **rotating phasor**. The length of a phasor represents the peak current and voltage, while the instantaneous current and voltage values are shown on the vertical axis.

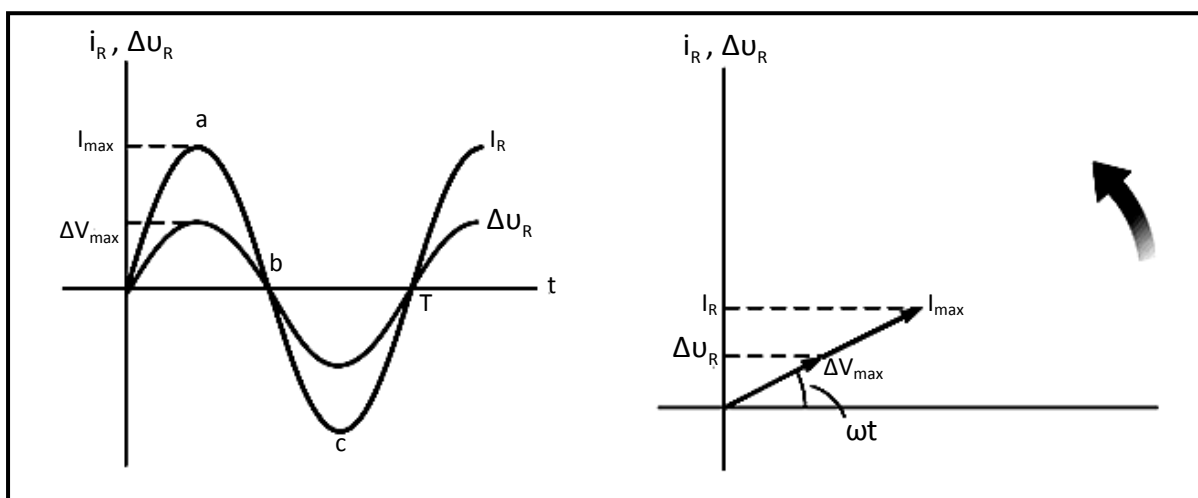


Figure 35. (Left) Graphs of AC voltage (Δv_R) and current (i_R) in a purely resistive AC circuit showing that current and voltage are always in phase. (Right) The phasor diagram on the right illustrates this information as well.

Pure AC capacitive circuits

A pure capacitive circuit contains a capacitor which is a device for storing electric charge. Consider the AC capacitive circuit shown below.

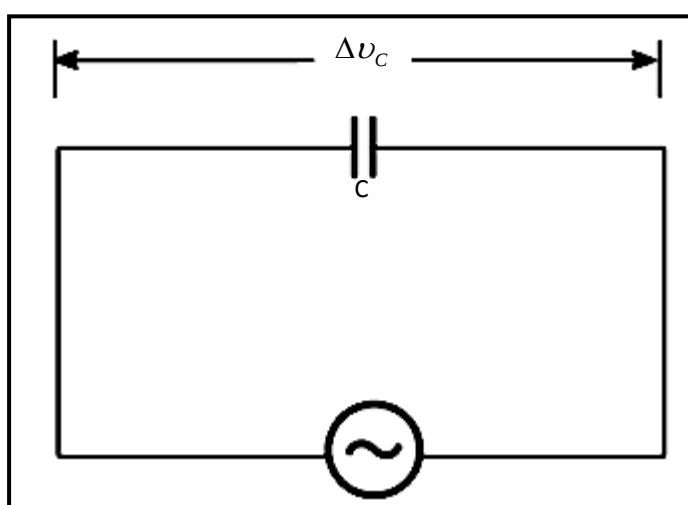


Figure 36. A purely capacitive AC circuit.



At any instant the instantaneous voltage is given as;

$$V_i = V_0 \sin \omega t$$

$$V_i = V_0 \sin 2\pi f t$$

The capacitance (**C**) is the ability to store charge. The unit for capacitance is **Farads (F)**. it is related to charge and voltage by the following equation.

$$C = \frac{Q}{V}$$

Thus the instantaneous (**Q_i**) charge on the capacitor (**C**) is;

$$Q_i = C V_i$$

$$Q_i = C V_0 \sin \omega t$$

$$Q_i = C V_0 \sin 2\pi f t$$

Using calculus (bit beyond our scope here!) we determine the instantaneous current. The result is the following equation.

$$I_i = \omega C V_0 \sin \left(\omega t + \frac{\pi}{2} \right)$$

$$I_i = 2\pi f C V_0 \sin \left(2\pi f t + \frac{\pi}{2} \right)$$

What this equation tells us is that in an AC capacitive circuit, the voltage lags (delays) behind the current by 90° ($\frac{\pi}{2}$ radians). The graph and phasor diagram for purely capacitive AC circuits is shown in figure 37 on the next page.

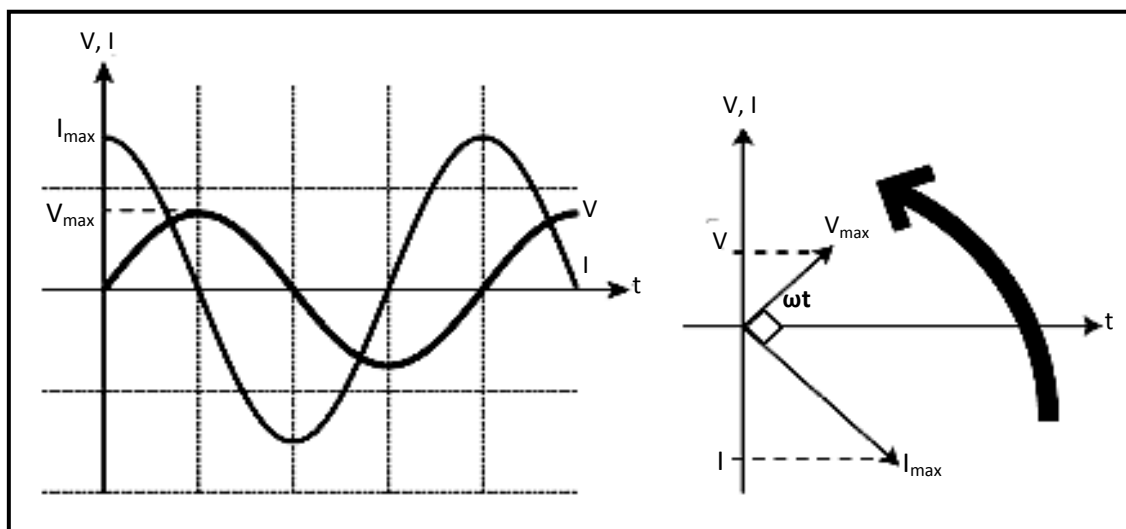


Figure 37. (Left) Graphs of current and voltage in a purely capacitive AC circuit. It shows how voltage lags behind current. (Right) The phasor diagram for a purely capacitive AC circuit is shown on the right.

The **capacitive reactance (X_C)** is a quantity that measures of the effect of a capacitor on an AC circuit. It has the unit Ohms (just like resistance) but is dependent on changes in frequency.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

The relationship between peak current (I_P), peak voltage (V_P) and capacitive reactance (X_C) is

$$I_P = \frac{V_P}{X_C}$$

$$I_P = V_P \cdot \omega C$$

$$I_P = V_P \cdot 2\pi f C$$

The same relationship also can be applied to RMS values.

$$I_{RMS} = \frac{V_{RMS}}{X_C}$$

$$I_{RMS} = V_{RMS} \cdot 2\pi f C$$

The equations above tell us that any change in frequency (f) affects capacitive reactance which in turn affects current.

1. An increase in frequency (f) leads to a decrease in capacitive reactance (X_C) which leads to an increase in current (I_P and I_{RMS}).
2. A decrease in frequency (f) leads to an increase in capacitive reactance (X_C) which leads to a decrease in current (I_P and I_{RMS}).

**Example 32**

A pure AC capacitive circuit containing a capacitance of $16\mu\text{F}$ has a peak voltage of 150V at 10Hz . Calculate;

- (a) The capacitive reactance of the circuit.

Solution

$$X_c = \frac{2}{2\pi fC}$$

$$X_c = \frac{1}{2 \times \pi \times 10 \times 16 \times 10^{-6}} = 995\Omega$$

- (b) The peak current and RMS current in the circuit.

Solution

$$I_0 = \frac{V_0}{X_c} = \frac{150\text{V}}{995\Omega} = 0.15\text{A}$$

$$I_{\text{RMS}} = \frac{V_{\text{RMS}}}{X_c}$$

$$I_{\text{RMS}} = \frac{V_{\text{RMS}}}{X_c}$$

$$I_{\text{RMS}} = \frac{150\text{V} / \sqrt{2}}{995\Omega} = 0.107\text{A}$$



Pure AC inductive circuits

A pure inductive circuit contains an inductor which is a device that opposes changes to current. Inductance is a quantity that describes the degree of a device to oppose changes in current. It is measured in Henrys (H).

Consider the AC inductive circuit shown in figure 38.

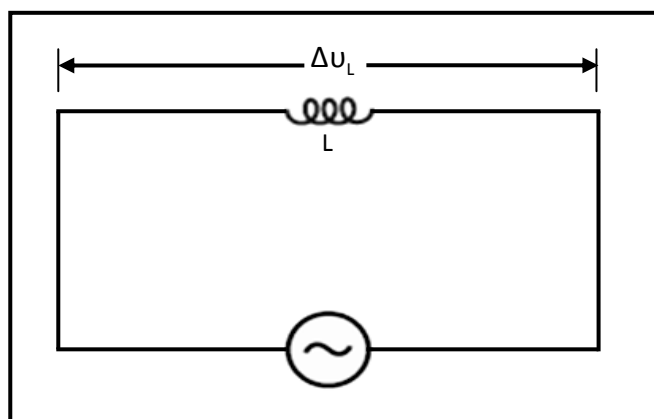


Figure 38. A purely inductive AC circuit.

An inductor is simply a coil of wire which behaves in a unique way when subject to alternating currents and voltages.

At any instant the instantaneous voltage is given as;

$$V_i = V_0 \sin \omega t$$

$$V_i = V_0 \sin 2\pi ft$$

Using calculus we can determine that the instantaneous current through the inductor (L) is;

$$I_i = \frac{V_0}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$I_i = \frac{V_0}{2\pi fL} \sin\left(2\pi ft - \frac{\pi}{2}\right)$$

What this tells us is that in an AC inductive circuit, the voltage leads (advances) the current by 90° ($\frac{\pi}{2}$ radians). Figure 39 shows the graphs of current and voltage in a purely inductive circuit and the phasor diagram representing an inductive circuit.

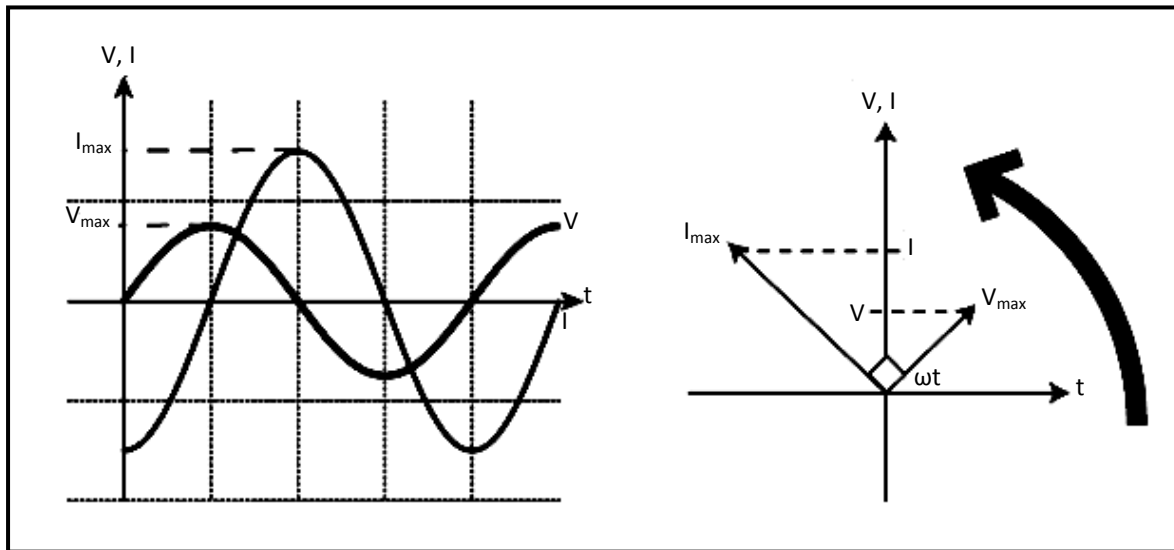


Figure 39. The graphs of current and voltage in a purely inductive circuit. It shows how voltage leads current. The phasor diagram also shows this.

The **inductive reactance, X_L** is a quantity that describes the effect of an inductor on an AC circuit. It also has the unit Ohms (Ω) (just like resistance) but is also dependent on changes in frequency (f).

$$X_L = \omega L$$

$$X_L = 2\pi fL$$

The relationship between the peak current (I_p), peak voltage (V_p) and capacitive reactance (X_L) is;

$$I_p = \frac{V_p}{X_L}$$

$$I_p = \frac{V_p}{\omega L}$$

$$I_p = \frac{V_p}{2\pi fL}$$

The same relationship also can be applied to RMS values.

$$I_{RMS} = \frac{V_{RMS}}{X_L}$$

$$I_{RMS} = \frac{V_{RMS}}{2\pi fL}$$



The equations on the previous page tell us that any change in frequency (f) affects the inductive reactance X_L which in turn affects the current.

1. Increase in frequency leads to an increase in inductive reactance which leads to a decrease in current.
2. Decrease in frequency leads to a decrease in inductive reactance which leads to an increase in current.

Example 33

An AC Inductive circuit with frequency 25Hz containing an inductor with an inductive reactance of 250Ω has a peak current of 1.2A. Find the;

- (a) RMS current and voltage.

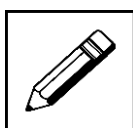
$$I_{\text{RMS}} = \frac{1.2\text{A}}{\sqrt{2}} = 0.85\text{A}$$

$$V_{\text{RMS}} = I_{\text{RMS}} X_L \frac{1.2}{\sqrt{2}} \times 250\Omega = 212\text{V}$$

- (b) inductance in henrys if the AC frequency is 40Hz.

$$L = \frac{X_L}{2\pi f} = \frac{250\Omega}{2\pi \times 40\text{Hz}} = 0.995\text{H}$$

Now check what you have just learnt by trying out the learning activity below!

**Learning Activity 11****20 minutes**

Answer the following questions in the spaces provided.

1. In PNG the normal household power mains supply has a p.d. of 240V RMS. What is the peak voltage of this AC voltage supply?



2. A machine that works on AC electricity had a label that read 120VAC and 150mA. Given that these values are RMS values, find the corresponding peak values for current and voltage.

-
3. Calculate the average power dissipated across a resistor in series with an AC supply that gives a peak voltage and current of 120V and 60mA.

-
4. A resistor is connected in series with an AC source of electricity. If the RMS voltage and current are 240V and 100mA respectively, find the;

(a) peak current and voltage.

(b) resistance value of the resistor.

(c) average power dissipated.



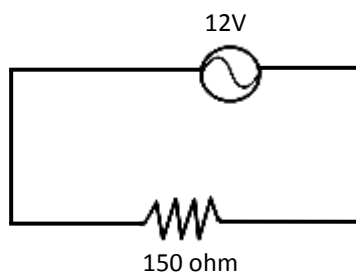
5. A peak voltage of 250V AC is applied across a 30Ω resistor. Find the;

(a) RMS current through the resistor.

(b) average power dissipated in the resistor.

(c) amount of electrical energy (in joules) used after 2 minutes.

6. The circuit below shows a resistor in series with an AC source of electricity which supplies a peak voltage of 12V.



Calculate;

(a) The peak current in the circuit.



- (b) The average power dissipated across the resistor.

-
7. Describe the effect of a capacitor on AC voltage and current.

-
8. What is capacitive reactance?

-
9. Describe the changes to capacitive reactance when the frequency of AC voltage is;

- (a) increased.

- (b) decreased.

-
10. Calculate the capacitive reactance of an AC circuit with a $50\mu\text{F}$ capacitor connected in series to a 50V RMS supply with a frequency of 60Hz.



11. A pure capacitive AC circuit has a capacitive reactance of 425Ω . If the circuit contains a peak current of 25mA at 30Hz , find the;

(a) RMS and peak voltage values.

(b) effective capacitance in the circuit.

-
12. Describe the effect of an inductor on AC voltage and current.

-
13. What is inductive reactance?

-
14. Describe the changes to inductive reactance when the frequency in an AC circuit is;

(a) increased.

(b) decreased.

-
15. Calculate the inductive reactance when a 150mH inductor is connected to a 240V RMS AC voltage at 50Hz .



16. A pure inductive AC Circuit is connected to an inductor of 0.5H . If there is a current of 20mA with frequency 50Hz , calculate the;
- (a) inductive reactance of the circuit.
- (b) RMS and peak voltage across the inductor.

Thank you for completing learning activity 11. Now check your work. Answers are at the end of the module.

Power transmission

Electrical energy for consumption is produced on a large scale using Alternating Current and Voltage. Most power production facilities are located away from populated areas.

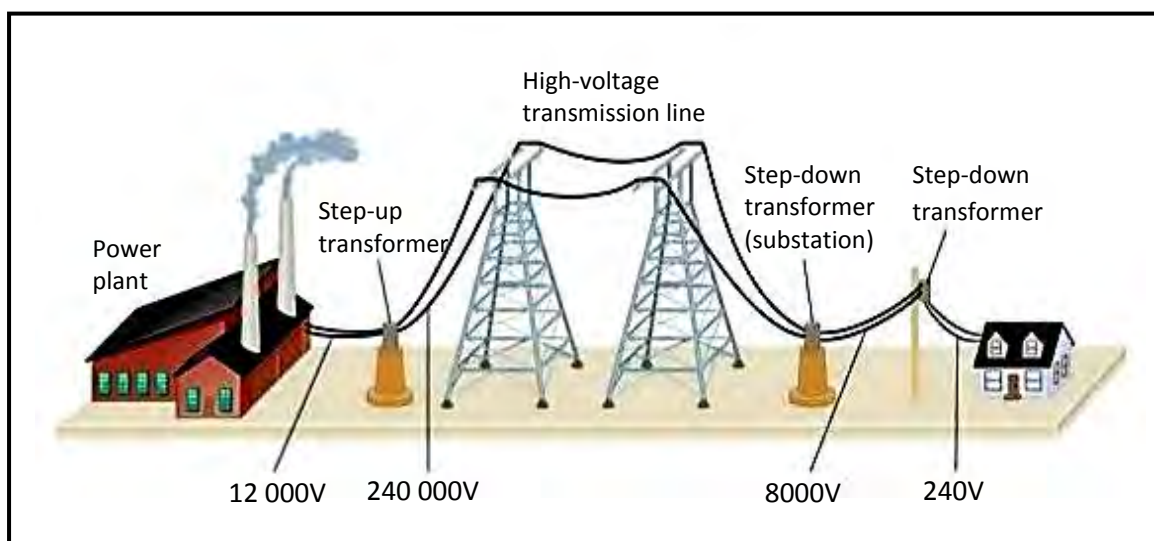


Figure 40. Power transmission from a power station to homes is transmitted at high AC voltages

Power transmission from over long distances must be transmitted in long conducting cables at high voltages to reduce or minimize power loss and voltage drop. This is because the



longer conducting cables have higher resistance. (Remember that resistance is proportional to length).

The objective of power transmission is to get as much power (electrical energy) from production facilities to areas where it can be used. We have to accept that some power will be lost during transmission. Electrical engineers who deal with power transmission deal with power loss by making adjustments so as to minimize the amount of power loss and voltage drop.

To calculate the power loss and voltage drop in power lines we use the following equations.

$$P_{\text{loss}} = I^2 R$$

$$V_{\text{drop}} = IR$$

I is the RMS current in the power lines and **R** is the resistance of the transmission lines due to length and other factors.

From these equations we can observe that

- (a) if we **double the current**, the **power loss increases by a factor of 4** and the **voltage drop doubles**.
- (b) if we **half the current**, we **reduce the power loss by a factor of 4** and **half the voltage drop**.

Thus power is transmitted at high AC voltages so that the amount of power loss and voltage drop is minimized. To prove these facts, let us look at two (2) examples.

Example 34

A consumer receives a power of 30kW at 250V. If the resistance of the transmission lines is 0.75Ω , calculate the;

- (i) current flowing in the lines,
- (ii) voltage drop in the lines,
- (iii) power loss due to the heating effects of electricity.

Solution

- (i) The current flowing is calculated as follows;

$$I = \frac{V}{P}$$

$$I = \frac{30000}{250V} = 120A$$



- (ii) The voltage drop (voltage lost) is calculated as follows;

$$V = IR$$

$$V = 120A \times 0.75\Omega = 90V$$

- (iii) The power loss due to the heating effect of electricity is calculated as follows;

$$P_{\text{loss}} = I^2 R$$

$$P_{\text{loss}} = (120A)^2 \times 0.75\Omega$$

$$P_{\text{loss}} = 10800W = 10.8kW$$

Example 35

Suppose the consumer in Example 28 receives 30kW at 750V. Calculate the;

- (a) current in the transmission lines,
- (b) voltage drop and
- (c) power loss in this case.

Solution

- (a) Current in the transmission lines;

$$\begin{aligned} I &= \frac{P}{V} \\ &= \frac{30000W}{750V} \\ &= 40A \end{aligned}$$

- (b) Voltage drop in the transmission lines;

$$V = IR$$

$$V = 40A \times 0.75\Omega = 30V$$

- (c) The power loss in the transmission lines;

$$P_{\text{loss}} = I^2 R$$

$$P_{\text{loss}} = 40^2 \times 0.75\Omega$$

$$P_{\text{loss}} = 1200W = 1.2kW$$

These two examples illustrate the effectiveness of reducing power loss and voltage drop by transmitting power at high voltages.

Now check what you have just learnt by trying out the learning activity on the next page!

**Learning Activity 12****20 minutes**

Answer the following questions in the spaces provided.

1. Why must we transmit power over long distances at high voltages and low currents?

2. Calculate the power loss when a current of 6A is transmitted over a long wire with a total resistance of 5Ω .

3. A power generation facility situated 20km from a city produces 3MW of electricity for consumption. If the transmission lines from the power facility have a resistance of $0.0025\Omega\text{m}^{-1}$,

(a) calculate the total resistance of the transmission lines.

(b) calculate the current and power loss when this power is transmitted at;

(i) 15kV



(ii) 50kV

Thank you for completing learning activity 12. Now check your work. Answers are at the end of the module.



Summary

You will now revise this module before doing **ASSESSMENT 5**.

Here are the main points. Refer to the module topics if you need more information.

- There are two main types of electric charges; positive charge and negative charge.
- The amount of electric charge (Q) is measured in Coulombs (C).
- The electrostatic force between charges is governed by a law of magnetism which states that like charges repel while unlike charges attract.
- The three (3) main methods of charging objects are;
 - By friction
 - By conduction
 - By induction
- Coulomb's law states that the electrical force between two charged objects (Q_1 and Q_2) is directly proportional to the product of the quantity of charge on the objects and inversely proportional to the square of the separation distance between the two objects. Mathematically, Coulomb's Law is stated as follows;

$$F = \frac{kQ_1Q_2}{d^2}$$

Where Q_1 and Q_2 are the magnitudes of the charges in Coulombs (C), d is the distance between the charges in metres (m) and k is a constant of proportionality with a value of $9.0 \times 10^9 \text{ Nm}^2\text{C}^{-2}$.

- An electric field (E) is an invisible region surrounding a charged object such that any other charged object that enters into this region experiences a force.
- Quantitatively an electric field is defined as the force exerted per unit charge on any charge that enters the electric field. It is a vector quantity and is calculated as;

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

- For any particular object with a charge of Q Coulombs, the Electric field E Newton per Coulomb at a distance of d metres is given by the equation;

$$E = \frac{kQ}{d^2}$$

- The electric potential of a charge V is defined as the amount of energy the charge has depending on its position in an electric field.
- The potential difference of a charge refers to the amount of work that must be done per unit charge to move a charge from one potential to another. It is given by the equation;

$$V = \frac{W}{Q}$$



- The electric potential at a distance d from a charge of Q Coulombs is given by the equation;

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

Electric Potential (V) is also related to Electric field (E) by the equation;

$$V = Ed$$

- Electric Current (I) is measured in Amperes (A) and is defined as the rate of flow of charge. Mathematically;

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

- The two main types of electric current are Direct Current (DC) and Alternating Current (AC).
- Conventional current is defined as the flow of electric charges over time from a region of high potential to a region of low potential.
- Potential difference (V) is the amount of work done per unit charge as a charge moves around a closed circuit. It is measured in Volt (V)
- Resistance (R) is any opposition to the flow of current. It is measured in Ohm (Ω).
- A series circuit consists of a complete path in which there is only one pathway for charges to move around the circuit.
- A parallel circuit is a complete path in which there is more than one pathway for charges to move around the circuit.
- An ammeter is used to measure current in a circuit. It is connected adjacent or beside a circuit component to measure the current passing through the component.
- A voltmeter is used to measure potential difference in a circuit. It is connected parallel to or across the component to measure the voltage across the component.
- In Series circuit, the current value is constant whereas the potential difference is divided among the resistors.
- For n resistors connected in series, the total resistance is;

$$R_T = R_1 + R_2 + \dots + R_n$$

- In a Parallel circuit, the potential difference in two parallel branches is the same but the current in those branches may not necessarily be the same.
- For n resistors connected parallel to each other, the total resistance is;

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$



- Emf (ϵ) is the amount of energy per unit charge stored in a cell when it is in an open circuit. Terminal voltage is the amount of energy per unit charge stored in a cell when the cell is in a closed circuit.
- All sources of emf have some internal resistance which reduces emf to terminal voltage. The relationship between current (I) supplied by a cell, its terminal voltage (V), emf (ϵ) and internal resistance (r) is given by the equation;

$$V = \epsilon - Ir$$

- Cells that are connected in series, give more energy per unit charge, but lower current. Cells connected in parallel, have lower energy per unit charge, but give higher current.
- Ohm's Law gives us a relationship between Current (I), voltage (V) and resistance (R) for a circuit component.

$$R = \frac{V}{I}$$

- On V-I graph, an ohmic conductor is represented by a straight line graph. The gradient of this straight line is the resistance. A non-ohmic conductor is represented by a curve.
- Resistance in a conductor is affected by the following factors;
 - Length of the conductor.
 - Cross sectional Area of the conductor (thickness).
 - Type of material from which the conductor is made (resistivity).
 - Temperature of the material.
- At a constant temperature, the resistivity of a conductor is given by;

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

- The amount of energy (W) in Joules used by a circuit component with a p.d. of V volts across it, I Amps of current in t seconds is given by;

$$W = VIt$$

- The electrical power of a circuit component is the rate at which it converts electrical energy into other forms of energy. It is measured in Watts (W) and can be calculated using the following formulae;

$$P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R}$$

- Kirchhoff's junction rule is a statement of conservation of charge. It states that the amount of charge moving into a junction is equal to the amount of charge leaving the junction.
- Kirchhoff's loop rule is a statement of conservation of energy. It states that the sum of all potentials in a closed loop must be equal to zero.



- Direct Current consists of charges moving in one direction only. Alternating current consists of charges which oscillate (or vibrate). Alternating current is produced by rotating a coil of wire in a magnetic field.
- Peak values of current and voltage are the maximum values that Alternating current and voltage can obtain at a certain time.
- Instantaneous values of current and voltage are the values of current and voltage at any given time. Instantaneous current and voltage are sinusoidal and are given by the following equations;

$$I = I_p \sin(\omega t) = I_p \sin(2\pi f t)$$

$$V = V_p \sin(\omega t) = V_p \sin(2\pi f t)$$

Where ω is the angular velocity of a coil of wire in a magnetic field, f is the frequency of the rotating wire, t is the instantaneous time in seconds and V_p and I_p are peak voltage and current.

- RMS values (or effective values) are the values of the current and voltage in an AC circuit that provide the same amount of power as their DC equivalents.
- RMS values for sinusoidal current and voltage is calculated as follows;

$$I_{\text{RMS}} = \frac{I_p}{\sqrt{2}}$$

$$V_{\text{RMS}} = \frac{V_p}{\sqrt{2}}$$

- Current and voltage are said to be “in phase” when both quantities reach their peak values at the same time. They are said to be “out of phase” when both quantities do not reach their peak values at the same time.
- A pure AC resistive circuit is one where an AC source provides energy for a resistor only. In such circuits, current and voltage are in phase.
- Capacitance (C) is the amount of charge (Q) stored in a capacitor for each unit of potential difference (V). It is measured in Farads (F).
- In pure AC capacitive circuits, current and voltage are out of phase by 90° . Current leads (reaches its peak first) while voltage lags (reaches its peak after).
- Capacitive reactance (X_c) is a measure of the effect of a capacitor on an AC circuit. It is measured in Ohms and is dependent on frequency.
- Inductance is a measure of resistance to a change in direction of current. It is measured in Henry (H).
- In a pure AC inductive circuit the current and voltage are out of phase by 90° . Voltage leads (reaches its peak first) while current lags (reaches its peak after).
- Inductive reactance (X_L) is the measure of the effect of an inductor on an AC circuit. It is measured in Ohms and is dependent on frequency.
- Electricity is produced and distributed by Alternating Current.



-
- AC has the advantage of being easy to produce on a large scale cheaply and being able to increase or decrease voltage to reduce power loss during transmission.
-

We hope you have enjoyed studying this module. We encourage you to revise well and complete Assessment 5.

**NOW YOU MUST COMPLETE ASSESSMENT 5 AND RETURN
IT TO THE PROVINCIAL CENTRE CO-ORDINATOR)**

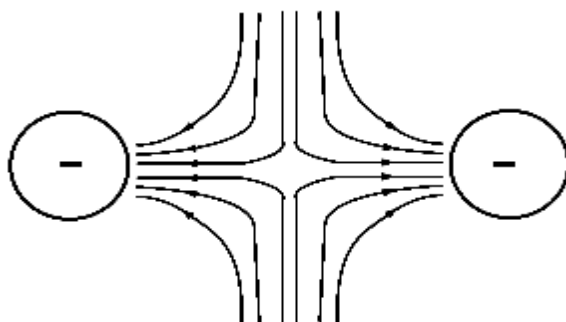
**Answers to Learning Activities 1 - 12**

Learning Activity 1

1.
 - a. P is a positive charge.
 - b. (ii) Force between Q and R.
 - c. Because charge Q and R are closer together.
 - d. To double the force between Q and R, the following can be done;
 - multiply the charge on Q only by 4. (i.e. quadruple its value)
 - multiply the charge on R only by 4 (i.e. quadruple its value)
 - half the distance Y.
 - e. If we double the distance X, we will reduce the force between P and Q to a quarter of its current value.
 2.
 - a. 3N repulsive force
 - b. 0.00389N attractive force
 - c. 0.05N repulsive force
 3. 4.24m
 4. 0.00005C
-

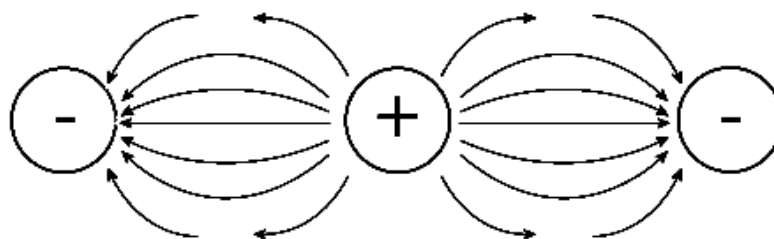
Learning Activity 2

1. (Explain in your own words) As a guide, the key ideas are;
 - An electric field is invisible influence surrounding any charged object
 - A force will be experienced by other non-zero charges that enter this field.
2.
 - (a)





(b)



3. 24NC^{-1}
4. 1.2N
5.
 - a. $18\,000\,000\text{NC}^{-1}$
 - b. $20\,000\,000\,000\text{NC}^{-1}$
 - c. $864\,000\,000\text{NC}^{-1}$
6. 0.3m

Learning Activity 3

1. (Explain in your own words) as a guide, the key ideas are;
 - Electric potential is energy possessed by a charge.
 - It depends on the position of the charge within an electric field.
2. When two positive charges are brought close together, their potential increases because each is moving in a direction that is opposite to the electric field exerted by both charges.
3. The difference between them is that electric potential depends on the position of a charge in an electric field and is always present for charges. Potential difference only occurs when charges change position, i.e. there is a change in potential.
4. 0.0048J

Learning Activity 4

1.
 - a. 12A
 - b. 6A
 - c. 1A
 - d. 0.8A
2.
 - a. 0.5C
 - b. 8C
 - d. 0.125C
 - d. 0.9C
3. 40V
4.
 - a. 0.6J
 - b. 0.2A



5. An ammeter is used to measure current. To measure the current through any component, we must always connect the ammeter in series to the component.
 6. A voltmeter is used to measure voltage. To measure the voltage across any component, we must always connect the voltmeter across (or parallel) to the component.
 7.
 - a. To measure the current through R, an ammeter can be connected at all points a, b, c or d since this circuit is a series circuit.
 - b. Voltmeter terminals can be connected at either at a and b or at a and c only to measure the p.d. across R.
 8.
 - a. 40Ω
 - b. 1.621Ω
 - c. 8.22Ω
 - d. 10.43Ω
 - e. 4Ω
 - f. 4.55Ω
 9.
 - a. $0.9k\Omega = 900\Omega$
 - b. $0.015A = 15mA$
 - c. $0.5k\Omega \rightarrow 7.5V$, $0.1k\Omega \rightarrow 1.5V$, $0.3k\Omega \rightarrow 4.5V$
 10.
 - a. $0.12k\Omega = 120\Omega$
 - b. $0.125A$
 - c. $0.3k\Omega \rightarrow 15V$, $0.05A$, $0.2k\Omega \rightarrow 15V$, $0.075A$
-

Learning Activity 5

1. Emf is the amount of voltage (energy per unit charge) when a cell is not supplying current to a circuit. The terminal voltage is the voltage supplied by a cell when it is supplying current to a circuit. It is lower than emf because of internal resistance in a cell.
 2. A cell produces potential difference and current by chemical reaction. A battery is simply a collection of one or more cells connected together.
 3. 0.3Ω
 4. $1.25A$
-

Learning Activity 6

1. Ohmic resistors follow Ohm's Law, where at a constant resistance, the relationship between voltage and current is proportional. Non-Ohmic resistors do not show such a proportional relationship between voltage and current.
 2.
 - a. R_C , R_B , R_A
-



- b. On V-I graphs lines which are straight and steepest belong to ohmic resistors with high values of resistance.
- c. (i) $R_A = 4.5\Omega$, (ii) $R_B = 2.5\Omega$ (iii) $R_C = 1.5\Omega$
3. $0.2k\Omega$
4. $0.00008A = 80mA$
-

Learning Activity 7

1. a. $86400J$ b. $6A$ c. 40Ω
2. a. $0.015A$
b. $0.5k\Omega \rightarrow 0.1125W$, $0.1k\Omega \rightarrow 0.0225W$, $0.3k\Omega \rightarrow 0.0675W$
c. $0.2025W$
-

Learning Activity 8

1. (a) $18A$, (b) $-0.08A$, (c) $-1.7\mu A$
2. $I = 0.44A$, Potential drops: (a) 2.5Ω ; $1.09V$, (b) 3Ω ; $1.30V$, (c) 6Ω ; $2.61V$
3. For 4Ω : $I = 0.79A$, $3.16V$, For 10Ω : $I = 0.88A$, $8.8V$, For 2Ω : $I = 0.09A$, $0.18V$
-

Learning Activity 9

1. A Galvanometer is an instrument that detects very tiny amounts of current that an ammeter would not detect. It is used in a Wheatstone bridge circuit to measure the current between two branches on a bridge circuit.
2. A Balanced Bridge means that the potential difference between two opposite branches is zero (or the potentials are equal). When this occurs, current does not flow from one branch to the other.
3. I. FALSE, this only happens if all 4 resistors have the same value.
II. TRUE, current splits into two at the junction entering the bridge.
III. FALSE, this only happens if all 4 resistors have the same value.
IV. FALSE, only true if all the resistors have the same value.
V. TRUE, if potential difference is the same, no current is detected by the galvanometer.
-



-
4. (a) $R_x = 30\Omega$ (b) $R_x = 1000\Omega$ (c) $R_x = 65.63\Omega$
5. A potentiometer is a circuit that is used to measure an unknown emf source by comparison with a known emf source.
6. Sliding contact varies resistance and potential.
1. $V_x = 8.125V$
2. $V_x = 1.36V$
-

Learning Activity 10

1. In DC, charges move in one direction only because polarity (position of high and low potential) is constant. In AC, the polarity changes (reverses) every few seconds, so the charges tend to have an oscillatory (vibration-type) of motion.
2. The two main reasons for using AC over DC are;
- a. AC generators produce electricity more cheaply and reliably.
- b. AC voltage can be stepped-up or down using transformers. Stepping up voltage is necessary to minimize power loss over transmission lines.
3. (a) 251.32 rad/s (b) $0.025s$
- (c) i. maximum at $0.00625s$
- ii. minimum at $0.01875s$
4. a. $237.05V, 9.88A$ b. $108.96V, 4.54A$
- c. $-169.71V, -7.07A$ d. $-74.16V, -3.09A$
5. Practically, RMS voltage and current are those values of AC that supply the same amount of power as their DC equivalents.
-

Learning Activity 11

1. $339.41V$
2. $169.71V, 212.13mA$
3. a. $339.41V, 141.42mA$ b. 2400Ω c. $24W$
4. $3.6W$
5. a. $5.89A$ b. $1041.67W$ c. $125\,000J$
-



6. a. 0.08A b. 1.92W
 7. A capacitor causes AC voltage to lag behind AC current.
 8. Capacitive reactance is a measure of the effect of a capacitor on an AC circuit.
 9. a. When AC frequency is increased, X_C decreases.
b. When AC frequency is decreased, X_C increases.
 10. 53.05Ω
 11. a. $V_{PEAK} = 10.625V$, $V_{RMS} = 7.51V$
b. $12.5\mu F$
 12. An inductor causes voltage to lead current.
 13. Inductive Reactance is a measure of the effect of an inductor on an AC circuit.
 14. a. When AC frequency increases, X_L increases.
b. When AC frequency decreases, X_L decreases.
 15. 47.12Ω
 16. a. 157.08Ω b. $V_{PEAK} = 4.44V$, $V_{RMS} = 3.14V$
-

Learning Activity 12

1. Power must be transmitted at high voltages and low currents over long distances in order to minimize power loss.
 2. 180W
 3. a. 50Ω
b. i. $P_{LOSS} = 2\text{ MW}$, $V_{DROP} = 10\text{ kV}$
ii. $P_{LOSS} = 180\text{ kW}$, $V_{DROP} = 3\text{ kV}$
-

If you have queries regarding the answers, then please visit your nearest FODE provincial centre and ask a distance tutor to assist you.



References

“Electrical Resistance”, http://en.wikipedia.org/wiki/Electrical_resistance_and_conductance

GIANCOLI, D.C., (1985), PHYSICS PRINCIPLES WITH APPLICATIONS, 2nd Edition, PRENTICE-HALL, LONDON, United Kingdom

KORIMAS. M & SOTO. R., (2005), A TEXT FOR FIRST YEAR PHYSICS AT UNIVERSITY OF PAPUA NEW GUINEA, Revised ed., University of Papua New Guinea, Port Moresby

POPLE, S, (1982), EXPLAINING GCSE PHYSICS, OXFORD UNIVERSITY PRESS, OXFORD, United Kingdom

“Resistance”, <http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>

TSOKOS, K.A., (2008) PHYSICS FOR IB DIPLOMA, 5th EDITION, CAMBRIDGE UNIVERSITY PRESS, CAMBRIDGE, United Kingdom

YONG, P.L., (2006), PACIFIC PHYSICS A LEVEL, Volume 2, PANPAC EDUCATION LTD, SINGAPORE

FODE PROVINCIAL CENTRES CONTACTS

PC NO.	FODE PROVINCIAL CENTRE	ADDRESS	PHONE/FAX	CUG PHONES	CONTACT PERSON		CUG PHONE
1	DARU	P. O. Box 68, Daru	6459033	72228146	The Coordinator	Senior Clerk	72229047
2	KEREMA	P. O. Box 86, Kerema	6481303	72228124	The Coordinator	Senior Clerk	72229049
3	CENTRAL	C/- FODE HQ	3419228	72228110	The Coordinator	Senior Clerk	72229050
4	ALOTAU	P. O. Box 822, Alotau	6411343 / 6419195	72228130	The Coordinator	Senior Clerk	72229051
5	POPONDETTA	P. O. Box 71, Popondetta	6297160 / 6297678	72228138	The Coordinator	Senior Clerk	72229052
6	MENDI	P. O. Box 237, Mendi	5491264 / 72895095	72228142	The Coordinator	Senior Clerk	72229053
7	GOROKA	P. O. Box 990, Goroka	5322085 / 5322321	72228116	The Coordinator	Senior Clerk	72229054
8	KUNDIAWA	P. O. Box 95, Kundiawa	5351612	72228144	The Coordinator	Senior Clerk	72229056
9	MT HAGEN	P. O. Box 418, Mt. Hagen	5421194 / 5423332	72228148	The Coordinator	Senior Clerk	72229057
10	VANIMO	P. O. Box 38, Vanimo	4571175 / 4571438	72228140	The Coordinator	Senior Clerk	72229060
11	WEWAK	P. O. Box 583, Wewak	4562231/ 4561114	72228122	The Coordinator	Senior Clerk	72229062
12	MADANG	P. O. Box 2071, Madang	4222418	72228126	The Coordinator	Senior Clerk	72229063
13	LAKE	P. O. Box 4969, Lae	4725508 / 4721162	72228132	The Coordinator	Senior Clerk	72229064
14	KIMBE	P. O. Box 328, Kimbe	9835110	72228150	The Coordinator	Senior Clerk	72229065
15	RABAU	P. O. Box 83, Kokopo	9400314	72228118	The Coordinator	Senior Clerk	72229067
16	KAVIENG	P. O. Box 284, Kavieng	9842183	72228136	The Coordinator	Senior Clerk	72229069
17	BUKA	P. O. Box 154, Buka	9739838	72228108	The Coordinator	Senior Clerk	72229073
18	MANUS	P. O. Box 41, Lorengau	9709251	72228128	The Coordinator	Senior Clerk	72229080
19	NCD	C/- FODE HQ	3230299 Ext 26	72228134	The Coordinator	Senior Clerk	72229081
20	WABAG	P. O. Box 259, Wabag	5471114	72228120	The Coordinator	Senior Clerk	72229082
21	HELA	P. O. Box 63, Tari	73197115	72228141	The Coordinator	Senior Clerk	72229083
22	JIWAKA	c/- FODE Hagen		72228143	The Coordinator	Senior Clerk	72229085

FODE SUBJECTS AND COURSE PROGRAMMES

GRADE LEVELS	SUBJECTS/COURSES
Grades 7 and 8	1. English
	2. Mathematics
	3. Personal Development
	4. Social Science
	5. Science
	6. Making a Living
Grades 9 and 10	1. English
	2. Mathematics
	3. Personal Development
	4. Science
	5. Social Science
	6. Business Studies
	7. Design and Technology- Computing
Grades 11 and 12	1. English – Applied English/Language & Literature
	2. Mathematics - Mathematics A / Mathematics B
	3. Science – Biology/Chemistry/Physics
	4. Social Science – History/Geography/Economics
	5. Personal Development
	6. Business Studies
	7. Information & Communication Technology

REMEMBER:

- For Grades 7 and 8, you are required to do all six (6) subjects.
- For Grades 9 and 10, you must complete five (5) subjects and one (1) optional to be certified. Business Studies and Design & Technology – Computing are optional.
- For Grades 11 and 12, you are required to complete seven (7) out of thirteen (13) subjects to be certified. Your Provincial Coordinator or Supervisor will give you more information regarding each subject and course.

GRADES 11 & 12 COURSE PROGRAMMES

No	Science	Humanities	Business
1	Applied English	Language & Literature	Language & Literature/Applied English
2	Mathematics A/B	Mathematics A/B	Mathematics A/B
3	Personal Development	Personal Development	Personal Development
4	Biology	Biology/Physics/Chemistry	Biology/Physics/Chemistry
5	Chemistry/ Physics	Geography	Economics/Geography/History
6	Geography/History/Economics	History / Economics	Business Studies
7	ICT	ICT	ICT

Notes:

You must seek advice from your Provincial Coordinator regarding the recommended courses in each stream. Options should be discussed carefully before choosing the stream when enrolling into Grade 11. FODE will certify for the successful completion of seven subjects in Grade 12.

CERTIFICATE IN MATRICULATION STUDIES

No	Compulsory Courses	Optional Courses
1	English 1	Science Stream: Biology, Chemistry, Physics
2	English 2	Social Science Stream: Geography, Intro to Economics and Asia and the Modern World
3	Mathematics 1	
4	Mathematics 2	
5	History of Science & Technology	

REMEMBER:

You must successfully complete 8 courses: 5 compulsory and 3 optional.