RTB | RWANDA TVET BOARD

RQF LEVEL 3

GENBE302

NETWORKING AND INTERNET TECHNOLOGIES

Basics of Electricity

TRAINEE'S MANUAL

October, 2024

RTB | RWANDA TVET BOARD

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TABLE OF CONTENT

ACRONYMS

AC: Alternative Circuit
BE: Basics of Electricity
DC: Direct current
EMF: Electromotive force
GEN: General
IC: Indicative Content
ICT: Information, Communication and Technology
LO: Learning outcome
MINEDUC: Ministry of Education
PPE: Personal Protective Equipment
RP: Rwanda Polytechnic
RTB: Rwanda TVET Board
TQUM Project: TVET Quality management
TVET: technical vocation and education training

INTRODUCTION

This trainee's manual includes all the knowledge and skills required in Network and Internet Technologies specifically for the module of **"Basics of Electricity".** Trainees enrolled in this module will engage in practical activities designed to develop and enhance their competencies. The development of this training manual followed the Competency-Based Training and Assessment (CBT/A) approach, offering ample practical opportunities that mirror real-life situations.

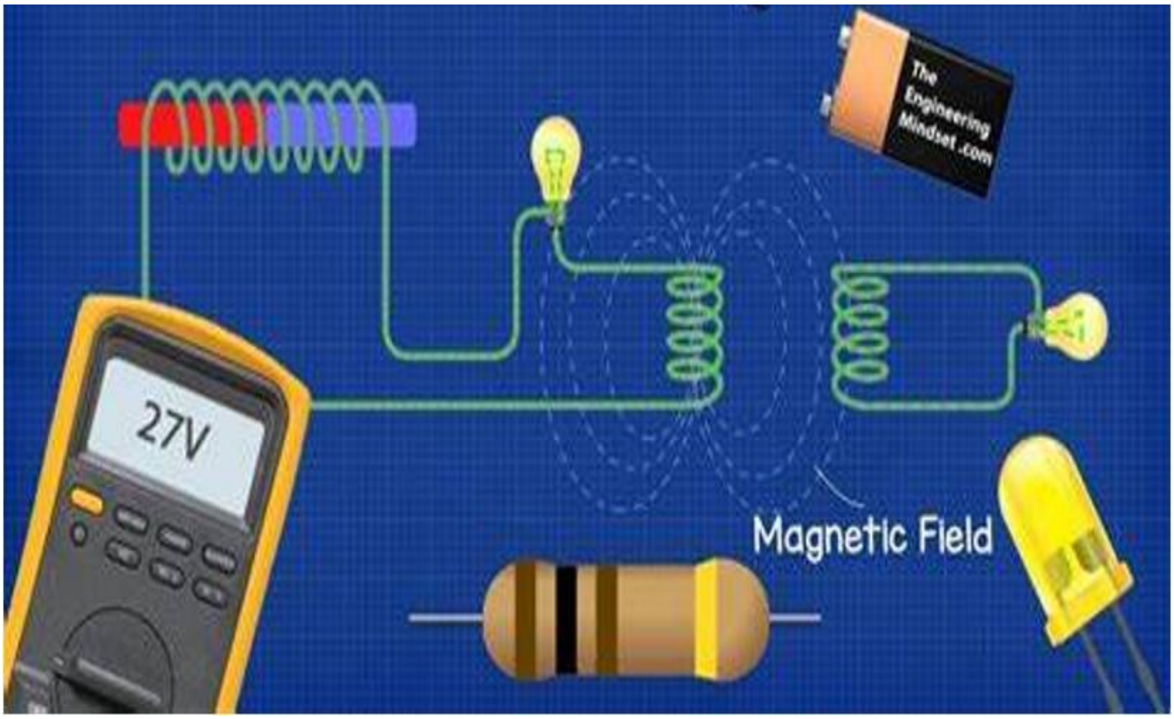
The trainee's manual is organized into Learning Outcomes, which is broken down into indicative content that includes both theoretical and practical activities. It provides detailed information on the key competencies required for each learning outcome, along with the objectives to be achieved.

As a trainee, you will start by addressing questions related to the activities, which are designed to foster critical thinking and guide you towards practical applications in the labor market. The manual also provides essential information, including learning hours, required materials, and key tasks to complete throughout the learning process.

All activities included in this training manual are designed to facilitate both individual and group work. After completing the activities, you will conduct a formative assessment, referred to as the end learning outcome assessment. Ensure that you thoroughly review the key readings and the 'Points to Remember' section.

MODULE CODE AND TITLE: GENBE302 BASICS OF ELECTRICITY

Learning Outcome 1: Apply basic concepts of electricity
Learning Outcome 2: Perform domestic electrical installations
Learning Outcome 3: Prepare Technical Report and Invoice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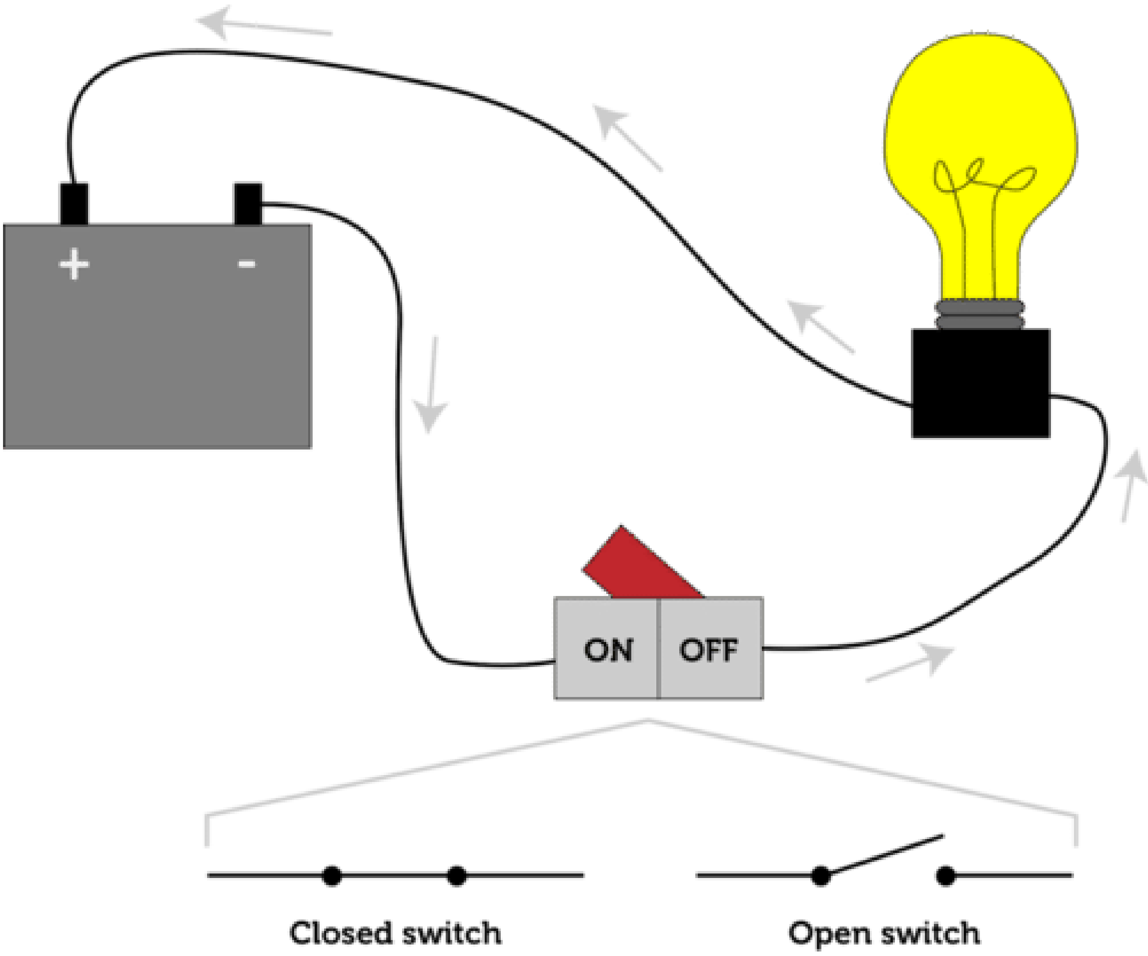
The Engineering Mindset.com
Magnetic Field


+
-
ON
OFF
Closed switch
Open switch

Indicative contents
1.1 Introduction to electricity **1.2 Identification of different electrical quantities** **1.3 Identification of electrical waveforms** **1.4 Identification of DC circuits laws and Theorems** **1.5 Identification of resonant circuits** **1.6 Introduction to magnetism and electro-magnetism** **1.7 Identification of transformers**

Key Competencies for Learning Outcome 1: Apply basic concepts of electricity

Knowledge	Skills	Attitudes
● Description of electrical quantities ● Description of electrical signals ● Description of DC circuits laws and theorems ● Description of Resonant circuits ● Description of magnetism and electro-magnetism ● Description of types of transformers	● Interpreting electric circuit ● Drawing of electric circuits ● Applying Measurement and instrumentation ● Calculation of electrical quantities ● Applying electrical quantities	● Having an innovative ● Having Creativity ● Having Critical thinking ● Having Teamwork ● Being Problem Solver ● Being Patient ● Having Punctuality ● Having Curiosity ● Being Honest

Duration: 35 hrs

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Introduce correctly the electricity according to the concepts of electricity
2. Identify properly electrical quantities according to their types.
3. Identify clearly types of electrical signals according to their characteristics.
4. Describe correctly DC circuits laws and theorems according to their applications
5. Identify properly the resonant circuits according to their types
6. Describe correctly magnetism, electromagnetism concepts and transformers according to magnetism and electromagnetism concepts
7. Describe correctly different types of transformers according to the magnetism and electromagnetism concepts

Resources

Equipment	**Tools**	**Materials**
● PPE ● Multimeter ● Clamp-on meter ● Megohmmeter wattmeter ● Phase sequence tester	● Electrical tool kit ● Drawing tool kit ● Calculator	● Electric wires ● Transformers ● Resistors ● Capacitors ● Inductors ● Lamps ● DC/AC power supply

Indicative content 1.1: Introduction to Electricity

Duration: 2

Theoretical Activity 1.1.1: Introduction to electricity

Tasks:

1: Answer the following questions related to the introduction to electricity.

i. What do you understand by the term electricity?
ii. Differentiate two types of electricity, static and dynamic.
iii. What are the sources of electricity
iv. What is an electric circuit?
v. What are the uses of electricity
vi. What are the hazards associated with electricity? What are the causes?
vii. How can one prevent electrical hazards?

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 1.1.1.**

5: In addition, ask questions where necessary.

Key readings 1.1.1.: Introduction to electricity

1. Definition

Electricity is the flow of electrical charge through a conductor.

2. Types of Electricity

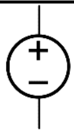
There are mainly two types of electricity.

2.1. Static electricity: It is when electrical charges develop on the surface of the material. It is usually caused by friction when two or more than two materials are rubbed together. Then, as a result, static electricity builds up and due to this these objects may be attracted to each other or may even cause a spark.

2.2. Current electricity: Current is the rate of flow of electrons in a conductor, usually a copper wire. This current is what is used for electric power.

There are two main types of electric current namely Direct current (DC) and Alternating current (AC).

A. **Direct Current (DC):** DC electricity flows continuously in one direction. It maintains a constant voltage and is commonly produced by batteries and solar cells. DC is mostly used in electronic devices.
Its symbol is shown in the figure below



B. **Alternating Current (AC):** AC electricity alternates direction periodically, typically in a sinusoidal waveform. It is the standard form of electricity in most electrical grids and is used in residential, commercial, and industrial power distribution.

Its symbol is shown in the figure below

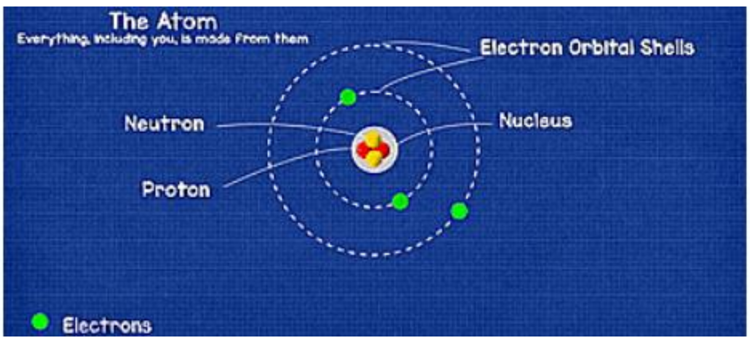
3. Source of Electricity

There are different sources of current electricity including the chemical reactions taking place in batteries. The most common source of current electricity is the generator (alternator). A simple generator produces electricity when a copper coil turns inside the magnetic field. In a power plant, electromagnets spinning inside many coils of copper wire generate huge quantities of current electricity.

4. How electricity works

4.1. Atoms

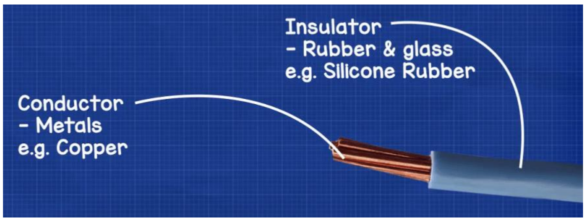
Everything is made from Atoms. At the centre of an Atom is the Nucleus, this houses two particles known as the Neutron and Proton. The Neutron has no electrical charge but the Proton has a positive electrical charge. The Nucleus becomes surrounded by negatively charged particles known as Electrons. Surrounding the Nucleus are different layers of orbital shells which act like flight paths for another type of particle known as the electron. The electrons travel long these paths much like satellites orbit around our planet, except that the electrons travel at almost the speed of light.



The negative charge of the neutrons is attracted to the positive charge of the Proton which keeps the electrons in orbit thus maintains equilibrium within the atom. Each orbital shell can hold a set number of electrons. The number of Protons, Neutrons and Electrons an Atom has tells us which material it is and the combination is unique for each material.

4.2. Conductors and insulators

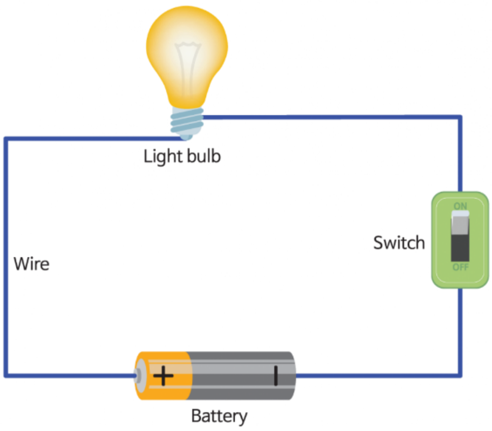
Materials which can pass electrons are known as “Conductors” meaning they can conduct electricity. Most Metals are conductors. Atoms which do not have free electrons are known as insulators, materials like glass and rubber are good examples of this. Conductors and Insulators are combined together to safely use electricity. This is done by surrounding the conductor with an insulator, this allows electrons to flow but it restricts where they can flow to. This is how a cables and wires work.



4.3. Circuit

The term circuits refers to a route which the electrons can flow along to get between the two terminals of the power source (Positive and Negative). When a circuit is closed then electrons can flow from one terminal to the other. When a circuit is open then there is a gap in the circuit so electrons can't flow.

We can place electrical components in the path of the free electrons which flow in a circuit. This will force the electrons to flow through the component and this can be used to perform work such as generate light.



5. Uses of Electricity

Electricity is an essential part of modern life and it helps us in many different ways. In the modern era, we are nothing without electricity. The major areas where we use electricity include:

1. Home Uses

When talking about household uses of electricity, we can immediately think of lighting, entertainment, cooking and heating water and working from home on computers and running other devices.

2. Safety in the Community

Electricity reduces the isolation of rural areas from other areas and safety is also achieved through the provision of external lighting, alarm systems, and even traffic lights, as electricity is the most important element for achieving security in homes, cities, and major areas.

3. **Medical Uses**

The use of electricity led to reaching the treatment of many diseases through the use of electrical therapy devices, and the operation of electrical machines and equipment when performing surgical operations, in addition to their ability to photograph the internal organs in the body through the use of X-rays, CT scans, MRIs, which led to a reduction in the death rate.

4. **Agricultural Productivity**

Electricity helps increase farmers 'productivity, as it allows farmers to operate electrical machinery, in addition to its role in helping them to use their time and make better use of them, obtain greater production quantities, develop irrigation strategies for them, and the level of their agricultural activities.

5. **Transportation and Entertainment**

Electricity helped provide rapid transportation, such as fast electric trains, and entertainment such as radio, television, cinema,

With electricity, some modern equipment, such as computers and robots that facilitated human life has been developed.

6. **Social Interaction**

Electricity is useful for activating communication in isolated rural areas with the surrounding external world, where people in these areas are isolated, as they do not have phones or any other type of communication device, which gives them the opportunity to communicate with other cities, besides helping these areas in an emergency, or If they need help.

7. **Industrial Growth**

The use of electrical machines increased in the current era, which led to an increase in the production of multiple commodities, and the ability to operate machines in all industries, whether large or small, which contributed to the growth of industries and improving the condition of members of society.

8. **Commercial sector**

The use of electricity in the commercial sector includes heating, cooling, and lighting for buildings and commercial squares, in addition to the electricity used by companies and commercial centres in all parts of cities for computers, fax machines, copying and printing machines, elevators and electrical drawers as well and many more.

6. Electrical Hazards

Electrical hazards refer to the potential dangers and risks that are associated with electrical systems. These hazards can cause dangers such as burns, electrocution, arc flash, electric shock, and other serious injuries. In extreme cases, they can even lead to fires or explosions, posing a threat to life, property, and the overall safety of a place and its occupants.

6.1. Example of electrical hazards

A. electrocution,
B. short circuits
C. arc flash,
D. electric shock,
E. burns,
F. and other serious injuries

6.2. Causes of Electrical Hazards

Electrical hazards, while dangerous, can be prevented when you're aware of the factors that contribute to them. Here's a list of the most common causes of electrical hazards:

Insufficient or damaged insulation: Over time, electrical insulation can deteriorate due to wear and tear, rodents, or exposure to moisture. This degradation can lead to exposed wires and increase the risk of electric shock or short circuits.

Circuit breaker failure: If the circuit breaker fails to trip during an overload, it loses its protective functioning, further increasing the risk of electrical hazards.

Exposure Damaged electrical appliances, Tools and Equipment: Loose connections, frayed wires, or cracked insulation can result in electrical malfunctions.

Improper use of extension cords: Practices like daisy chaining and overloading can cause overheating and ignite electrical fires.

Overhead Power Lines: Overhead powered and energized electrical lines have high voltages which can cause major burns and electrocution to workers.

Inadequate Wiring and Overloaded Circuits: Using wires of inappropriate size for the current can cause overheating and electrical fires to occur.

Exposed Electrical Parts: Examples of exposed electrical parts include temporary lighting, open power distribution units, and detached insulation parts on electrical cords. These hazards can cause potential shocks and burns.

No or Improper Grounding: Removing or disconnecting the metallic ground pin responsible for returning unwanted voltage to the ground increases the risk of electrocution.

Wet Conditions: Water greatly increases the risk of electrocution especially if the equipment has damaged insulation.

Inadequate maintenance – Failing to regularly inspect electrical systems, ignoring warning signs, or bypassing safety procedures can trigger severe electrical hazards over time.

6.3. Ways of preventing electrical hazards

A. Use the correct wire suitable for the operation and the electrical load to work on. Use the correct extension cord designed for heavy-duty use.
B. Make sure to not overload an outlet and use proper circuit breakers.

C. Thoroughly check for cracks, cuts, or abrasions on cables, wires, and cords. In case of any defects, have them repaired or replaced.
D. Do not fix any damaged electrical appliances, Tools and Equipment unless you are qualified to do so.
E. Turn off all power sources before replacing damaged insulation and never attempt to cover them with electrical tape.
F. Secure electrical appliances, Tools and Equipment with proper guarding mechanisms.
G. Remember to maintain a minimum distance of 10 feet from overhead power lines and nearby equipment and ensure that nothing is stored under overhead power lines.
H. Ensure proper grounding to eliminate unwanted voltage and reduce the risk of electrocution.
I. Never operate electrical equipment in wet locations. Have a qualified electrician inspect electrical equipment that has gotten wet before energizing it.
J. Conduct regular electrical inspections to avoid electrical hazards in the workplace.

Points to Remember

- Electricity is the flow of electrical charge through a conductor, which can be static or current. This current electricity is what is used for electric power.
- Direct current is like the energy you are getting from a battery. Whereas an Alternating current is from alternator.
- Conductors and Insulators are combined together to form electric cables to safely use electricity.
- The electric circuit is the route which the electrons can flow along to get between the two terminals of the power source (Positive and Negative). A circuit is closed and opened to control the electrons' flow.
- Electricity is an essential part of modern life and it helps us in many different ways from lighting, powering of electronic devices and other heavy equipment.
- Even though electricity is useful to human being, it can also presents hazards (potential dangers and risks). However, these hazards can be prevented when you're aware of their causes and ways of preventing them.

Application of learning 1.1.

Observe the electrical system in your school or at your home, take pictures and report areas you found that might cause electrical hazards.

Indicative content 1.2: Identification of Different Electrical Quantities

Duration: 3

Theoretical Activity 1.2.1: Description of Electric quantities

Tasks:

1: Answer the following questions related to the electric quantities

i. What do you understand electric quantities?

ii. Describe the following basic quantities:

a) Electric charge
b) Electric current
c) Electrical potential (Voltage)
d) Electromotive force (e.m.f)
e) Resistance
f) Conductance
g) Electrical Power
h) Electrical Energy

iii. What is Ohm's law?

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key readings 1.2.1.

5: In addition, ask questions where necessary.

Key readings 1.2.1.: Description of Electric quantities

Electric Quantities

Electrical quantities are the physical properties that can be measured or calculated in electrical and electronic circuits. These electrical quantities used to analyse circuits are electric charge, electric current, voltage, resistance, conductance, electric power and electrical energy.

1. Description of Electric Charge

Electric charge or simply charge is the property of subatomic particles like protons and electrons. The electric charge is denoted by symbol Q or q and measured in Coulombs (C). The electric charge has two types 1) Positive charge – carried by a proton 2) Negative charge – carried by a electron

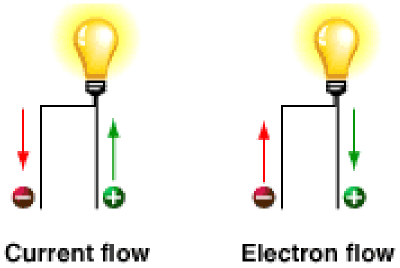
In the nature, the smallest amount of charge that exists is the charge carried by an electrons, denoted by *e*, where it is equal to 1.6×10^{-19}C. Though, a proton also carries a charge of 1.6×10^{-19}C, but it is positive.

2. Description of Electric current

As seen in key readings 1.1.1., Current is the rate of flow of electrons in a conductor.

For solid conductors, electric current refers to directional negative-to-positive electrons from one atom to the next. Whereas, for liquid conductors and gas conductors, electric current refers to electrons and protons flowing in the opposite direction.

Current is the flow of electrons, but current and electron flow in the opposite direction. Current flows from positive to negative and electrons flow from negative to positive.



In SI, the current is measured in **amperes**, which is abbreviated "**amps**". The symbol for amps is a letter "**A**". Amps are represented in equations by the letter "I". This amp is defined as the number of electrons passing through a cross-section area of a conductor in one second.

For example, A current of **one amp** means that charges of one coulomb (or 6.241×10^{18} electrons) passing through a cross-section point of a conductor in one second.

Effects of Electric Current

When a current flows through a conductor, there are a number of signs which tell if a current is flowing or not. Following are the most prominent signs:

A. Heating Effect of Electric Current

When an electric current flows through a conductor, heat is generated in the conductor. The heating effect ''H'' depends on the following factor, 1) The time for which the current flows ''t'', 2) The electrical resistance of the conductor ''R'' and 3) The amount of current ''I''. As a result, the heating effect is given by the formula

$H=I^2Rt$

This means that H is directly proportional to the three factors. The longer the time, higher resistance and large amount of current, the higher the heat.

B. Magnetic Effect of Electric Current

Another prominent effect that is noticeable when an electric current flows through the conductor is the build-up of the magnetic field. We can observe this when we place a compass close to a wire carrying a reasonably large direct current, and the compass needle deflects.

The magnetic field generated by a current is put to good use in a number of areas. By winding a wire into a coil, the effect can be increased, and an electromagnet can be made.

C. Chemical Effect of Electric Current

When an electric current passes through a chemical solution, the solution ionises and breaks down into ions. Depending on the nature of the solution and the electrodes used, the following effects can be observed in the solution:

1. Change in the colour of the solution
2. Metallic deposits on the electrodes
3. Release of gas or production of bubbles in the solution

3. Description of Voltage

Voltage is defined as the amount of potential energy between two points on a circuit. One point has more charge than another. Basically, the voltage can be considered as the electric pressure that forces the electric charge to flow in an electric circuit. If the work done in moving a unit positive charge (Q) from one point to another in the electric field is W, then the voltage between two points is given by,

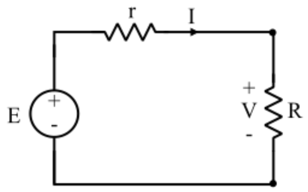
$$Voltage\ (V) = \frac{Work\ done\ (W)}{Charge\ (Q)}$$

Where, W is the work done measured in joules (J) and Q is the charge in Coulombs (C). Thus, the voltage is measured in Joules per Coulomb (J/C). However, in practice, we measure the voltage in volts with the symbol of letter "V"

4. Description of Electromotive force (EMF)

Electromotive force is the energy per unit electric charge which an energy source (battery or generator) imparts. The EMF is denoted by the letter 'E'. The SI unit of EMF is the same as the voltage, which is **Volts**.

$E = I\ (R + r)$ or $E = V + Ir)$



5. Description of Resistance

5.1. General overview

Resistance (also known as ohmic resistance or electrical resistance) is a measure of how difficult it is for electric current to flow through a material (the opposition to current flow in an electrical circuit). Resistance, denoted in equation as "R" is measured in ohms, symbolised by the Greek letter omega (Ω).

When the potential difference is applied to a conductor, the current starts flowing, or the free electrons start moving. While moving, the free electrons collide with the atoms and molecules of the conductor. Due to collision or obstruction, the rate of flow of electrons or electric current is restricted. Hence, we can say that there is some opposition to the flow of electrons or current. Thus, this opposition offered by a substance to the flow of electric current is called resistance.

The larger/higher resistance, the greater the barrier against the flow of current. From this, Good conductors have low resistance, while insulators have high resistance.

The resistance of conducting material is:

1. directly proportional to the length of the material
2. inversely proportional to the cross-sectional area of the material
3. depends on the nature of the material
4. It depends on the temperature

Mathematically, the resistance of a conducting material can be expressed as,

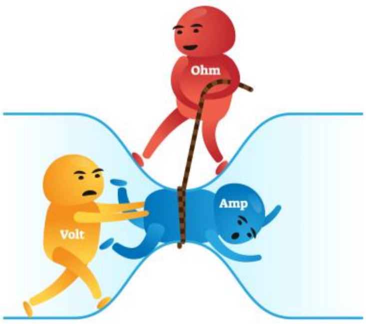
$$R = \frac{\rho * L}{A}$$

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

Where R = resistance of the conduct, L = length of the conductor, ρ= constant of proportionality of the material known as specific resistance or resistivity of the material and A = cross-sectional area of the conductor.

5.2. Ohm's Law

Ohm's law is a fundamental principle in electrical engineering that describes the relationship between electric current, voltage, and resistance.



Ohm's Law defines this relationship and can be stated in three ways

1. Applied voltage equals circuit current times the circuit resistance. The following equation is a mathematical representation of this concept. V = I x R

2. Current is equal to the applied voltage divided by the circuit resistance. The following equation is a mathematical representation of this concept. I = V / R

3. Resistance of a circuit is equal to the applied voltage divided by the circuit current. The following equation is a mathematical representation of this concept. R (or Ω) = V / I

6. **Description of conductance**

6.1. General overview

Conductance, or electrical conductance, measures a material's ability to conduct electricity, essentially showing how easily an electrical current can flow through it. It is the opposite of electrical resistance, mathematically expressed as 1/R. Conductance is expressed as G and the measuring unit was "mho". Later after a few years, researchers replaced the unit with “**Siemens**” which was denoted by the letter **S**.

As G is the opposite of R, the conductance is:

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

Where I = is the current, V = Voltage

$$G = \frac{A * \sigma}{L}$$

Where A = cross-sectional area of the conductor, **σ** is the conductivity expressed as Siemens per meter, L = length of the conductor.

6.2. Conductivity

A conductor’s conductance depends on several factors including its form, dimensions and the material’s property called its conductivity.

Conductivity is attributed to the ability of a material to transfer energy. It quantifies the effect of matter on current flow in response to an electric field. It is also understood as a material property that determines the density of the conductive current in response to an applied electric field.

Conductivity is expressed as **σ** and measured as Siemens per meter.

7. Description of Power

Electrical Power is defined as the rate at which work is done on an electrical system. As we know, doing work generates energy. Thus, power can be given as the rate of consumption of electrical energy. It is denoted by “P”.

Mathematically, the electric power is given by,

$$P = \frac{Work\ done\ (W)}{Time\ (t)}$$

Where, W is work done measured in Joules (J) and t in time in seconds (s). Thus, the unit of electric power is Joules per second (J/s). But, in practice, we use the SI unit of power that is Watt (W).

As power deals with the rate of consumption or generation thus, it is referred to as energy consumed/generated per unit time. Now we are aware that work done is given the product of Voltage and charge. Hence,

$$P = \frac{Voltage\ (V) * Charge\ (Q)}{Time\ (t)}$$

Since Current equals Charge over time, hence, the electric power is simply the product of the voltage across a circuit element and the current flowing through the element.

$$P = Voltage\ (V) * Current\ (I)$$

8. Description of Electrical Energy

8.1. General overview

Energy is the capacity or the ability for doing work. Same as for electricity, electrical energy is defined as the overall work done over a certain period of time in an electric circuit. Electric energy is denoted as "E".

The equation for electrical energy is the following: **E = P x t**

As Power = W/t, therefore E = W*t/t, then E = W

The amount of work done by energy is equal to moving an amount of "Q" coulombs of charges by "V" volts of voltage: **W = V*Q**

From Ohms' law, **V = IR** and thus on substituting the value of V, we get **W = I*R*Q**

We know **I = Q/t**, So **Q = I*t** Thus on substituting the value of Q, we get **$E = I^2 * R * t$**

Now again, put the value of I = V/R (Ohm's law),

Therefore, energy is given as **$E = V^2 t/R$**

The unit of electrical energy is Joule or Watt – Second. However, It is a very basic and small unit, for this reason Why (Watt-hour) or kWh (kilo-watt-hour) is used for commercial application to measure the consumption of electrical energy through energy metering.

8.2. Considerations in Electrical Energy consumption

It cannot be denied that human activities nowadays are significantly dependent on electricity energy. Many electronic devices, electric appliances relies on consuming electricity energy thus the need for economic use of electrical energy is a paramount consideration.

As the energy depends on power over a given time, You pay for the energy used. The more electric appliances you use, the more the power is required. Moreover, the longer they are left switched on, the higher electrical energy consumed. For example, the more lamps turned on and or, more computers plugged, the greater **P** used; the longer they are on, the greater **t** is. Thus the more energy consumed.

The energy unit on electric bills is the kilowatt-hour written as **kW/h** consistent with the relationship **E = Pt**. It is easy to estimate the cost of operating electric appliances if you have some idea of their power consumption rate in watts or kilowatts, the time they are on in hours, and the cost per kilowatt-hour for your electric utility.

Practical Activity 1.2.2: Application on electrical quantities

Task:

1: Referring to previous activity (1.2.1) you are requested to perform the given task. The task should be done individually.

i. Determine the p.d. which must be applied to a 2kΩ resistor in order that a current of 10mA may flow.

ii. What is the resistance of a coil which draws a current of (a) 50mA and (b) 200µA from a 120V supply?

iii. Calculate the power dissipated when a current of 4mA flows through a resistance of 5k.

iv. An electric heater consumes 3.6MJ when connected to a 250V supply for 40 minutes. Find the power rating of the heater and the current taken from the supply.

2: List out procedures and formulas to be used to perform the given tasks (1.2.1).

3: Referring to procedures and formulas provided on task 2, Perform the given tasks

4: Present your work to the trainer and whole class

5: Read key reading 1.2.2 and ask clarification where necessary

6: Perform the task provided in application of learning 1.2

Key readings 1.2.2: Application on electrical quantities

Resistance in electrical circuit is given by the following formula

by Ohm's law R=V/I

by Pouillet law

R=$\frac{\rho l}{A}$ $(ohms)$

by temperature variation $R_\theta = R_0(1 + \alpha_0\theta)$ and If the resistance of a material at room temperature (approximately 20°C), R_{20}, and the temperature coefficient of resistance at 20°C, α_{20}, are known then the resistance R_0 at temperature 0°C is given by: $R_\theta = R_{20}[1 + \alpha_{20}(\theta - 20)]$ $R_\theta = R_{20}](1 + \alpha_{20(}\theta - 20)]$

The power sources such as generator, battery, etc. are used to produce EMF.

The EMF can be given by, E=I(R+r) ⇒E=V+Ir.

Power deals with the rate of consumption or generation thus, it is referred to as energy consumed/generated per unit time.

W = VQ **P = VQ/t**

Thus **P = VI** Thus **P = I^2R**

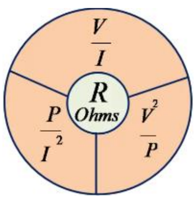
Therefore, **P = V^2t/R**

The work done will be: **W = VQ** **W = VI. t** **E= I^2R. t**

Thus **E = V^2t/R**

Points to Remember

- The relationship between resistance, voltage and power



- **Electric current:** Electrical current is the flow of charged particles. **I = V/R**

- **Electrical potential:** The potential difference is the amount of energy utilized by one coulomb of charge.
- **Electromotive force (e.m.f):** Electromotive force is defined as *the electric potential produced by either an electrochemical cell or by changing the magnetic field.* EMF is the commonly used acronym for electromotive force.

  V =IR
- **Power:** Electrical Power is defined as the rate at which work is done on an electrical system or is given by the product of potential difference V and current I, The unit of power is **watt (W)**. Hence $P = V X I$ **w]**

  P = VI , P = I2R , P = V2t/R
- **Energy:** If the power is measured in watts and the time in seconds then the unit of energy is watt-seconds or joules. If the power is measured in kilowatts and the time in hours then the unit of energy is kilowatt-hours, often called the 'unit of electricity'. The 'electricity meter' in the home records the number of kilowatt-hours used and is thus an energy meter.

  Electrical energy= Power x Time
- **Resistance:** The flow of electric current is subject to friction

  $$\textbf{Resistance R} = \frac{\textbf{Potential difference}}{\textbf{Current}}$$
- **Conductance *(G):*** is the reciprocal of resistance. Whereas resistance of a conductor measures the *opposition* which it offers to the flow of current, the conductance measures the inducement which it offers to its flow.

  $$\mathbf{G} = \frac{1}{R}$$

Application of learning 1.2.

1. A 100 W electric light bulb is connected to a 250 V supply. Determine (a) the current flowing in the bulb, and (b) the resistance of the bulb.
2. An electric kettle has a resistance of 30Ω. What current will flow when it is connected to a 240 V supply? Find also the power rating of the kettle.
3. A 12 V battery is connected across a load having a resistance of 40Ω. Determine the current flowing in the load, the power consumed, and the energy dissipated in 2 minutes.
4. Determine the power dissipated by the element of an electric fire of resistance 20Ωwhen a current of 10 A flows through it. If the fire is on for 6 hours, determine the energy used and the cost if 1 unit of electricity costs 7p.

Indicative content 1.3: Identification of Electrical Waveforms

Duration:4 hrs

Theoretical Activity 1.3.1: Description of electrical waveforms

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of electrical waveforms

i. What are types of electrical signals waveforms

ii. List components of electrical signals waveforms

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 1.3.1.**

5: In addition, ask questions where necessary.

Key readings 1.3.1.: Description of electrical waveforms

1. Waveform

AC electricity is a type of electricity which alternates its direction in a back-and-forth motion, While direct current (DC) electricity flows in one direction through a wire,The direction alternates between 50 and 60 times per second, depending on the electrical system of the country.

AC generator

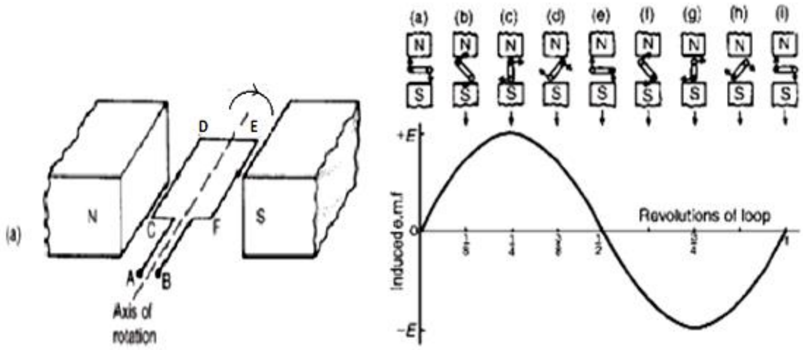


Figure 1 a) A single turn coil rotating between two magnets **b) Waveforms**

Let a single turn coil be free to rotate at constant angular velocity symmetrically between the poles of a magnet system as shown in Figure 1.a). An e.m.f. is generated in the coil (from Faraday's Laws) which varies in magnitude and reverses its direction at regular intervals. The reason for this is shown in Figure 1.b).

.In positions (a), (e) and (i) the conductors of the loop are effectively moving along the magnetic field, **no flux is cut and hence no e.m.f. is induced.**

. In position (c) **maximum flux is cut and hence maximum e.m.f. is induced.**

.In position (g), **maximum flux is cut and hence maximum e.m.f. is again induced.** However, using Fleming's right-hand rule, the induced e.m.f. is in the opposite direction to that in position (c) and is thus shown as -E.

. In positions (b), (d), (f) and (h) **some flux is cut and hence some e.m.f. is induced**.

If all such positions of the coil are considered, in one revolution of the coil, one cycle of alternating e.m.f. is produced as shown. This is the principle of operation of the ac generator (i.e. the alternator).

Waveforms

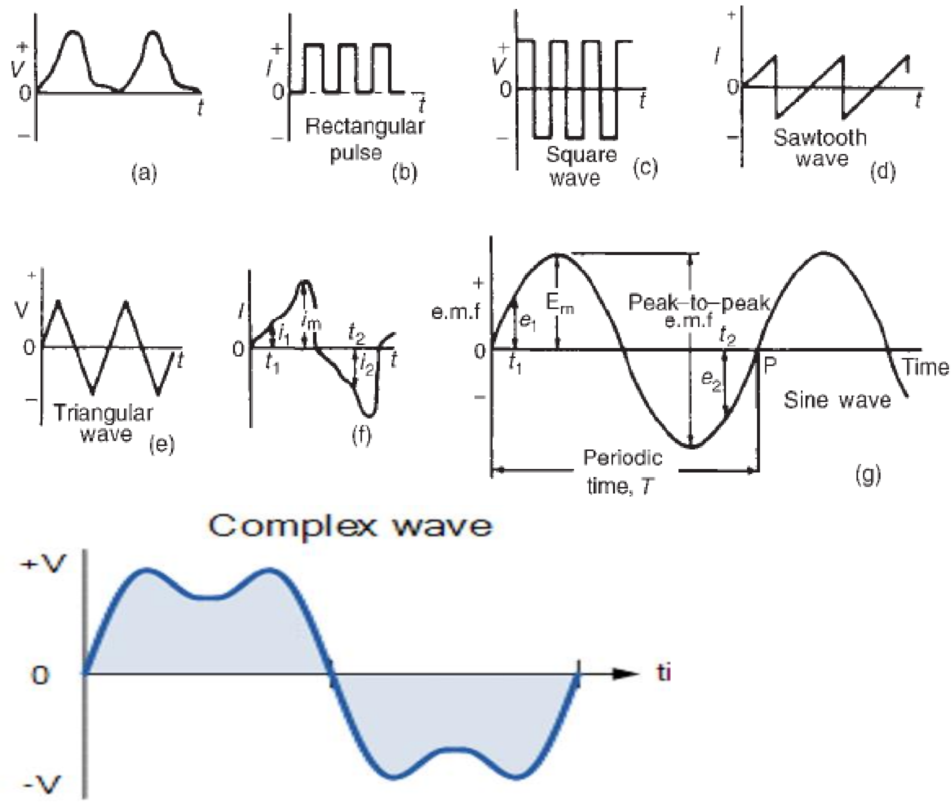


Figure 2: Types of electric signal waveforms

a) **SQUARE WAVEFORM:** The square waveform also called a pulse train, or pulse wave is a periodic waveform consisting of instantaneous transitions between two levels.

b) **TRIANGULAR WAVEFORM:** The triangular waveform shows the signal that is sent to the solenoid coil of the system. The signal varies in three ways: polarity, frequency, and amplitude.

c) **COMPLEX WAVEFORM:** A complex waveform varies from instant to instant but can be resolved into a number of sine-wave components, each of a different frequency and probably of different amplitude.

d) **SINUSOIDAL WAVEFORM:** The sine wave or sinusoid is a mathematical function that describes a smooth repetitive oscillation. It is a continuous uniform wave with a constant frequency and amplitude.

If values of quantities which vary with time t are plotted to a base of time, the resulting graph is called a **waveform**.

Uni-directional Waveforms –these electrical waveforms are always positive or negative in nature flowing in one forward direction only as they do not cross the zero-axis point. Common uni-directional waveforms include Square-wave timing signals, Clock pulses and Trigger pulses.

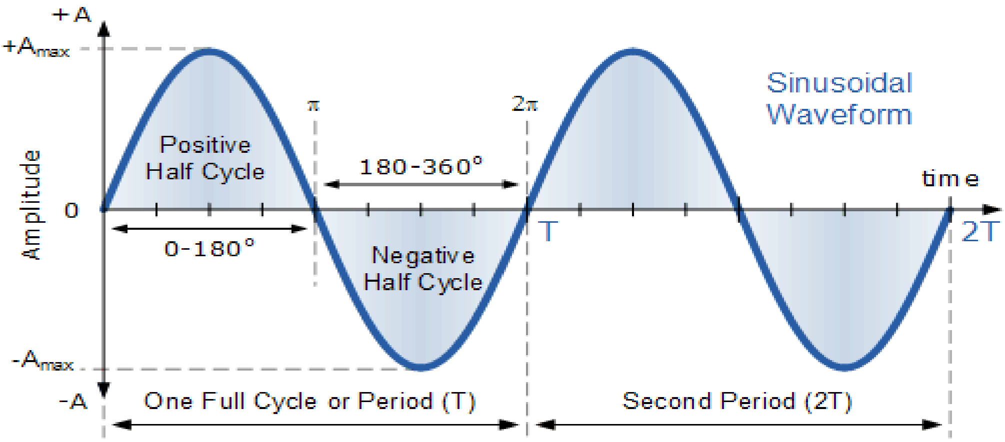
Bi-directional Waveforms–these electrical waveforms are also called alternating waveforms as they alternate from a positive direction to a negative direction constantly crossing the zero-axis point. Bi-directional waveforms go through periodic changes in amplitude, with the most common by far being the Sine-wave.

Some typical waveforms are shown in Figure 2.

· Waveforms (a) and (b) are **unidirectional waveforms**, for, although they vary considerably with time, they flow in one direction only (i.e. they do not cross the time axis and become negative).

· Waveforms (c) to (g) are called **alternating waveforms** since their quantities are continually changing in direction (i.e. alternately positive and negative). A waveform of the type shown in Figure 2 (g) is called a **sine wave**. It is the shape of the waveform of e.m.f. produced by an alternator and thus the mains electricity supply is of '**sinusoidal form'**.

A Sine Wave Waveform



Units of periodic time, (T) include Seconds (s), milliseconds (ms), and microseconds (µs).

For sine wave waveforms only, we can also express the periodic time of the waveform in either degrees or radians, as one full cycle is equal to 360o (T = 360o) or in Radians as 2pi, 2π (T = 2π), then we can say that 2π radians = 360o – (Remember this!).

We now know that the time it takes for electrical waveforms to repeat themselves is known as the periodic time or period which represents a fixed amount of time. If we take the reciprocal of the period, (1/T) we end up with a value that denotes the number of times a period or cycle repeats itself in one second or cycles per second, and this is commonly known as Frequency with units of Hertz, (Hz). Then Hertz can also be defined as "cycles per second" (cps) and 1Hz is exactly equal to 1 cycle per second.

Both period and frequency are mathematical reciprocals of each other and as the periodic time of the waveform decreases, its frequency increases and vice versa with the relationship between *Periodic time* and *Frequency* given as.

Relationship between Frequency and Periodic Time

$$\textbf{Frequency} = \frac{1}{Periodic\ time} \quad \text{or } f = \frac{1}{T}\ Hz$$

$$\textbf{Periodic time} = \frac{1}{Frequency} \quad \text{or } T = \frac{1}{f}\ sec$$

Where: ƒ is in Hertz and T is in Seconds.

One Hertz is exactly equal to one cycle per second, but one hertz is a very small unit so prefixes are used that denote the order of magnitude of the waveform such as kHz, MHz, and even GHz.

2. Properties of Alternating Current

One complete series of values is called a **cycle** (i.e. from O to P in Figure 2 (g)). Basic properties of alternating current include the following list

a. Period: The time taken for an alternating quantity to complete one cycle is called the **period** or the **periodic time (*T*)**, of the waveform. In the figure 2. g) It is the time taken from O to P.

$$T = \frac{1}{f} \quad \text{or } f = \frac{1}{T}\ sec$$

b. Frequency: The number of cycles completed in one second is called the **frequency**, ***f***, of the supply and is measured in **hertz** **(Hz)**. The standard frequency of the electricity supply in Great Britain is 50 Hz.

c. Wavelength: The Greek letter (lambda) is used to represent wavelength in mathematical expressions. Thus, **= c/f**

Where **c: speed of light=3.10^{8} m/s**, **f: frequency in Hertz**. As shown in the figure, It is very similar to period as discussed above, except that wavelength is measured in distance per cycle where period is measured in time per cycle.

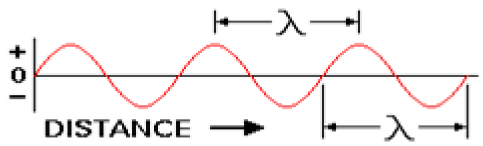


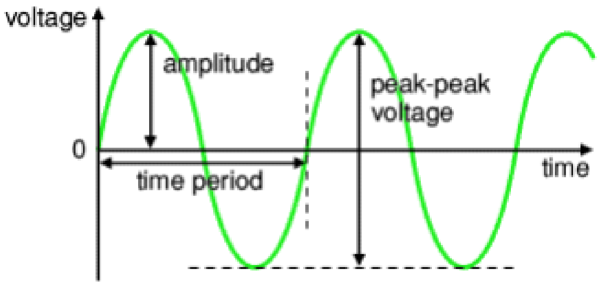
Figure 3

d. Amplitude: the *amplitude* of a sine wave is the value of that sine wave at its peak.

This is the maximum value, positive or negative, that it can attain

3. Components of electric signal waveforms (Period, Frequency, Current, Voltage, amplitude)

- **Period:** – This is the length of time in seconds that the waveform takes to repeat itself from start to finish. This value can also be called the *Periodic Time*, (T) of the waveform for sine waves, or the *Pulse Width* for square waves.
- **Frequency:** – This is the number of times the waveform repeats itself within a one-second time period. Frequency is the reciprocal of the time period, (ƒ = 1/T) with the standard unit of frequency being the *Hertz*, (Hz).
- **Amplitude:** – This is the magnitude or intensity of the signal waveform measured in volts or amps.



An electrical signal is a voltage or current which conveys information, usually it means a voltage. The term can be used for any voltage or current in a circuit.
The voltage-time graph on the right shows various properties of an electrical signal. In addition to the properties labelled on the graph, there is frequency which is the number of cycles per second. The diagram shows a sine wave but these properties apply to any signal with a constant shape.

• **Amplitude** is the magnitude or intensity of the signal waveform measured in volts or amps.

• **Peak voltage** is another name for amplitude.

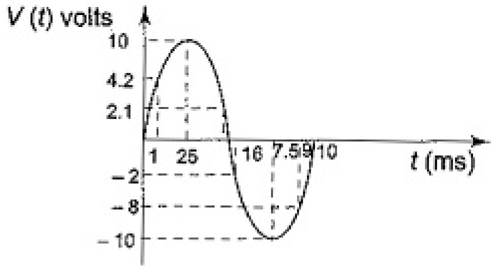
• **Peak-peak voltage** is twice the peak voltage (amplitude). When reading an oscilloscope trace it is usual to measure peak-peak voltage.

• **Time period** is the time taken for the signal to complete one cycle. It is measured in seconds (s), but time periods tend to be short so milliseconds (ms) and microseconds (µs) are often used. 1ms = 0.001s and 1µs = 0.000001s. This value can also be called the *Periodic Time*, (T) of the waveform for sine waves, or the *Pulse Width* for square

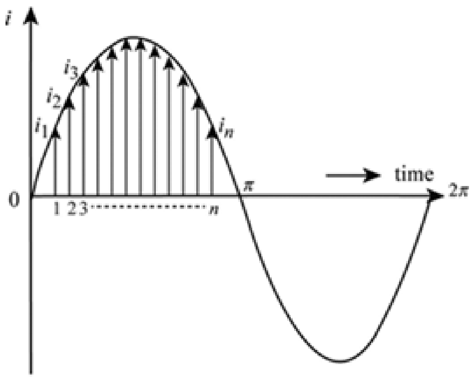
• **Frequency** is the number of cycles per second. This is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, (ƒ = 1/T) with the standard unit of frequency being the **Hertz** (Hz), but frequencies tend to be high so kilohertz (kHz) and megahertz (MHz) are often used.

Where 1kHz = 1000 Hz and 1MHz = 1000000Hz.

• **Instantaneous value:** The instantaneous value is "the value of an alternating quantity (it may ac voltage or ac current or ac power) at a particular instant of time in the cycle". There are uncountable number of instantaneous values that exist in a cycle.
At any given time, it has some instantaneous value. This value is different at different points along the waveform.



In Figure above, during the positive cycle, the instantaneous values are positive and during the negative cycle, the instantaneous values are negative. In Fig. 4.12 shown at time 1 ms, the value is 4.2 V; the value is 10 V at 2.5 ms, – 2 V at 6 ms and – 10 V at 7.5 and so on.
Consider the single cycle alternating current wave in Figure below:



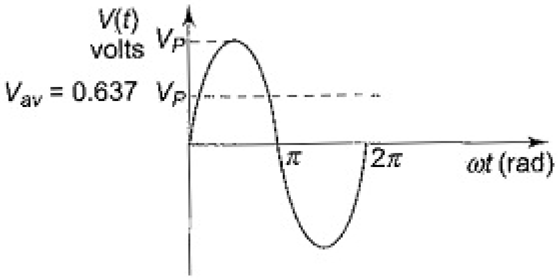
The instantaneous value at t=1 is i1
At t = n is, in
The average value for one alternation (0 to π) is

$$iavg = \frac{i1 + i2 + i3 + \cdots \dots \dots + in}{n}$$

• **Average value:** The average value is defined as "the average of all instantaneous values during one alternation". That is, the ratio of the sum of all considered instantaneous values to the number of instantaneous values in one alternation period.
Whereas the average value for the entire cycle of alternating quantity is zero. Because the average value obtained for one alteration is a positive value and for another alternation is a negative value. The average values of these two alternations (for the entire cycle) cancel each other and the resultant average value is zero. So, the average value of a sine wave is defined over a half-cycle, and not a full cycle period.

$$Vav = \frac{2Vp}{\pi} = 0.637\ Vp$$

The average value of a sine wave is shown by the dotted line in Figure below:



$$Average\ or\ mean\ value = \frac{area\ under\ the\ curve}{length\ of\ base}$$

For a sine wave, average value=0.637xmaximum value (i.e 2/π x maximum value)

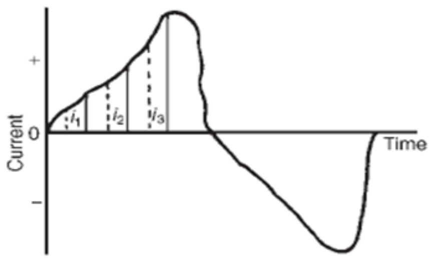
• **RMS (Root Mean Square) value:** The Root Mean Square (RMS) value is "the square root of the sum of squares of means of an alternating quantity".

It can also express as "the effect produced by a certain input of AC quantity which is equivalent to an effect produced by the equal input of DC quantity".

Consider one example, the heat produced by a resistor when one ampere direct current (DC) passed through it, is not an equal amount of heat produced when one ampere of alternating current (AC) passed through the same resistor. Since the AC current is not constant value rather than it is varying with the time. The heat produced by AC quantity (equal amount of DC quantity) is nothing but RMS value of an alternating parameter or quantity.

$Vrms = \frac{Vp}{\sqrt{2}} = 0.707\ Vp$ **or**

$$irms = \frac{imax}{\sqrt{2}} = 0.707\ Vp$$



I= $\sqrt{\frac{i^2 1 + i^2 2 + \ldots\ldots\ldots + i^2 n}{n}}$

For a sine wave, rms value = 0.707 x maximum value (i.e. $\frac{1}{\sqrt{2}}$ **x maximum value)**

Form factor = $\frac{rms\ value}{average\ value}$ **For a sine wave, form factor =1.11**

Peak factor = $\frac{maximum\ value}{rms\ value}$ **For a sine wave, peak factor =1.41**

• Peak Factor: The peak factor of any waveform is defined as the ratio of the peak value of the wave to the rms value of the wave.

Peak factor = $\frac{Vp}{Vrms}$

Peak factor of the sinusoidal waveform = $\frac{Vp}{\frac{Vp}{\sqrt{2}}} = \sqrt{2 = 1.414}$

• Form Factor: Form factor of a waveform is defined as the ratio of rms value to the average value of the wave.

From factor = $\frac{Vrms}{Vav}$

Form factor of a sinusoidal waveform can be found from the above relation.

For the sinusoidal wave,

The form factor = $\frac{Vp/\sqrt{2}}{0.637\ Vp} = 1.11$

Sine function

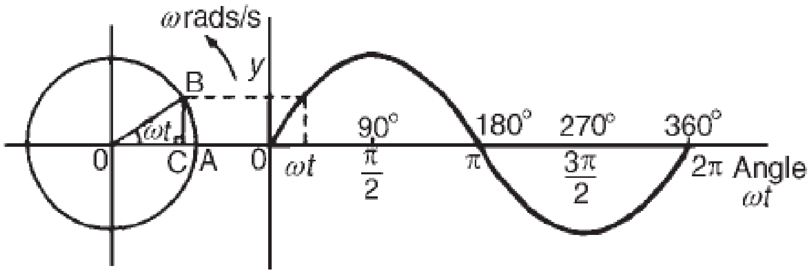


Figure 5

In Figure 5, OA represents a vector that is free to rotate anticlockwise about 0 at an angular velocity of ω rad/s. A rotating vector is known as a **phasor**. After time t seconds the vector OA has turned through an angle ωt. If the line BC is constructed perpendicular to OA as shown, **then Sin ωt** = $\frac{BC}{OB}$ **i.e BC = OB Sin ωt**

If all such vertical components are projected onto a graph of y against angle ωt (in radians), sine curve results of maximum value OA, A sine curve may not always start at 0°. To show this a periodic function is represented by

y = sin (ωt ± ϕ),

Thus, any quantity which varies sinusoidally can be represented by:

y = $A_m$sin (ωt ± ϕ)

Where:

- **A_m**: Amplitude or maximum value
- **2 A_m:** Peak to peak value
- **ω [rad/s]**: Angular velocity

T=2π/ ω[S]: Periodic time

f= ω /2π [Hz]: Frequency

ϕ: phase angle [angle of lag or lead (compared with **y = sin (ωt)**]

3. LEADING AND LAGGING FUNCTIONS

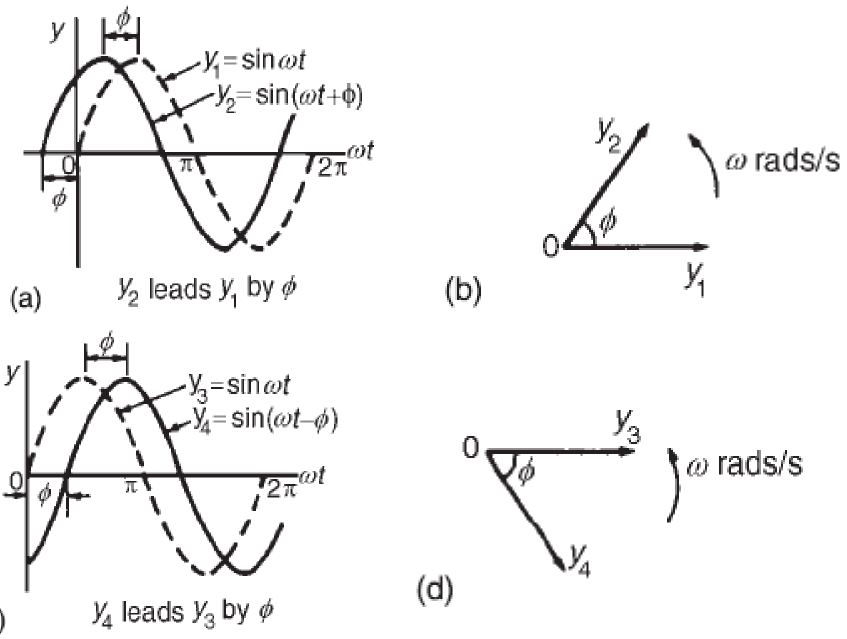


Figure 6

In Figure 6 (a), $\mathbf{y_2}$ **= sin (ωt+ϕ)** starts **ϕ radians earlier** than $\mathbf{y_1}$ **= sin ωt** and is thus said **to lead** y_1 by ϕ radians. Phasors y_1 and y_2 are shown in Figure 6(b) at the time when t= 0.

In Figure 6(c), $\mathbf{y_4}$ **= sin (ωt+ ϕ)** starts **ϕ radians later** than $\mathbf{y_3}$ **= sin ωt** and is thus said **to lag** y_3 by ϕ radians. Phasors y_3 and y_4 are shown in Figure 6(d) at the time when t= 0.

Practical Activity 1.3.2: Apply Calculation on electrical waveforms

Task:

Task1: Referring to previous activity (1.3.1) you are requested to perform the given task. The task should be done individually.

i. An alternating current completes 4 cycles in 5ms. What is its frequency?

ii. Determine the peak and mean values for a 240V mains supply.

iii. An alternating voltage is given by v=75sin(200πt-0.25) volts. Find (a) the amplitude, (b) the peak-to-peak value, (c) the r.m.s. value, (d) the periodic time, (e) the frequency, and (f) the phase angle (in degrees and minutes) relative to 75sin200πt.

Task2: List out procedures and formulas to be used to perform the given tasks (1.3.2).

Task3: Referring to procedures and formulas provided on task 2, Perform the given tasks.
Task4: Present your work to the trainer and whole class
Task5: Read key reading **1.3.2** and ask clarification where necessary Perform the task provided in application of learning **1.3**

Key readings 1.3.2: Apply Calculation on electrical waveforms

The number of cycles completed in one second is called the frequency, f, of the supply and is measured in hertz, Hz.

$$T = \frac{1}{f} \quad \text{or } f = \frac{1}{T}$$

Instantaneous values are the values of the alternating quantities at any instant of time. They are represented by small letters, i, v, e, etc.,

The largest value reached in a half cycle is called the peak value or the maximum value or the crest value or the amplitude of the waveform. Such values are represented by Vm, Im, Em, etc..

A peak-to-peak value of e.m.f. is the difference between the maximum and minimum values in a cycle.

The average or mean value of a symmetrical alternating quantity, (such as a sine wave), is the average value measured over a half cycle, (since over a complete cycle the average value is zero)

Average or mean value= $\frac{Area\ under\ the\ curve}{Length\ of\ base}$

For a sine wave: Average value = 0.637 x maximum value (i.e 2/$\sqrt{\pi}$ x maximum value

The effective value of an alternating current is that current which will produce the same heating effect as an equivalent direct current. The effective value is called the root mean square (r.m.s.) value and whenever an alternating quantity is given, it is assumed to be the rms value. The symbols used for r.m.s. values are I, V, E, etc. For a non-sinusoidal waveform the r.m.s. value is given by:

$$I=\sqrt{\frac{i^2 1+i^2 2+\ldots\ldots+i^2 n}{n}}$$

For a sine wave: Average value = 0.707 x maximum value (i.e 1/$\sqrt{2}$ x maximum value

Form factor=$\frac{r.m.s\ value}{average\ value}$ **For a sine wave, form factor = 1.11**

Peak factor=$\frac{Maximum\ value}{r.m.s\ value}$ **For a sine wave, peak factor = 1.41**

- **y = sin (ωt ± ϕ),**

Thus, any quantity which varies sinusoidally can be represented by:

$y = A_m \sin(\omega t \pm \phi)$

Where,

A_m: Amplitude or maximum value

2 A_m: Peak to peak value

ω [rad/s] : Angular velocity

T=2π/ ω[S]: Periodic time

f= ω /2π [Hz]: Frequency

ϕ: phase angle [angle of lag or lead (compared with **y = sin (ωt)**

Points to Remember

- Amplitude is the same as maximum value or crest value
- Angular velocity ω= 2πf
- Frequency f=1/T
- **$y = A_m \sin(\omega t \pm \phi)$**

Application of learning 1.3.

An alternating voltage, v, has a periodic time of 0.01s and a peak value of 40V. When time t is zero, v=-20V. Express the instantaneous voltage in the form **v=VmSin(ωtø).**

Indicative content 1.4: Identification of DC Circuits Laws and Theorems

Duration:8 hrs

Theoretical Activity 1.4.1.1: Description of DC circuits laws

Tasks:

Task 1: In small groups, you are requested to answer the following questions related to the description of DC circuits laws and Theorems.

i. Describe Ohm's law
ii. Describe Series, parallel and mixed connection of resistors, capacitors and inductors.
iii. Describe Kirchhoff's laws

Task 2: Provide the answer for the asked questions and write them on papers.

Task 3: Present the findings/answers to the whole class

Task 4: For more clarification, read the key **readings 1.4.1.**

Task 5: In addition, ask questions where necessary.

Key readings 1.4.1.1: Description of DC circuits laws

- **Description of DC circuits laws**

1. Introduction

A network is an interconnection of elements, components, input signals, and output signals. The networks are of two types, i.e active network and passive network. An active network contains one or more sources of supply whereas a passive network does not contain any source of supply voltage or current.

2. Electrical Circuit Network Analysis

Electric circuits can be DC circuits, AC circuits, or a combination of both. In practical applications, we use both AC and DC circuits involving inductors, capacitors, and resistors. Depending on the application, the number of passive components (resistors, inductors, and capacitors) in the circuit varies.

Electrical circuit network analysis can be defined as the process by which the circuit's electrical parameters, such as voltage, current, equivalent resistance, total power losses, etc., are calculated. Using the known elements or parameters, the unknown parameters or quantities in the circuit are determined through analysis.

All circuits can be analysed as either series circuits or parallel circuits.

3. Circuit terminology

We are developing methods for analysing a circuit. So far, we've defined the most common components (resistor, capacitor, and inductor) and sources (voltage and current). Now we need a crisp vocabulary to talk about circuits. This article is a glossary of terms and concepts we use in circuit analysis and design.

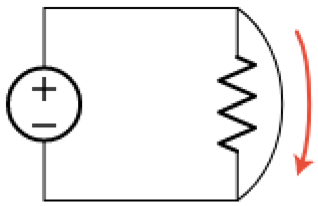
3.1 Common terms used Circuit analysis

a) Circuit: Circuit comes from the word circle. A circuit is a collection of components, power sources, and signal sources, all connected so current can flow in a complete circle. You can also call a circuit a network.

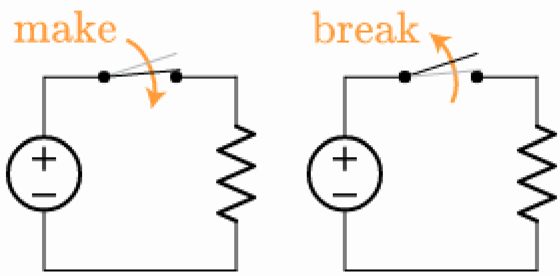
b) Closed circuit: A circuit is closed if the circle is complete, if all currents have a path back to where they came from.

c) Open circuit: A circuit is open if the circle is not complete, if there is a gap or opening in the path.

d) Short circuit: A short is a path of low resistance. It is usually by mistake. The resistor shown below is the intended path for current, and the curved wire going around it is the short. Current is diverted away from its intended path, sometimes with damaging results. The wire shorts out the resistor by providing a low-resistance path for current (probably not what the designer intended).



e) Make or break: You make a circuit by closing the current path, such as when you close a switch. Breaking a circuit is the opposite. Opening a switch breaks the circuit.

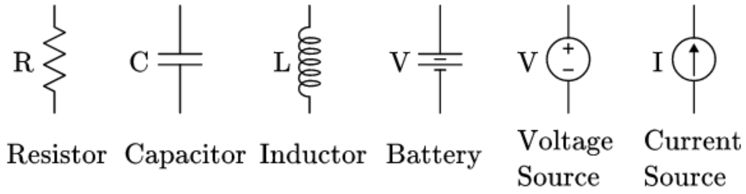


The phrase "make or break situation" means whatever happens the outcome is definitely going in one of two directions.

f) Schematic: A schematic is a drawing of a circuit. A schematic represents circuit elements with symbols and connections as lines.

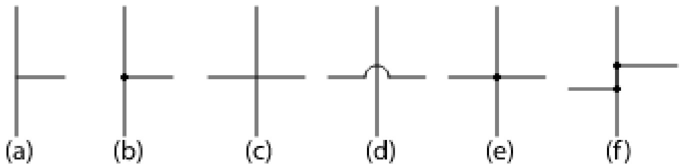
g) Elements and components: The term element means a component or a source. The term component refers to resistors, capacitors, inductors, transistors, etc. I typically don't include sources when I say components.

h) Symbols: Elements are represented in schematics by symbols. Here are the symbols for the common 2-terminal elements.



i) Lines: Connections between elements are drawn as lines, which we often think of as "wires." When drawn on a schematic, lines represent perfect conductors with zero resistance. Every component or source terminal touched by a line has the same voltage.

j) Dots: Connections between lines can be indicated by dots. Dots are an unambiguous indication that lines are connected. If the connection is obvious, you don't have to use a dot.

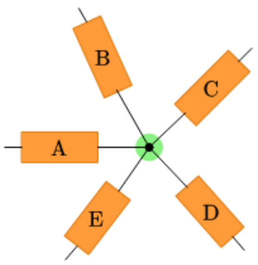


(a) and (b) are both good. (c) no dot indicates no connection. (d) also indicates no connection; the horizontal wire "hops" over the vertical wire.

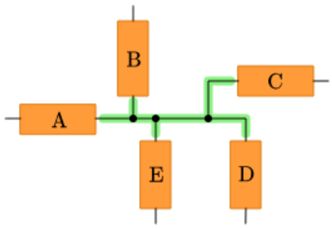
(d) is very clear but takes extra effort and space to draw. For crossing connected lines, (e) is acceptable, but risks looking too much like (c), so (f) is the better practice.

k) Reference Designator: When you place an element in a schematic you often give it a unique name, known as a reference designator.

l) Node: A junction where 2 or more elements connect is called a node. The schematic below shows a single node (the black dot) formed by the junction of five elements (abstractly represented by orange rectangles).

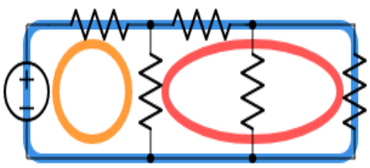


m) Distributed node: Since lines on a schematic represent perfect zero-resistance conductors, there is no rule that says lines from multiple elements are required to meet in a single point junction. We can draw the same node as a distributed node like the one in the schematic below. These two representations of the node mean exactly the same thing.



n) Branch: A branch is a connection between nodes. A branch contains an element (resistor, capacitor, source, etc.). The number of branches in a circuit is the same as the number of elements.

o) Loop: A loop is any closed path going through circuit elements. To draw a loop, select any node as a starting point and draw a path through elements and nodes until the path comes back to the node where you started. There is only one rule: a loop can visit (pass through) a node only one time. It is ok if loops overlap or contain other loops. Some of the loops in our circuit are shown here. (You can find others, too. If I counted right, there are six.)



p) Mesh

A *mesh* is a loop that has no other loops inside it. You can think of this as one mesh for each "open window" of a circuit.

r) Reference Node: During circuit analysis we usually pick one of the nodes in the circuit to be the reference node. We assign a voltage of v=0 to the reference node. Voltages at the other nodes are measured relative to the reference node.

You can pick any node to be the reference node, but two common choices that simplify circuit analysis are,

- the negative terminal of the source powering the circuit, or
- the node connected to the greatest number of branches.

s) Ground: The reference node is often referred to as ground. The concept of ground has three important meanings.

Ground is

- the reference point from which voltages are measured,
- the return path carrying electric current back to its source,
- a direct physical connection to the Earth, for safety.

Ground gets its name from the third meaning, but all three roles are equally important. You will come across various symbols for ground. They all indicate which node is the reference node.

4. Ohm's Law

The relationship between Voltage, Current and Resistance in any DC electrical circuit was firstly discovered by the German physicist Georg Ohm.

Georg Ohm found that, at a constant temperature, the electrical current flowing through a fixed linear resistance is directly proportional to the voltage applied across it, and also inversely proportional to the resistance. This relationship between the Voltage, Current and Resistance forms the basis of **Ohm's Law** and is shown below.

4.1 Ohms Law Relationship

$$Current, (I) = \frac{Voltage\ (V)}{Resistance, (R)}\ in\ Amperes, (A)$$

By knowing any two values of the Voltage, Current or Resistance quantities we can use **Ohm's Law** to find the third missing value. **Ohm's Law** is used extensively in electronics formulas and calculations so it is "very important to understand and accurately remember these formulas".

a) To find the Voltage, (V)

[V = I x R]   V (volts) = I (amps) x R (Ω)

b) To find the Current, (I)

[I = V ÷ R]   I (amps) = V (volts) ÷ R (Ω)

c) To find the Resistance, (R)

[R = V ÷ I]   R (Ω) = V (volts) ÷ I (amps)

Quantity	**Ohm's Law symbol**	**Unit of measure (abbreviation)**	**Role in circuits**	**In case you're wondering:**
Voltage	E	Volt (V)	Pressure that triggers electron flow	E = electromotive force (old-school term)
Current	I	Ampere, amp (A)	Rate of electron flow	I = intensity
Resistance	R	Ohm (Ω)	Flow inhibitor	Ω = Greek letter omega

4.2 Series, parallel and mixed connection of resistors, capacitors and inductors.

1. Calculation of resistance in series, parallel and mixed connection

Resistors are circuit elements that impart electrical resistance. While circuits can be highly complicated, and there are many different ways in which resistors can be arranged in a circuit, resistors in complex circuits can typically be broken down and classified as being connected in series, in parallel and in mixed.

1.1 Resistors in series

Figure below shows three resistors R_1, R_2 and R_3 connected end to end, i.e., in series, with a battery source of V volts. Since the circuit is closed a current I will flow and the p.d. across each resistor may be determined from the voltmeter readings V_1, V_2 and V_3

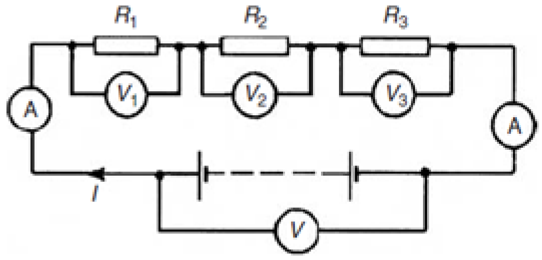


Figure (a) Three resistors connected in series to a Voltage source.

In a series circuit

(a) The current I is the same in all parts of the circuit and hence the same reading is found on each of the two ammeters shown.

(b) The sum of the voltages V_1, V_2 and V_3 is equal to the total applied voltage, ***V****, i.e.*

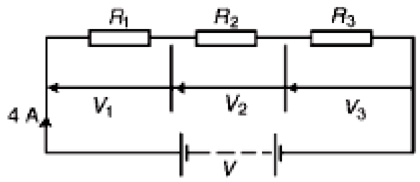
$\mathbf{V=V_1+V_2+V_3}$

From Ohm's law: $V_1 = IR_1$, $V_2 = IR_2$, $V3 = IR_3$ and $V=IR$

Where R is the total circuit resistance, Since $V=V_1 +V_2 +V_3$ then $IR=IR_1+IR_2+IR_3$

Dividing throughout by I gives:

$R=R_1+R_2+R_3$



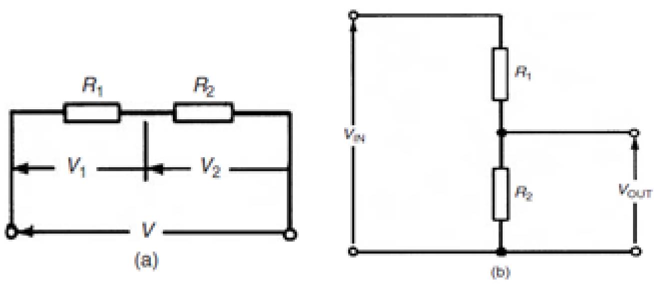
(c)Thus for a series circuit, the total resistance is obtained by adding together the values of the separate resistances.

$\mathbf{R_S=R_1+R_2+R_3+\ldots\ldots\ldots\ldots+RN=\sum_{i=1}^{N} Ri}$

. **Potential divider or voltage divider**

The voltage distribution for the circuit shown in Figure below is given by:

$\mathbf{V_1=(\frac{R1}{R1+R2})\ V}$ **and** $\mathbf{V_2=(\frac{R2}{R1+R2})\ V}$



The circuit shown above (b) is often referred to as a **potential divider circuit**. Such a circuit can consist of a number of similar elements in series connected across a voltage source, voltages being taken from connections between the elements. Frequently the divider consists of two resistors as shown in Figure, where

$V_{OUT}=(\frac{R2}{R1+R2})\ VIN$

A potential divider is the simplest way of producing a source of lower e.m.f. from a source of higher e.m.f., and is the basic operating mechanism of the **potentiometer**, a measuring device for accurately measuring potential differences.

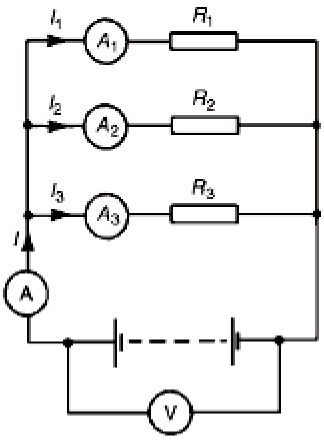
Parallel networks

Figure below shows three resistors, R_1, R_2 and R_3 connected across each other, i.e., in parallel, across a battery source of V volts. Resistors are in parallel if they have two common points.

In a parallel circuit:

(a) The sum of the currents I_1, I_2 and I_3 is equal to the total circuit current, I, i.e. ***$I = I_1 + I_2 + I_3$,***

(b) The source p.d., V volts, is the same across each of the resistors.



$I_1=\frac{V}{R1}$, $I_2=\frac{V}{R2}$, $I_3=\frac{V}{R3}$, and $I=\frac{V}{R}$

Where R is the total circuit resistance,

Since $I = I_1+I_2+I_3$

$$\frac{V}{R}=\frac{V}{R_1}+\frac{V}{R_2}+\frac{V}{R_3}$$

Then,

Dividing throughout by V gives:

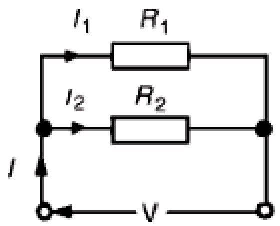
$$\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

This equation must be used when finding the total resistance R of a parallel circuit. For the special case of **two resistors in parallel,** $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}=\frac{R_2\ \ +R_1}{R1R2}$ $\quad R=\frac{R_2\ \ +R_1}{R_1+R_2}$

When two resistors are in parallel

- **CURRENT DIVIDER**

For the circuit shown in Figure below, the total circuit resistance, R_T is given by:



$$R_T = \frac{R_2 \quad R_1}{R_1 + R_2}$$

and V= IR$_T$ = I $\left(\frac{R_1 R_2}{R_1+R_2}\right)$

Current I$_1$ = $\frac{V}{R_1} = \frac{I}{R_1}\left(\frac{R_1 R_2}{R_1+R_2}\right) = \left(\frac{R_2}{R_1+R_2}\right)(I)$

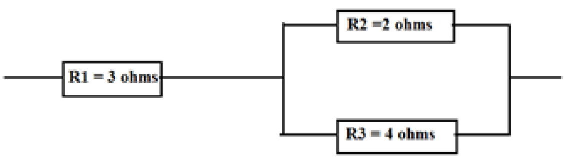
Similarly,

Current I$_2$ = $\frac{V}{R_2} = \frac{I}{R_2}\left(\frac{R_1 R_2}{R_1+R_2}\right) = \left(\frac{R_1}{R_1+R_2}\right)(I)$

$I_1 = \left(\frac{R_2}{R_1+R_2}\right)(I)$ $\qquad$ $I_2 = \left(\frac{R_1}{R_1+R_2}\right)(I)$

Mixed circuits

A mixed network of resistors has resistors in series with others in parallel. To find the total resistance you reduce the circuit.



The figure above shows a mixed network of 3 resistors.

- Resistors R2 and R3 are in parallel
- The resultant of R2 and R3 is in series with R1.

First,

$$\frac{1}{R_{2,3}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{R_2 X R_3}{R_{2+}R_3} = \frac{2X4}{2+4} = \frac{8}{6} = \frac{4}{3}\ Ohms$$

The circuit is reduced in as follow

$R_{tot} = R_1 + R_{2,3} = 3 + 4/3 = 13/3$ ohms

4.3. Calculation of capacitance in series, parallel and mixed connection

Capacitance

Static electric fields arise from electric charges, electric field lines beginning and ending on electric charges. Thus the presence of the field indicates the presence of equal positive and negative electric charges on the two plates of Figure below. Let the charge be +Q coulombs on one plate and -Q coulombs on the other. The property of this pair of plates which determines how much charge corresponds to a given p.d. between the plates is called their capacitance:

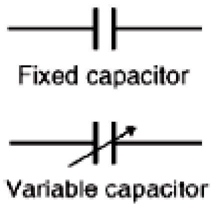
The unit of capacitance is the farad F (or more usually μF =10^{-6} F or pF= 10^{-12} F), which is defined as the capacitance when a p.d of one volt appears across the plates when charged with one coulomb.

Capacitors

Every system of electrical conductors possesses capacitance. For example, there is capacitance between the conductors of overhead transmission lines and also between the wires of a telephone cable. In these examples the capacitance is undesirable but has to be accepted, minimised or compensated for. There are other situations where capacitance is a desirable property**.**

Devices specially constructed to possess capacitance are called capacitors (or condensers, as they used to be called). In its simplest form a capacitor consists of two plates which are separated by an insulating material known as a dielectric. A capacitor has the ability to store a quantity of static electricity.

The symbols for a fixed capacitor and a variable capacitor used in electrical circuit



diagrams are shown below.

The charge *Q* stored in a capacitor is given by:

Q = I x t Coulombs

where **I** is the current in amperes and **t** the time in seconds.

Types of capacitors

Capacitors used in electronics can be either fixed or variable. Fixed capacitors can be either electrolytic or non-electrolytic capacitors.

· **Fixed capacitors**

According to the type of the dielectric material used between the plates, the capacitors are classified into non-electrolytics, namely air, mica, paper, ceramic and electrolytic capacitors.

In air capacitor

The dielectric between the plates is air. The capacitance of the air capacitor usually lies between 10 to 400 pF.

In mica capacitor

Thin mica sheets are stacked between tinfoil sections (plates) to provide required capacitance. The entire unit is generally moulded in a Bakelite case. Mica capacitors are often used for small capacitance values of 50 to 500 pF.

In paper capacitor two rolls of tinfoil conductors separated by a tissue paper are rolled into a Compact cylinder. The entire cylinder is generally encased in plastic module. Paper capacitors are used for medium capacitance values of 0.001 to 2 µF with the voltage rating as high as 2000V.they have a large physical size as compared to their capacitance and also become inefficient as the frequency of applied ac voltage exceeds a few MHZ. These fact prevent their use in most of FM, TV circuits except in low frequency portion of the circuits i.e audio stages.

The ceramic dielectric materials are used in ceramic capacitors. When ceramics are used as dielectric very high value of dielectric constant can be obtained. The capacitance up to 0.01 µF can be obtained in much less space than a paper capacitor if ceramic material is used.

Fig: Ceramic capacitors

Because of the high value dielectric constant of ceramic. this type of capacitor have very large capacitance compared to their size

Advantages:

They are economical, small in size with high capacitance thus occupy less space and have high working voltage and minimum losses.

In air, paper, mica and ceramic capacitors there is no required polarity, since either side (plate) can be made more positive. It means that any plate of these capacitors can be connected to the positive terminal of the voltage source.

Electrolytic capacitors

Very high value of capacitance can be obtained if electrolytes of borax, phosphate or carbonate are used as dielectric material. These types of capacitors are called ***electrolytic capacitors*** and they can provide capacitance values up to 5000 µF. Between two aluminium electrodes absorbent gauze soaked with electrolyte is placed. When DC voltage is applied between the electrodes the electrolytic action accumulates a molecular-thin (extremely thin) layer of aluminium oxide at the junction between the positive electrode and the electrolyte. Since the oxide film is an insulator, there is capacitance between the positive aluminium electrode and the soaked gauze. The negative aluminium electrode simply provides a connection to the electrolyte.

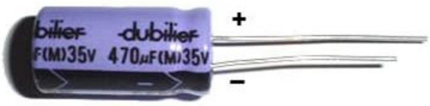


Fig:Electrolytic capacitors

Electrolytic capacitors must be connected in the circuit in such a way that the applied

voltage maintains the positive electrode more positive than the negative electrode.
If the electrolytic capacitor is connected in opposite (wrong) polarity, the reversed electrolysis forms gas and the capacitor becomes hot and may explode.

· **Variable capacitors**

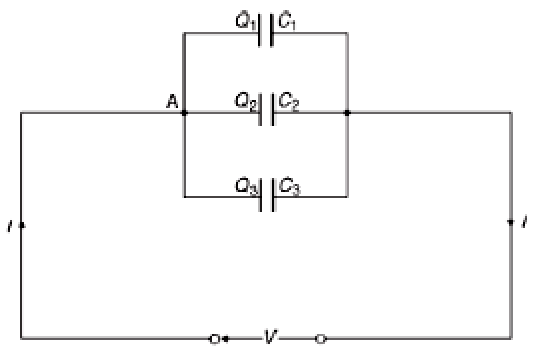
Besides fixed value capacitors, variable capacitors are also widely used in electronics. A variable capacitor is one whose capacitance can be varied by rotating a shaft. It consists of two sets of metals plates separated from each other by air. The stationary plate is called a stator. The other set is connected to the shaft and can be rotated and it is called a rotor. By rotating a rotor plate, plates can be made to move in and out form the stator plate. Capacitances can maximum when rotor plate falls in and minimum when they are out.
Variable capacitors as a variable resistor affords continuous variation in capacitance between a fixed minimum and a fixed maximum values. Variable capacitor consists of a set of fixed plates (stator) and a set of rotating plates (rotor) connected on a common shaft. When the rotor is rotated, the plates effective surface is changed and therefore the capacitance between the plates changes. If the capacitance adjustments are seldom required, the rotor axle is provided with a screwdriver slot rather than with a knob. Capacitor of this type is referred to as ***trimmer*** capacitor.
Nowadays direct stamping of capacitance values of numeric codes are widely used. If the printed (stamped) numerical value is less than 1 (for example 0.1) then it is the actual value of capacitance expressed in micro-Farad (µF). If the printed numerical value is greater than 1 then it is the actual value of capacitance expressed in pico - Farad (pF). The capacitance value, voltage rating and the polarity of electrolytic capacitors are always directly stamped on the surface of the capacitor.
The variety of ways that combinations of capacitors can be made is divided into two methods. They are:

- ✓ Parallel Combination
- ✓ Series Combination
- ✓ Parallel and Series (mixed) Combination

These methods have different equivalent capacitance and we will be looking at them in detail.

Parallel Combination of Capacitors

Figure below shows three capacitors, C1, C2 and C3, connected in parallel with a supply voltage V applied across the arrangement.



Total charge, $Q_T = Q_1 + Q_2 + Q_3$

When the charging current I reaches point A it divides, some flowing into C_1, some flowing into C_2 and some into C_3. Hence the total charge Q_T=Ixt is divided between the three capacitors. The capacitors each store a charge and these are shown as Q_1, Q_2 and Q_3 respectively. Hence

$$Q_T = Q_1 + Q_2 + Q_3$$

But $Q_T = CV, Q_1 = C_1V,\ \ Q_2 = C_2V \text{ and } Q_3 = C_3V$

Therefore CV = $C_1V+C_2V+C_3V$ where C is the total equivalent circuit capacitance.

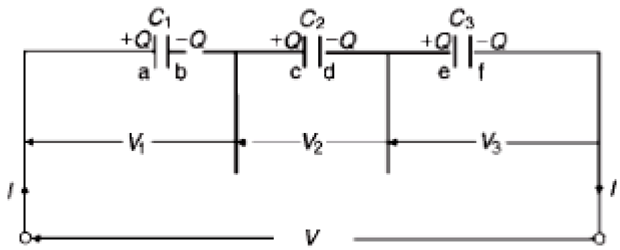
It follows that for n parallel-connected capacitors,

$$C = C_1 + C_2 + C_3$$

i.e. the equivalent capacitance of a group of parallel-connected capacitors is the sum of the capacitances of the individual capacitors. (Note that this formula is similar to that used for **resistors** connected in **series**)

Capacitors connected in series

Figure below shows three capacitors, C_1, C_2 and C_3, connected in series across a supply voltage V. Let the p.d. across the individual capacitors be V_1, V_2 and V_3 respectively as shown.



Charge on each capacitor = Q

In a series circuit: **V = V1 + V2 + V3**

Since V = Q/C, then Q/C = Q/C1 + Q/C2 + Q/C3

where C is the total equivalent circuit capacitance**. i.e. 1/C = 1/C1 + 1/C2 + 1/C3**

For n series-connected capacitors:

1/C = 1/C1 + 1/C2 + 1/C3 + ... + 1/Cn

i.e. for series-connected capacitors, the reciprocal of the equivalent capacitance is equal to the sum of the reciprocals of the individual capacitances. (Note that this formula is similar to that used for **resistors** connected in parallel.

For the special case of two capacitors in series:

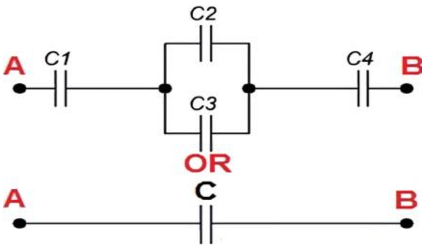
1/C = 1/C1 + 1/C2 = (C2 + C1) / (C1 * C2)

Hence C = (C1 * C2) / (C1 + C2)

2.3 Series-parallel (mixed) connection of capacitors

A series-parallel connection of capacitors is a circuit that has sections of capacitors both in parallel and in series.

The illustration below shows an example of a mixed-capacitor circuit.



When calculating the total capacity of such a circuit section with a series-parallel connection of capacitors, this section is divided into the simplest sections consisting only of groups with series or parallel connections of capacitors. Further, the calculation algorithm is as follows:

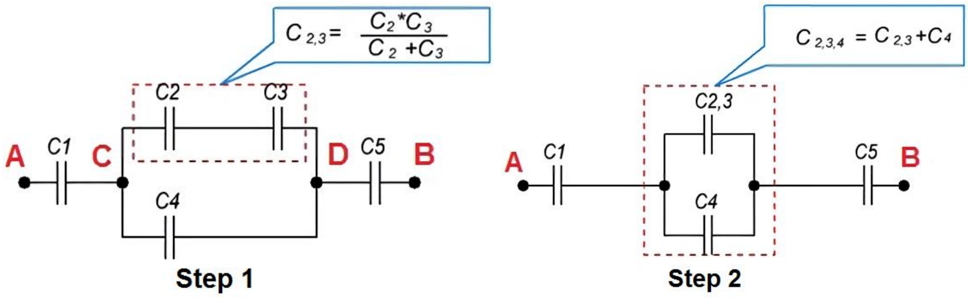
Determine the equivalent capacitance of the sections with a series connection of capacitors.

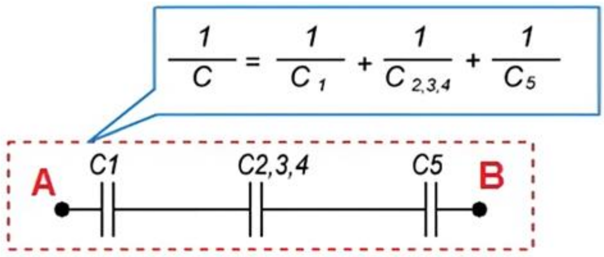
If these sections contain capacitors connected in series, first calculate their capacitance.

After calculating the equivalent capacitances of the capacitors, redraw the circuit. Usually, a circuit of equivalent capacitors connected in series is obtained.

Calculate the capacitance of the resulting circuit.

One example of a mixed capacitance calculation is shown in the figure below:





Step 3

Energy stored in Capacitors

The energy, W, stored by a capacitor is given by

W = (1/2) CV² joules

Application of Capacitors

Capacitors are mostly applied in electronics circuits including

1. Filtering systems where the capacitor acts as a frequency selective device
2. Signal by pass-where capacitors are used mostly to protect microchip systems form noise
3. Coupling or DC blocking

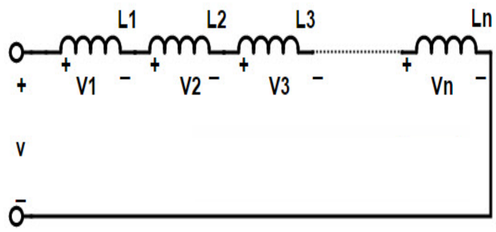
Tuned circuits such as in radio for frequency control(variable capacitors are here used

3. Calculation of inductance in series, parallel and mixed connection

3.1 Inductors Connected in Series

Assume that inductors connected in the circuit do not have any coupling between them. This implies that there are no flux lines from one inductor linking with another, and hence there will be no mutual flux between the coils.

The end-to-end connection of two or more inductors is called "series connection of inductors". In this connection the inductors are connected in series so the effective turns of the inductor increase. The series connection of the inductors is shown in below diagram:



The inductance of series connected inductors is calculated as the sum of the individual inductances of each coil since the current change through each coil is the same.

This series connection is similar to that of the resistors connected in series, except the resistors are replaced by inductors. If the current I is flowing in the series connection and the coils are L1, L2, and so on, the common current in the series inductors is given by: $I_{Total} = I_{L1} = I_{L2} = I_{L3} \ldots = I_n$

If the individual voltage drops across each coil in this series connection are VL1, VL2, VL3, and so on, the total voltage drop between the two terminals VT is given by: $V_{Total} = V_{L1} + V_{L2} + V_{L3} \ldots + V_n$

As we know that the voltage drop can be represented in terms of self-inductance L, this implies: V = L di/ dt.

This can also be written as: LT di/dt = L1 di/dt + L2 di/dt + L3 di/dt + . . . + Ln di/dt

Therefore, the total inductance is: $L_{Total} = L_1 + L_2 + L_3 + ... + L_n$

This means the total inductance of the series connection is the sum of individual inductances of all inductors. The above equation is true when there are no mutual inductance affects between the coils in this series configuration.

The mutual inductance of the inductors will make a change in value of the total inductance in the series combination of inductors.

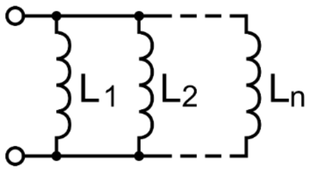
Assume that there are two inductors connected in series with the alternating voltage source which can generate a varying current in the circuit as shown in the above figure.

If there is no mutual inductance in the circuit, then the total inductance is given as**: $L_T = L_1 + L_2$**

It is important to remember that the total inductance is always greater than the largest inductor in the series arrangement of inductors.

3.2 Inductors connected in parallel

Inductors are said to be connected in parallel when two terminals of an inductor are respectively connected to each terminal of other inductors or inductor. Similar to the parallel connection of resistors, the total inductance in parallel connection of inductors is somewhat lesser than smallest inductance of an inductor in that connection.



When the inductors are connected in parallel, the current flow through each inductor is not exactly equal to the total current, but the sum of each individual current through parallel inductors gives the total current (as it divides among parallel inductors).

We know that, in a parallel network the voltage remains constant and the current divides at each parallel inductor. If I_{L1}, I_{L2}, I_{L3} and so on I_{Ln} are the individual currents flowing in the parallel connected inductors L_1, L_2 and so on L_n, respectively, then the total current in the parallel inductors is given by

$I_{Total} = I_{L1} + I_{L2} + I_{L3} . . . . + I_n$

If the individual voltage drops in the parallel connection are V_{L1}, V_{L2}, V_{L3} and so on V_{Ln}, then the total voltage drop between the two terminals V_T is:

$V_{Total} = V_{L1} = V_{L2} = V_{L3} . . . . = V_n$

The voltage drop in terms of self-inductance can be expressed as V = L di/ dt. This implies total voltage drop,

$V_T = L_T$ di/dt

⇒ L_T di/dt ($I_{L1} + I_{L2} + I_{L3}$ . . .. + In)

⇒ L_T ((di1)/dt + (d_{i2})/dt + (di3)/dt . . ..)

Substituting V / L in place of di/dt, the above equation becomes

$V_T = L_T (V/L_1 + V/L_2 + V/L3 \ldots)$

As the voltage drop is constant across the circuit, then $v = V_T$. So, we can write: $1/L_T = 1/L_1 + 1/L_2 + 1/L_3 \ldots$

This means that the reciprocal of total inductance of the parallel connection is the sum of reciprocals of individual inductances of all inductors. The above equation is true when no mutual inductance is affected between the parallel connected coils.

For avoiding complexity in dealing with fractions, we can use the product over sum method to calculate the total inductance. If two inductors are connected in parallel, and if there is no mutual inductance between them, then the total inductance is given as: $\mathbf{L_T = (L_1 \times L_2)/ (L_1 + L_2)}$

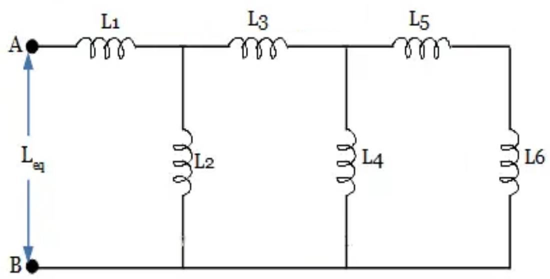
If the current flow through each inductor is less than the total current, the magnetic field generated by each inductor is also less than that of the field generated by total current through it.

In case of resistors in parallel, most of the current flows through the smallest resistor as it offers the least opposition to the current flow than larger resistors.

Likewise, if the inductors are connected in parallel, current chooses the least opposition path of the inductor when current in that circuit is decreased or increased while each inductor individually opposes that change (increase or decrease of current).

3.3 Inductors connected in mixed

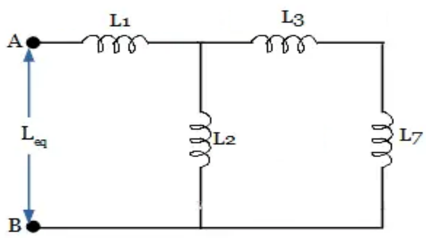
Let us solve a problem to calculate equivalent inductance of the given circuit.



In the above example, inductor L4 is in parallel with a series combination of L5 and L6. The equivalent inductance value of these three inductors L4, L5 and L6 are

$$L7 = \frac{L4 * (L5 + L6)}{L4 + (L5 + L6)}$$

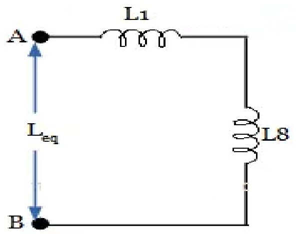
Now, the circuit get reduced as below,



If you look at the circuit, inductor L2 is in parallel with the series combination of inductors L3 and L7. The corresponding equivalent inductance value is

$$L8 = \frac{L2 * (L3 + L7)}{L2 + (L3 + L7)}$$

Again, the circuit is reduced as below,



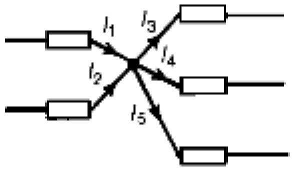
In the reduced circuit, the inductors L1 and L8 are in series.
Thus, the equivalent inductance is given by,

$Leq = L1 + L8$

Kirchhoff's Laws

Kirchhoff's laws state:

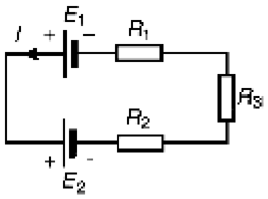
(a) Current Law. At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the junction, **i.e. ΣI =0**



Thus referring to this figure

$I1 + I2 = I3 + I4 + I5$ or $I1 + I2 - I3 - I4 - I5 = 0$

(b) Voltage Law. In any closed loop in a network, the algebraic sum of the voltage drops (i.e. products of current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop.



So, $E1 - E2 = IR1 + IR2 + IR3$

Using Kirchhoff's method of analysis requires several steps, as listed in the following procedure.

Problem-Solving Strategy: Kirchhoff's Rules

1. Label points in the circuit diagram using lowercase letters **a**, **b**, **c**, …. These labels simply help with orientation.
2. Locate the junctions in the circuit. The junctions are points where three or more wires connect. Label each junction with the currents and directions into and out of it. Make sure at least one current points into the junction and at least one current points out of the junction.

3. Choose the loops in the circuit. Every component must be contained in at least one loop, but a component may be contained in more than one loop.
4. Apply the junction rule. Again, some junctions should not be included in the analysis. You need only use enough nodes to include every current.
5. Apply the loop rule. Use the map in Figure below.

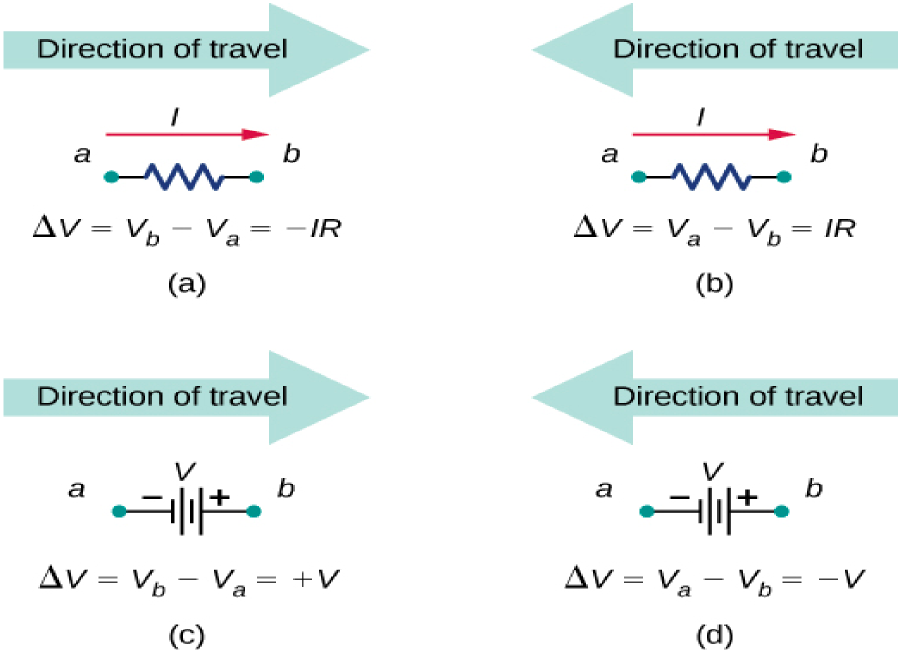


Figure: Each of these resistors and voltage sources is traversed from **a** to **b**. (a) When moving across a resistor in the same direction as the current flow, subtract the potential drop. (b) When moving across a resistor in the opposite direction as the current flow, add the potential drop. (c) When moving across a voltage source from the negative terminal to the positive terminal, add the potential drop. (d) When moving across a
voltage source from the positive terminal to the negative terminal, subtract the potential drop.

Let's examine some steps in this procedure more closely. When locating the junctions in the circuit, do not be concerned about the direction of the currents. If the direction of current flow is not obvious, choosing any direction is sufficient as long as at least one current points into the junction and at least one current points out of the junction. If the arrow is in the opposite direction of the conventional current flow, the result for the current in question will be negative but the answer will still be correct.

The number of nodes depends on the circuit. Each current should be included in a node and thus included in at least one junction equation. Do not include nodes that are not linearly independent, meaning nodes that contain the same information.

Consider Figure below. There are two junctions in this circuit: Junction **b** and Junction **e**. Points **a**, **c**, **d**, and **f** are not junctions, because a junction must have three or more connections. The equation for Junction **b** is I1=I2+I3, and the equation for

Junction **e** is I2+I3=I1. These are equivalent equations, so it is necessary to keep only one of them.

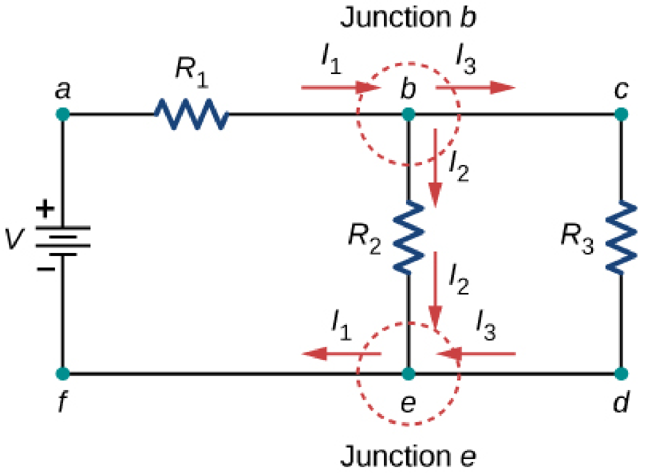


Figure 10.4.6: At first glance, this circuit contains two junctions, Junction **b** and Junction **e**, but only one should be considered because their junction equations are equivalent.

When choosing the loops in the circuit, you need enough loops so that each component is covered once, without repeating loops. Figure below shows four choices for loops to solve a sample circuit; choices (a), (b), and (c) have a sufficient amount of loops to solve the circuit completely. Option (d) reflects more loops than necessary to solve the circuit.

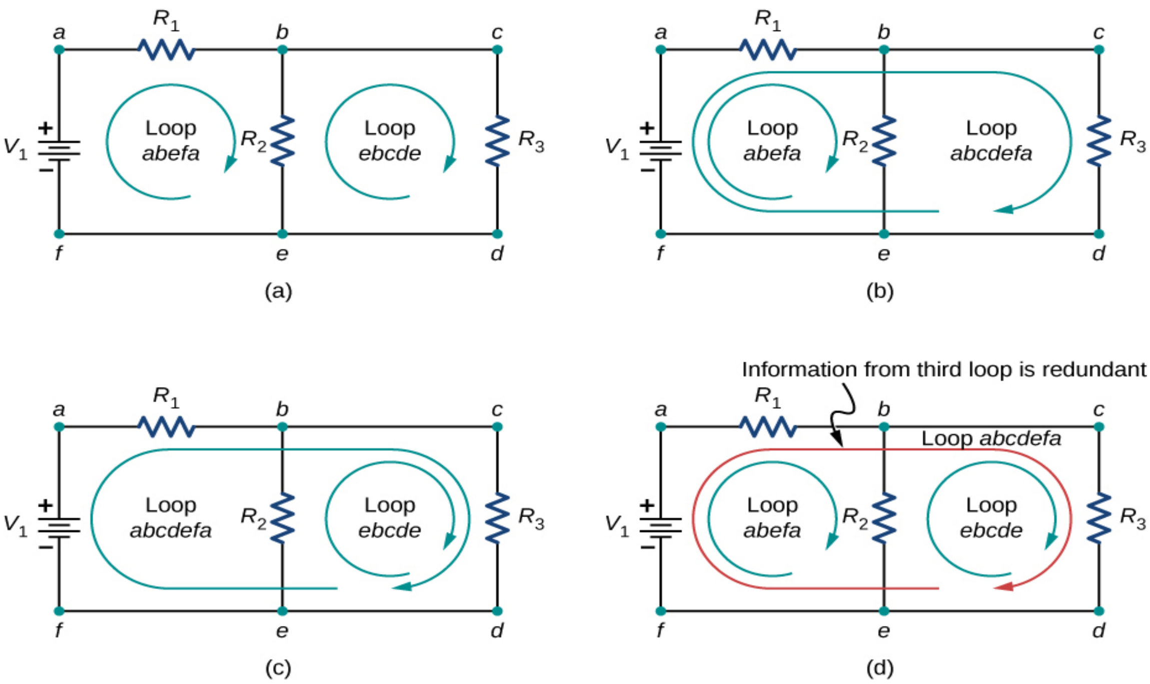


Figure: Panels (a)–(c) are sufficient for the analysis of the circuit. In each case, the two loops shown contain all the circuit elements necessary to solve the circuit completely. Panel (d) shows three loops used, which is more than necessary. Any two loops in the system will contain all information needed to solve the circuit. Adding the third loop provides redundant information.

Procedure for Applying Rules

1. Assume all voltage sources and resistances are given. (If not label them V1, V2 ..., R1, R2 etc)
2. Label each branch with a branch current. (I1, I2, I3 etc)
3. Apply junction rule at each node.
4. Applying the loop rule for each of the independent loops of the circuit.
5. Solve the equations by substitutions/linear manipulation.

Theoretical Activity 1.4.1.2: Description of DC circuits Theorems

Tasks:

Task 1: In small groups, you are requested to answer the following questions related to the description of DC circuits Theorems.

i. **What do you understand by Thevenin Theorem**
ii. **Describe Norton's theorem**

Task 2: Provide the answer for the asked questions and write them on papers.

Task 3: Present the findings/answers to the whole class

Task 4: For more clarification, read the key **readings 1.4.1.2**

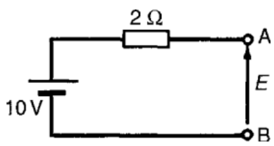
Task 5: In addition, ask questions where necessary.

Key readings 1.4.1.2: Description of DC Circuits Theorems

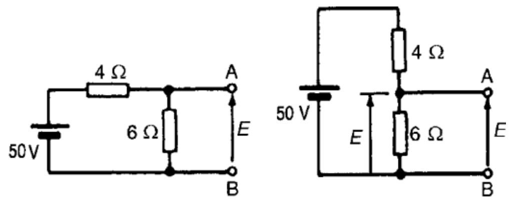
1. **THEVENIN'S THEOREM**

The following points involving d.c. circuit analysis need to be appreciated before proceeding with problem susing **Thévenin's** and **Norton's theorems**:

(i) The open-circuit voltage, *E*, across terminals AB in figure below is equal to 10V, since no current flows through the 2Ωresistor and hence no voltage drop occurs.



(ii) The open-circuit voltage, *E*, across terminals AB in figure (a) below is the same as the voltage across the 6Ωresistor. The circuit may be redrawn as shown in Figure (b) below

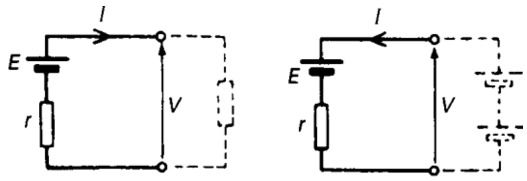


(a) (b)

$$E = \left(\frac{6}{6+5}\right)(50)$$

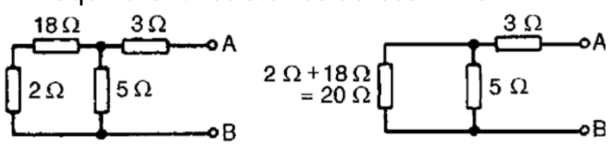
by voltage division in a series circuit, i.e. ***E*=30V**

(iii) For the circuit shown in Figure (a) below representing a practical source supplying energy, ***V*=*E* −*Ir***, where *E* is the battery e.m.f., *V* is the battery terminal voltage and *r*is the internal resistance of the battery. For the circuit shown in Figure(b), ***V = E − (−I)r,*** *i.e.****V = E + Ir***



(a) (b)

(iv) The resistance 'looking-in' at terminals AB in Figure (a) below is obtained by reducing the circuit in stages as shown in Figure (b) to (d). Hence the equivalent resistance across AB is 7Ω.

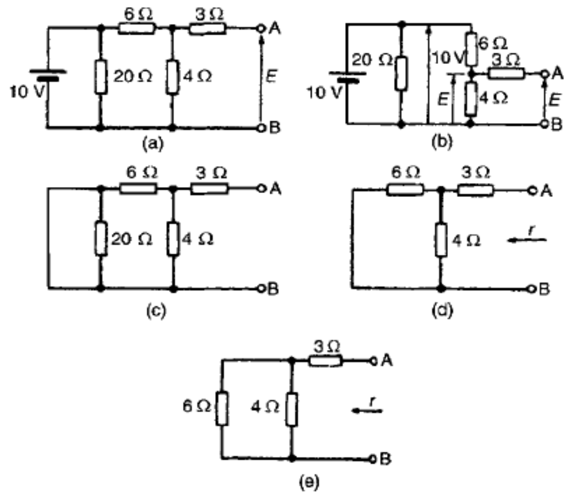


(a) (b)

(c) (d)

(v) For the circuit shown in Figure (a) below, the 3Ωresistor carries no current and the p.d. across the 20Ω resistor is 10V. Redrawing the circuit gives Figure(b),from which

$$E = \left(\frac{6}{6+5}\right) * 10 = 4V$$



(Vi) If the 10V battery in Figure (a) is removed and replaced by a short - circuit, as shown in Figure (c), then the 20Ωresistor may be removed. The reason for this is that a short circuit has zero resistance, and 20Ωin parallel with zero ohms gives an equivalent resistance of **(20×0)/(20+0)** i.e. **0Ω**. The circuit is then as shown in Fig. (d), which is redrawn in Fig. (e).

From Figure (e), the equivalent resistance across AB,

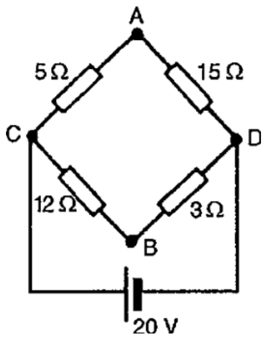
$$r = \left(\frac{6 * 4}{6 + 4}\right) + 3 = 2.4 + 3 = 5.4\Omega$$

(vii) To find the voltage across AB in Figure below: Since the 20V supply is across the 5Ωand 15Ω resistors in series then, by voltage division, the voltage drop across AC,

$$VAC = \left(\frac{5}{5 + 15}\right)(20) = 5V$$

Similarly,

$$VCB = \left(\frac{12}{12 + 3}\right)(20) = 16V$$



Vc is at potential of +20v

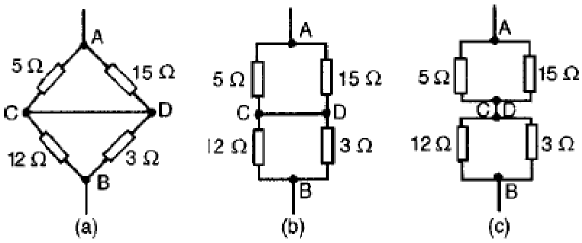
$$VA = VC - VAC = +20 - 5 = 15V$$

$$VB = VC - VBC = +20 - 16 = 4V$$

Hence the voltage between AB is $V_A - V_B$ = 15−4=11V and current would flow from A to B since A has a higher potential than B.

(viii) In Figure (a), to find the equivalent resistance across AB the circuit may be redrawn as in Figures (b) and (c). From Fig. (c), the equivalent resistance across AB

$$= \frac{5 * 15}{5 + 15} + \frac{12 * 3}{12 + 3} = 3.75 + 2.4 = 6.15\Omega$$



(ix) In theworked problems in Sections 13.5 and 13.7following, it may be considered that Thévenin'sand Norton's theorems have no obvious advantagescompared with, say, Kirchhoff's laws.However, these theorems can be used to analysepart of a circuit and in much more complicatednetworks the principle of replacing the supplyby a constant voltage source in series with aresistance (or impedance) is very useful.

Thévenin's theorem states

Thévenin's theorem states: ***The current in any branch of a network is that whichwould result if an e.m.f. equal to the p.d. across a break made in the branch, were introduced into the branch,all other e.m.f.'s being removed and represented by theinternal resistances of the sources*.**

The procedure adopted when using Thévenin's theoremis summarised below. To determine the current inany branch of an active network (i.e. one containing asource of e.m.f.):

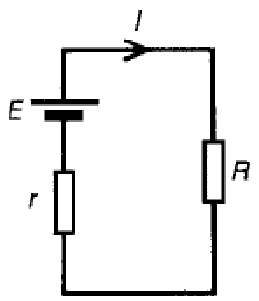
(i) Remove the resistance *R* from that branch,

(ii) Determine the open-circuit voltage, *E*, across the break,

(iii) Remove each source of e.m.f. and replace them by their internal resistances and then

determine theresistance, *r*, 'looking-in' at the break,

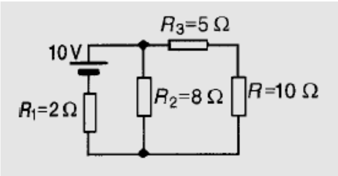
(iv) Determine the value of the current from the equivalent circuit shown in Figure here after, i.e.



$I = \frac{E}{R+r}$

Examples

Use Thévenin's theorem to find the current flowing in the 10Ωresistor for the circuit shown in Figure below



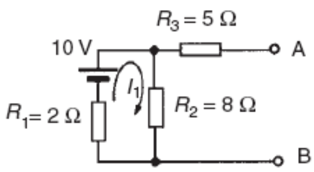
ANSWER

Following the above procedure:

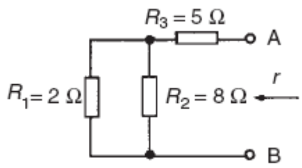
(i) The 10Ωresistance is removed from the circuit as shown in Figure (a)

(ii) There is no current flowing in the 5Ωresistor and current I_1 is given by

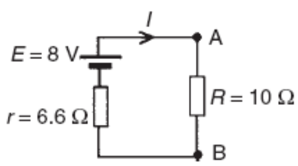
$$I1 = \frac{10}{R1 + R2} = \frac{10}{2+8} = 1A$$



(a)



(b)



(c)

P.d. across $R_2 = I_1R_2 = 1×8 = 8V$. Hence p.d.across AB, i.e. the open-circuit voltage across thebreak, E =8V

(iii) Removing the source of e.m.f. gives the circuit of Figure (b) Resistance,

$$r = R3 + \frac{R1R2}{R1 + R2} = 5 + \frac{2 * 8}{2 + 8} = 5 + 1.6 + 6.6\Omega$$

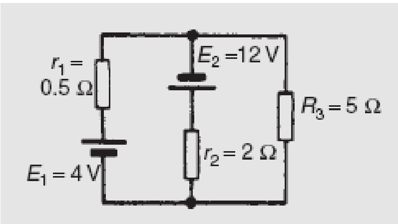
(iv) The equivalent Thévenin's circuit is shown inFig (c)

Current $I = \frac{E}{R+r} = + \frac{8}{10+6.6} = \frac{8}{16.6} = 0.482A$

Hence the current flowing in the 10Ωresistor is **0.482A**.

Example 2

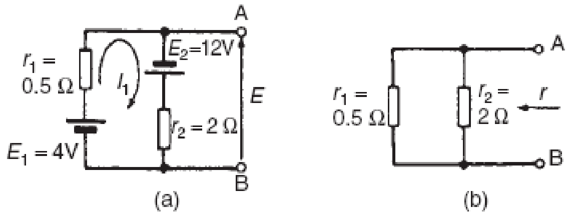
Determine the current in the 5Ωresistance of the network shown in Fig. below using Thévenin's theorem. Hence find the currents flowing in the other two branches.

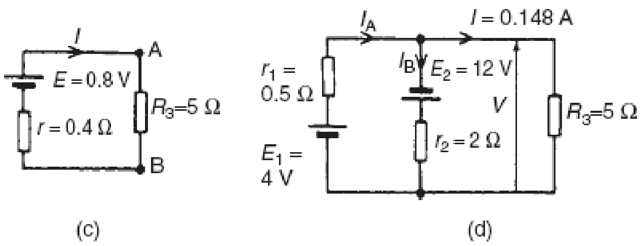


ANSWER

Following the procedure:

(i)The 5Ω resistance is removed from the circuit as shown in Fig.(a)





(ii) Current $I = \frac{12+4}{0.5+2} = \frac{16}{2.5} = 6.4A$

p.d acrossAB

$E = E1 - I1r1 = 4 - (6.4)(0.5) = 0.8V$

(Alternatively,

$E = E2 - I1r1 = -12 + (6.4)(0.5) = 0.8V$

(iii) Removing the sources of e.m.f. gives the circuitshown in Fig (b), from which resistance

$$r = \frac{0.5 * 2}{0.5 + 2} = \frac{1}{2.5} = 0.4\Omega$$

(v) The equivalent Thévenin's circuit is shown in Fig. 13.44(c), from which, current

$$I = \frac{E}{R + 5} = \frac{0.8}{5.4} = 0.148A$$

Current in 5Ω **resistor**

From Figure (d),

$$Voltage, V = I_1 R_3 = (0.148)(5) = 0.74V$$

$$V = E_1 - I_A r1 \;\; i.e\; 0.74 = 4 - (I_A)(0.5)$$

Hence **current** $IA = \frac{4-0.74}{0.5} = \frac{3.26}{0.5} = 6.25A$

Also from Fig. (d),

$$V = E_2 - I_b r_b \;\; i.e\; 0.74 = 12 + (I_B)(2)$$

Hence Current IB,

$$I_B = \frac{12 + 0.74}{2} = \frac{12.74}{2} = 6.37A$$

6. NORTON'S THEOREM

Norton's theorem states**:** The current that flows in any branch of a network is the same as that which would flow in the branch if it were connected across a source of electrical energy, the short-circuit current of which is equal to the current that would flow in a short-circuit across the branch, and the internal resistance of which is equal to the resistance which appears across the open-circuited branch terminals.

The procedure adopted when using Norton's theorem is summarized below. To determine the current flowing in a resistance *R* of a branch AB of an active network:

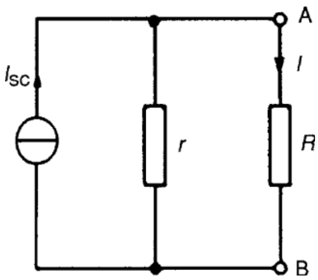
(i) Short-circuit branch AB

(ii) Determine the short-circuit current *I*SC flowing in the branch

(iii) Remove all sources of e.m.f. and replace them by their internal resistance (or, if a current source exists, replace with an open-circuit), then determine the resistance *r*, 'looking-in' at a break made between A and B

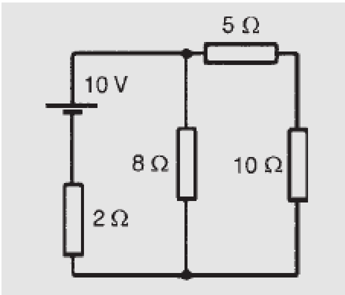
(iv)Determine the current *I* flowing in resistance *R*from the Norton equivalent network shown inFig. 13.53, i.e.

$$I = \left(\frac{r}{r+R}\right) ISC$$



Examples

1. Use Norton's theorem to determine the current flowing in the 10Ω resistance for the circuit shown in Figure below



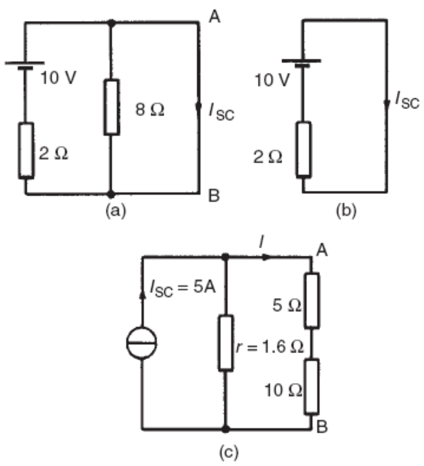
ANSWER

Following the above procedure:

(i) The branch containing the 10Ωresistance is short-circuited as shown in Fig. (a)

(ii) Fig. (b) is equivalent to Fig. (a).

$$I_{SC} = \frac{\mathbf{10}}{\mathbf{2}} = \mathbf{5A}$$



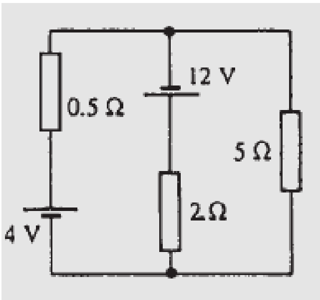
(iii) If the 10V source of e.m.f. is removed from Fig. (a) the resistance 'looking-in' at a break made between A and B is given by:

$$r = \frac{2 * 8}{2 + 8} = 1.6\Omega$$

(iv)From the Norton equivalent network shown in Fig.(c) the current in the 10Ω resistance, by current division, is given by:

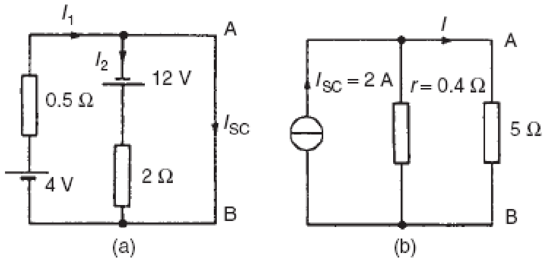
$$I = \left(\frac{1.6}{1.6 + 5 + 10}\right)(5) = 0.482A$$

2.Determine the current in the 5Ωresistance of the network shown in Fig. 13.58 using Norton's theorem. Hence find the currents flowing in the other two branches.



Following the procedure:

(i) The 5Ωbranch is short-circuited as shown in Fig. 13.59(a)



(ii) From Fig. 13.59(a),

$$ISC = I_1 - I_2 = \frac{4}{0.5} - \frac{12}{2} = 8 - 6 = 2A$$

(iii) If each source of e.m.f. is removed the resistance 'looking-in' at a break made between A and B is given by:

$$r = \frac{0.5 * 2}{0.5 + 2} = 0.4\Omega$$

(iv) From the Norton equivalent network shown in Fig. 13.59(b) the current in the 5Ωresistance is given by:

$$I = \left(\frac{0.4}{0.4 + 5}\right)(2) = 0.148A$$

as obtained previously in example2 using Thévenin's theorem. The currents flowing in the other two branches are obtained in the same way as in example 2. Hence the current flowing from the 4V source is **6.52A** and the current flowing from the 12V source is **6.37A**.

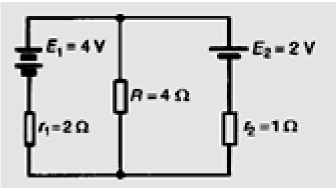
3.**SUPERPOSITION THEOREM**

The superposition theorem states:

"In any network made up of linear resistances and containing more than one source of e.m.f., the resultant current flowing in any branch is the algebraic sum of the currents that would flow in that branch if each source was considered separately, all other sources being replaced at that time by their respective internal resistances."

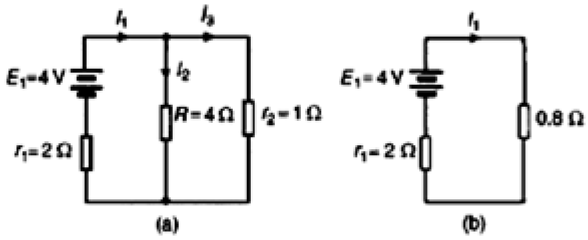
Example

Figure below shows a circuit containing two sources of e.m.f., each with their internal resistance. Determine the current in each branch of the network by using the superposition theorem.



Procedure:

1. Redraw the original circuit with source E_2 removed, replaced by r_2 only, as shown in Figure(a) below



2. Label the currents in each branch and their directions as shown in Figure (a) and determine their values. (Note that the choice of current directions depends on the battery polarity, which, by convention is taken as flowing from the positive battery terminal as shown) R in parallel with r_2 gives an equivalent resistance of (4×1)/(4+1)=0.8Ω

From the equivalent circuit of Figure (b),

$$I_1 = \frac{E2}{r1 + 0.8} = \frac{4}{2 + 0.8} = 1.429A$$

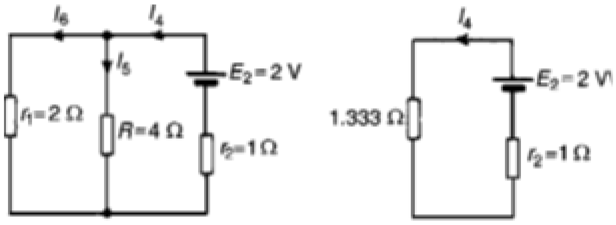
$$I_2 = \left(\frac{1}{4+1}\right) I_1 = \frac{1}{5}(1.429) = 0.286A$$

And

$$I_3 = \left(\frac{4}{4+1}\right) I_1 = \frac{4}{5}(1.429) = 1.143A$$

By current division

3. Redraw the original circuit with source*E*1 removed, being replaced by *r*1 only, as shown in Figure below (a)



(a) (b)

4. Label the currents in each branch and their directions as shown in Fig. 13.18(a) and determine their values. r_1 in parallel with *R* gives an equivalent resistance of (2×4)/(2+4)=8/6=1.333Ω

From the equivalent circuit of Figure (b)

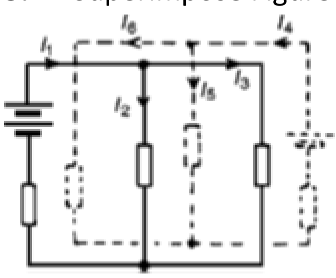
$$I_4 = \frac{E_2}{1.333 + r2} = \frac{2}{1.333 + 1} = 0.857A$$

From Figure (a),

$$I_5 = \left(\frac{2}{2+4}\right) I_4 = \frac{2}{6}(0.857) = 0.286A$$

$$I_6 = \left(\frac{4}{2+4}\right) I_4 = \frac{4}{6}(0.857) = 0.571A$$

5. Superimpose Figure (a) in step 3 on to Fig. (a) in step 1



7. Determine the algebraic sum of the currents flowing in each branch. Resultant current flowing through source 1, i.e.

$I_1 - I_6 = 1.429 - 0.571 = 0.858A$ **(discharging)**

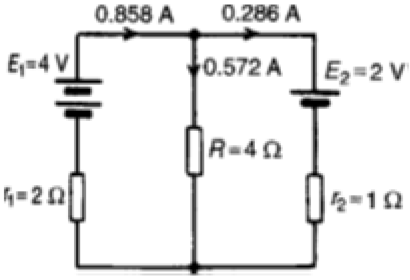
Resultant current flowing through source 2, i.e

$I_4 - I_3 = \mathbf{0.857 - 1.143 = -0.286A}$ **(Charging)**

Resultant current flowing through resistor *R*, i.e

$I_2 - I_5 = \mathbf{0.286 - 0.286 = -0.572A}$

The resultant currents with their directions are shown in Figure below



Maximum power transfer

Maximum Power Transfer occurs when the resistive value of the load is equal in value to that of the voltage sources internal resistance allowing maximum power to be supplied

Generally, this source resistance or even impedance if inductors or capacitors are involved is of a fixed value in Ohm´s.

However, when we connect a load resistance, R_L across the output terminals of the power source, the impedance of the load will vary from an open-circuit state to a short-circuit state resulting in the power being absorbed by the load becoming dependent on the impedance of the actual power source. Then for the load resistance to absorb the maximum power possible it has to be "Matched" to the impedance of the power source and this forms the basis of **Maximum Power Transfer**.

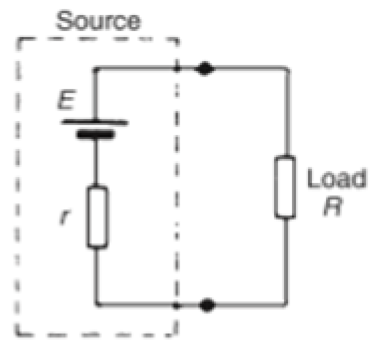
The **Maximum Power Transfer Theorem** is another useful circuit analysis method to ensure that the maximum amount of power will be dissipated in the load resistance when the value of the load resistance is exactly equal to the resistance of the power source. The relationship between the load impedance and the internal impedance of the energy source will give the power in the load. Consider the circuit below.

In our Thevenin equivalent circuit above, the maximum power transfer theorem states that ***"the maximum amount of power will be dissipated in the load resistance if it is equal in value to the Thevenin or Norton source resistance of the network supplying the power"*.**

In other words, the load resistance resulting in greatest power dissipation must be equal in value to the equivalent Thevenin source resistance, then $R_L = R_S$ but if the load resistance is lower or higher in value than the Thevenin source resistance of the network, its dissipated power will be less than maximum.

The maximum power transfer theorem states:

" The power transferred from a supply source to a load is at its maximum when the resistance of the load is equal to the internal resistance of the source"

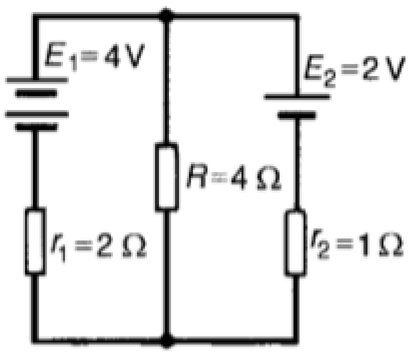


Practical Activity 1.4.2: Application of DC circuits laws and Theorems

Task:

Task1: Referring to previous activity (1.4.1.1&1.4.1.2) you are requested to perform the given task. The task should be done **individually**.

i. Use Kirchhoff's laws, Thevenin's, Superposition and Norton's theorem to determine the currents flowing in each branch of the network shown below



Task2: List out procedures and formulas to be used to perform the given tasks (1.4.2).

Task3: Referring to procedures and formulas provided on task 2, Perform the given tasks

Task4: Present your work to the trainer and whole class

Task5: Read key reading 1.4.2 and ask clarification where necessary Perform the task provided in application of learning 1.4

Key readings 1.4.2 : Application of DC circuits laws and Theorems

- **Resistors in series:** $R = R1 + R2 + R3$

Resistors in parallel:

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{RN}$$

Capacitors in series:

Capacitors in series:

$$\frac{1}{C} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} + \cdots \frac{1}{CN}$$

Capacitors in parallel: $C = C1 + C2 + C3 + \cdots + CN$

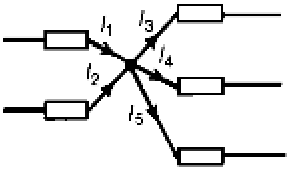
Inductors in series: $L_{Total} = L_1 + L_2 + L_3 + ... + L_n$

Inductors in parallel: $1/L_T = 1/L_1 + 1/L_2 + 1/L_3 \ldots$

- **Kirchhoff's laws state:**

(a) Current Law.

At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the junction, i.e. ΣI= 0



Thus referring to this figure

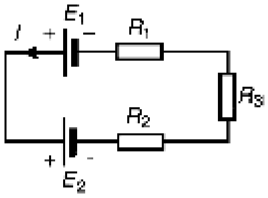
$I_1 + I_2 = I_3 + I_4 + I_5$

or

$I_1 + I_2 - I_3 - I_4 - I_5 = 0$

(b) Voltage Law.

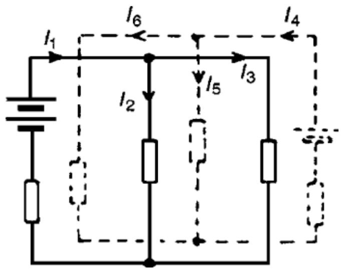
In any closed loop in a network, the algebraic sum of the voltage drops (i.e. products of current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop.



So, $E_1 - E_2 = IR_1 + IR_2 + IR_3$

The superposition theorem states:

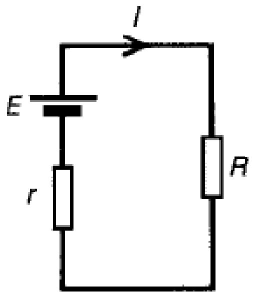
In any network made up of linear resistances and containing more than one source of e.m.f., the resultant current flowing in any branch is the algebraic sum of the currents that would flow in that branch if each source was considered separately, all other sources being replaced at that time by their respective internal resistances.



Thevenin's theorem states:

The current in any branch of a network is that which would result if an e.m.f. equal to the p.d. across a break made in the branch, were introduced into the branch, all other e.m.f.'s being removed and represented by the internal resistances of the sources.

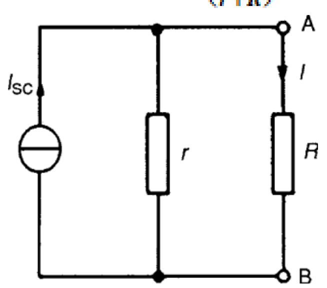
$$I = \frac{E}{R+r}$$



Norton's theorem states:

The current that flows in any branch of a network is the same as that which would flow in the branch if it were connected across a source of electrical energy, the short-circuit current of which is equal to the current that would flow in a short-circuit across the branch, and the internal resistance of which is equal to the resistance which appears across the open-circuited branch terminals.

$$I = \left(\frac{r}{r+R}\right) I_{SC}$$



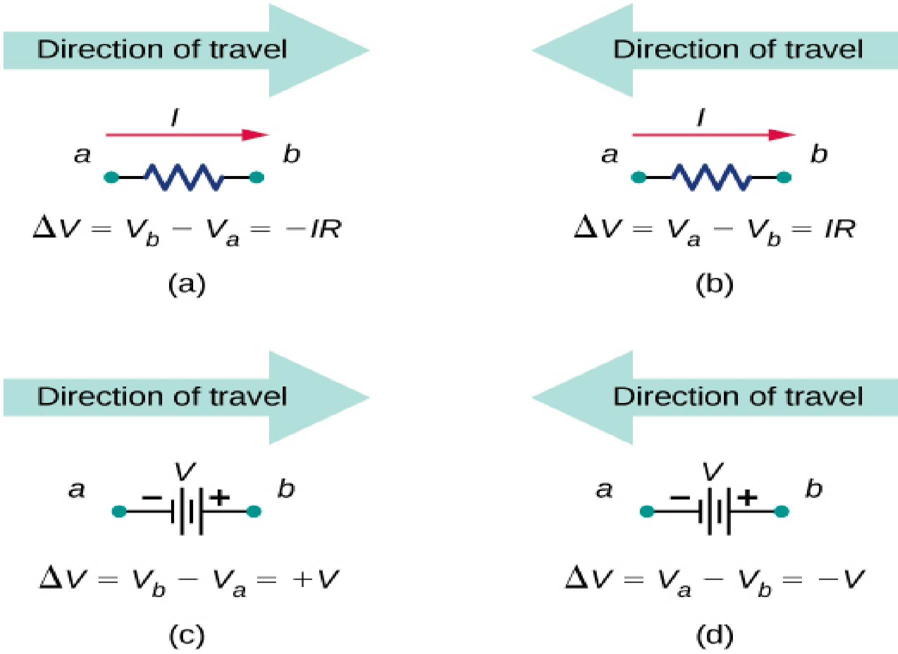
The maximum power transfer theorem states:

The power transferred from a supply source to a load is at its maximum when the resistance of the load is equal to the internal resistance of the source.

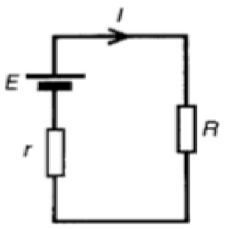
Points to Remember

- **In a DC network you must know the following terms:**

Each of these resistors and voltage sources is traversed from **a** to **b**. (a) When moving across a resistor in the same direction as the current flow, subtract the potential drop. (b) When moving across a resistor in the opposite direction as the current flow, add the potential drop. (c) When moving across a voltage source from the negative terminal to the positive terminal, add the potential drop. (d) When moving across a voltage source from the positive terminal to the negative terminal, subtract the potential drop.

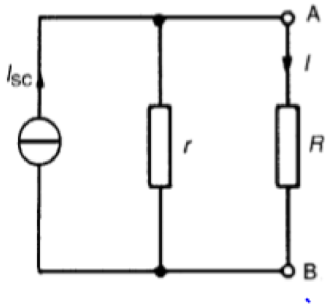


8. Kirchhoff's laws: $\Sigma I = 0$ in a junction $\Sigma(EMF) = \Sigma(\text{Voltage drops})$ in a closed loop
9. The equivalent circuit for Thevenin's theorem



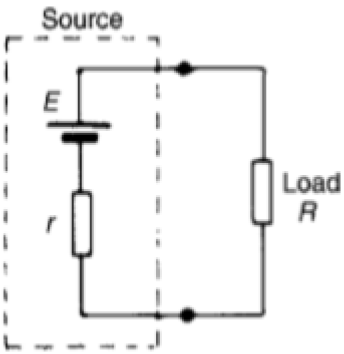
$$I = \frac{E}{R + r}$$

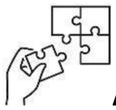
- The equivalent circuit for Northon's theorem



$$I = \left(\frac{r}{r+R}\right) I_{SC}$$

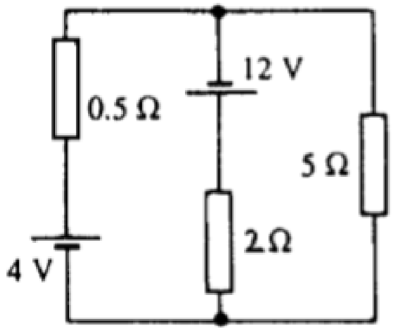
- The equivalent circuit for maximum power transfer





Application of learning 1.2.

1. Determine the current in the 5Ω resistance of the network shown in Figure below using Norton's theorem and Thevenin's theorem. Hence find the currents flowing in the other two branches



Indicative content 1.5: Identification of Resonant Circuits

Duration: 6

Theoretical Activity 1.5.1.: Describe resonant circuits

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of resonant circuits.

i. Describe phasor diagram for series and for parallel circuit

ii. Discuss on condition for series resonance and for parallel resonance

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 1.5.1.1.**

5: In addition, ask questions where necessary.

Key readings 1.5.1.1.: Description resonant circuits

- **Introduction to resonant circuits**

Single-phase series AC circuit

Circuit impedance

Impedance (symbol Z) is a measure of the overall opposition of a circuit to current, in other words: how much the circuit **impedes** the flow of current. It is like resistance, but it also takes into account the effects of capacitance and inductance. Impedance is measured in ohms, symbol.

Impedance is more complex than resistance because the effects of capacitance and inductance vary with the frequency of the current passing through the circuit and this means **impedance varies with frequency**! The effect of resistance is constant regardless of frequency.

Impedance can be split into two parts:

Resistance R (the part which is constant regardless of frequency)

Reactance X (the part which varies with frequency due to capacitance and inductance)

Reactance, X

Reactance (symbol X) is a measure of the opposition of capacitance and inductance to current. Reactance varies with the frequency of the electrical signal. Reactance is measured in ohms, symbol Ω.

There are two types of reactance: capacitive reactance (Xc) and inductive reactance (X_L). The **total reactance (X)** is the *difference* between the two: **$X = X_L - Xc$**

- **Capacitive reactance X_C** $XC=1/2\pi fc$

Where: Xc =reactance in ohms (Ω),

f=frequency in hertz (Hz),

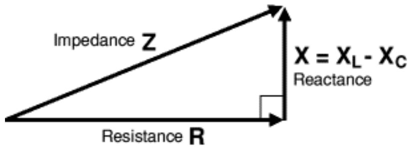
C=capacitance in farads (F)

o **Inductive reactance, X_L**

$X_L = 2fL$ X_L = reactance in ohms (Ω)

where: f = frequency in hertz (Hz)

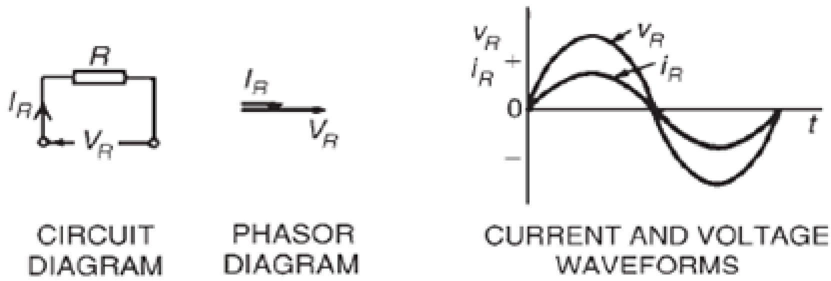
L = inductance in henrys (H)



Impedance, $Z = \sqrt{R^2 + X^2}$

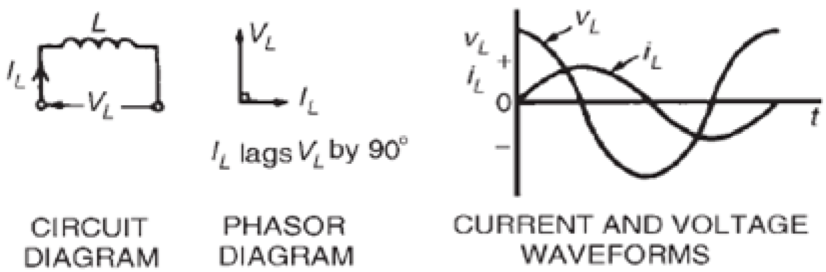
· **Purely resistive a.c. circuit**

In a purely resistive a.c. circuit, the current I_R and applied voltage V_R are in phase.



. **Purely inductive ac circuit**

In a purely inductive a.c. circuit, the current **I_L lags** the applied voltage **V_L** by 90° (i.e. π/2 rads). In a purely inductive circuit the opposition to the flow of alternating current is called the **inductive reactance, *X_L***



$$XL = \frac{VL}{IL} = 2\pi f L\Omega$$

Where ***f*** is the supply frequency, in hertz, and ***L*** is the inductance, in **henry's**.

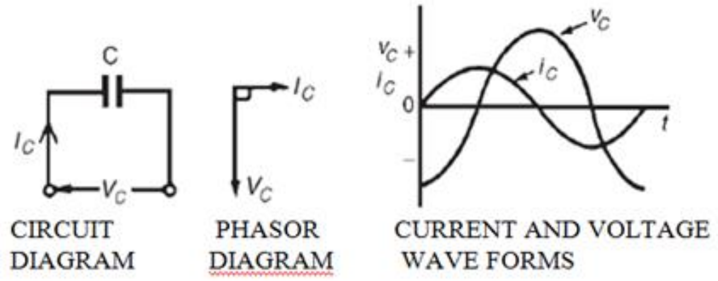
X_L is proportional to ***f.***

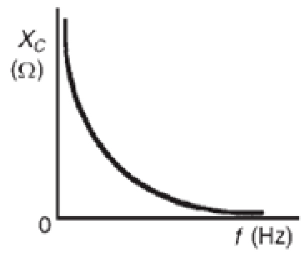
Pure capacitive ac circuit

In a purely capacitive a.c. circuit, the current **I_C leads** the applied voltage **V_C** by 90° (i.e. 2π rads). In a purely capacitive circuit the opposition to the flow of alternating current is called the **capacitive reactance, X_C**

$$XC = \frac{VC}{IC} = \frac{1}{2\pi f C}\Omega$$

Where C is the capacitance in **farads**, X_C varies with frequency f



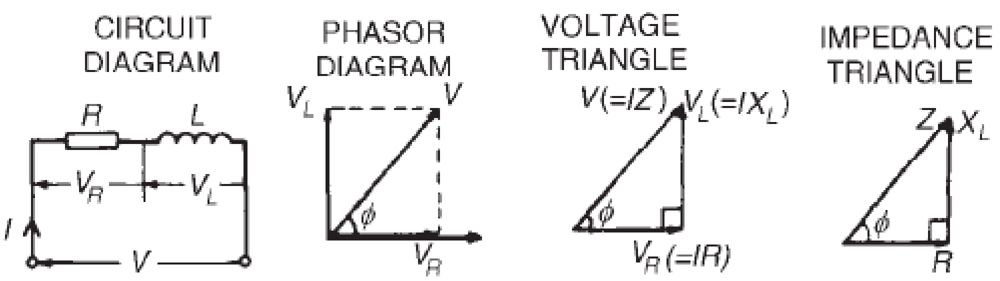


Variation of X_C In function of frequency

R-L circuit

In an a.c. circuit containing inductance L and resistance R, the applied voltage V is the phasor sum of V_R and V_L (see Figure 15.6), and thus the **current I lags** the applied voltage V by an angle lying between 0° and 90° (depending on the values of VR and VL), shown as angle φ. In any a.c. series circuit the current is common to each component and is thus taken as the reference phasor.

From the phasor diagram of Figure 15.6, the **'voltage triangle'** is derived.



For the R-L circuit:$V = \sqrt{(VR^2 + VL^2)}$ by **(Pythagoras theorem) and tan Ɵ =$\frac{VL}{VR}$ = by trigonometric ratio**

In a.c circuit, the ratio is applied voltage (V) over current (I)

$$Z = \frac{VL}{VR}\Omega$$

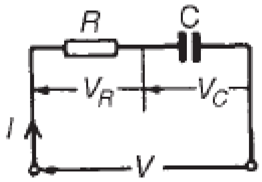
If each side of the voltage triangle is divided by current I then the '**impedance triangle'** is derived.

For the R – L circuit$Z = \sqrt{(R^2 + XL^2)}$

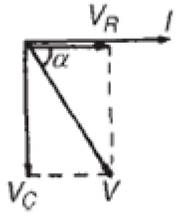
$$\tan\emptyset = \frac{XL}{R}, \sin\emptyset\frac{XL}{Z} \textit{ and } \cos\emptyset = \frac{R}{Z}$$

R-C circuit

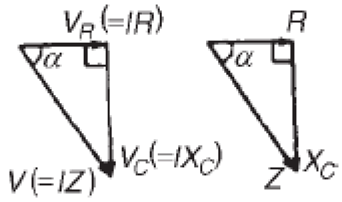
In an a.c. series circuit containing capacitance C and resistance R, the applied voltage V is the phasor sum of V_R and V_C and thus the current I leads the applied voltage V by an angle lying between 0° and 90° (depending on the values of V_R and V_C), shown as angle α .



Circuit diagram



Phasor diagram



Voltage & Impedance triangle

From the phasor diagram, the 'voltage triangle' is derived. For the $R-C$ circuit:

$V = \sqrt{(VR^2 + VC^2)}$ **by (pythogoras'theorem)**

$\tan\emptyset = \frac{VC}{VR}$, **By trigonometric ratio**

In an a.c. circuit, the ratio (applied voltage V)/(current I) is called the **impedance *Z***, i.e.

$Z = \frac{V}{I}\Omega$

If each side of the voltage triangle is divided by current I then the **'impedance triangle'** is derived.

For R-C circuit $Z = \sqrt{(R^2 + Xc^2)}$

$\tan\emptyset = \frac{Xc}{R}$, $\sin\emptyset \frac{Xc}{Z}$ *and* $\cos\emptyset = \frac{R}{Z}$

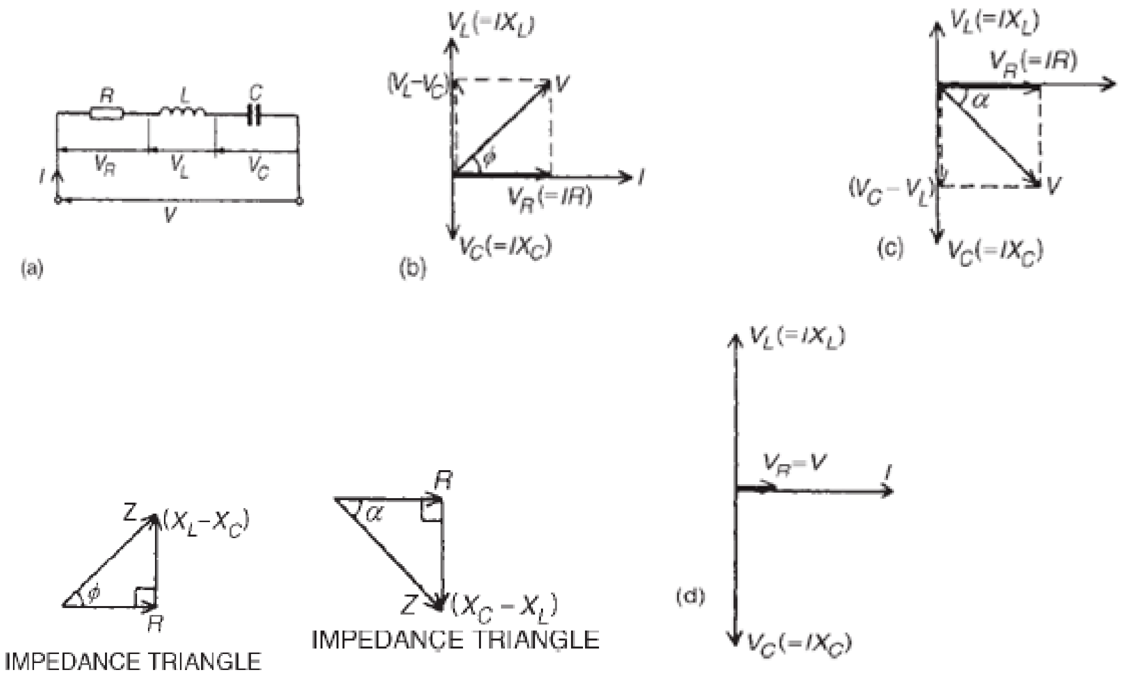
R-L-C series a.c circuit

In an a.c. series circuit containing resistance R, inductance L and capacitance C, the applied voltage V is the phasor sum of V_R, V_L and V_C. V_L and V_C are anti-phase, i.e. displaced by 180°, and there are three phasor diagrams possible each depending on the relative values of VL and VC

when $XL > XC$

$Z = \sqrt{[R^2 + (XL^2 - Xc^2)]}$

And $\tan\emptyset = \frac{XL-XC}{R}$



$Z = \sqrt{[R^2 + (XC - XL^2)]}$ And And $\tan\emptyset = \frac{XC - XL}{R}$

Practical Activity 1.5.1.2: Calculation of series resonant circuits

Task:

1: Referring to previous activities (1.5.1.1) you are requested to perform the given task. The task should be done **individually**.

i. A coil having a resistance of 10Ω and an inductance of 125mH is connected in series with a 60μF capacitor across a 120V supply. At what frequency does resonance occur? Find the current flowing at the resonant frequency.

ii. A 30μF capacitor is connected in parallel with an 80Ω resistor across a 240V, 50Hz supply. Calculate (a) the current in each branch, (b) the supply current, (c) the circuit phase angle, (d) the circuit impedance, (e) the power dissipated, and (f) the apparent power.

2: List out procedures and formulas to be used to perform the given tasks (1.5.1.2).

3: Referring to procedures and formulas provided on task 2, Perform the given tasks (a and b)

4: Present your work to the trainer and whole class.

5: Read key reading **1.5.1.2** and ask clarification where necessary Perform the task provided in application of learning **1.5**

Key readings 1.5.1.2: Calculation of series resonant circuits

- **Impedance (Z)**

Impedance is the total opposition to the flow of current in an AC circuit. It's a complex number that combines resistance (R) and reactance (X).

- Impedance (Z): $Z = \sqrt{R^2 + (XL - XC)^2}$

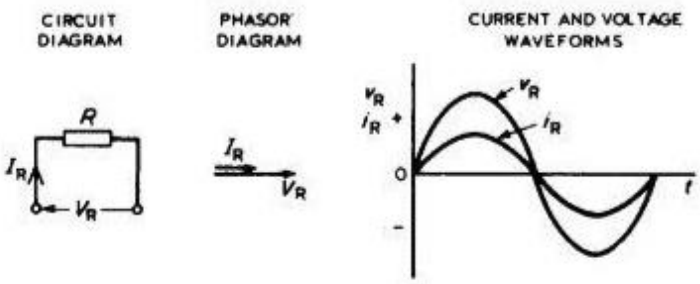
Phase Angle (θ)

The phase angle is the difference in phase between the voltage and current.

- Inductive circuit: XL > XC, θ is positive (voltage leads current)
- Capacitive circuit: XL < XC, θ is negative (current leads voltage)
- Resistive circuit: XL = XC, θ is zero (voltage and current are in phase)

- Purely resistive a.c. circuit

In a purely resistive a.c. circuit, the current IR and applied voltage VR are in phase

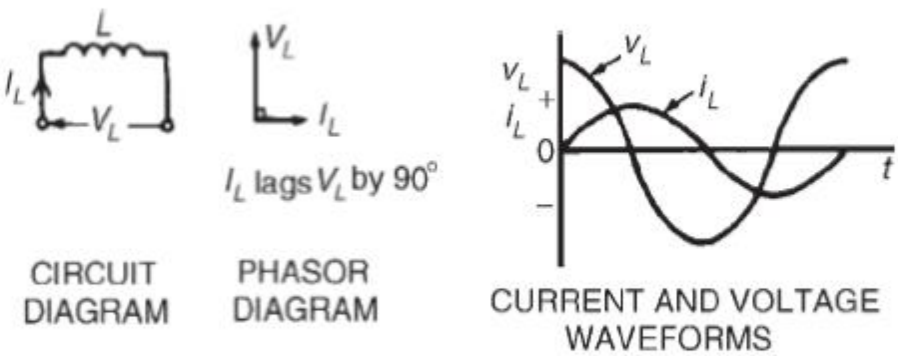


- Purely inductive a.c. circuit

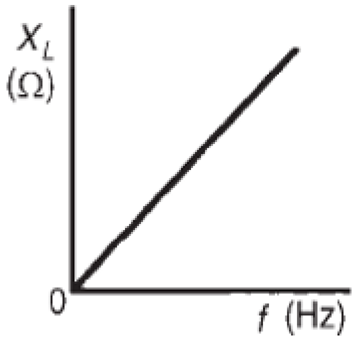
In a purely inductive a.c. circuit, the current IL lags the applied voltage VL by 90° (i.e. /2 rads). See Figures below. In a purely inductive circuit the opposition to the flow of alternating current is called the inductive reactance, XL

$$XL = \frac{VL}{IL} = 2\pi FL\Omega$$

Where f is the supply frequency, in hertz, and L is the inductance, in henry's.

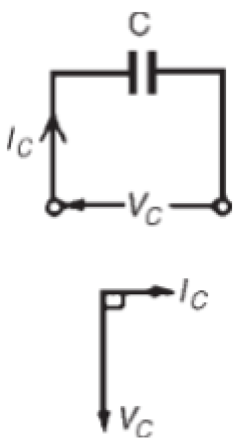


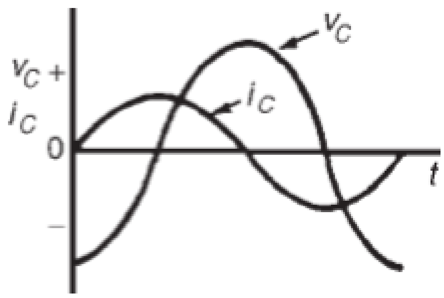
XL is proportional to f as shown below.



➢ Purely capacitive AC circuit

In a purely capacitive a.c. circuit, the current IC leads the applied voltage VC by 90° (i.e. /2 rads). See Figures below. In a purely capacitive circuit the opposition to the flow of alternating current is called the capacitive reactance, XC

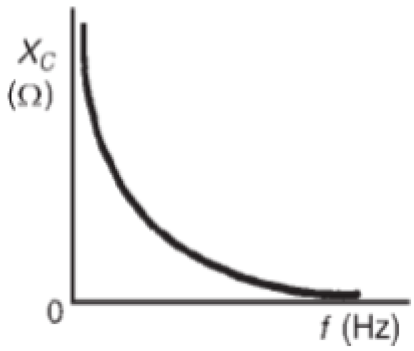




Xc = Vc / Ic = 1 / (2πfC) Ω

Where C is the capacitance in farads.

XC varies with frequency f as shown below



➢ R–L series AC circuit

In an a.c. circuit containing inductance L and resistance R, the applied voltage V is the phasor sum of VR and VL (see Figures below), and thus the current I lags the applied voltage V by an angle lying between 0° and 90° (depending on the values of VR and

VL), shown as angle ϕ. In any a.c. series circuit the current is common to each component and is thus taken as the reference phasor. From the phasor diagram of Figure 15.6, the 'voltage triangle' is derived.

For the R-L circuit : $V = \sqrt{(VR^2 + VC^2)}$ by (Pythagoras' theorem) $\text{And } \tan\emptyset = \frac{VL}{VR}$ by (trigonometric ratio)

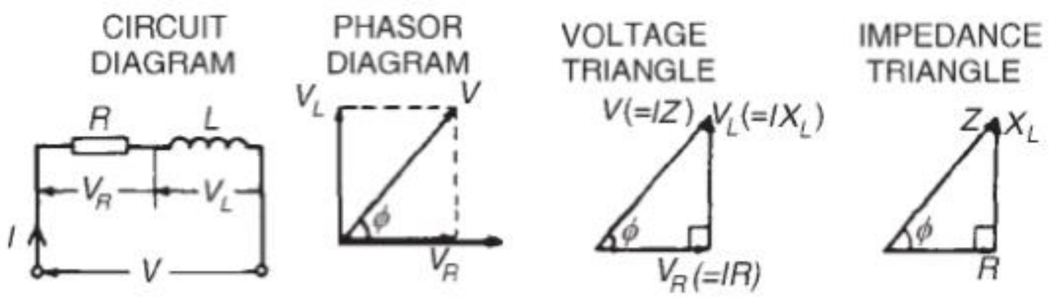
In an a.c circuit the ratio applied voltage (V) over current(I) Is called the impedence Z

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

If each side of the voltage triangle in Figures below is divided by current, I then the 'impedance triangle' is derived.

For the R – L circuit $Z = \sqrt{(R^2 + XL^2)}$

$$\tan\emptyset = \frac{XL}{R}, \sin\emptyset \frac{XL}{Z} \ and \ \cos\emptyset = \frac{R}{Z}$$



- R–C series AC circuit

In an a.c. series circuit containing capacitance C and resistance R, the applied voltage V is the phasor sum of VR and VC (see Figures below) and thus the current I leads the applied voltage V by an angle lying between 0° and 90° (depending on the values of VR and VC), shown as angle From the phasor diagram, the 'voltage triangle' is derived. FOR R-C circuit

$V = \sqrt{(VR^2 + VC^2)}$ by (pythogoras'theorem)

$$\tan\emptyset = \frac{VC}{VR}, By \text{ trigonometric ratio}$$

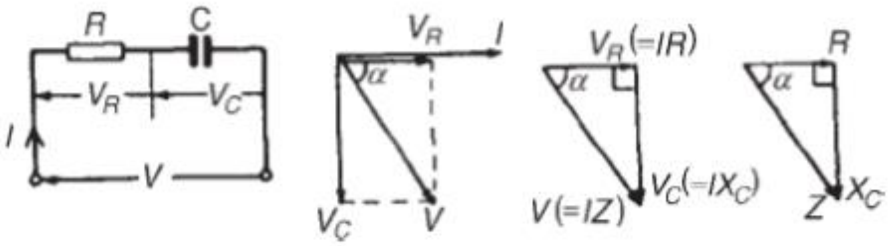
In an a.c. circuit, the ratio (applied voltage V)/ (current I) is called the impedance *Z*, i.e.

$$Z = \frac{V}{I}\Omega$$

(applied voltage V)/ (current I) is called the impedance Z, i.e. If each side of the voltage triangle in Figures below is divided by current, I then the 'impedance triangle' is derived.

For the R-C circuit: $Z = \sqrt{(R^2 + XC^2)}$

$\tan \alpha = XC / R$, $\sin \alpha = XC / Z$, and $\cos \alpha = R / Z$

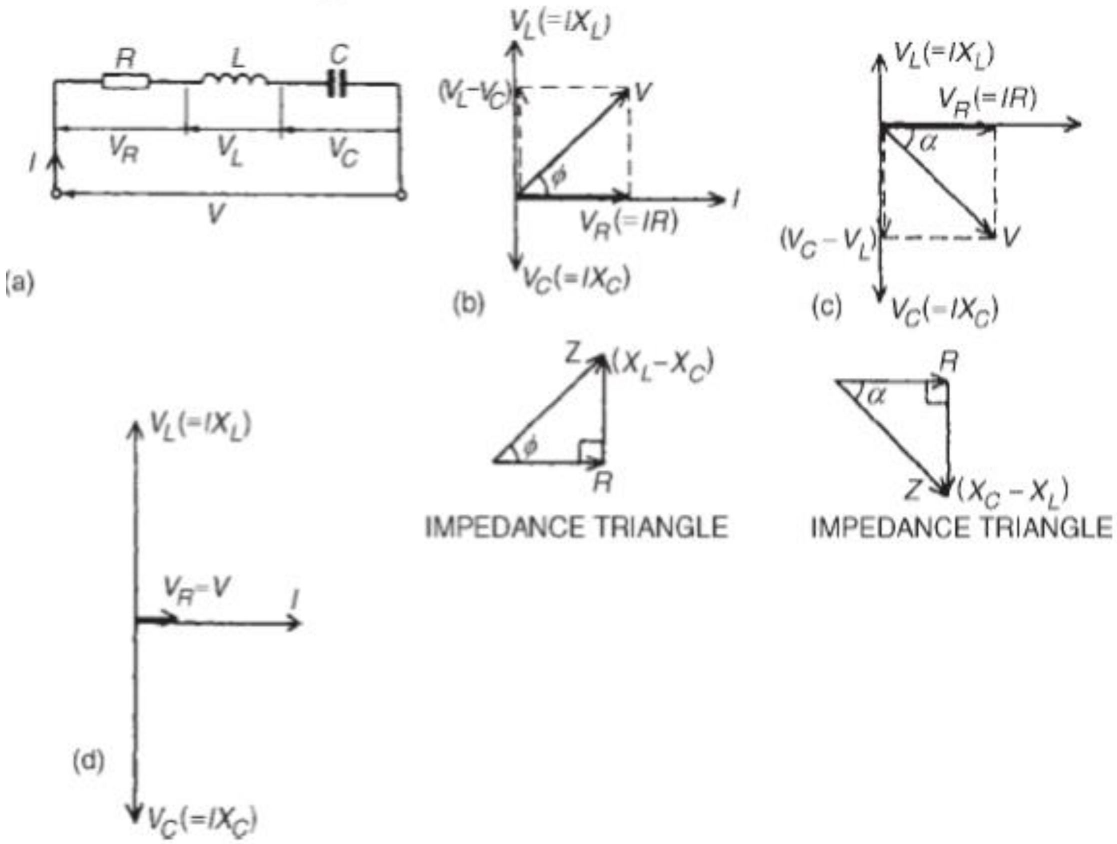


- R–L–C series AC circuit

In an a.c. series circuit containing resistance R, inductance L and capacitance C, the applied voltage V is the phasor sum of VR, VL and VC (see Figures below). VL and VC are anti-phase, i.e. displaced by 180°, and there are three phasor diagrams possible each depending on the relative values of VL and VC

When XL > XC (Figure (b) below:

$Z = \sqrt{(R^2 + (XL - XC)^2)}$ and $\tan \phi = (XL - XC) / R$



When XC > XL (Figure(c) below) :

$$Z = \sqrt{[R^2) + (XC - XL)^2]}$$

$$\text{And } \tan \emptyset = \frac{XC - XL}{R}$$

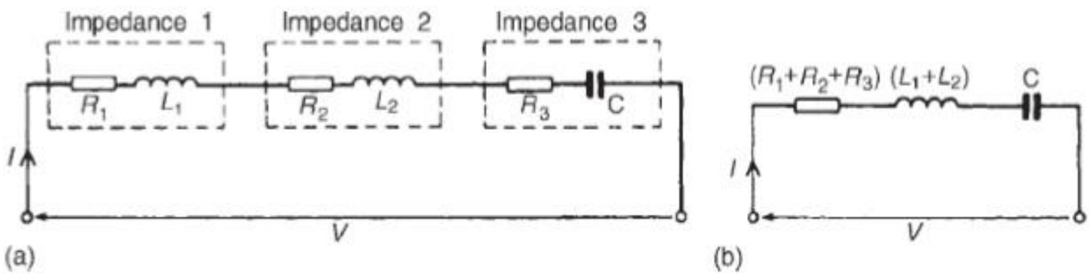
When XL = XC (Figure (d) below), the applied voltage V and the current I are in phase. This effect is called series resonance

Series connected impedances

For series-connected impedances the total circuit impedance can be represented as a single L– C–R circuit by combining all values of resistance together, all values of inductance together and all values of capacitance together, $\frac{1}{C} = \frac{1}{C1} + \frac{1}{C1} + \frac{1}{C1} + \cdots . \frac{1}{CN}$

(Remembering that for series connected capacitors

For example, the circuit of Figure (a) below showing three impedances has an equivalent circuit of Figure (b) below.



Type of Impedance	*Value of Impedance*	*Phase angle for current*	*Power factor*
Resistance only	R	0°	1
Inductance only	ωL	90° lag	0
Capacitance only	$1/\omega C$	90° lead	0
Resistance and Inductance	$\sqrt{[R^2 + (\omega L)^2]}$	$0 < \phi < 90°$ lag	1 > p.f. > 0 lag
Resistance and Capacitance	$\sqrt{[R^2 + (-1/\omega C)^2]}$	$0 < \phi < 90°$ lead	1 > p.f. > 0 lead
R-L-C	$\sqrt{[R^2 + (\omega L - 1/\omega C)^2]}$	between 0° and 90° lag or lead	between 0 and unity lag or lead

- Power in AC circuits

The value of power at any instant is given by the product of the voltage and current at that instant.

For a purely resistive a.c. circuit, the average power dissipated, P, is given by:

$$\mathrm{P} = VI = I^2R = \frac{V^2}{\mathrm{R}} \ Watts\ (vand\ i\ being\ rms\ value)$$

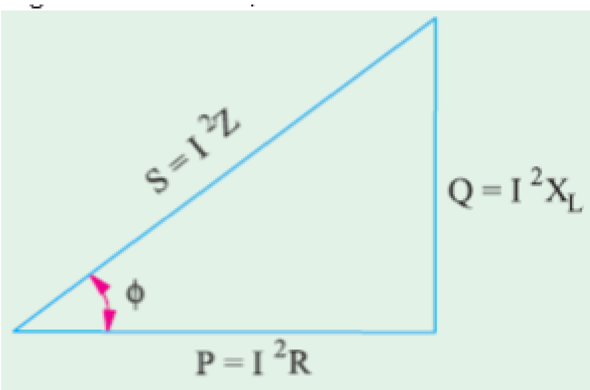
For a purely inductive a.c. circuit, the average power is zero. (c) For a purely capacitive a.c. circuit, the average power is zero. For an R–L, R–C or R–L–C series a.c. circuit, the average power P is given by:

$\mathrm{P} = VI \cos \emptyset\ watts$

$P = I^2R$ *watts* (*v and i being rms value*)

Power triangle and power factor

For figure shown below,



apparent power (S)

It is given by the product of r.m.s. values of applied voltage and circuit current. ∴ S = VI = (IZ) . I = I2Z volt-amperes (VA) (ii) active power (P or W) It is the power which is actually dissipated in the circuit resistance. P = I2R = VI cosϕ watts (iii) reactive power (Q) It is the power developed in the inductive reactance of the circuit. Q = I2.XL = I2.Z sin ϕ = I.(IZ).sinϕ = VI sin ϕ volt-amperes-reactive (VAR)

$S^2 = P^2 + Q^2 OR\ S = \sqrt{P^2} + S^2$

Apparent power,S=VI voltamperes (va)

Active power, P=VI $\cos \emptyset$

Reactive power Q=VI$\sin \emptyset$

Power facto= true power/apparent power

p.f=$\cos \emptyset$=$\frac{R}{Z}$

Points to Remember

- **Formula used in Series AC circuits:**

$XL = \frac{VL}{IL} = 2\pi FL\Omega$ **Xc = Vc / Ic = 1 / (2πfC) Ω**

For the R – L circuit$Z_= \sqrt{(R^2 + XL^2)}$

$\tan\emptyset = \frac{XL}{R}$, $\sin\emptyset \frac{XL}{Z}$ *and* $\cos\emptyset = \frac{R}{Z}$

- For the R-L circuit : $V_= \sqrt{(VR^2 + VC^2)}$ by (Pythagoras' theorem)

  And $\tan\emptyset = \frac{VL}{VR}$ **by (trigonometric ratio)**

In an a.c circuit the ratio applied voltage (V) over current(I) Is called the impedence Z

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

- **R–C series AC circuit**

$V = \sqrt{(VR^2 + VC^2)}$ by (pythogoras'theorem)

$\tan\emptyset = \frac{VC}{VR}$, By trigonometric ratio

- In an a.c. circuit, the ratio (applied voltage V)/ (current I) is called the **impedance *Z***, i.e.
- $Z = \frac{V}{I}\Omega$

Theoretical Activity 1.5.2.1: Description of parallel resonant circuits

Tasks:

1: In small groups, you are requested to answer the following questions related to description of parallel resonant circuits.

i. Describe phasor diagram for series and for parallel circuit

ii. Discuss on condition for series resonance and for parallel resonance

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

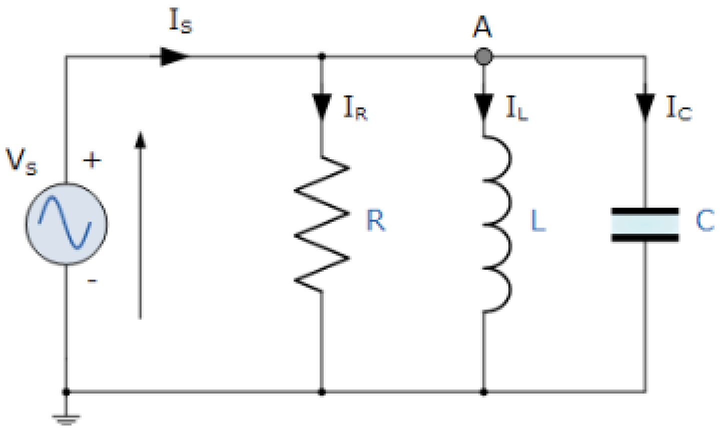
4: For more clarification, read the key **readings 1.5.2.1**

5: In addition, ask questions where necessary.

Key readings 1.5.2.1.: Description of parallel resonant circuits

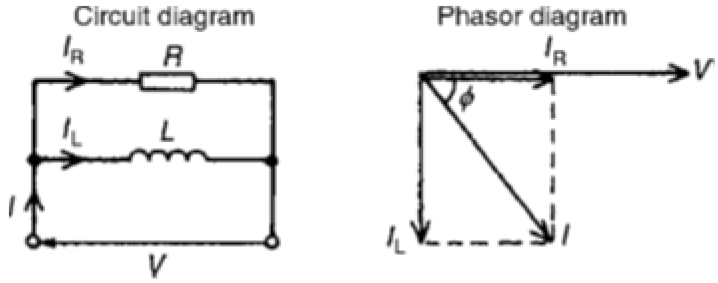
Single-phase parallel RLC circuits

single-phase parallel R-L-C circuit is an electrical circuit composed of a resistor (R), an inductor (L), and a capacitor (C) connected in parallel across a single-phase AC power source.



- **R-L Parallel AC circuit**

In the two-branch parallel circuit containing resistance *R* and inductance L shown in Figure below, the current flowing in the resistance, $\mathbf{I_R}$, is in-phase with the supply voltage **V** and the current flowing in the inductance, $\mathbf{I_L}$, lags the supply voltage by 90^0. **The supply current *I* is the phasor sum of $\mathbf{I_R}$ and $\mathbf{I_L}$** and thus the current I lags the applied voltage V by an angle lying between 0◦ and 90◦ (depending on the values of I_R and I_L), shown as angle φ in the phasor diagram.



From the phasor diagram: $I = \sqrt{(IR^2 + IL^2)}$ (by Pythagoras' theorem) where

$IR = V / R$ and $IL = V / XL$

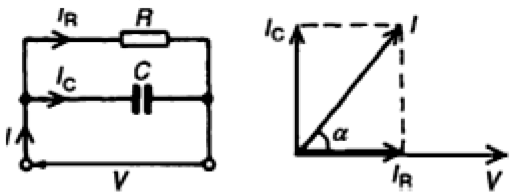
$\tan \phi = IL / IR$, $\sin \phi = IL / I$, and $\cos \phi = IR / I$

(by trigonometric ratios)

Circuit impedance, $Z = V / I$

- **R-C Parallel a.c circuit**

In the two branches parallel circuit containing resistance R and capacitance C shown in Figure below, $\mathbf{I_R}$ is in-phase with the supply voltage **V** and the current flowing in the capacitor, $\mathbf{I_C}$, leads **V** by 90◦. **The supply current I is the phasor sum of $\mathbf{I_R}$ and $\mathbf{I_C}$** and thus the current I leads the applied voltage V by an angle lying between 0◦ and 90◦ (depending on the values of IR and IC), shown as angle α in the phasor diagram.



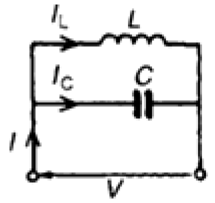
From the phasor diagram: $I = \sqrt{(IR^2 + IC^2)}$ (by Pythagoras' theorem)

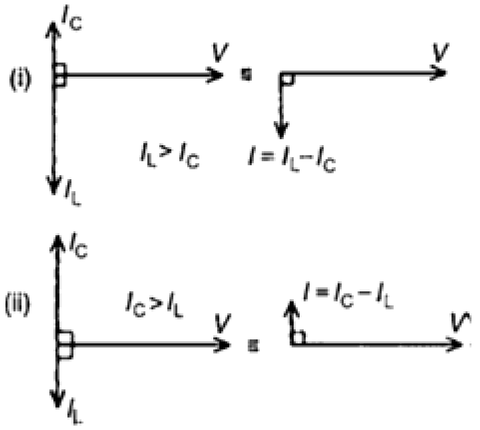
where $IR = V / R$ and $IC = V / XC$

tan α = IC / IR, sin α = IC / I, and cos α = IR / I
Circuit impedance, Z = V / I

- **L-C Parallel a.c circuit**

In the two branch parallel circuit containing inductance *L* and capacitance *C* shown in Figure below **I_L** lags **V** by 90◦ and ***I_C*** leads ***V*** by 90◦





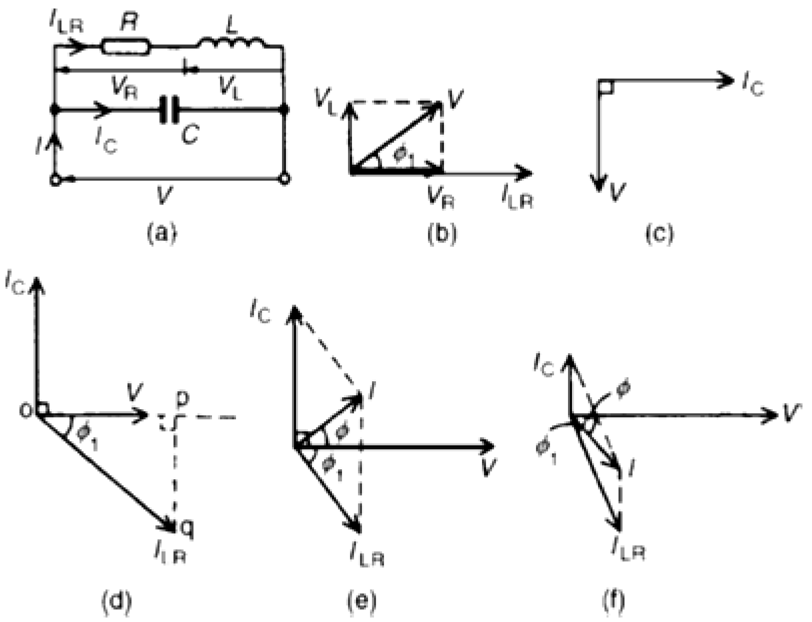
Theoretically there are three phasor diagrams possible, each depending on the relative values of I_L and I_C:

(i) I_L >I_C (giving a supply current, I =I_L −I_C lagging V by 90◦)
(ii) I_C >I_L (giving a supply current, I =I_C −I_L leading V by 90◦)
(iii) I_L =I_C (giving a supply current, *I* =0). The latter condition is not possible in practice due to circuit resistance inevitably being present

For the L-C parallel circuit, IL = V / XL
IC = V / XC I = phasor difference between IL and IC, and
Z = V / I

- **LR-C Parallel a.c circuit**

In the two branch circuit containing capacitance *C* in parallel with inductance *L* and resistance *R* in series (such as a coil) shown in Figure(a), the phasor diagram for the LR branch alone is shown in Figure(b) and the phasor diagram for the *C* branch is shown alone in Figure(c). Rotating each and superimposing on one another gives the complete phasor diagram shown in Figure (d).



The current I_{LR} of Figure (d) may be resolved into horizontal and vertical components. The horizontal component, shown as **op** is **I_{LR} cos φ_1** and the vertical component, shown as ***pq*** is

I_{LR} sin $\varphi 1$.

There are three possible conditions for this circuit:

(i) $I_C > I_{LR}$ sin $\varphi 1$ (giving a supply current *I* leading *V* by angle *φ*—as shown in Figure (e))

(ii) I_{LR} sin$\varphi > I$C (giving *I* lagging *V* by angle *φ*—as shown in Figure (f))

(iii) $I_C = I_{LR}$ sin $\varphi 1$ (this is called **parallel resonance**,)

There are two methods of finding the phasor sum of currents I_{LR} and I_C in Figure (e) and (f). These are:

(i) **by a scaled phasor diagram**, or

(ii) **by resolving each current into their 'in-phase'** (i.e. horizontal) and '**quadrature**' (i.e. vertical) **components**.

Impedance of LR branch **$ZLR = \sqrt{R^2 + XL^2}$**

Current $ILR = V / ZLR$ and $IC = V / XC$

Supply current I = phasor sum of ILR and IC (by drawing) = $\sqrt{(ILR \cos \phi_1)^2 + (ILR \sin \phi_1 \sim IC)^2}$ (by calculation)

where ~ means 'the difference between'.

Circuit impedance $Z = V / I$

$\tan \phi_1 = VL / VR = XL / R$

$\sin \phi_1 = XL / ZLR$ and $\cos \phi_1 = R / ZLR$

$\tan \phi = (ILR \sin \phi_1) / (ILR \cos \phi_1) \approx IC / (ILR \cos \phi_1)$ and $\cos \phi = (ILR \cos \phi_1) / I$

Practical Activity 1.5.2.2: Calculation of parallel resonant circuits

Task:

1: Referring to previous activities (1.5.2.1) you are requested to perform the given task. The task should be done **individually**.

i. A 30μF capacitor is connected in parallel with an 80Ω resistor across a 240V, 50Hz supply. Calculate (a) the current in each branch, (b) the supply current, (c) the circuit phase angle, (d) the circuit impedance, (e) the power dissipated, and (f) the apparent power.

2: List out procedures and formulas to be used to perform the given tasks (1.5.2.2).

Task3: Referring to procedures and formulas provided on task 2, Perform the given tasks

4: Present your work to the trainer and whole class.

5: Read key reading 1.5.2.2 and ask clarification where necessary Perform the task provided in application of learning 1.5.2

Key readings 1.5.2.2: Calculation of parallel resonant circuits

Single-phase parallel RLC circuits

In parallel circuits, such as those shown in Figures below, the voltage is common to each branch of the network and is thus taken as the reference phasor when drawing phasor diagrams.

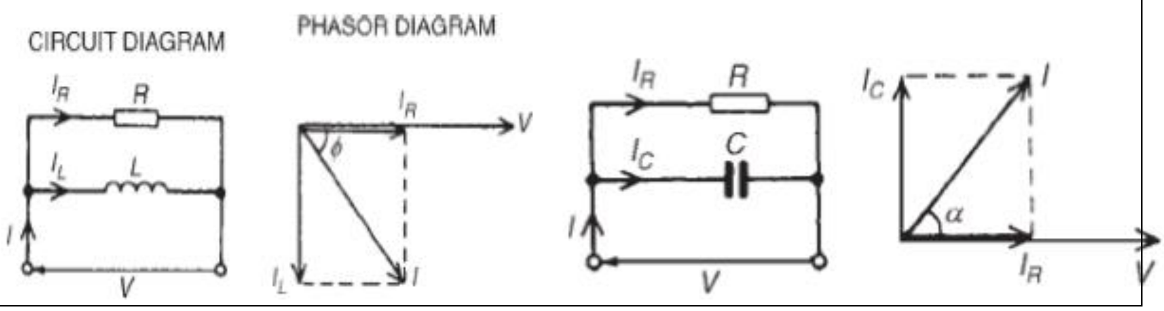
For any parallel a.c. circuit:

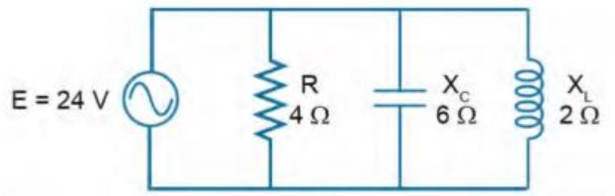
True or active power, P = VI cosϕ watts (W) or P = IR2R watts

Apparent power, S = VI volt-amperes (VA)

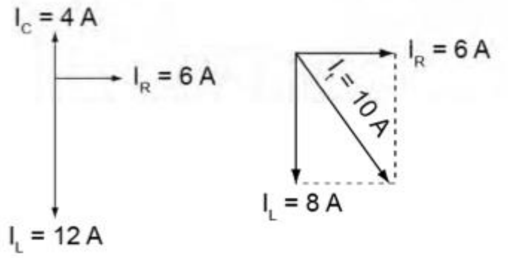
Reactive power, Q = VI sinϕ reactive volt-amperes (var)

Power factor = (true power) / (apparent power) = P / S = cos ϕ





$I_R = \frac{E}{R} = \frac{24\,V}{4\,\Omega} = 6\,A$ $\quad I_C = \frac{E}{X_C} = \frac{24\,V}{6\,\Omega} = 4\,A$ $\quad I_L = \frac{E}{X_L} = \frac{24\,V}{2\,\Omega} = 12\,A$



I_t = Total Current

$I_t = \sqrt{I_R^2 + (I_c - I_L)^2}$

$I_t = \sqrt{6^2 + 8^2}$

$I_t = \sqrt{100}$

$I_t = 10\,A$

Z_t = Total Impedance

$Z_t = \frac{E}{I_t} = \frac{24\,V}{10\,A}$

$Z_t = 2.4\,\Omega$

R–L parallel AC circuit

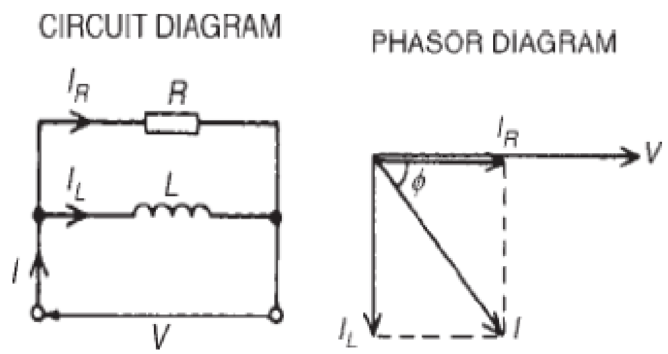
In the two-branch parallel circuit containing resistance R and inductance L shown below, the current flowing in the resistance, IR, is in-phase with the supply voltage V and the current flowing in the inductance, IL, lags the supply voltage by 90°. The supply current I is the phasor sum of IR and IL and thus the current I lags the applied voltage V by an angle lying between 0° and 90° (depending on the values of IR and IL), shown as angle ϕ in the phasor diagram. From the phasor diagram:

$I = \sqrt{(IR^2 + IL^2)}$, by Pythagoras' theorem

where IR = V/R and IL = V/XL

tan ϕ = IL/IR, sin ϕ = IL/I, and cos ϕ = IR/I (by trigonometric ratios)

Circuit impedance, Z = V/I



R–C parallel AC circuit

In the two branch parallel circuit containing resistance R and capacitance C shown in Figures below, IR is in-phase with the supply voltage V and the current flowing in the capacitor, IC, leads V by 90°. The supply current I is the phasor sum of IR and IC and thus the current I leads the applied voltage V by an angle lying between 0° and 90° (depending on the values of I= and I=), shown as angle α in the phasor diagram.

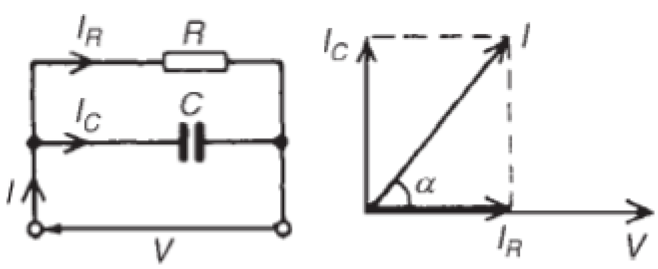
From the phasor diagram:

I = √ (IR² + IC²), by Pythagoras' theorem

where IR = V/R and IC = V/XC

tan α = IC/IR, sin α = IC/I, and cos α = IR/I (by trigonometric ratios)

Circuit impedance Z = V/I



L–C parallel AC circuit

In the two branch parallel circuit containing inductance L and capacitance C shown in Figures below, IL lags V by 90° and IC leads V by 90°. Theoretically there are three phasor diagrams possible each depending on the relative values of IL and IC:

IL > IC (giving a supply current, I = IL - IC lagging V by 90°)

(ii) IC > IL (giving a supply current, I = IC - IL leading V by 90°)

(iii) IL = IC (giving a supply current, I = 0).

For the L-C parallel circuit,IL=V/XL,IC=V/XC

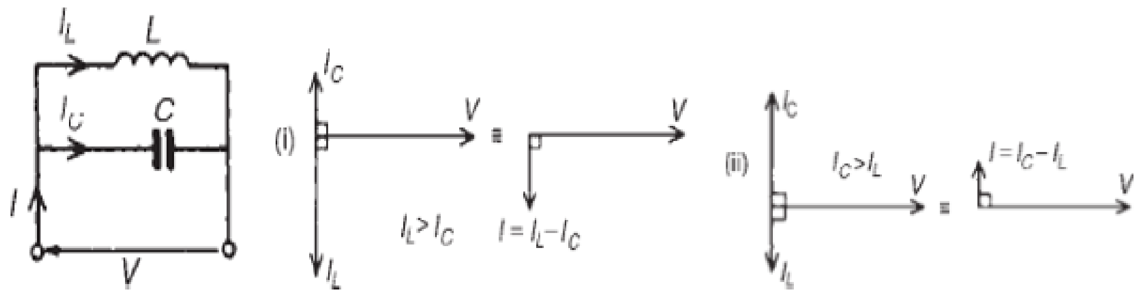
I=Phasor difference between IL and IC, and Z=V/I

I = √ (IR² + IC²), by Pythagoras' theorem

where IR = V/R and IC = V/XC

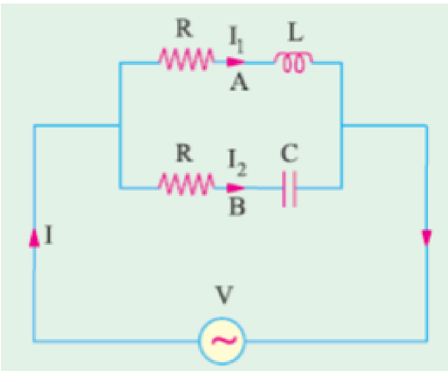
tan α = IC/IR, sin α = IC/I, and cos α = IR/I (by trigonometric ratios)

Circuit impedance Z = V/I



Vector or Phasor Method

Consider the circuits shown in Fig. below. Here, two reactors A and B have been joined in parallel across an r.m.s. supply of V volts. The voltage across two parallel branches A and B is the same, but currents through them are different



For Branch A, $Z_1 = \sqrt{(R_1^2 + X_1^2)}$; $I_1 = V/Z_1$; $\cos \phi_1 = R_1/Z_1$ or $\phi_1 = \cos^{-1}(R_1/Z_1)$

Current I1 lags behind the applied voltage by ϕ1 (Fig.(a) below).

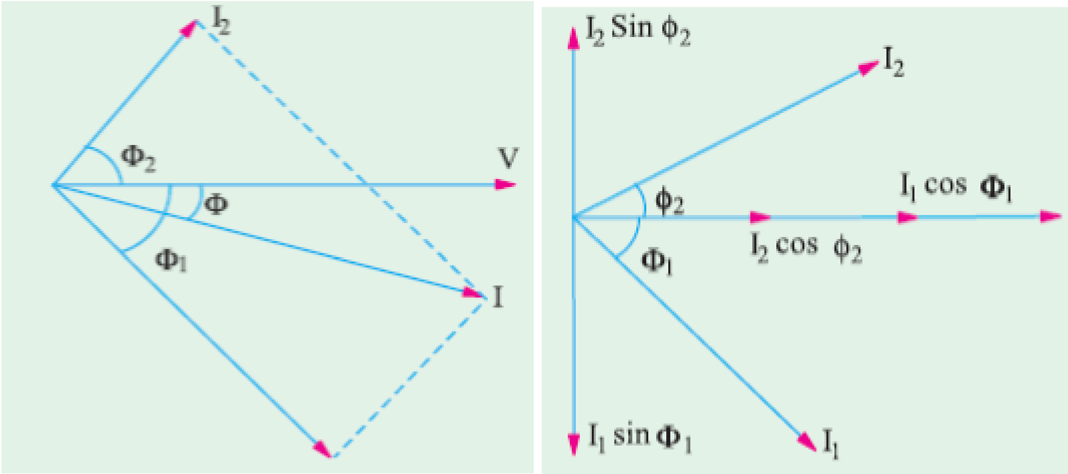
$$Z_2 = \sqrt{(R^2 + XC^2)}; I_2 = \frac{V}{Z_2}; \cos \emptyset = \frac{R_2}{Z_2} \quad OR\, \emptyset_2 = \cos^{-1}\frac{R_2}{Z_2}$$

Current I2 leads V by ϕ2 (Fig. below). Resultant Current I The resultant circuit current I is the vector sum of the branch currents I1 and I2 and can be found by (i) using parallelogram law of vectors, as shown in Fig.(a) below.

(ii) Resolving I2 into their X- and Y-components (or active and reactive components respectively) and then by combining these components, as shown below. Method (ii) is preferable, as it is quick and convenient. With reference to Fig.(b) below.

we have Sum of the active components of I1 and I2

$I = I_1 \cos \phi_1 + I_2 \cos \phi_2$



(a) (b)

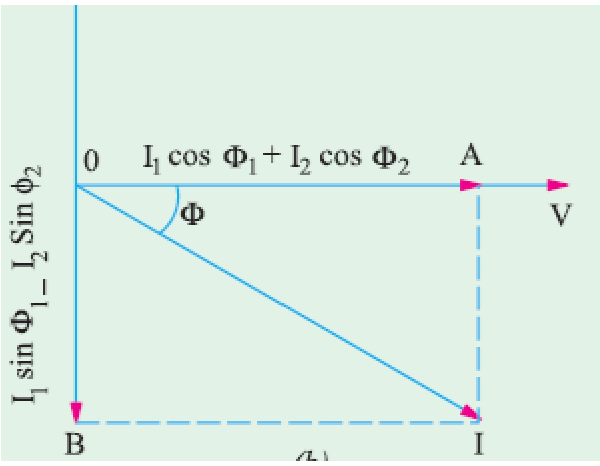
Sum of the reactive components of I1 and I2 = I2 sin ϕ2 − I1 sin ϕ1 If I is the resultant current and ϕ its phase, then its active and reactive components must be equal to these X-and Y-and Y-components respectively [Fig. below] I cos ϕ = I1 cos ϕ1 + I2 cos ϕ2 and I sin ϕ = I2 sin ϕ2 – I1 sin ϕ1

$$I = \sqrt{(I_{1\cos\emptyset 1} + I_{2\cos\emptyset 2})^2 + (I_{2\sin\emptyset 1} + I_{1\sin\emptyset 2})^2}$$

$$\tan\emptyset = \frac{I_{2\sin\emptyset 2 - I_1 \sin\emptyset 2}}{I_{1\cos\emptyset 2 + I_2 \cos\emptyset 2}} = \frac{Y - Component}{X - Component}$$

If tan ϕ is positive, then current leads and if tan ϕ is negative, then current lags behind the applied voltage V. Power factor for the whole circuit is given by

$$\cos\emptyset = \frac{I_{1\cos\emptyset 2 + I_2 \cos\emptyset 2}}{I} = \frac{X - Component}{I}$$



Admittance Method

$$Y = \frac{1}{Z} = \frac{I}{V} \quad OR\, Y = \frac{r.m.s.amperes}{r.m.s\ volt}$$

Its unit is Siemens (S)

Admittance of a circuit is defined as the reciprocal of its impedance. Its symbol is Y.

Difference between Series RLC Circuit and Parallel RLC Circuit

S.NO	RLC SERIES CIRCUIT	RLC PARALLEL CIRCUIT
1	Resistor, inductor and capacitor are connected in series	Resistor, inductor and capacitor are connected in parallel
2	Current is same in each element	Current is different in all elements and the total current is equal to vector sum of each branch of current i.e $I_s^2 = I_R^2 + (I_C - I_L)^2$
3	Voltage across all the elements is different and the total voltage is equal to the vector sum of voltages across each component i.e $V_s^2 = V_R^2 + (V_L - V_C)^2$	Voltage across each element remains the same
4	For drawing phasor diagram, current is taken as reference vector	For drawing phasor diagram, voltage is taken as reference vector

5	Voltage across each element is given by : V_R= IR, V_L = I X_L, V_C = I X_C	Current in each element is given by: I_R = V / R , I_C = V / X_C , I_L = V / X_L
6	Its more convenient to use impedance for calculations	Its more convenient to use admittance for calculations
7	At resonance, when X_L = X_C, the circuit has minimum impedance	At resonance, when X_L = X_C, the circuit has maximum impedance

Applications of RLC Circuit

It is used as a low pass filter, high pass filter, band-pass filter, band-stop filter, voltage multiplier and oscillator circuit. It is used for tuning radio or audio receivers.

Points to Remember

- **Formula used in Parallel AC circuits:**

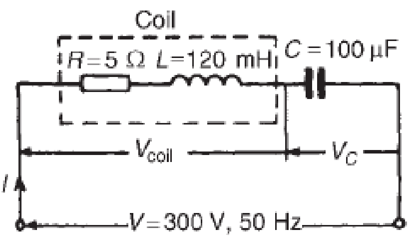
$I = \sqrt{(IR^2 + IL^2)}$ $\cos \phi = IR / I$ $I = \sqrt{(IR^2 + IC^2)}$ Supply current

I = phasor sum of ILR and IC (by drawing)

$= \sqrt{[(ILR \cos \phi_1)^2 + (ILR \sin \phi_1 \sim IC)^2]}$

Application of learning 1.5.

1. A coil of resistance 5Ω and inductance 120 mH in series with a 100 μF capacitor is connected to a 300 V, 50 Hz supply. Calculate (a) the current flowing, (b) the phase difference between the supply voltage and current, (c) the voltage across the coil and (d) the voltage across the capacitor.



2. A resistor of 25Ω is connected in series with a capacitor of 45 μF. Calculate (a) the impedance, and (b) the current taken from a 240 V, 50 Hz supply. Find also the phase angle between the supply voltage and the current.

3. A coil of inductance 159.2 mH and resistance 40 Ohm is connected in parallel with a 30 μF capacitor across a 240V, 50 Hz supply. Calculate

(a) the current in the coil and its phase angle,

(b) the current in the capacitor and its phase angle,

(c) the supply current and its phase angle,

(d) the circuit impedance,

(e) the power consumed,

(f) the apparent power, and

(g) the reactive power. Draw the phasor diagram

Indicative content 1.6: Introduction to Magnetism and Electro-Magnetism

Duration:5 hrs

Theoretical Activity 1.6.1: Description of magnetism and electro-

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of magnetism and electro-magnetism.

i. **What do you understand by magnetic field, magnetic flux and magnetic flux density?**
ii. **Describe the types of magnetic materials.**
iii. **What are the applications of magnetism?**
iv. **Explain laws of Faraday law of induction**
v. **What are the applications of electromagnetism?**

2: Provide the answer for the asked questions and write them on papers.
3: Present the findings/answers to the whole class
4: For more clarification, read the key **readings 1.6.1.**
5: In addition, ask questions where necessary.

Key readings 1.6.1.: Description of magnetism and electro-magnetism

Introduction to magnetism and electro-magnetism

1. Definition of Terms

a) What is Magnetism?

Magnetism is a term used to describe any phenomenon that can be attributed to a magnetic field. Magnets can exert forces on other magnets or magnetic materials. A magnetic field is described as a region where magnets/magnetic materials experience a force.

b) What is Electromagnetism?

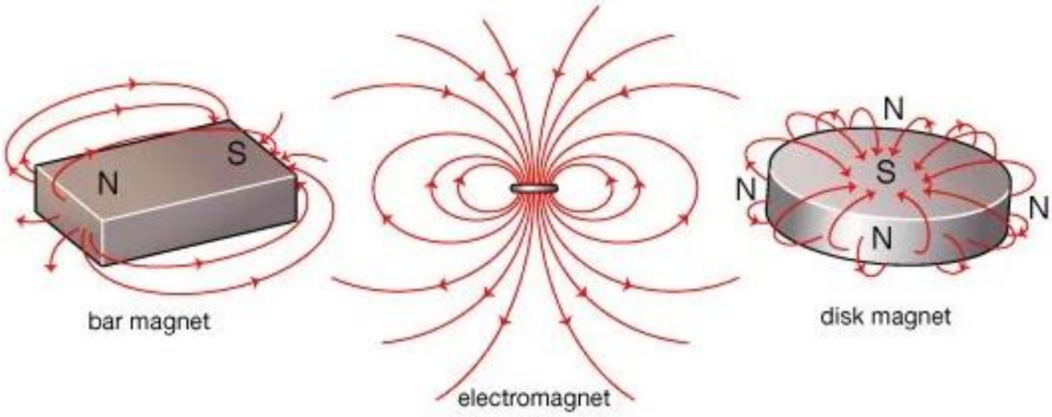
Electromagnetism is a term that describes phenomena that can be attributed to electric or magnetic forces. Electric and magnetic fields are interrelated, and they can be considered to be aspects of one electromagnetic force.

What is a Magnetic Field?

"A magnetic field is the area around a magnet, magnetic object, or an electric charge in which magnetic force is exerted."

Magnetic field and electric field are both interrelated and are components of the electromagnetic force, one of the four fundamental forces of nature.

To become magnetised, another strongly m



magnetic substance must enter the magnetic field of an existing magnet. The magnetic field is the area around a magnet that has magnetic force.

All magnets have north and south poles. Opposite poles are attracted to each other, while the same poles repel each other.The force generated by the aligned atoms creates a magnetic field. The piece of iron has become a magnet.

Properties of Magnetic Field Lines

- Magnetic field lines never cross each other
- The density of the field lines indicates the strength of the field
- Magnetic field lines always make closed loops
- Magnetic field lines always emerge or start from the north pole and terminate at the south pole.

What makes a magnetic field?

Magnetic fields are created by moving electric charge. When electrons, which have a negative charge, move around in certain ways, a magnetic field can be created. These fields can be created inside the atoms of magnetic objects or within wires (electromagnetism).

Electromagnets

The solenoid is very important in electromagnetic theory since the magnetic field inside the solenoid is practically uniform for a particular current, and is also versatile, inasmuch that a variation of the current can alter the strength of the magnetic field. An electromagnet, based on the solenoid, provides the basis of many items of electrical equipment, examples of which include electric bells, relays, lifting magnets and telephone receivers.

Magnetic flux Φ

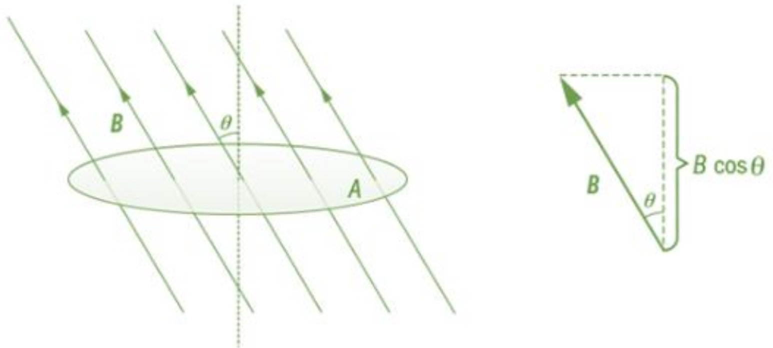
Magnetic Flux is defined as the surface integral of the normal component of the Magnetic Flux (B) propagating through that surface. It is indicated by ϕ or ϕ_B. Its SI unit is **Weber(Wb)**. The study of Magnetic Flux is done in Electromagnetism which is a branch of physics that deals with the relation between Electric Current and Magnetic Field.

Magnetic Flux Definition

Magnetic Flux is defined as,
The number of Magnetic Field lines flowing through a closed surface is known as Magnetic Flux. It calculates the total magnetic field that travels across a specific surface area.
The region under consideration might be any size and can be oriented in any direction about the magnetic field direction.
Magnetic Flux Symbol
The Greek letter Phi or the Phi suffix B is often used to represent Magnetic Flux. The symbol for Magnetic Flux is **φ or φ_B**.
Magnetic Flux Formula
Magnetic Flux Formula is given as:
$\boldsymbol{\varphi_B = B.A = B\ A\ \cos\theta}$
where

- **A** is the Surface Area
- **B** is the Magnetic Field
- **θ** is the Angle at which lines pass through the Area
- **φ_B** is the Magnetic Flux

We use the Field-Line picture of a Magnet or a set of magnets to compute the Magnetic Flux. The scalar product of the magnetic field and area 'A' gives the Magnetic Flux through a plane of area 'A' that is put in a Uniform Magnetic Field of magnitude B. It's also necessary to consider the angle at which the field lines travel across the given surface area.



Mathematically,
$\boldsymbol{\varphi_B = B.A = B\ A\ \cos\theta}$
where, **θ** is the angle between vectors A and B.
The resultant flux depends on the glancing angle in the following manner:

- When the angle is 90°, the flux is lowest as Cos 90° is zero.
- When the angle is 0°, the flux is largest as Cos 0° is 1.

The following are the SI and CGS units of Magnetic Flux:

- Weber **(Wb)** is the SI unit for Magnetic Flux.
- **Volt-Seconds** is the fundamental unit of Magnetic Flux
- **Maxwell** is the CGS unit of Magnetic Flux

Magnetic Flux Density Formula

Magnetic Flux Density Formula is given as:

$B = F / I L$

where,

- **I** is the current flowing through the wire
- **L** is the length of wire
- **F** is the total force acting on the wire

Also: **$B = \Phi / A$ tesla**

Magnetic Field Intensity

Magnetic field strength is also magnetic field intensity or magnetic intensity. It is represented as vector H and is defined as the ratio of the MMF needed to create a certain Flux Density (B) within a particular material per unit length of that material. Magnetic field intensity is measured in units of amperes/metre.

It is given by the formula:

$H = B / \mu - M$

Where,

- **B** is the magnetic flux density
- **M** is the magnetization
- **μ** is the magnetic permeability

The SI unit of magnetic field intensity is Tesla. One tesla (1 T) is defined as the field intensity generating one newton of force per ampere of current per metre of conductor.

Magnetic Field created by a Current-Carrying Conductor

Ampere suggested that a magnetic field is produced whenever an electrical charge is in motion. As the current through the conductor increases, the magnetic field increases proportionally. When we move further away from the wire, the magnetic field decreases with the distance. Ampere's law describes this. According to the law, the equation gives the magnetic field at a distance r from a long current-carrying conductor I.

$$B = \frac{\mu 0 I}{2\pi r}$$

In the equation, μ_0 is a special constant known as the permeability of free space (**$\mu_0 = 4\pi \times 10^{-7}$ T· m/A**).

Materials with higher permeability possess the ability to concentrate on magnetic fields.

The magnetic field has direction as it is a vector quantity. For conventional current flowing through a straight wire, this can be found by the right-hand rule. Imagine gripping your right hand around the wire with your thumb pointing in the current direction to use this rule. The fingers show the direction of the magnetic field, which wraps around the wire.

Force on a current-carrying conductor

If a current-carrying conductor is placed in a magnetic field produced by permanent magnets, then the fields due to the current-carrying conductor and the permanent magnets interact and cause a force to be exerted on the conductor. The force on the current-carrying conductor in a magnetic field depends upon:

(a) the flux density of the field, B teslas (b) the strength of the current, I amperes, (c) the length of the conductor perpendicular to the magnetic field, l metres, and (d) the directions of the field and the current.

When the magnetic field, the current and the conductor are mutually at right angles then:

$$\text{Force } F = BIl \text{ newtons}$$

When the conductor and the field are at an angle ø° to each other then:

Force F = BIl sinø newtons

Since when the magnetic field, current and conductor are mutually at right angles, F=BIl, the magnetic flux density B may be defined by B=F/Il, i.e. the flux density is 1T if the force exerted on 1m of a conductor when the conductor carries a current of 1A is 1N.

Types magnetic materials

There are Five types of magnetic materials. Examples of magnetic materials are:

- Paramagnetic materials
- Diamagnetic materials
- Ferromagnetic materials
- Ferrimagnetism

Diamagnetic materials have a weak, negative susceptibility to magnetic fields. Diamagnetic materials are slightly repelled by a magnetic field and do not retain the magnetic properties when the external field is removed. In diamagnetic materials all the electrons are paired so there is no permanent net magnetic moment per atom. Diamagnetic properties arise from the realignment of the electron paths under the influence of an external magnetic field. Most elements in the periodic table, including copper, silver, and gold, are diamagnetic.

Paramagnetic materials have a small, positive susceptibility to magnetic fields. These materials are slightly attracted by a magnetic field and do not retain the magnetic properties when the external field is removed. Paramagnetic properties are due to the presence of some unpaired electrons, and from the realignment of the electron paths caused by the external magnetic field. Paramagnetic materials include magnesium, molybdenum, lithium, and tantalum.

Ferromagnetic materials have a large, positive susceptibility to an external magnetic field. They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of **magnetic domains**. In these domains, large numbers of atom's moments (10^{12} to 10^{15}) are aligned parallel so that the magnetic force within the domain is strong. When a ferromagnetic material is in the unmagnetized state, the domains are nearly randomly organized and the net magnetic field for the part as a whole is zero. When magnetising force is applied, the domains become aligned to produce a strong magnetic field within the part. Iron, nickel, and cobalt are examples of ferromagnetic material. Components with these materials are commonly inspected using the magnetic particle method.

Ferrimagnetism can be defined as a kind of magnetism where magnetic moments have opposing moments similar to that of antiferromagnetism; however, the antiparallel moments do not cancel each other out, and a spontaneous magnetization occurs in absence of *H* below a characteristic temperature called Néel temperature (TN). F

Ferrimagnetism, type of permanent magnetism that occurs in solids in which the magnetic fields associated with individual atoms spontaneously align themselves, some parallel, or in the same direction (as in ferromagnetism), and others generally antiparallel, or paired off in opposite directions (as in antiferromagnetism).

- **Applications of magnetism**

Ferromagnetism is very important in industry and modern technology, and is the basis for many electrical and electromechanical devices such as:

a) Electromagnets,
b) Electric motors,
c) Generators,
d) Transformers,
e) Magnetic storage (e.g., tape recorders and hard disks),
f) Magnets are used in magnetic compass, doorbells, and refrigerators,
g) Magnets are used in dynamos, motors, loudspeakers, microphones, etc.,
h) Ceramic magnets are used in computers,Magnets are used in toys to give magic effects.

Practical Activity 1.6.2: Calculation on magnetism and electro-magnetism

Task:

1: Referring to previous activities (1.6.1) you are requested to perform the given task. The task should be done **individually**.

i. A magnetic pole face has a rectangular section having dimensions 200mm by 100mm. If the total flux emerging from the pole is 150 µWb, calculate the flux density

2: List out procedures and formulas to be used to perform the given tasks (1.6.2).

3: Referring to procedures and formulas provided on task 2, Perform the given tasks

4: Present your work to the trainer and whole class.

5: Read key reading **1.6.2** and ask clarification where necessary Perform the task provided in application of learning **1.6**

Key readings 1.6.2: Calculation on magnetism and electro-magnetism

Magnetic flux density is the amount of flux passing through a defined area that is perpendicular to the direction of the flux

Magnetic Flux Formula

Magnetic Flux Formula is given as:

$\varphi_B = B.A = B\ A\cos\theta$

The **force on the current-carrying conductor** in a magnetic field depends upon:

(a) the flux density of the field, B teslas (b) the strength of the current, I amperes, (c) the length of the conductor perpendicular to the magnetic field, l metres, and (d) the directions of the field and the current.

When the magnetic field, the current and the conductor are mutually at right angles then:

Force $F = BIl$ newtons

When the conductor and the field are at an angle ø° to each other then:

Force $F = BIl \sin\phi$ newtons

Points to Remember

Magnetic flux refers to the total number of magnetic field lines passing through a given area. It is a scalar quantity.

Formula:

$\Phi = B \cdot A \cdot \cos\theta$

- Φ= Magnetic flux (measured in Weber, Wb)
- B = Magnetic field strength (in Tesla, T)
- A = Area through which the field lines pass (in square meters, m^2)
- θ = Angle between the magnetic field and the normal to the surface (in degrees or radians)

When the magnetic field is perpendicular to the surface ($\theta = 0°$), the formula simplifies to $\Phi = B \cdot A$

2. Magnetic Flux Density (B)

Magnetic flux density is the amount of magnetic flux passing through a unit area. It describes how concentrated the magnetic field is in a specific region.

Formula:

$B = \Phi / A$

- B = Magnetic flux density (measured in Tesla, T)
- Φ = Magnetic flux (in Weber, Wb)
- A = Area through which the flux is passing (in square meters, m^2)

Alternatively, in terms of force and charge

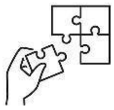
$B = F / (q * v * \sin\theta)$

- F = Force on a moving charge (in newtons, N)
- q = Charge (in coulombs, C)
- v = Velocity of the charge (in meters per second, m/s)
- θ = Angle between velocity and magnetic field (in degrees or radians)

The formula used to calculate the flux density is: $B = \Phi / A$ tesla

The formula for reluctance

$E = -L * (dI/dt) = -N * (d\Phi/dt)$ then $L = N * (d\Phi/dt) * (dt/dI)$



Application of learning 1.6.

1. The maximum working flux density of a lifting electromagnet is 1.8T and the effective area of a pole face is circular in cross-section. If the total magnetic flux produced is 353mWb, determine the radius of the pole face.
2. A 750 turns coil of inductance 3 H carries a current of 2A. Calculate the flux linking the coil and the e.m.f. induced in the coil when the current collapses to zero in 20 ms.

Indicative content 1.7: Identification of Transformers

Duration: 7

Theoretical Activity 1.7.1: Description of transformers

Tasks:

1: In small groups, you are requested to answer the following questions related to the of description of transformers.

i. What do you understand by an electrical transformer?
ii. What are main parts of single-phase transformer.
iii. Explain the working principle of transformer.
iv. Discuss on different types of transformers.

2: Provide the answer for the asked questions and write them on papers.
3: Present the findings/answers to the whole class
4: For more clarification, read the key **readings 1.7.1.**
5: In addition, ask questions where necessary.

Key readings 1.7.1: Description of transformers

1.A **transformer** is a device that transfers electrical energy from one circuit to another by electromagnetic induction. The electrical energy is always transferred without a change in frequency, but may involve changes in amplitudes of voltage and current. Because a transformer works on the principle of electromagnetic induction, it must be used with an input source voltage that varies with time. There are many types of power that fit this description; for ease of explanation and understanding, transformer action will be explained using a sinusoidal AC voltage as the input source.

2. **Parts of a Single-phase Transformer**

The major parts of a single-phase transformer consist of

1. Core

The core acts as a support to the winding in the transformer. It also provides a low reluctance path to the flow of magnetic flux. The winding is wound on the core, as shown in the picture. It is made up of a laminated soft iron core in order to reduce the losses in a transformer. The factors, such as operating voltage, current, power, etc., decide core composition. The core diameter is directly proportional to copper losses and inversely proportional to iron losses.

2. Windings

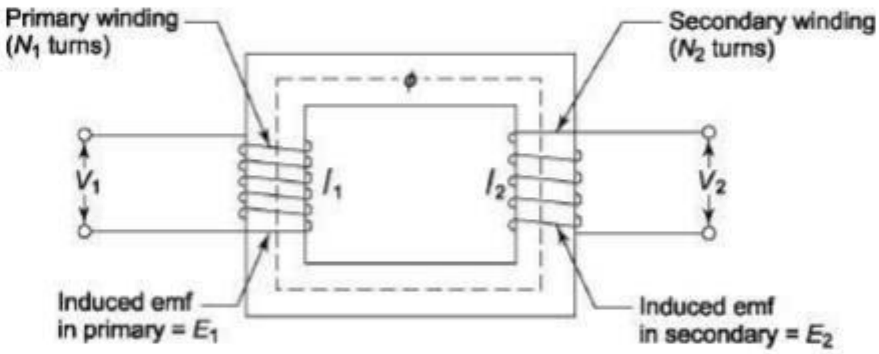
Windings are the set of copper wires wound over the transformer core. Copper wires are used due to the following:

- The high conductivity of copper minimises the loss in a transformer because when the conductivity increases, resistance to current flow decreases.
- The high ductility of copper is the property of metals that allows it to be made into very thin wires.

There are mainly two types of windings: primary windings and secondary windings.

- Primary winding: The set of turns of windings to which the supply current is fed.
- Secondary winding: The set of turns of winding from which output is taken.

The primary and secondary windings are insulated from each other using insulation coating agents.



3. **working principle of transformer**

When alternating current flows through the primary winding (or coil) of a transformer, a varying magnetic flux is induced in the secondary winding. This varying magnetic flux induces a varying electromotive force (emf) or voltage in the secondary winding, which in turn produces a current through the secondary winding if a load impedance is connected across it. Thus, a transformer cannot operate with direct current. When the secondary is an open-circuit and an alternating voltage $\mathbf{V_1}$ is applied to the primary winding, a small current called the no-load current $\mathbf{I_0}$ flows, which sets up a magnetic flux in the core. This alternating flux links with both primary and secondary coils and induces in them e.m.f.'s of $\mathbf{E_1}$ and $\mathbf{E_2}$ respectively by mutual induction. The induced e.m.f. **E** in a coil of **N**turns is given by:

E = -N * (dΦ/dt) volts

here $d\phi/dt$ is the rate of change of flux. In an ideal transformer, the rate of change of flux is the same for both primary and secondary and thus $E_1/N_1=E_2/N_2$, i.e. **the induced e.m.f. per turn is constant**. Assuming no losses, $\mathbf{E_1=V_1}$ and $\mathbf{E_2=V_2}$ Hence;

$$\frac{V1}{N1} = \frac{V2}{N2} OR \frac{V1}{V1}$$

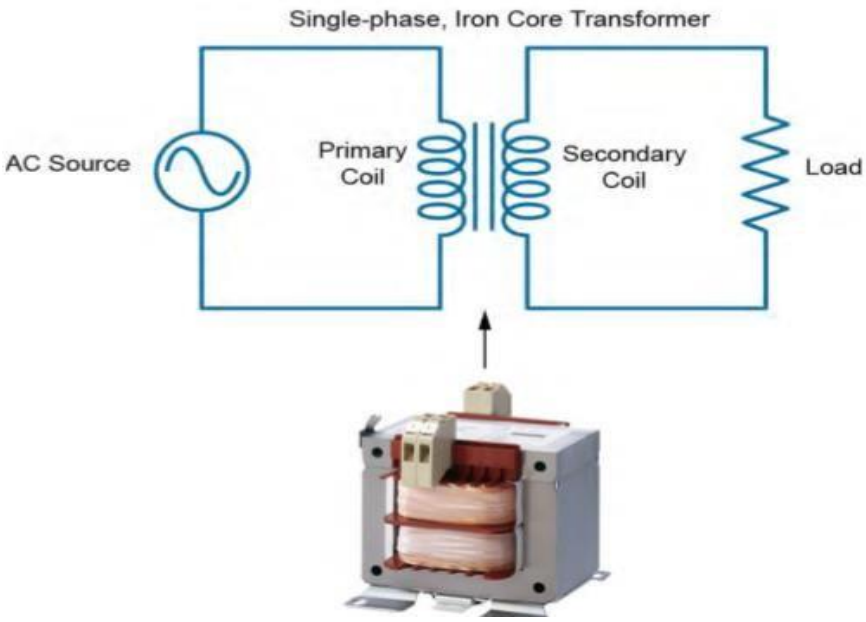
V_1/V_2 is called the voltage ratio and N_1/N_2 the turns ratio, or the **'transformation ratio'** of the transformer. If N_2 is less than N_1 then V_2 is lessthan V_1 and the device is termed a **step-down transformer**. If N_2 isgreater then N_1 then V_2 is greater than V_1 and the device is termed a **step-up transformer**.

When a load is connected across the secondary winding, a current I_2 flows. In an ideal transformer losses are neglected and a transformer is considered to be 100% efficient. Hence input power =output power, or $V_1I_1= V_2I_2$, i.e., in an ideal transformer, the **primary and secondary volt-amperes are equal**. Thus:

$$\frac{V1}{V2} = \frac{I2}{I1} OR \frac{V1}{V1}\ Combine\ equations\ \frac{V1}{V1} = \frac{N1}{N2} = \frac{I1}{I2}$$

The **rating** of a transformer is stated in terms of the volt-amperes that it can transform without overheating. With reference to Figure1 (a), the transformer rating is either V_1I_1 or V_2I_2, where I_2 is the full-load Secondary current.

K=transformation ratio for voltages, currents and turns and it is constant



4. **different classification of transformers are:**

The transformers are classified based on voltage levels, Core medium used, windings Arrangements, use and installation place, etc. Here we discuss different types of transformers

Are the step up and step down Transformer, Distribution Transformer, Potential Transformer, Power Transformer, 1-φ and 3-φ transformer, Auto transformer, etc.

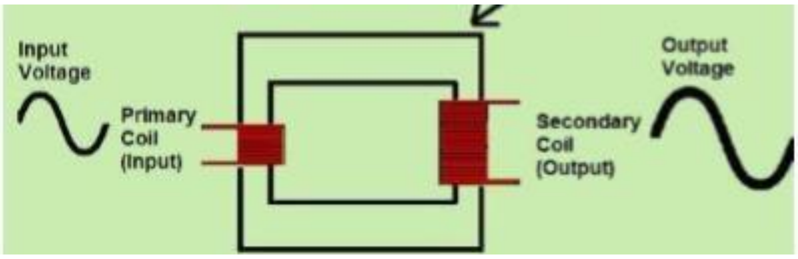
Transformers Based on Voltage Levels

These are the most commonly used transformer types for all the applications. Depends upon The voltage ratios from primary to secondary windings, the transformers are classified as step Up and step-down transformers.

Step-Up Transformer

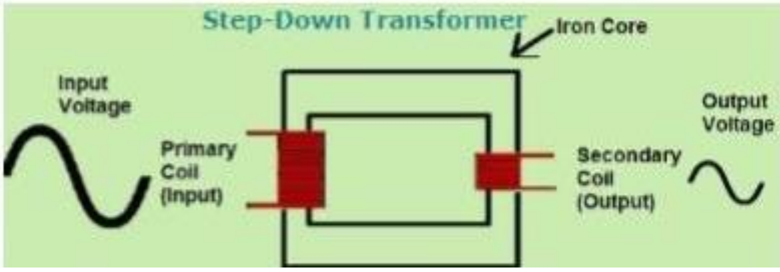
As the name states that, the secondary voltage is stepped up with a ratio compared to primary

Voltage. This can be achieved by increasing the number of windings in the secondary than the Primary windings as shown in the figure. In power plant, this transformer is used as connecting Transformer of the generator to the grid.



Step-Down Transformer

It used to step down the voltage level from lower to higher level at secondary side as shown below so that it is called as a step-down transformer. The winding turns more on the primary side than the secondary side.



Transformer Based on the Core Medium Used

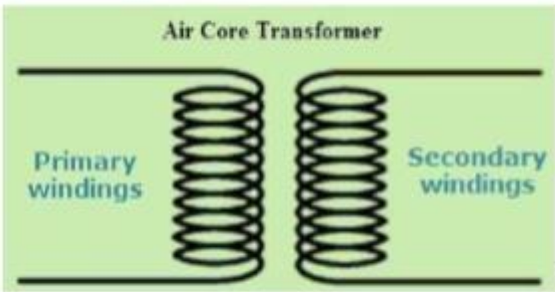
Based on the medium placed between the primary and secondary winding the transformers Are classified as Air core and Iron core

Air Core Transformer

Both the primary and secondary windings are wound on a non-magnetic strip where the flux Linkage between primary and secondary windings is through the air.

Compared to iron core the mutual inductance is less in air core, i.e. the reluctance offered to

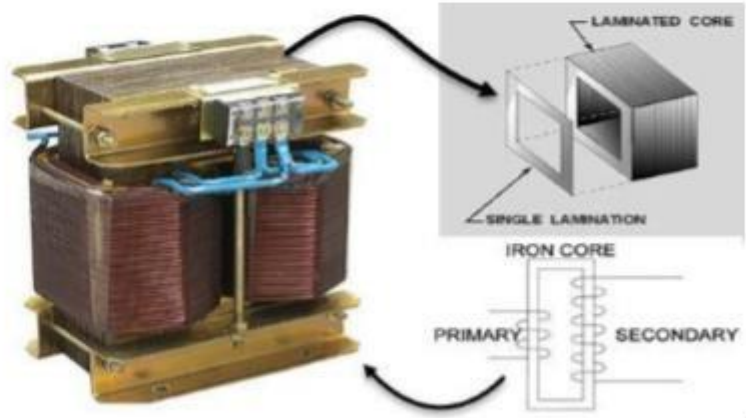
The generated flux is high in the air medium. But the hysteresis and eddy current losses are Completely eliminated in air-core type transformer.



Air Core Transformer

Iron Core Transformer

Both the primary and secondary windings are wound on multiple iron plate bunch which Provide a perfect linkage path to the generated flux. It offers less reluctance to the linkage flux Due to the conductive and magnetic property of the iron. These are widely used transformers in Which the efficiency is high compared to the air core type transformer.



Iron Core

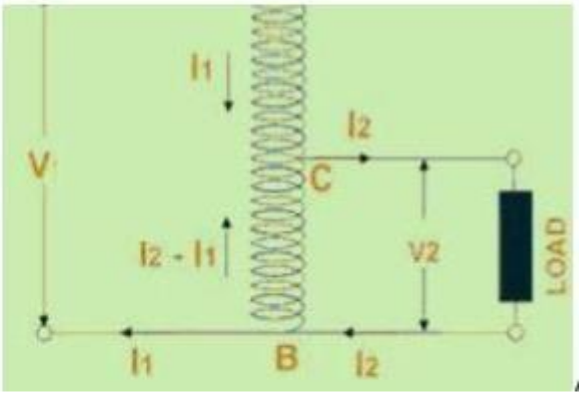
Transformer

Transformers Based on Winding Arrangement

Autotransformer

Standard transformers have primary and secondary windings placed in two different directions,

But in autotransformer windings, the primary and the secondary windings are connected to Each other in series both physically and magnetically as shown in the figure below.



Auto Transformer On a single common coil which forms both primary and secondary winding in which voltage is

Varied according to the position of secondary tapping on the body of the coil windings.

Step-Up and Step-Down Transformer

If N1 > N2, V1 > V2, that is the output voltage is less than the primary voltage. The transformer is said to be a step-down transformer.

If N1 < N2, V1 < V2, that is the output voltage is greater than the primary voltage. The transformer is said to be a step-up transformer.

For an ideal transformer, input VA = output VA

V1I1=V2I2

Example:

A transformer has a 6:1 voltage ratio. Find the current in the secondary if the current in the primary is 200 mA.

Solution:

$$\frac{VP}{VS} = \frac{IS}{IP}$$

$$\frac{VPIP}{VS} = IS$$

Transposing for I_s:

Substitution:

$$IS \frac{6 * 0.2}{1} = 1.2A$$

Practical Activity 1.7.2: Calculation about transformer.

Task:

1: Referring to previous activities (1.7.1) you are requested to perform the given task. The task should be done **individually**.

i. A 4500V/225V, 50 Hz single-phase transformer is to have an approximate e.m.f. per turn of 15V and operate with a maximum flux of 1.4 T. Calculate (a) the number of primary and secondary

2: List out procedures and formulas to be used to perform the given tasks (1.7.2).

3: Referring to procedures and formulas provided on task 2, Perform the given tasks.

4: Present your work to the trainer and whole class.

5: Read key reading 1.7.2 and ask clarification where necessary Perform the task provided in application of learning 1.7

Key readings 1.7.2 Calculation about transformer

The combination equations on transformer is given as

$$\frac{E1}{E2} = \frac{N1}{N2}$$

$$E2 = \frac{N2}{N1} * E2$$

$$\frac{V1}{N1} = \frac{V2}{N2} OR \frac{V1}{V1}$$

E.m.f equation of a transformer

The magnetic flux 8 set up in the core of a transformer when an alternating voltage is applied to its primary winding is also alternating and is sinusoidal. Let φm be the maximum value of the flux and f is the frequency of the supply. The time for 1 cycle of the alternating flux is the periodic time T, where T=1/fseconds. The flux rises sinusoidally from zero to its maximum value in ¼ cycle, and the time for ¼ cycle is 1/4fseconds.

Hence the average rate of change of flux and since 1 Wb/s =1 volt, the

average e.m.f. induced in each turn=4fφm volts. As the flux 8 varies sinusoidally, then a sinusoidal e.m.f. will be induced in each turn of both primary and secondary windings.

For a sine wave, form factor

rms value / average value = 1.11

rms value = form factor × average value = 1.11 × average value

Thus rms e.m.f. induced in each turn

= 1.11 × 4fΦ volts = 4.44fΦ volts

Therefore, rms value of e.m.f. induced in primary,

$E_1 = 4.44f\Phi m N_1$ volts and rms value

of e.m.f. induced in secondary,

$E_2 = 4.44f\Phi m N_2$ volts

Dividing equations

$E_1 / E_2 = N_1 / N_2$

Points to Remember

- **Emf equation of transformer formula**

$V_1 / V_2 = N_1 / N_2 = I_2 / I_1$

$E_1 = 4.44f\Phi m N_1$ volts

Application of learning 1.7.

1. A 5kVA single-phase transformer has a turns ratio of 10: 1 and is fed from a 2.5kV supply. Neglecting losses, determine (a) the full-load secondary current, (b) the primary current at full load kVA.
2. A single-phase, 50 Hz transformer has 25 primary turns and 300 secondary turns. The cross-sectional area of the core is 300 cm2. When the primary winding is

connected to a 250 V supply, determine (a) the maximum value of the flux density in the core, and (b) the voltage induced in the secondary winding.

Learning outcome 1 end assessment

Theoretical assessment

1. Complete the following table:

Quantity	**Name**	**Unit**
Length		
	kilogram	
Thermodynamic temperature		
Luminous intensity		
		mol

2. States:

A) Kirchhoff Current and Voltage's Low

B) Ohm's Law

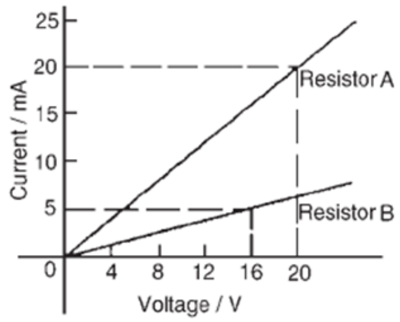
3. Define the following terms:
   a) Electric current
   b) Voltage
   c) Electric field
   d) Inductance
   e) Capacitance
   f) Resistance
   g) Amplitude
   h) Peak value
   i) Peak to peak value
   j) Wavelength
4. **Fill in the following sentences with a suitable term**.

The area around a magnet is called the ……………………….. and it is in this area that the effects of the ………………………….. Produced by the magnet can be detected. The magnetic flux density is calculated using the following formula……………………and expressed in …………..In vacuum (in free space) the Permeability of free space is equal to ………………

Practical assessment

A new house located in Rwamagana district, the house has different equipment like lamps,resistor , capacitors, batteries, ac load and are connected in the circuit in different ways. The given equipment is supplied and consume power and you are asked to find unknown values in the tasks below referring to the given data:

1. A) The current/voltage relationship for two resistors A and B is as shown in Figure below. Determine the value of the resistance of each resistor.



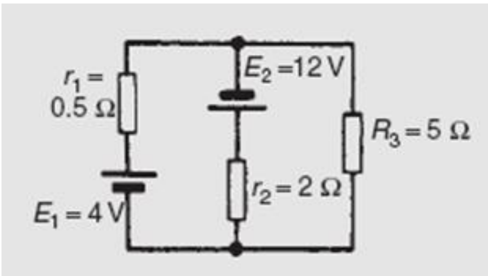
2. Capacitances of 1µF, 3µF, 5µF and 6µF are connected in parallel to a direct voltage supply of 100 V. Determine:

(a) the equivalent circuit capacitance,

(b) the total charge and

(c) the charge on each capacitor.

3. Determine the current in the 5Ωresistance of the network shown in Fig. using Thévenin's theorem. Hence find the currents flowing in the other two branches.



4. A coil consists of a resistance of 100Ω and an inductance of 200 mH. If an alternating voltage, *v*, given by ***v* = 200 sin 500t volts** is applied across the coil. Calculate(a) the circuit impedance, (b) The current flowing, (c) The p.d. across the resistance, (d) The p.d. across the inductance and (e) The phase angle between voltage and current.

END

References

1. C. R. Robertson, Electronic, Electrical, Fundamental Principles, 3rd Editio. Amsterdam: Elsevier Ltd., 2008.

2. D. M. Buchla, Experiments in electronics fundamentals and electric circuits fundamentals to accompany, Fourth Edi. Prentice Hall, 2010.

3. Sean Westcott and J. R. Westcott, Basic Electronics: Theory & Practice. Dulles, Virginia, 2015.

4. John Bird, Electrical Circuit Theory Technology, Third Edit. Elsevier Ltd, 2007.

Learning Outcome 2: Perform domestic electrical installations

Indicative contents
2.1 Realisation of Electrical Diagrams
2.2 Selection of Tools, Materials and Equipment
2.3 Electrical Conduit Laying
2.4 Wiring/ Cabling and Connection of Wires/ Cables
2.5. Installation of Different Types of Switches
2.6. Installation of Different Types of Power Sockets Outlets
2.7. Installation of Different Electrical Lighting Circuit
2.8. Installation of Protection Devices and Systems
2.9. Installation of Electric Bells
2.10. Testing Techniques of Electrical Installation

Key Competencies for Learning Outcome 2: Perform domestic electrical installations

Knowledge	Skills	Attitudes
• Description of electrical diagrams	• Interpreting electrical diagram • Drawing /Design electrical circuit • Selecting tools, materials and equipment • Apply Electrical laying conduit • Apply Measuring • Apply Wiring / cabling / labelling • Installation of switches, power sockets outlets • Installation of electrical lighting circuit, and protection devices • Testing techniques and installation of electric bells	• Having an innovative spirit • Having Creativity • Having Critical thinking • Having Teamwork • Having Problem Solving • Having Patience • Having Punctuality • Having Curiosity

Duration: 40 hrs

Learning outcome 2 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Realise correctly Electrical Diagrams according to their types
2. Select properly Tools, Materials and Equipment according to their types
3. Perform correctly Electrical Laying Conduit according to electrical diagrams
4. Perform correctly Wiring/ Cabling and Connection of Wires/ Cables according to electrical diagrams
5. Install correctly Different Types of Switches according to their types
6. Install correctly Different Types of Power Sockets Outlets according to their types
7. Install correctly Different Electrical Lighting Circuit according to their types
8. Install correctly Protection Devices and Systems According to their types
9. Test properly electrical installation according to testing Techniques
10. Install correctly Electric Bells According to their types

Resources

Equipment	Tools	Materials
● Ppe, ● Powered electrical screwdriver, ● Multi-meter, ● Reverting machine, ● Drilling machine, ● Electric grinder, ● Clamp-on ammeter, ● Megohmmeter, ● Wattmeter, ● Phase sequence tester, ● Multi-function tester	● Electrical tool kit, ● Drawing tools	● One-way switch, ● Double pole one-way switch, two gang switches, ● Door release push button, ● Ring push button, bell push button, cables, wires, two-way switch, ● Intermediate switch, ● Pull-switch, ● Two gang two-way switch, ● Smart switches, ● Timer switch, ● Twilight switch, sensors, ● Sockets, ● conduits, ● Drawing papers, ● Protective devices (fuse

		circuit breakers ,…), switchboxes, screws, ● Lamps, ● Lamp holders, ● Insulating tape

Indicative content 2.1: Realization of Electrical Diagrams.

Duration: 4

Theoretical Activity 2.1.1: Description of electrical diagrams

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of electrical diagrams.

i. List any five symbols used in electrical installation
ii. Give different symbols of electrical switches
iii. What are types of electrical diagrams?

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 2.1.1.**

5: In addition, ask questions where necessary.

Key readings 2.1.1: Description of electrical diagrams

- Introduction to electrical diagrams

1. Definition of Terms

Electrical diagrams

Electrical diagrams are drawings which are used to represent electrical circuits, these circuits are represented by using lines, symbols, and number combinations. Electrical diagrams show the wiring between components and the relative position of the components.

An Electric Circuit

An Electric Circuit is simply an interconnection of circuit elements such as resistors, capacitors, voltage or current source etc. Depending on the type of circuit elements and the way they are connected, we can have different types of circuits.

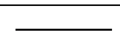
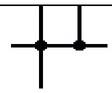
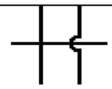
Electrical symbols

Electrical symbols and electronic symbols are those symbols that are used for drawings schematic diagrams.

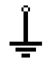
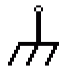
An electrical symbol is a pictogram used to represent various electrical and electronic devices or functions, such as wires, batteries, resistors, and transistors, in a schematic diagram of an electrical or electronic circuit.

Electronic symbols are also known as symbol schematics because they are used in an electronic circuit schematic.

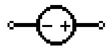
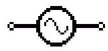
Electrical Wiring Symbols for Wire

Name	Meaning / Function	Symbol
Electrical Wire	Conduct Electricity	
Connected Wires	Wires are Connected	
Not Connected Wires	Wires are not Connected	

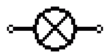
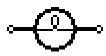
Electrical Wiring Symbols for Ground

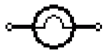
Name	Meaning / Function	Symbol
Earth Ground	Protection against Electrical Shock	
Chassis Ground	Connected to Chassis of a Circuit	
Common Ground	For Analog and Digital Grounding	

Power Supply Symbols

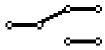
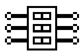
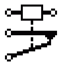
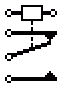
Name	Meaning / Function	Symbol
Voltage Source	Constant Voltage Source	
Current Source	Constant Current Source	
AC Voltage Source	Source of AC Voltage	
Battery	Constant Voltage Source	
Battery Cell	Constant Voltage Source	
Generator	Mechanical Voltage Source	

Lamp and Light Bulb Symbols

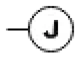
Name	Meaning / Function	Symbol
Lamp or Light Bulb	Generates Light with Flow of Current	
Lamp or Light Bulb	Generates Light with Flow of Current	

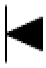
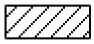
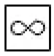
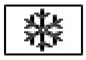
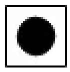
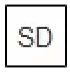
Lamp or Light Bulb	Generates Light with Flow of Current	

Switch and Relay Symbols

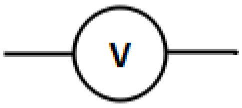
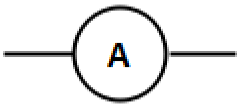
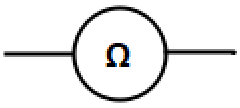
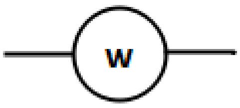
Name	Meaning / Function	Symbol
SPST Toggle Switch	Disconnect Current when Open	
SPDT Toggle Switch	Select Between 2 Connections	
Push Button Switch (N.O)	Switch Momentary – Generally Open	
Push Button Switch (N.C)	Switch Momentary – Generally Closed	
DIP Switch	Onboard Configuration	
SPST Relay	Single Pole Single Throw	
SPDT Relay	Single Pole Double Throw	
Jumper	Jumper to Close Connection	
Solder Bridge	Solder Connection	

Other Important Electrical Wiring Symbols

Name	Meaning / Function	Symbol
Electrical Switch box	Box to Install Switches	
Circuit Breaker	Trip to Break the Electric Circuit and Stop Flow of Electricity	
Dishwasher Outlet	Outlet for Dishwasher	
Fan Outlet	Outlet for Fan	
Junction Box	Install Junction Box	
TV Outlet	Outlet for Television	

Exhaust Fan	Outlet for Exhaust Fan	
Water Heater Outlet	Outlet for Water Heater	
Telephone Jack Outlet	Outlet for Telephone Jack	
Electrical Panel	Install Electrical Panel	
Distribution Box	Install Distribution Box	
Thermostat	Install Thermostat	
Air Condition	Install Air Condition	
Fire Alarm	Install Fire Alarm	
Alarm	Install Alarm	
Doorbell	Install Doorbell	
Smoke Detector	Install Smoke Detector	

Meter Symbols

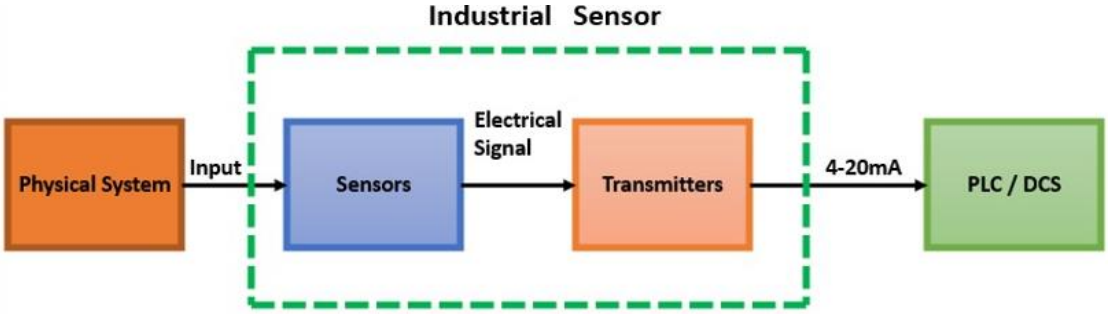
Symbol	**Name**	**Description**
	Voltmeter	It is the symbol that shows Voltmeter which is used to measure the voltage.
	Ammeter	It represents the ammeter whose work is to measure the current in the circuit.
	Ohmmeter	It is the symbol of the ohmmeter which is needed to measure the value of a resistor.
	Wattmeter	This represents the power meter which shows the power consumption.

Types of electrical diagrams

a) Block diagram

A block diagram is a kind of electrical layout that uses blocks to illustrate the main parts of a complicated system, with connecting lines showing how those parts are related.

It is the most basic kind of electrical drawing since it just emphasises each component's function and shows the system's process flow.



The first step in constructing a complicated circuit for any project is to create a block diagram since they are simpler to create. It is deficient in details on component placement and wiring.

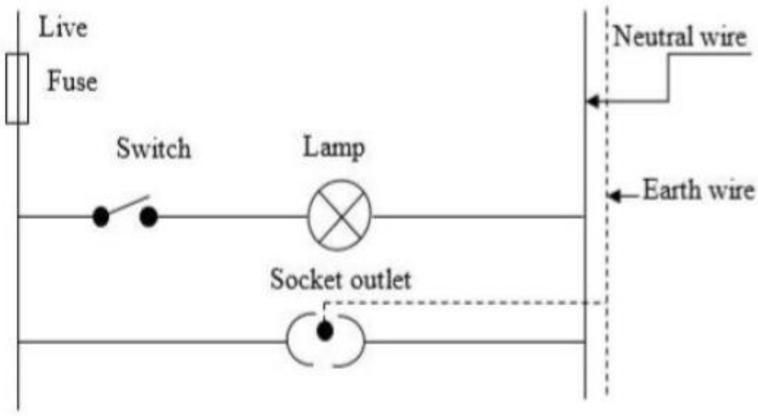
It ignores any minor components and entirely illustrates the system's major parts. Consequently, block diagrams are not used by electricians.

b) Circuit Drawing (Diagram)

In this, electrical circuit is graphically represented in a simplified manner. It includes the position information (in cm or m or mm) of various elements like light fixtures, receptacle boxes, junction boxes, ceiling fans, etc.

Advantages of circuit diagram

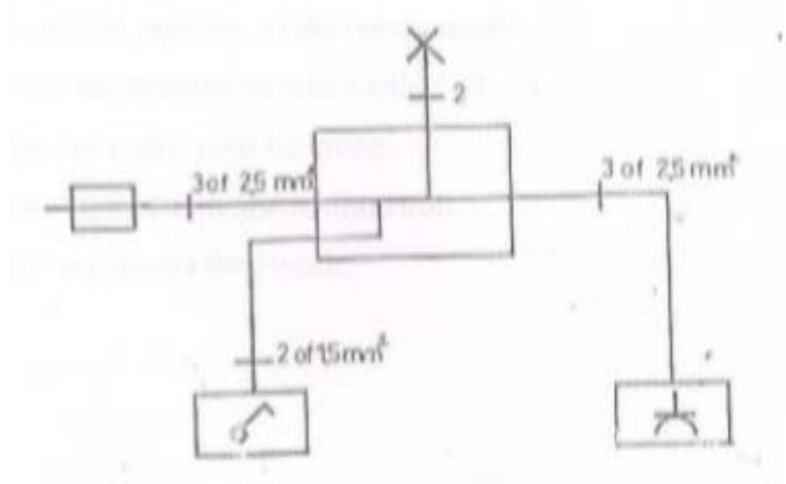
1. It facilitates easy fault tracing.



c) **schematic diagram**

schematic diagram is a graphical representation of a plan or a model that is presented in a simple, accessible way.

A schematic diagram used for electronics uses standardized symbols and simple line drawings to represent various electronic components.
Example: One way switches with socket out-let



Advantages of schematic diagram

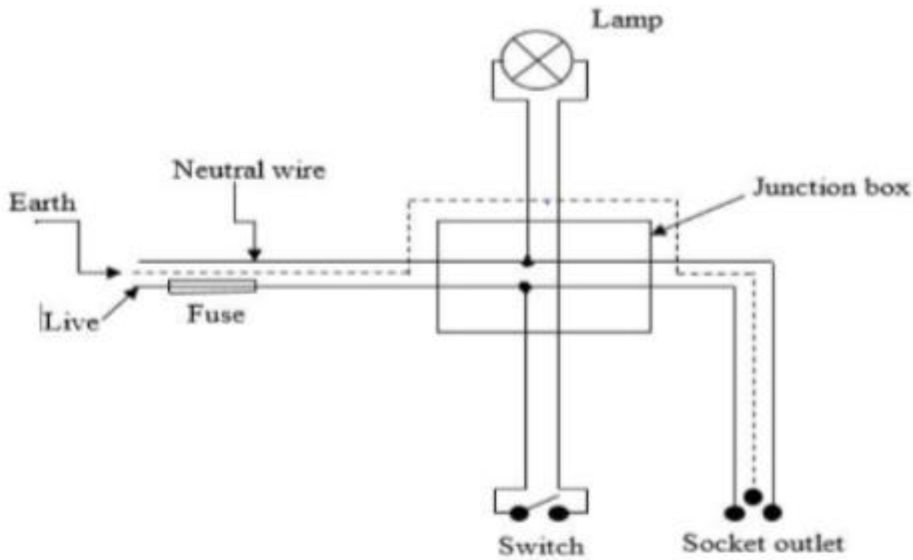
1. Shows the sizes of wires
2. Purchase of requires materials
3. Purchase of the correct length of wires
4. Know the circuit supply
5. Type of installation

Disadvantage of schematic diagram

1. Not easy to connect the circuit

c) Wiring Diagram

The electrical wiring diagram is a pictorial representation of the circuit which shows the wiring between the parts or elements or equipment.



It gives detailed information about wiring such that one can get an idea of making connection between the devices. It includes relative position, arrangement of the devices and also terminals on the devices.

Advantages of wiring diagram

1. To know physical appearance of the installation and the components
2. To know how to correct easily
3. It facilitate easy connection

e) Architecture Plan

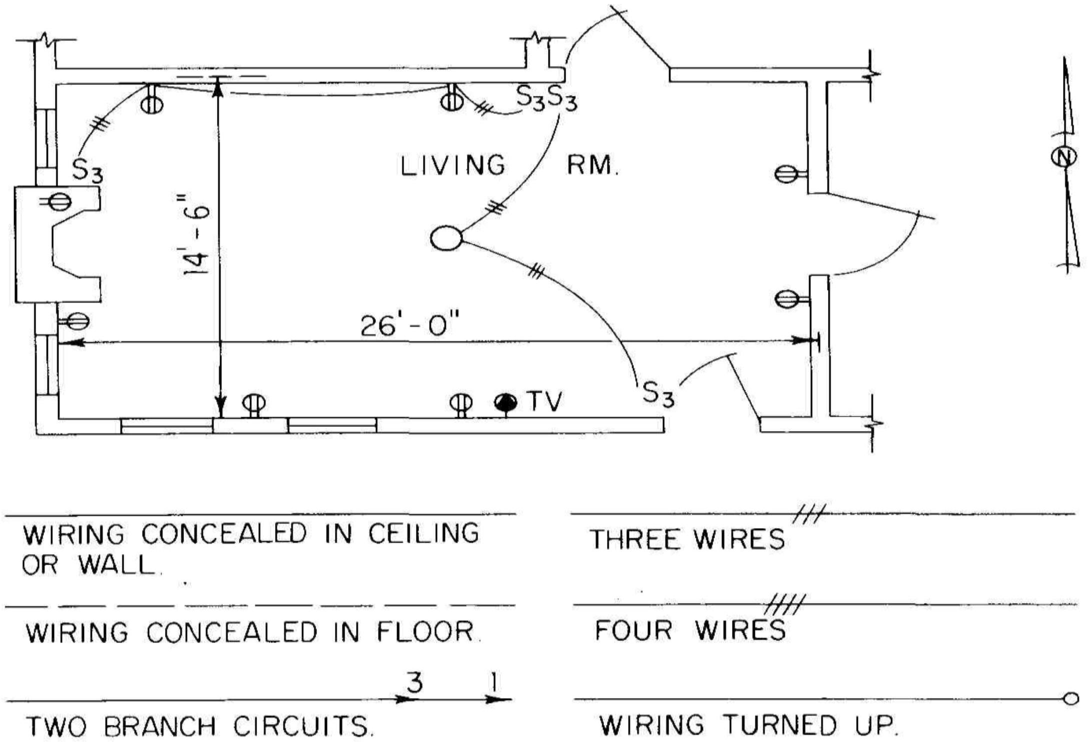
While constructing a house, there are several electrical devices that need to be placed at certain locations so you can have easy access to them. This is where an Architecture plan comes into play. A fully drawn electrical map enables the architects to install the power outlets and other equipment according to your needs.

An Architecture plan is a visual representation that shows how the wiring of a house should be installed so all the necessary devices could be placed at their right place. Not only this but many times an electrical plan also illustrates how a particular gadget would work. For instance, it will show the internal winding of a transformer, a light bulb, etc.

Purpose and Benefit

Among many, one of the purposes of an Architecture plan, as mentioned earlier, is to demonstrate the wiring of a building. Because many times such a wiring system is required to be concealed within the walls, it is imperative to have a map of such a network that assumes that there are no elevations, or if there are any, they are transparent.

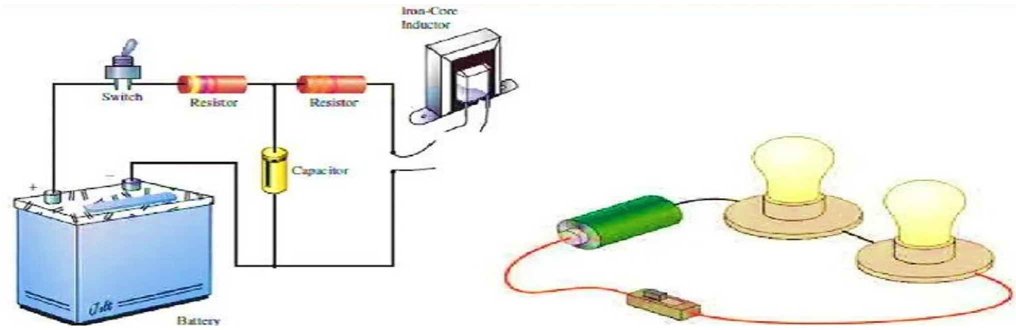
The benefit of creating an Architecture plan is to make the tasks of the engineers, architects, and designers easy, especially when they are into preparing new devices, buildings, and blueprints respectively. Another benefit of having such a map is to check and ensure that the final output works as expected. If there are any flaws in the wiring or the circuit, they can be eliminated right on the map so the implementation process doesn't get delayed.



f) Pictorial diagram (diagram in pictures)

The visual representation may not always accurately represent the true circuit. In practical terms, it depicts the circuit's visual look in real time.

It is not often utilised since it is not able to understand (or) troubleshoot an actual circuit. It is hard for someone with little electrical understanding to analyse and diagnose the circuit.



Practical Activity 2.1.2: Drawing of electrical circuit diagram

Task:

1: Referring to previous activities (2.1.1) you are requested to perform the given task. The task should be done **individually**.

- An electrical company is invited to install a house of three rooms. The owner gives the installer the following instructions:
  - ➔ In the bedroom there is one lamp controlled from two (2) positions and one socket outlet.
  - ➔ Outside lamp and one lamp in the sitting room are controlled by a double light switch.
  - ➔ The dining room, bathroom, store and kitchen comprise one lamp and socket outlet and lamps are controlled in one direction.

As installer you are asked to draw:

- The layout diagram (Architecture)
- The circuit diagrams
- The wiring diagram and list the tools, equipment and materials to be used in the given task.

2: Illustrate out symbols to be used to perform the given tasks (2.1.2).

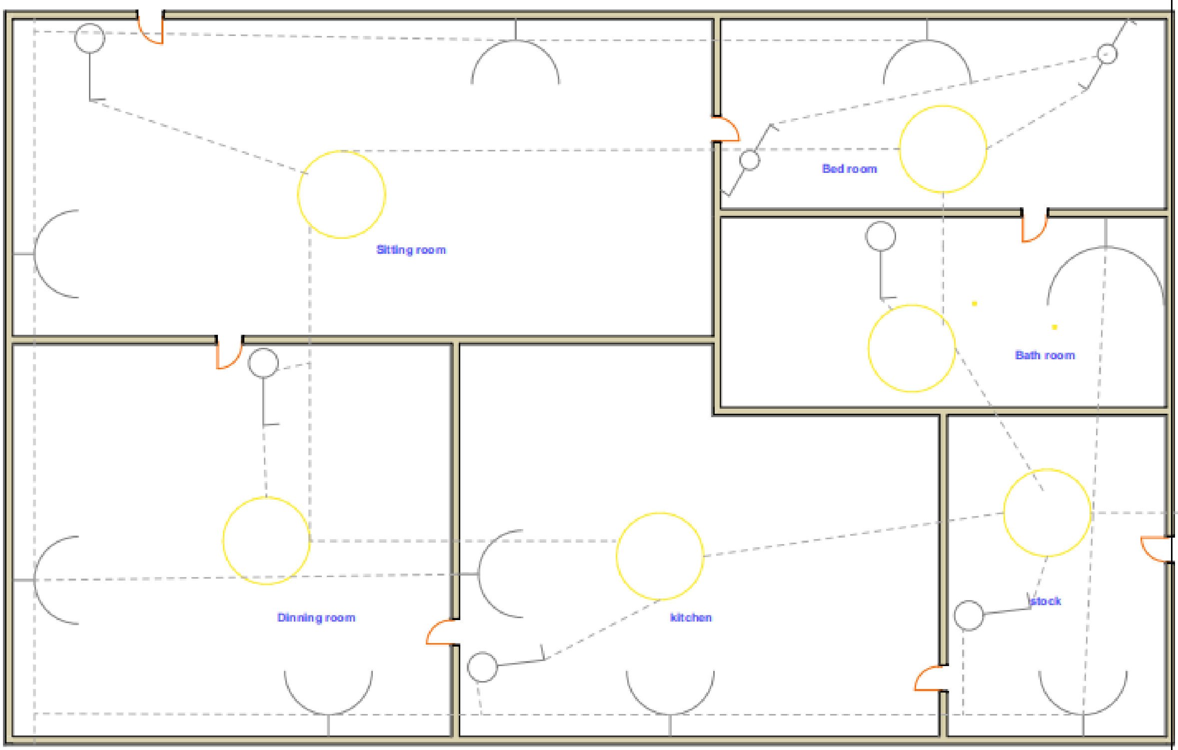
3: Referring to the symbols provided on task 2, Perform the given tasks

4: Present your work to the trainer and whole class.

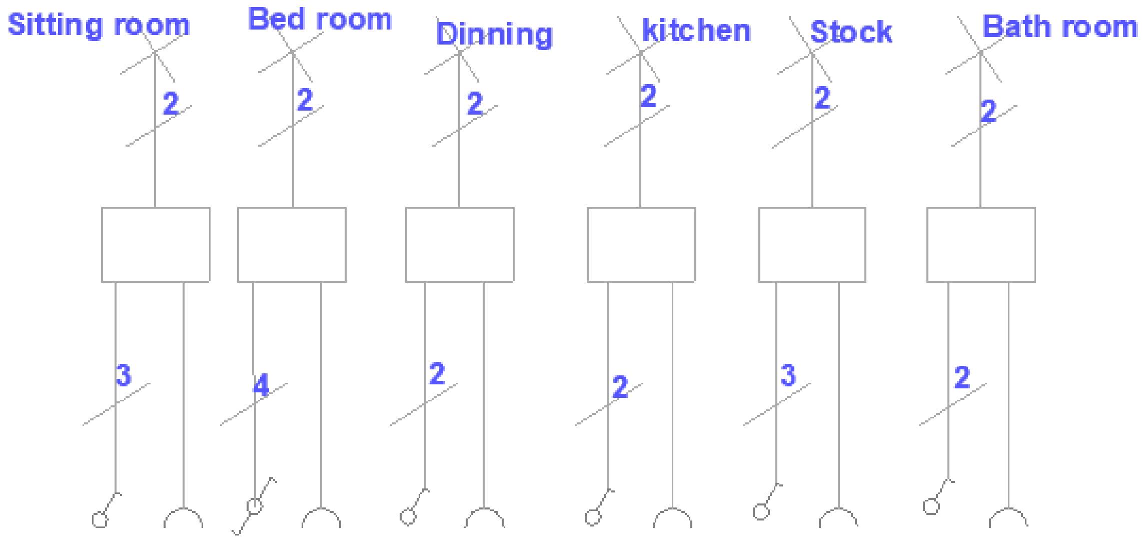
5: Read key reading **2.1.2** and ask clarification where necessary Perform the task provided in application of learning **2.1**

Key readings 2.1.2 Drawing of electrical circuit diagram

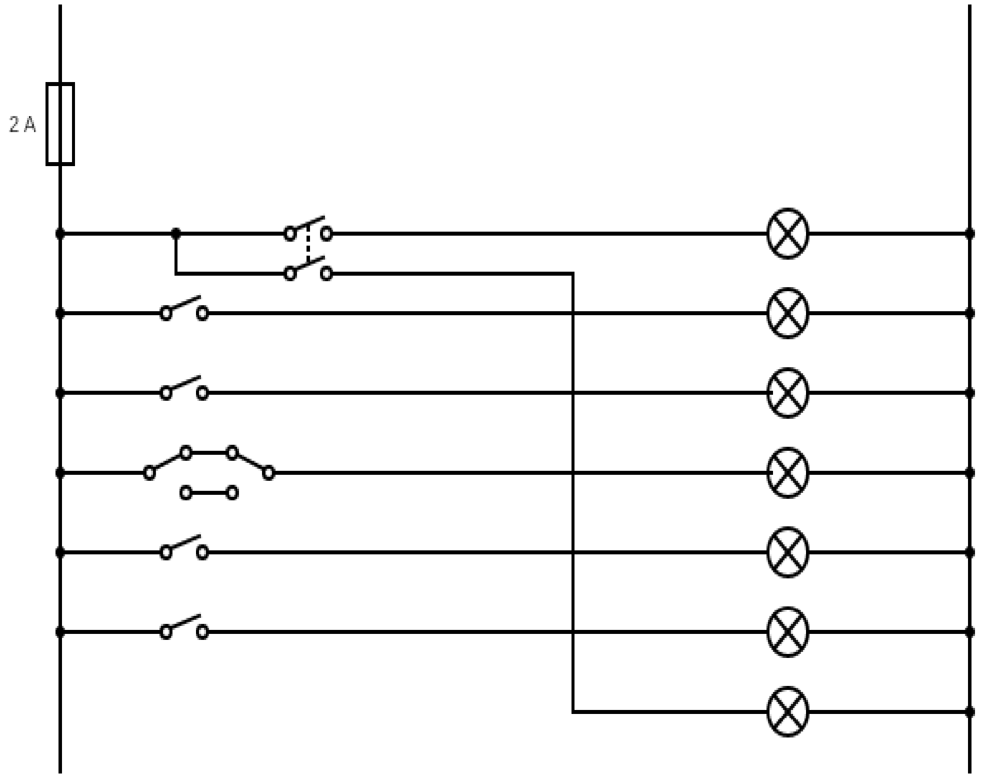
Layout Diagram



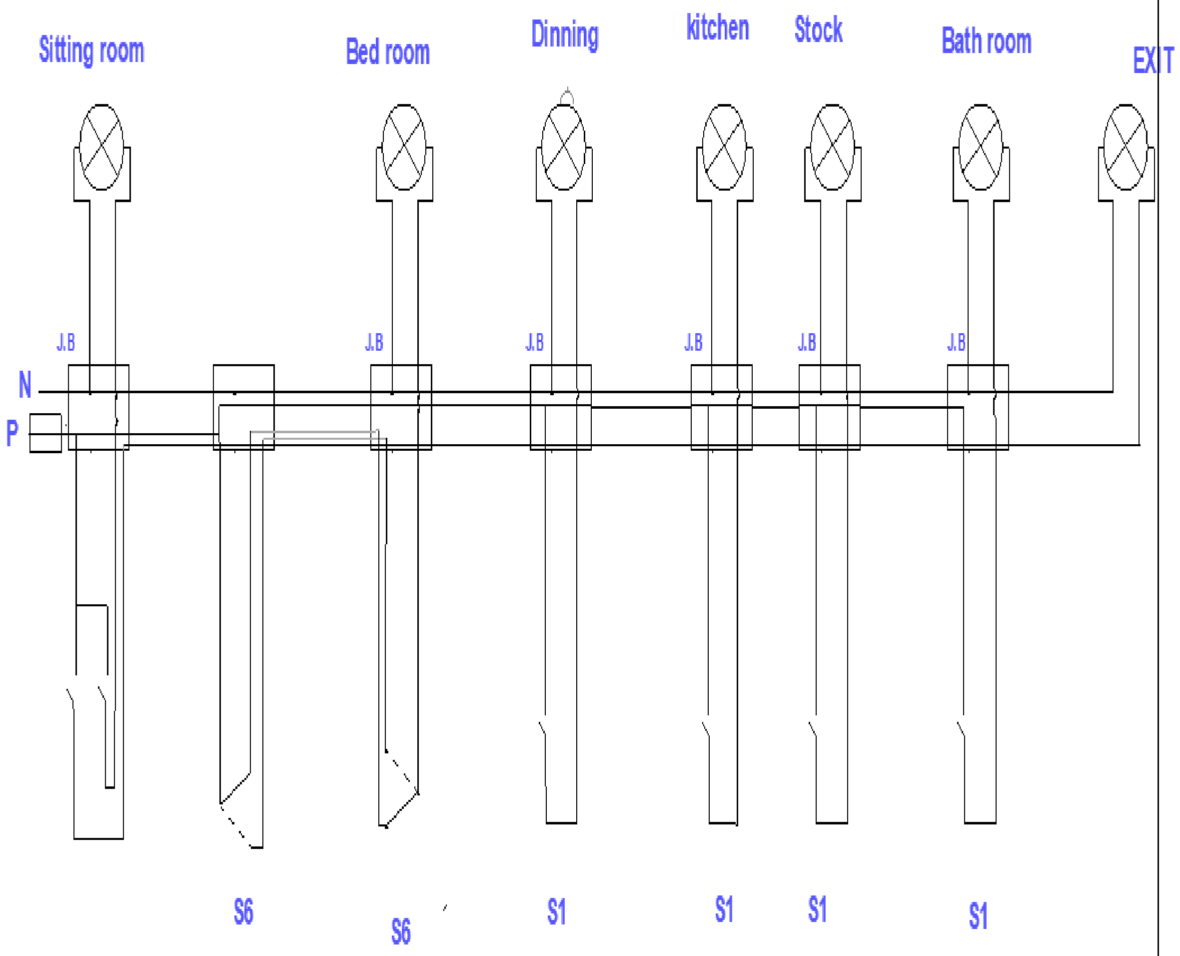
SCHEMATIC DIAGRAM



Circuit diagram

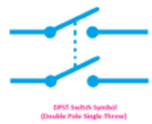


Wiring diagram



Single Pole Double Through or SPDT Switch Symbol

Symbol of Double Pole Single Through or DPST Switch

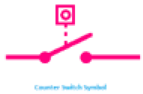


Double Pole Double Through or DPDT Switch Symbol

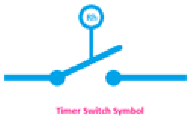
Symbol of Single Pole Multiple Through or SPMT Switch

Float Switch Symbol

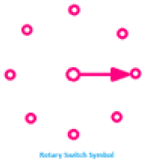
Symbol of Counter Switch



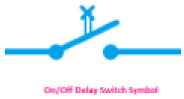
Timer Switch Symbol



Rotary Switch Symbol



On/Off Delay Switch Symbol



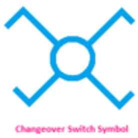
Symbol of Normally Open or NO Switch

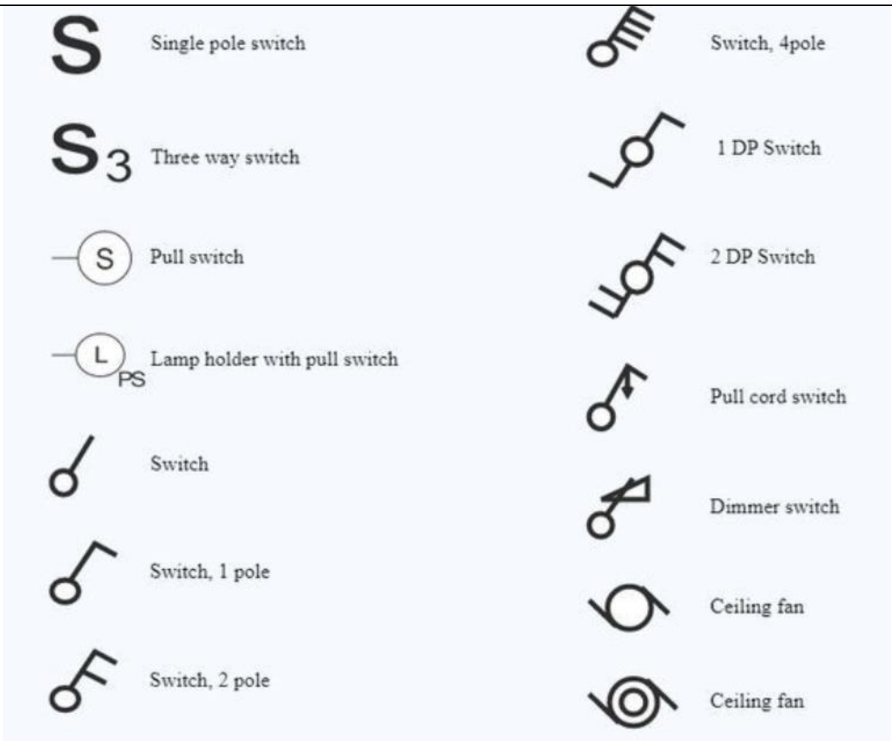
Symbol of Normally Closed or NC Switch

Mercury Switch Symbol

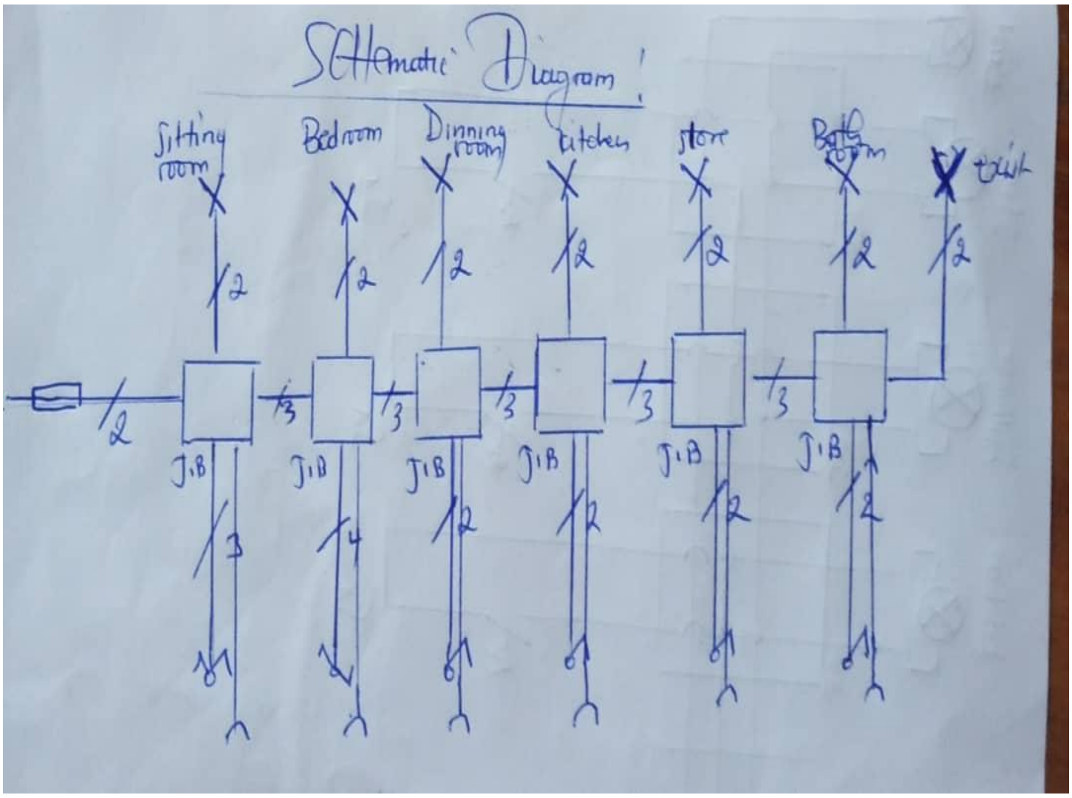
Selector Switch Symbol

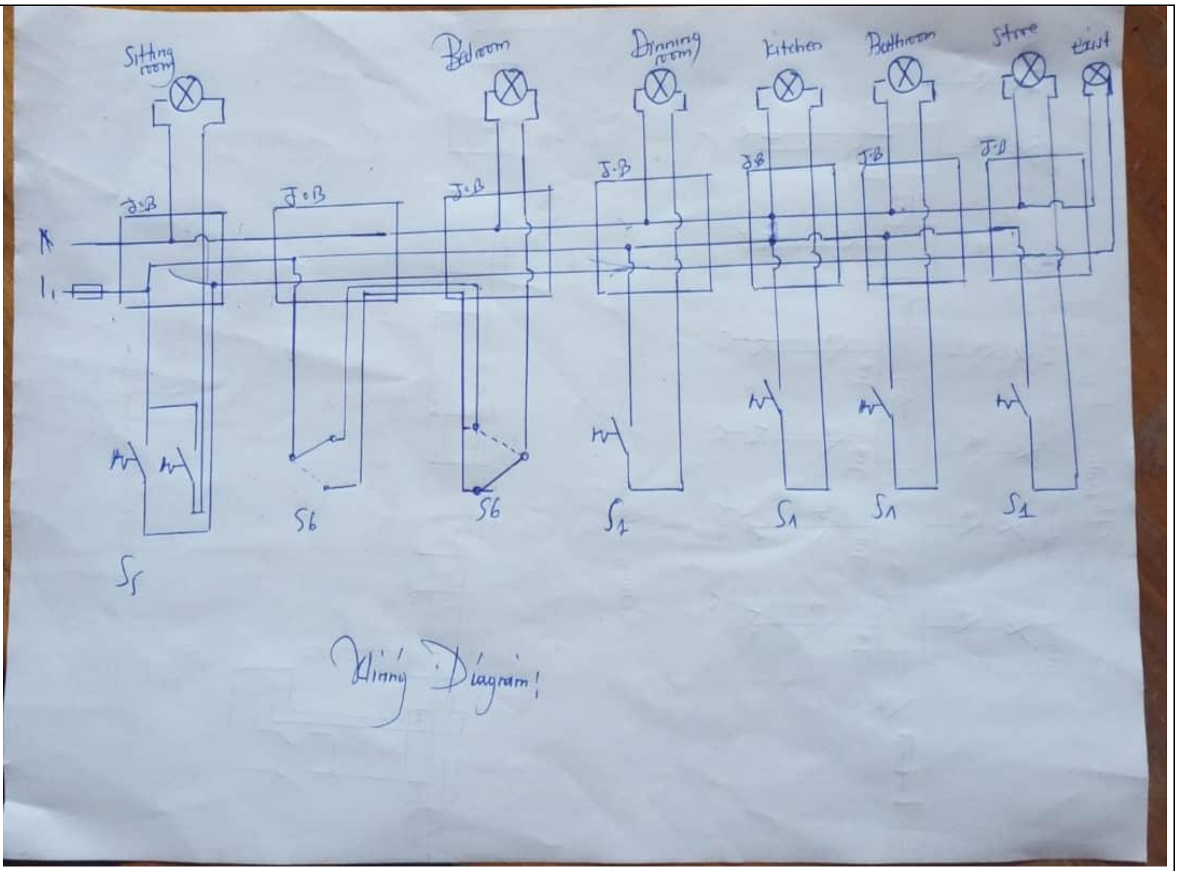
Symbol of Changeover Switch

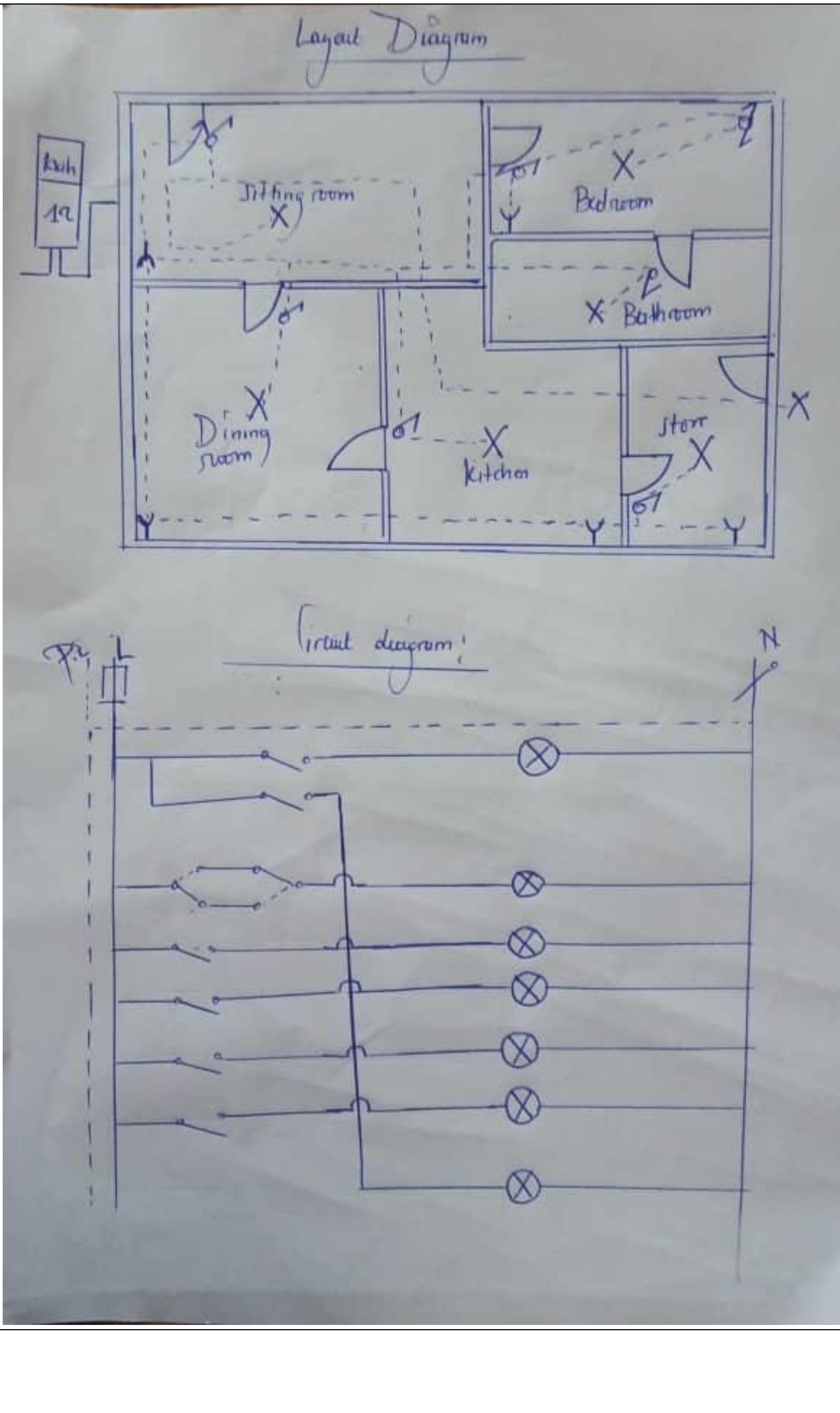




Here are some examples of assembled symbols to make a complete circuit based on their types.




Sitting room
Bedroom
Dinning room
Kitchen
Bathroom
Store
J.B
S6
S1
Wiring Diagram



Layout Diagram
kwh
Sitting room
Bedroom
Bathroom
Dining room
Kitchen
Store
Circuit diagram
L
N

Points to Remember

- **ELECTRICAL SWITCHES SYMBOLS**

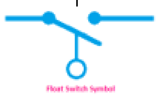
Single Pole Double Through or SPDT Switch Symbol

Symbol of Double Pole Single Through or DPST Switch

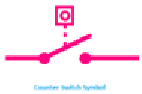
Double Pole Double Through or DPDT Switch Symbol

Symbol of Single Pole Multiple Through or SPMT Switch

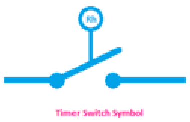
Float Switch Symbol



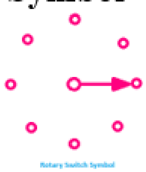
Symbol of Counter Switch



Timer Switch Symbol



Rotary Switch Symbol



On/Off Delay Switch Symbol

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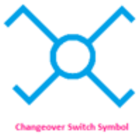
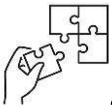
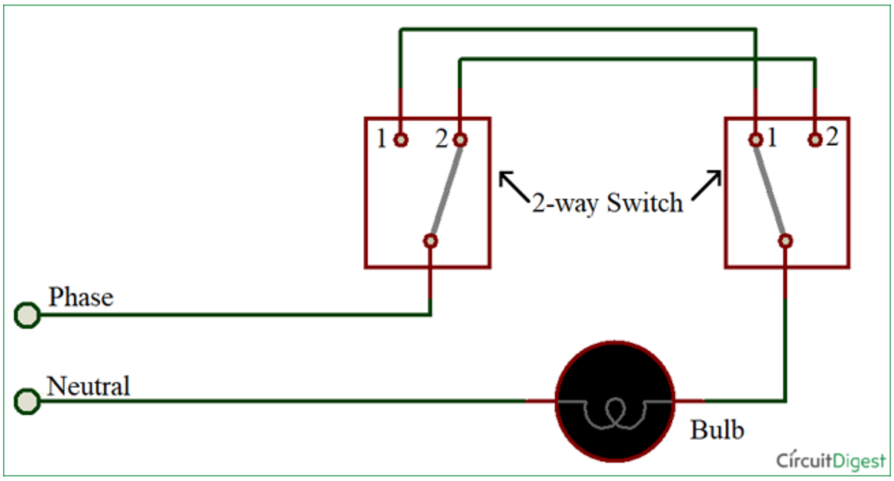




Application of learning 2.1.

Observe carefully the following diagram

a) **Name the type of diagram shown below.**



b) **Draw its circuit diagram**

Indicative content 2.2: Selection of Tools, Materials and Equipment

Duration: 1

Theoretical Activity 2.2.1: Description of tools, materials and equipment.

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of tools, materials and equipment.

i: Differentiate electrical tools from electrical materials.

I v0063zzzxxxi: Give examples of equipment used in electrical installation.

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 2.2.1.**

5: In addition, ask questions where necessary.

Key readings 2.2.1.: Description of tools, materials and equipment

- **Description of tools, materials and equipment**

1. Definition of terms

a) What are electrical tools?

Electrical tools are used to do the electrical work like electrical wiring installations. By using this tool, we can do the installation of electrical wire properly and quickly. We must be able to choose the right equipment or tools to do the electrical work then only the quality of our work will improve. By using electrical tool, we could do the electrical tasks effortlessly.

Electrical tools are tools used to work on an electrical system. These can include a wide range of tools such as **wire and cable cutters, wire strippers, coaxial compression tools, telephony tools, wire cutter/strippers, cable tie tools, accessories**,

b) What is an electrical material ?

Electrical Materials or Electrical Supplies are essential parts or elements used in a construction project to connect your home, office or building to an electrical power source. Electrical parts can vary from a small house circuit to as big as a large industrial plant.

c) What is equipment in electrical engineering?

Electrical equipment includes any machine powered by electricity. It usually consists of an enclosure, a variety of electrical components, and often a power switch. Examples of these include: Lighting, Major appliance.

Electrical equipment is typically any machine powered by electricity and includes components that are part of the electrical distribution system.

Types of tools

Tape Measure

A standard tape measure is used for all kinds of field measurements, such as setting heights for switches and outlets, centering lighting fixture boxes, and marking surfaces for cutouts.

Hammer

A hammer is used to secure electrical boxes equipped with nail-on brackets to wall studs and other framing members in a home. You’ll also need one to drive wire staples when anchoring new electrical cable to framing members.

Torpedo Level

A small level, such as a torpedo level, fits easily in a tool pouch and is used to make sure your work is level and plumb. A great installation starts with level boxes and straight switch and outlet receptacles.

A torpedo level should be part of every homeowner's standard toolkit; it will have plenty of uses beyond electrical work.

Flashlight

Electrical repair and improvement work involves a lot of dark places, from attics and basements, to wall and ceiling cavities, to the insides of electrical boxes. A tactical flashlight is needed as much for safety as it is for convenience. A couple of hand flashlights and a headlamp are good additions to an DIY electrician's toolbox.

Utility Knife

A utility knife, or *box cutter,* is handy for cutting sheathing from non-metallic (Romex) cable, to cut off electrical tape, and to open cardboard boxes.

Phillips Screwdrivers

Electricians keep screwdrivers with them at all times, for removing and installing cover plates, outlets, switches, and many other devices. It's best to have a few different lengths of Phillips screwdrivers, as well as #1, #2, and #3 tip sizes.

Screwdrivers with insulating rubber jackets covering the handles are designed for better safety when doing electrical work.

Straight-Blade Screwdrivers

As with Phillips screwdrivers, you will likely need more than one size of straight-blade screwdrivers. If you have to choose just one, pick a medium blade; it will suit most projects.

Straight-blade screwdrivers are also available with insulated handles for better safety when doing electrical work.

Allen Wrench Set (Hex Set)

Allen wrenches are used to tighten hex-head screws, which are sometimes found on ceiling fans, light fixtures, and appliances. It's a good idea to own both a metric and a standard set of Allen wrenches.

Tongue-and-Groove Pliers

Tongue-and-groove pliers are known by many names, including *channel-lock*, *groove joint,* and *straight-jaw pliers*. This tool is most often used for plumbing work, but a pair of tongue-and-groove pliers also has many uses for electrical projects. It will see frequent use for removing knockouts from metal electrical boxes, tightening cable clamps, and adjusting expansion-type ceiling fan boxes.

Non-Contact Voltage Tester

Perhaps the most important specialty electrical tool you can own is a voltage tester. A voltage tester is used for a quick safety check to make sure there's no voltage in an electrical wire or device before you start working on it. Non-contact voltage testers, powered by batteries, are the simplest and safest types of testers because they can detect electricity just by being near an outlet slot or wire.

This is a tool every DIYer needs in the toolbox. It will be used for virtually every home electrical repair project.

Wire Strippers

Another essential electrical specialty tool for homeowners is a good pair of wire strippers. Wire strippers are used to cut and strip insulation from electrical wires. A wire stripper tool has a row of gauged holes for stripping wires of different sizes, and it usually includes cutting jaws for trimming the wire ends. Some types are combination tools that can also be used to crimp wires and to strip the vinyl jacket off NM cable.

Needle-Nose Pliers

Another essential specialty electrical tool is a pair of needle-nose pliers (also called *long-nose pliers*). It will be used for bending and twisting wires whenever you are making screw-terminal connections. The long, narrow tip makes this a great tool for detailed work. Most needle-nose pliers also include cutting jaws for trimming wires.

Linesman Pliers

A pair of linesman pliers is an electrician's do-it-all tool. It has a squared-off end that is great for twisting wires together, a center cutting blade for trimming wire, and a grip area between the handles for pulling wire.

Diagonal Cutting Pliers

Diagonal cutting pliers, sometimes called *side snips* or *dikes,* are used to cut wires. They are specially designed with a cutting edge that goes down to the tip of the jaws, allowing you to get into tight areas to trim wires. Some types are sold in a pair along with a voltage detector to sense live wires. You can also find combination tools that include wire-stripping slots built into the handles.

Fish Tape

A fish tape is used to pull stranded or solid wire conductors through metal or PVC conduit. Cable lube is available to assist you in pulling the wires through the conduit. A fish tape can also be helpful when you are pulling NM cable through wall cavities.
This is a tool used when making wiring improvements, such as adding or extending circuits.

Voltmeter or Multimeter

A voltmeter is used to read voltage levels and verify that circuits are "live" or off. Unlike a circuit tester, this tool gives you reading on *how much* voltage is being carried. More sophisticated forms of the tool are known as multimeters, and they can not only read voltage levels but also amperage, resistance, and DC voltage and amperage. They do, however, require practice to learn how to use them properly.

Wire Crimpers

Wire crimpers are used to crimp lugs or connection terminals onto wires. This tool is not often used for routine circuit repairs, but it has many uses when working with appliances or electronics. Many types can also be used to strip wire insulation.

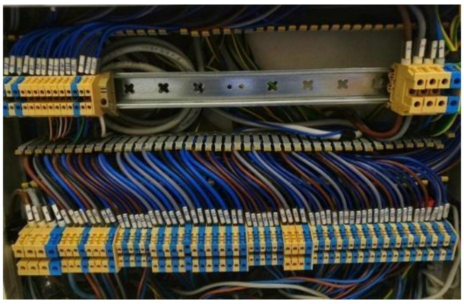
Types of materials

Electrical materials are an essential part of any electrical project. From electrical wire that carries electrical current, to circuit breakers that protect against electrical overloads and fires. These materials play a crucial role in ensuring the safety and functionality of electrical systems.

Explosion Proof Enclosures

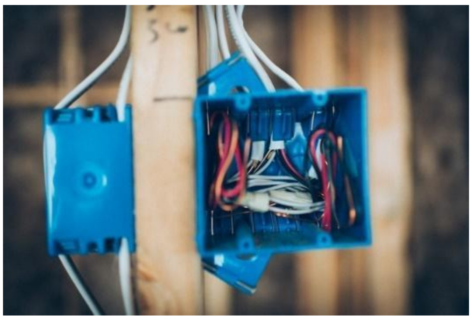
Explosion Proof is a product design to contain an electrical short so that it doesn't ignite a hazardous atmosphere causing an explosion. Refineries, gas stations, paint booths are examples of where these products would be used. They are heavy duty steel or aluminium by design, or can be fiberglass as well.

Electrical Connectors



Electrical Connector is a part that will join or adapt one part to another. Connector range in size from 3/8" to 6". They can be indoor, outdoor, corrosive protected or explosion proof.

Electrical Box

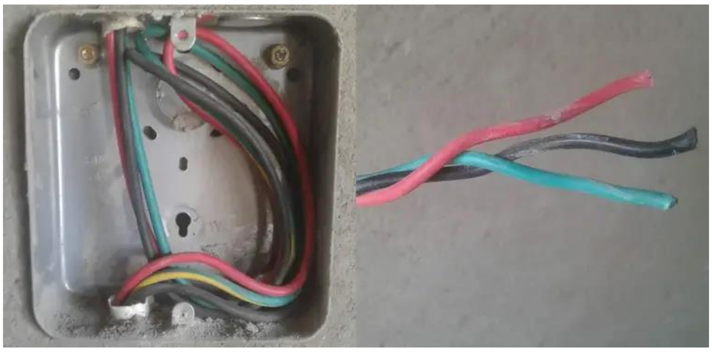


Electrical Box is an enclosure used for many purposes such as pulling, connecting or terminating an electrical circuit. An Electric box can be set screwed or indoor; it can be rain tight, or outdoor. They can be made of steel, aluminium, plastic, stainless steel, or cast iron. Requirements can include corrosive protection or explosion protection by design.

Lugs

Lugs are the electrical connectors that terminate the electrical circuit. Lugs are made of copper, aluminium, or bronze. They are made for the smallest wire size, 26 gauge to the largest 2000 MCM. Lugs can be mechanical or set screw; compression or crimp, solder or weld; or clamp type. T&B, Burndy, Penn Union, Panduit, and 3M are some different manufacturers of lugs.

wire.



A wire is a conductor that is used to carry electrical current. There are various types of wire, including copper wire, aluminium wire, stranded wire, and solid wire.

Copper wire is the most common type of wire used in electrical work. It is a good conductor and is easy to work with.

Stranded wire is made up of a group of smaller wires twisted together, and is more flexible than solid wire.

Solid wire is a single strand of wire and is not as flexible as stranded wire.

A wire is used in a number of electrical applications. Like transmitting electrical current from one point to another. Electrical wire is also to ground electrical systems.

It is very important to choose the right type of wire for your project. Different types of wire have different characteristics and are suitable for various electrical applications.

Cable.

A cable is a group of wires that are bound together and encased in a protective sheath. There are many types of cable, available on the market. Types of cable include Romex, coaxial, and fibre optic cable.

Romex is a type of non-metallic sheathed cable that is commonly used in residential wiring.

Coaxial cable is used for transmitting high-frequency signals, such as those used in television and internet connections.

Fibre optic cable is made up of strands of glass or plastic and is used for transmitting data over long distances.

Cable is used in a variety of electrical applications, like connecting devices and transmitting data. It is important to choose the right type of cable for your project. suitable for different uses.

Conduit.

A conduit is a tube or pipe that is used to protect and route the electrical wire. There are a variety of types of conduit. They include metal conduits, plastic conduits, and flexible conduits.

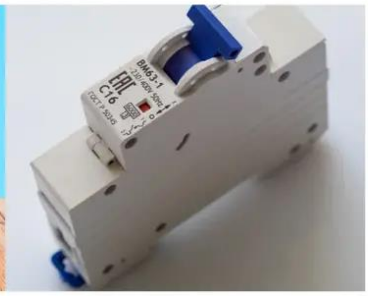
Metal conduit is made of metal and is used in applications where the wire needs to be protected from physical damage.

A plastic conduit is made of plastic and is less expensive than a metal conduit.

A flexible conduit is made of a flexible material, such as metal or plastic. And is used in applications where the wire needs to be able to move or flex.

Conduit is used in a variety of electrical applications, protecting wire and providing a clean and organised look. It is vital to choose the right type of conduit for your electrical work. Different types of conduits have different characteristics and applications.

Circuit breakers.



Circuit breakers are devices that are used to protect against electrical overloads. They are designed to trip when there is an overload, protecting the electrical system and preventing a fire from starting.

There are several circuit breakers, including standard circuit breakers, GFCI (Ground Fault Circuit Interrupter) circuit breakers, and AFCI (Arc Fault Circuit Interrupter) circuit breakers.

Standard circuit breakers are the most common type and are used to protect against overcurrents. GFCI circuit breakers are used to protect against ground faults.

Wire nuts.

Wire nuts are a type of electrical connector that is used to secure two or more electrical wires together. Wire nuts are commonly used in residential and commercial wiring applications to connect wires to devices such as switches, outlets, and fixtures.

Electrical tape.

Electrical tape is a type of insulating tape that is commonly used in electrical wiring applications. It is made from a flexible, insulating material that is coated with a conductive adhesive.

Cable ties.

Cable ties, also known as zip ties or tie wraps, are a popular and convenient way to organize and secure cables and wires.
They are made from a flexible, durable plastic material and feature a ratcheting mechanism that allows them to be tightened down securely.
To use a cable tie, simply thread the end of the tie through the head. And then wrap it around the cables or wires you want to secure.

Grommets.

Grommets, also known as edging or cord grips, are small, rubber or plastic rings that are used to protect wires and cables as they pass through holes or openings in walls, floors, or other surfaces.
They are commonly used in electrical wiring, automotive wiring, and other applications where wires and cables need to be protected from damage.
Grommets are easy to use and provide an affordable and effective way to protect wires and cables.

Cable clamps.

Cable clamps, also known as wire clamps or cord clamps, are a type of fastening device that is used to secure and organise cables and wires.
They are commonly used in electrical wiring, automotive wiring, and other applications where cables and wires need to be secured in place.
Cable clamps are available in a variety of sizes and styles, so you can choose the one

that best fits your needs. Some cable clamps are designed to be mounted to a surface, such as a wall or a floor, while others are designed to be attached to a cable or wire.
To use a cable clamp, simply place it around the cables or wires you want to secure, and then tighten it down until it is secure.

Types of equipment

Equipment refers to the various tools, machines, devices, and apparatus used in various fields, industries, or activities to perform specific tasks, achieve objectives, or carry out functions. Equipment is designed and built to serve specific purposes and is often specialised for particular applications.
All power tools used when performing a given task such as powered electrical screw driver, multi-meter, reverting machine, drilling machine, Electric grinder, clamp-on ammeter, megohmmeter, wattmeter, phase sequence tester, multi-function tester are equipment.

Practical Activity 2.2.1: Selection of tools materials and equipment

Task:

1: Referring to previous activities (2.2.1) you are requested to perform the given task. The task should be done **individually**.

i. Based on the criteria, observe careful and select tools materials and equipment

2: List the criteria to be used to select tools, materials and equipment.

3: Referring to procedures and formulas provided on task 2, Perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading **2.2.2** and ask clarification where necessary Perform the task provided in application of learning **2.2**

Key readings 2.2.2 Selection of tools materials and equipment

CRITERIA TO CONSIDER WHILE SELECTING TOOL

- What type of tool are you looking for?
- What are the specific tasks you need the tool to perform?
- What is your budget?
- What are your team's skills and experience level?
- What are your priorities in terms of features and functionality?

CRITERIA TO CONSIDER WHILE SELECTING MATERIAL

The criteria to consider while selecting a material can be categorised into several key factors:

Functional Requirements:

- Mechanical properties: Strength, stiffness, hardness, fatigue resistance, creep resistance, etc.
- Physical properties: Density, thermal conductivity, electrical conductivity, thermal expansion, etc.
- Chemical properties: Corrosion resistance, reactivity, biocompatibility, etc.
- Performance requirements: Wear resistance, friction coefficient, optical properties, etc.

Economic Considerations:

- Cost: Initial material cost, processing costs, fabrication costs, waste disposal costs.
- Availability: Ease of procurement, lead times, transportation costs.
- Sustainability: Environmental impact of material extraction, processing, use, and disposal.

Manufacturing Considerations:

- Formability: Ability to be shaped into desired forms.
- Machinability: Ease and cost of machining.
- Joinability: Ability to be joined to other materials.
- Recyclability: Ability to be recycled and reused.

Environmental Considerations:

- Resource depletion: Impact of material extraction on natural resources.
- Pollution: Environmental impact of material processing and use.
- End-of-life disposal: Toxicity and disposal options for the material.

Other Considerations:

- Aesthetics: Appearance, colour, texture, etc.
- Safety: Toxicity, flammability, etc.
- Regulations: Compliance with industry standards and regulations.

CRITERIA TO CONSIDER WHILE SELECTING EQUIPMENT

The criteria to consider when selecting equipment can be categorised into several key factors:

Functional Requirements:

- Performance: Does the equipment have the capacity and power to handle the required workload?
- Accuracy: Does the equipment meet the required accuracy and precision specifications?
- Reliability: Is the equipment known for its reliability and uptime?
- Versatility: Can the equipment be used for multiple applications or tasks?
- Safety: Does the equipment meet all safety standards and regulations?

Economic Considerations:

- Cost: What is the initial purchase price of the equipment?
- Operating cost: What are the ongoing costs associated with operating the equipment, such as energy consumption, maintenance, and repair?
- Return on investment (ROI): How quickly will the equipment pay for itself through increased productivity or cost savings?

Operational Considerations:

- Ease of use: Is the equipment easy to set up, operate, and maintain?
- Training requirements: How much training is required for operators to use the equipment safely and effectively?
- Maintenance requirements: What are the maintenance requirements for the equipment, and are they easy to perform?
- Availability of spare parts: Are spare parts readily available in case of breakdowns?

Environmental Considerations:

- Energy efficiency: How energy-efficient is the equipment?
- Environmental impact: What is the environmental impact of the equipment, both in terms of its production and use?
- Noise pollution: How much noise does the equipment generate?
- Waste disposal: How will the equipment be disposed of at the end of its useful life?

Points to Remember

- **Electrical tools** are tools used to work on an electrical system. These can include a wide range of tools such as **wire and cable cutters, wire strippers, coaxial compression tools, telephony tools, wire cutter/strippers, cable tie tools, accessories**,
- **Electrical equipment** is typically any machine powered by electricity and includes components that are part of the electrical distribution system

- **Electrical Materials or Electrical Supplies** are essential parts or elements used in a construction project to connect your home, office or building to an electrical power source.
- When selecting tools, materials, and equipment for electrical work, you can enhance safety, efficiency, and the overall quality of your electrical installations and repairs.
- **Element to consider while selecting**

TOOL:

- What type of tool are you looking for?
- What are the specific tasks you need the tool to perform?
- What is your budget?
- What are your team's skills and experience level?
- What are your priorities in terms of features and functionality?

MATERIAL:

- Functional Requirements
- Economic Considerations
- Manufacturing Considerations
- Environmental Considerations

EQUIPMENT:

- Functional Requirements
- Economic Considerations
- Operational Considerations
- Environmental Considerations

Application of learning 2.2.

Observe carefully the following picture and select accordingly tool, material and equipment used in electrical installation.

Indicative content 2.3: Electrical Laying Conduit

Duration: 4

Theoretical Activity 2.3.1: Description of electrical laying conduit

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of electrical conduit laying.

i: What are the types of electrical conduit?

ii: Give the size of electrical conduits.

iii: What are the laying techniques?

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **2.3.1.**

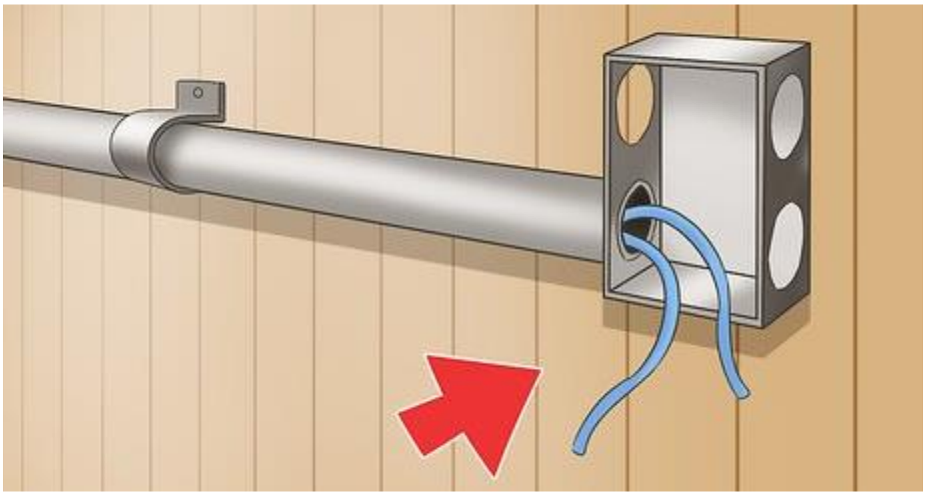
5: In addition, ask questions where necessary.

Key readings 2.3.1.: Description of electrical laying conduit

- **Description of Electrical Conduit**

What is an Electrical Conduit

Electrical conduit is a durable tube or enclosure where electrical wires are enclosed for protection from damage. Sometimes, these are also called wire ways or raceways. Electrical conduit is very essential where the electric wiring is exposed so that it protects the wires & individuals who may approach near the electric wires. The material used to make this conduit is plastic or metal and may be bendable or stiff. The electrical conduit diagram is shown below:



How does Electrical Conduit Work?

The electrical conduit works by providing adequate protection for homes, buildings from electrocution. Generally, conduits allow different wires to run current safely throughout the same pipe. The correct time to utilize an electrical conduit is whenever you are running a wire manually for electricity or when re-wiring a home.

Types of Electrical Conduit

There are different types of electrical conduits that are commonly used in residential and other commercial buildings. They are;

- Electrical Metallic Tubing.
- Rigid Metal Conduit.
- Intermediate Metal Conduit.
- Flexible Metal Conduit.
- Liquid-tight Flexible Metal.
- Electrical Non-Metallic Tubing.
- Rigid PVC Conduit.




a. Electrical Metallic Tubing

Electrical Metallic Tubing or EMT is a common example of an unbending electric conduit. This type of conduit is made with Aluminum or Galvanized steel. As compared to Rigid Metal Conduit (RMC), it is lighter and thinner but it can also be strong and bendable with using a tube bender tool, so it is known as a thin wall conduit.

b. Rigid Metal Conduit

The rigid metal conduit or RMC is very expensively available electrical wiring in the market because it provides extra power & strength. It is made with heavyweight Galvanised Steel and installed with threaded fittings.

c. Intermediate Metal Conduit

A Lightweight & thinner version of RMC is IMC which is used in the same applications as RMC. Because this conduit is lighter & very easier to work as compared to RMC, it is more frequently used in new constructions.

d. Flexible Metal Conduit

FMC (Flexible metal conduit) is available in a spiral construction and it is flexible so that it can simply bend throughout different structures & walls. A typical flexible metal conduit is used in indoor locations which are dried out and used at fixed appliances like a garbage disposer. These conduits are mainly guard's electrical wiring in industrial & commercial buildings.

e. Liquid-tight Flexible Metal

The liquid-tight flexible metal conduit or LFMC is a special type of FMC. This conduit is available with a plastic coating, so used with sealed fittings to make it waterproof. It is frequently used with outdoor equipment like AC (air conditioner) units. So this type of conduit is mainly designed for utilizing in locations where dampness could become a problem. This type of conduit should be used in combination with liquid-tight fittings.

f. Electrical Non-Metallic Tubing

Electrical nonmetallic tubing or ENT is a flexible and thin-walled corrugated plastic conduit and it is flame-retardant & moisture-resistant. This type of conduit is very simple to bend & installed with glued plastic & snap-lock fittings.

Not like electrical metallic tubing (EMT), this conduit cannot be used in exposed locations but used inside walls. In addition, to use in normal metal-frame or wood walls, electrical metallic tubing can be used in concrete block constructions &can be roofed with concrete.

g. PVC Conduit

PVC conduit or polyvinyl chloride conduit is related to plastic plumbing pipes. These conduits can be simply installed by plastic fittings with glue. It can be simply bent once heated within a heater box. These conduits can be used in underground and corrosive environments.

The main benefits of using these conduits are, installation is easy, versatile, less weight, not expensive, used in underground and concrete.

Advantages

The advantages of electric conduit include the following.

- These wiring systems are waterproof.
- Its appearance is good.
- Long life.
- Alternation is achievable.
- It is consistent.
- It is a strong & very famous system.
- PVC type's conduits are highly resistant to corrosion.
- There is no possibility for fire.
- Protection from electric shock.
- Easy maintenance.
- When cables are damaged, we can replace them easily.
- It provides protection from chemicals, moisture, etc.

Disadvantages

The disadvantages of electric conduit include the following.

- Installation is not easy.
- Very difficult to find the fault.
- Expensive.
- Takes more time while installation.
- Electric shock risk.
- Maintaining extra connections is complicated in the future.
- As compared to the concealed system, this wiring system beauty is less.
- Mechanical damage is possible in PVC plastic conduits.

Applications

The applications of electric conduit include the following.

- Electrical conduit is available in different types and styles which are used to run electrical wiring around your home or exposed areas like a garage, basement, laundry areas, barn, etc.
- Electrical metal conduit (EMC) is used in commercial, industrial & residential constructions
  The flexible metal conduit (FMC) is used to connect lighting fixtures and on top of suspended ceilings.
  A rigid metal conduit (RMC) is mainly used in outdoor applications for providing structural support mainly for electrical cables.
- Intermediate metal conduit (IMC) is mainly used for strong connections & outdoor exposures.
  IMCs can be used as an equipment grounding conductor through their fittings.
- Liquid-tight flexible metal conduit (LTFMC) is mainly used for connecting outside AC equipment or & also disposals in kitchen sinks. In residence, its usage is quite restricted.
- Rigid polyvinyl chloride (RPC) is mainly used in wet areas & they have good resistance to highly acidic chemicals.
- RPC is completely waterproof, so perfect for wet locations in commercial and industrial buildings.

Conduit Fittings

Conduit fittings are available in a huge variety of sizes, shapes and materials, and they're normally used for connecting runs of conduit together, and for connecting conduit ends to boxes, enclosures or electrical devices. Fittings are needed to connect conduits to boxes or enclosures of different sizes and when the direction of most metallic conduits has to be changed. There are also straps and clamps, which are used to provide additional support to conduits and to keep them secured. You may need to use special types of fittings if a conduit run is likely to be exposed to moisture, vapours, or hazardous conditions.

Types of Electrical Fittings

Electrical Conduit fittings can be listed as follows, based on the function they serve and how they are installed:

a) Conduit Bodies: These are tubular units with openings at each end for admitting conduits, and providing access to the wires. There are quite a few designs and you'll find conduit bodies that connect two conduits in a straight line, create 90° bends and join two different types or sizes of conduit. Even the access point for the wires can either be exposed, or have a cover with screws. Since conduit bodies can perform such a wide range of functions, and some are also intended to be used as pull-boxes, they are marked with the purposes they are rated to serve, as well as the internal volume.

b) Bends: To save time, equipment and labor costs, you can tackle changes in the direction of a conduit with pre-fabricated bends. Commonly called 'factory bends' or 'elbows', they are available in a variety of lengths and curvatures, and according to NEC requirements, you can bend certain tubings by hand, using a mechanical bender, or a hydraulic bender for larger ones. However, an installation may require a lot of bends, and bending conduits on location might damage them or reduce the internal diameter. Even with the use of factory bends, the NEC does restrict the number of bends you can have between pull boxes to a maximum of 360°, including offsets at the box or enclosure.

45° Elbow Fitting

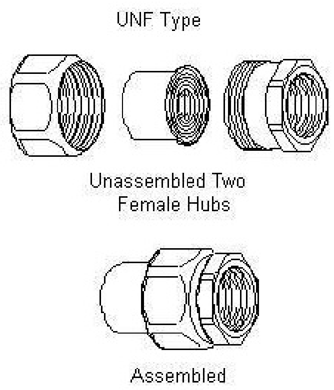
90° Elbow Fitting

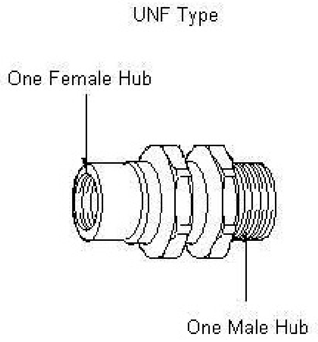
c) Coupling: Conduit couplings are essential for almost any coupling system, for securely linking together lengths of conduit and attaching site-fabricated bends. Even though PVC conduits with a belled side can be linked without couplings, they would still be needed for sections where the conduit has been cut to size. Couplings are available in a variety of sizes and some of them, like rigid conduit couplings, are threaded on the inside. However, when the conduit is passing through a wall or making some other transition, consider using a conduit body instead. Even for the first sections of conduit entering or leaving the box or enclosure, use pull boxes or bodies so the conductors can easily be retracted if the enclosure needs to be removed.

d) Drains: In areas where the temperature varies significantly, or the conduit runs from a warm area to a cooler one, moisture in the air starts condensing. To prevent drips and water-logging in the conduit runs, install drains at the lowest points of each run that might be affected, or at locations where water might get trapped and accumulate. For embedded and buried conduits, installing a run within the encased part may be difficult. You can create a low-point or a dip just before the conduit goes underground and install a drain there.

e) Bushings and Locknuts: Bushings create a smooth entry point to conduits without any sharp edges, protecting the conductors from damage during wire pulls. They are also extremely important when the conduit system enters an enclosure or bus box. A bushing is installed on the inside of the box opening and threaded into the conduit end, separating the conductors from the edges of both the opening and the conduit end. Locknuts are threaded on the inside, with teeth on one surface or both, which grip the surface. They installed on both sides of the opening to ensure that both the conduit and bushing are held firmly in place. If the locknut has teeth on only one side, that side should face the box.

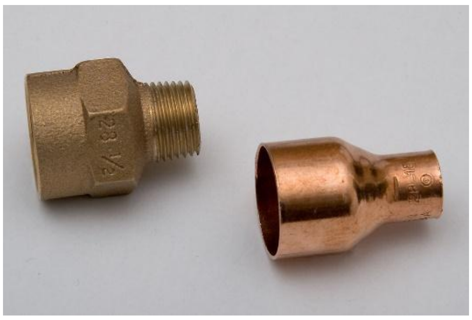
f) Unions: Conduits often run along areas where space is constrained and couplings are difficult to install. Apart from that, sections might at some point get damaged, which is where unions are very useful. They have two separate heads and a locking mechanism which can connect two pieces of conduit together, even if they can't be physically turned. Unions are available in different configurations with male and female heads, or a combination of both. The heads can be fit on each individual conduit end and secured together, usually with a surface nut that slips over the two parts and locks them together.





g) Nipples and Hubs: Nipples can save time and money when a conduit is needed between enclosures that are placed close to each other, or for short runs where field-threading the ends of a conduit is difficult. Like prefabricated bends, nipples are threaded on both ends and can be installed quickly and easily. As per the NEC, a nipple cannot exceed 24 inches in length, beyond which it is considered a raceway and can only be used for three current carrying conductors. Hubs are used to connect conduits to bus boxes or enclosures that don’t have a factory-threaded entry.

i) Reducers and Reducing Washers: A reducer is a special kind of combination coupling that allows you to connect raceways of one trade size to larger or smaller ones. Although it’s generally better to use a pull box, reducers are handy for areas that have limited space. Reducing washers, or threaded reducers, are similar to hubs, except both the inner and outer surfaces are threaded. They are used to connect conduits to enclosure or box openings that have a larger diameter, with locknuts on both sides to fasten them in place.



j) Straps and Clamps: Long runs of conduit and tubing require additional support to keep them from sagging or breaking under their own weight. Straps are used to mount the conduit to ceilings or walls using screws or bolts. To fasten conduit runs to fixed structures, like beams, hangers or unistrut channels, the conduit is supported using clamps. For most installations, the NEC specifies the maximum length of unsupported RMC and EMT running in a straight line as 10 feet, and within three or five feet of a box. For liquid tight flexible conduits, this reduces to every 4.5 feet of conduit length and within 12 inches of a box or enclosure.

Sizes of electricals conduits

The size of a conduit for the purpose of wiring should be such that the required number of wires of required sizes can be easily drawn through it. Negligence in this respect leads to excessive strain in drawing cables through it, and also there is risk of damaging the insulation of cables.

Besides, during future extension it will be impossible to accommodate higher sizes of cables in replacement of lower sizes or one or two more cables in the conduit. There will then be no other alternative but to draw out all cables from the old conduit and to draw them through a conduit of larger size. For this reason conduit wiring is to be designed with the idea of future expansion in mind. That is why the outside diameter of the narrowest conduit used in a wiring system is usually 19 mm (3/4").

Size of Wires

Each application requires a certain wire size for installation, and the right size for a specific application is determined by the wire gauge. Sizing of wire is done by the American wire gauge system. Common wire sizes are 10, 12 and 14 – a higher number means a smaller wire size, and affects the amount of power it can carry. For example, a low-voltage lamp cord with 10 Amps will require 18-gauge wire, while service panels or subpanels with 100 Amps will require 2-gauge wire.

Cable Size

Cable size is the gauge of individual wires within the cable, such as 14, 12, 10 etc. – again, the bigger the number, the smaller the size. The number of wires follows the wire-gauge on a cable. So, 10/3 would indicate the presence of 3 wires of 10-gauge within the cable. Ground wire, if present, is not indicated by this number, and is represented by the letter 'G'.

Wire Lettering

The letters THHN, THWN, THW and XHHN represent the main insulation types of individual wires. These letters depict the following NEC requirements:

- T – Thermoplastic insulation
- H – Heat resistance
- HH – High heat resistance (up to 194°F)
- W – Suitable for wet locations
- N – Nylon coating, resistant to damage by oil or gas

X – Synthetic polymer that is flame-resistant

Practical Activity 2.3.2: Laying Electrical Conduct

Task:

1: Referring to previous activities (2.3.1) you are requested to perform the given task. The task should be done **individually**.

When installing house different joins are used in connection of more than one conduit

i. You are asked to draw T joint, 90-, and 45-degrees joints

ii. Use PVC conduit and hacksaw to construct drawn joints.

2: List out procedures used to draw T joint and to use PVC conduit.

3: Referring to the task3, Perform the given tasks

4: Present your work to the trainer and whole class.

5: Read key reading **2.3.2** and ask clarification where necessary Perform the task provided in application of learning **2.3**

Key readings 2.3.2 Laying Electrical Conduct

❖ **Some cutting techniques used when laying cables:**

Cable Length Measurement

Cable Cutting Tools

Conductor Cutting

Conduit Cutting

Cable Management

❖ **Joining techniques**

When laying cables, you may need to join or connect cables together to achieve the desired length or to create branching points in your installation.

Splicing: Splicing involves joining two cable ends together by stripping the insulation from the conductors and connecting them

Connector Installation: Connectors are used to terminate or join cables in many applications.

Junction Boxes: Junction boxes provide a safe and enclosed space for joining multiple cables or conductors.

Testing: After making cable connections, test them to ensure they are functioning correctly. Use appropriate testing equipment to verify continuity, signal quality, or power transmission

Laying techniques of electrical conduits

Laying electrical conduit is a critical part of electrical installation, providing a protective pathway for electrical wiring while also helping to organise and secure the cables. Conduits can be made of metal, such as steel or aluminium, or non-metallic materials like PVC (polyvinyl chloride).

Steps for cutting techniques used when laying cables

1. **Safety First:**
   - Before starting any work, ensure your safety by wearing appropriate personal protective equipment (PPE) such as gloves and safety glasses.
2. **Select the Right Tools:**
   - Choose the appropriate tools for the type of cable you are working with. Common tools include cable cutters, wire strippers, and utility knives.
3. **Measure and Plan:**
   - Measure and plan the length of cable needed for the installation. Consider factors such as distance, bends, and any obstacles.
4. **Marking the Cable:**
   - Use a marker or tape to mark the points where you need to cut the cable. This ensures accuracy and helps prevent mistakes.
5. **Cutting Techniques:**
   - Different types of cables may require different cutting techniques. Here are some general guidelines:
     - Cable Cutters: Use cable cutters for cutting larger cables. Place the cable in the jaws of the cutter and apply pressure to make a clean cut.
     - Wire Strippers: If your cable has insulation that needs to be removed, use wire strippers to strip away the outer layer, exposing the inner conductors.
     - Utility Knife: For smaller cables or those with tough insulation, a utility knife may be used. Score the insulation carefully and then bend it to break it cleanly.
6. **Removing Insulation:**
   - If you're working with multi-conductor cables, use wire strippers to remove the insulation from the ends of the conductors. Be careful not to nick or damage the conductors.

7. Checking for Damage:

- Inspect the cut ends for any signs of damage or nicks. Damaged cables can lead to performance issues or safety hazards.

8. Organising and Bundling:

- Organise the cables neatly and bundle them together using cable ties or other suitable methods. This helps to prevent tangling and makes the installation look more professional.

9. Connection Preparation:

- If you are connecting the cables to devices or terminals, prepare the ends according to the specifications of the connectors. This may involve further stripping, crimping, or soldering.

1**0. Secure and Test:**

- Once the cables are laid and connected, secure them in place using appropriate clips, clamps, or conduits. Test the cable installation to ensure proper connectivity and functionality.

❖ **Installation of Conduit and Junction Box in slab:**

Points to remember while Installing of Conduit and Junction Box in slab

1. Make sure the right size of conduit is used per the approved Electrical Pipe Routing Plan.
2. Before the concrete is poured, the ceiling Conduits must be laid in the prepared shutter works of the ceiling slab. - Pipes, junction boxes, components, joints, etc. should be placed along the pipes.
3. Use a deep junction box for fan, spotlight, surface mounted lighting fixtures and cable pulling.
4. Use long radius bend or PVC Conduit bending spring used as per site requirement for the wall drop.
5. Suitable adhesive used for Joints between PVC conduits and fittings. PVC conduit sanded before gluing for better insertion on the fitting
6. Ensure some distance between the conduits and try to avoid the overlapping of conduits.
7. Ensure at least 1” - 25mm spacing gap between PVC conduits running in parallel. So, that Placed PVC conduit is fully covered by concrete and will avoid honeycomb or structural defects in the future.
8. In-wall drops where vertical conduits are used should be Concealed and brought out of beams, all such ends should be protected on the bottom of beams using paper for future extension (extension done by couplers)
9. Light / Fan points should be marked using paint (yellow or red) for identification on slab shuttering.

Points to Remember

❖ **The types of electrical conduit are:**

Different types of electrical conduits that are commonly used in residential and other commercial buildings. They are;

- Electrical Metallic Tubing.
- Rigid Metal Conduit.
- Intermediate Metal Conduit.
- Flexible Metal Conduit.
- Liquid-tight Flexible Metal.
- Electrical Non-Metallic Tubing.
- Rigid PVC Conduit.

❖ **The size of electrical conduit**

The size of a conduit for the purpose of wiring should be such that the required number of wires of required sizes can be easily drawn through it

Laying electrical conduit is a critical part of electrical installation, providing a protective pathway for electrical wiring while also helping to organise and secure the cables. Conduits can be made of metal, such as steel or aluminium, or non-metallic materials like PVC (polyvinyl chloride

❖ **The laying techniques are:**

Laying techniques in electrical installations involve the proper methods for routing, securing, and connecting electrical cables and wires to ensure safety, functionality, and compliance with electrical codes and regulations

❖ **The advantages of electrical conduit**

- These wiring systems are waterproof.
- Its appearance is good.
- Long life.
- Alternation is achievable.
- It is consistent.
- It is a strong & very famous system.
- PVC type's conduits are highly resistant to corrosion.
- There is no possibility for fire.
- Protection from electric shock.
- Easy maintenance.
- When cables are damaged, we can replace them easily.
- It provides protection from chemicals, moisture, etc.

❖ **Joining techniques**

When laying cables, you may need to join or connect cables together to achieve the desired length or to create branching points in your installation.

Splicing: Splicing involves joining two cable ends together by stripping the insulation from the conductors and connecting them

Connector Installation: Connectors are used to terminate or join cables in many applications.

Junction Boxes: Junction boxes provide a safe and enclosed space for joining multiple cables or conductors.

Testing: After making cable connections, test them to ensure they are functioning correctly. Use appropriate testing equipment to verify continuity, signal quality, or power transmission

Application of learning 2.3.

Mrs R has a house of three rooms and a bathroom in the house. He wants to install it using a wall mounted installation. He suggested using different conduits depending on the working place. As electrician you are invited to do the following tasks:

a) Select the types of piping to be used in bathroom
b) Measure and plan the switching position and power supply as electrician
c) What bends will be used?

Indicative content 2.4: Wiring Cabling and Connection of Wire and Cables

Duration: 3

Theoretical Activity 2.4.1: Description of wiring cabling and connection of wires and cables

Tasks:

1: In small groups, you are requested to answer the following questions related to the of description of Wiring / Cabling and Connection of wires/cables.

i. Explain the types of wire/cables
ii. What are the elements to consider while selecting and sizing Wire/Cable?
iii. Describe the wire/cable colour coding
iv. State the wire/cable connection techniques
v. Explain the wire/cable labelling and termination techniques

2: Provide the answer for the asked questions and write them on papers.
3: Present the findings/answers to the whole class
4: For more clarification, read the key **readings 2.4.1.**
5: In addition, ask questions where necessary.

Key readings 2.4.1.: Description of wiring cabling and connection of wires and cables

1. Definition of Terms

a) Wiring:

Electrical wiring is an electrical installation of cabling and associated devices such as switches, distribution boards, sockets, and light fittings in a structure. Wiring is subject to safety standards for design and installation.

b) Connection of wires:

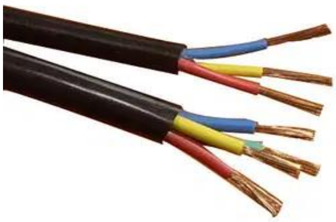
An electrical connection is any structure that allows electricity to flow through it.
Connecting wires allows an electrical current to travel from one point on a circuit to another because electricity needs a medium through which it can move. Most of the connecting wires are made up of copper or aluminium.

c) Electrical cables

Electrical cables help transport electrical energy from one point to another. Electrical cables are composed of **electrically** conducting materials with insulation layers. These when connected to devices at the right terminals generate power to run it. Based on the application, a variety of factors determine the type of cable to be used.

What is an Electrical Cable?

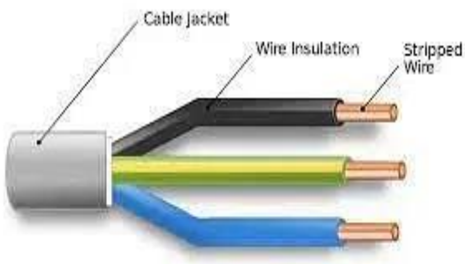
Electric cables are current-carrying wires which are bonded, twisted, or braided together in a single assembly. These wires are made from electrically conducting materials that are secured with one or more **insulation layers**. The entire setup is called a **Cable Assembly**. These cables carry electrical signals and aid the generation, transmission, and distribution of electric power.



Components of an Electrical Cable

The electric cable is composed of three major components:

1. **Conductors: Conductors** are the electricity transmitting wires in a cable. These are made from high conducting metals like Copper and Aluminum which have low resistance and can be used for high voltage applications.
2. **Insulators:** The conducting wires are set apart using insulation materials to prevent any abnormalities in the current flow path. Being bad conductors of electricity, these prevent short circuits and unwanted current flow paths. In earlier times, paper, cloth, or rubber were used as insulating materials, however, these are now replaced with different synthetic polymers based on their application. Examples: Polyethylene, Butyl Rubber, etc.
3. **Sheath:** These wires protect the cable from atmospheric conditions like high moisture in the air, chemical reactions, or fire attacks. Commonly used sheaths are made from polyvinyl chloride **(PVC)**.



Properties of Electrical Cable

Listed below are some **standard properties** of cable wires:

1. **Strength and Flexibility**: Wires must have great insulation against external influences and should be easily installable. Eg: telephone lines, cameras, etc.
2. **Fire Retardant:** Fire accidents and exhausts can cause damage to the wires. A fire-resistant material of wires minimises damage in times of fire attacks.

3. **Long Life and Heat Resistance:** Frequent maintenance of wirings in public or private facilities is not feasible. Wiring materials should hence be capable of withstanding heat as per standards and should be viable.
4. **Non-toxic and Environment-Friendly:** Based on the site of installation, wiring materials must not contribute to producing pollutants that can damage property and life.
5. **Simple Usage:** Complex circuits limit the application of the wirings. Hence, for domestic and commercial uses, the wirings are mostly comprehendible and outer insulation is ensured for security reasons.
6. **Cost-Effective:** Cables are the backbones of electrical circuits. This makes it necessary to ensure they are available at a fair price.

Applications

The **electric cable applications** include the following.

- Electrical cables are widely used to provide wiring in buildings, industries, etc
- These cables are used to transmit electrical energy from one location to another.
- These are widely used in electronic devices.

2. Types of wire/cables

The three wires used to carry electricity from one place to another are:

1) Live wire (L)
2) Neutral wire (N)
3) Earth wire (E)

1. Live wire (L): The live wire has an insulation that is red in color, it carries high voltage and brings in the current.

2. Neutral wire (N): The insulation of the neutral wire is black in color and provides a return path for the current to flow in. It has zero potential.

3. Earth wire (E): The insulation of the earth wire is green in colour. It has no charge.

3. Wire/Cable selection and sizing

Cable selection is about choosing the appropriate type of conductor and selecting a suitable size/cross-section area/ diameter of the conductor according to the application. Cable sizes are usually defined in terms of cross-sectional area, Kcmil (Kilo circular mils) or AWG (American Wire Gauge).

Standards available for the cable selection and size are:

IEC (International Electrotechnical Commission)

- NEC (National Electrical Code)
- BS (British Standards)

Significance of Selecting the Right Cable Size and Type:

Selecting the right cable size and type is significant because of the following reasons:

- If cable size is very small, when the current exceeds the cable ampacity, the cable will heat up and get damaged. So, there is a need to choose the cable size for which it is capable enough to withstand the full load current and the short circuit current that could flow through the cable.

- Increasing the cross-section area of the cable will require more material to be used in its construction, causing it to become expensive. Therefore, it will be hard to maintain a good balance between the cable cost and its usage requirements. So, the cable's diameter is to be sized as per the requirements.
- It must be ensured to provide a load with a suitable voltage i.e. with minimum voltage drop. Cable with a small diameter will have a higher resistance. Also, it will cause more voltage drop across the cable. That's why there is a need to select such a cable which causes no or less voltage drop.
- There is a need to choose the best cable type according to the requirement of application as every type of conductor has its own resistance, thermal conductivity, etc.

Selection Criteria of Cables:

Selecting the appropriate cable size (also known as wire gauge or cross-sectional area) for an electrical installation is crucial to ensure safety and efficiency. The size of the cable is determined by factors such as the electrical load, voltage, ambient temperature, and the length of the cable run. Below are the general steps to help you choose the right cable size:

Current Carrying Capacity: It is determined by evaluating the amount of current to be drawn by the equipment or load connected at the receiving end of the cable. The safety margin for overload current is also provided in it.

Voltage Drop: Due to resistance of the cable, power losses occur, causing the voltage to be dropped by some magnitude. In addition to it, voltage drop also varies with respect to temperature as temperature affects the resistance. If we know the values of resistance of cable and current flowing from cable, then we can determine the voltage drop across that cable by using the formula V=I*R.

Short Circuit Rating: It is the capability of a cable to withstand short circuit current for the specific duration of the fault before it has been cleared without any damage.

Determine the Electrical Load:

Calculate the total electrical load in amperes (A) for the circuit. This load depends on the devices and appliances connected to the circuit.

Voltage and Phase:

Identify the circuit's voltage and phase (single-phase or three-phase). This information is essential for cable selection.

Ambient Temperature:

Consider the ambient temperature of the installation location. High temperatures can affect cable capacity, so adjust the cable size accordingly.

Derating Factors:

Apply derating factors if the cables are installed in conditions that affect their ampacity, such as bundling, high temperatures, or specific installation methods. Consult local codes for guidance.

Cable Size Selection:

Use cable sizing tables, voltage drop calculations, or online calculators to determine the appropriate cable size (cross-sectional area) in square millimeters (mm^2) or American Wire Gauge (AWG) based on the current, voltage, temperature, and voltage drop requirements.

Overcurrent Protection:

Select the appropriate circuit breaker or fuse based on the cable size to protect the circuit from overcurrent.

Safety and Code Compliance:

Ensure that your cable size selection complies with local electrical codes and regulations.

Cable Type and Insulation:

Choose the appropriate cable type based on the application and environmental conditions. Ensure that the cable insulation is suitable for the installation environment.

Conductor Material:

Determine whether you need copper or aluminium conductors. Copper is a better conductor but more expensive, while aluminium is often used for larger loads due to its cost-effectiveness.

Cable Colour:

Follow standard color-coding for cable insulation (e.g., black for hot, white for neutral, green or bare for ground) to maintain consistency and safety.

Labelling:

Properly label cables to indicate their function, circuit, and termination points for ease of identification and troubleshooting.

It's essential to consult local electrical codes, standards, and guidelines when selecting the cable size for your electrical installation. If you are unsure or have a complex installation, it's advisable to consult with a qualified electrician or electrical engineer to ensure a safe and compliant electrical system. Choosing the wrong cable size can lead to safety hazards and operational problems in electrical circuits.

Calculate the Rating current according to the cable carrying capacity.

What is the current-carrying capacity of cable?

The conductor cross section plays a very significant role. The smaller it is, the greater the electrical resistance of the conductor.

A constant current flow heats a conductor with a small cross section much more than a conductor with a larger cross section.

IEEE regulations on cables carrying capacities

Current carrying capacity of a cable is defined as the amperage a conductor can carry before melting either the conductor or the insulation.

Heat, caused by an electrical current flowing through the conductor, will determine the amount of current a wire will handle.

Theoretically, the amount of current that can be passed through a single bare copper wire can be increased until the heat generated reaches the melting temperature of the copper.

There are many factors which will limit the amount of current that can be passed through a wire. These major determining factors are:

- **Conductor Size**
- **Conductor Number**
- **Installation Conditions**
- **Ambient Temperature**

Even in the design of a simple single insulated wire many factors must be considered: **temperature**, voltage, DC resistance of the conductor, insulation, O.D., required **flexibility**, physical properties of the conductor (tensile **strength**, voltage drop, conductivity, **weight**) and when necessary, specific electrical Cable size is selected as follows:

1. Cable is calculated on current capacity
2. Voltage drop is calculated (and cable size increased if necessary)
3. 3. Fault level withstand is calculated (and cable size increased if necessary)

Conductor Size:

The larger the circular mil area, the greater the current carrying capacity.

Conductor Number:

Heat dissipation is lessened as the number of individually insulated conductors, bundled together, is increased.

Installation conditions:

Restricting the heat dissipation by installing the conductors in conduit, duct, trays or raceways lessens the current carrying capacity.

Ambient Temperature:

The higher the ambient temperature, the less heat required to reach the maximum temperature rating of the insulation.

4. **Wire/cable colour coding**

The colour-coding helps electricians, technicians, and maintenance personnel easily recognize and differentiate wires, making installation, troubleshooting, and maintenance more efficient and safer.

Apply colour coding system in accordance with standards

Different wire colours used in electrical installation

- Violet
- White
- Red

- Brown
- Yellow
- Black
- Blue
- Yellow-green

Identification by number

Identification by testing

Identification by colour

This means that the wires are connected according to the colour of the wires.

Single Phase

Under National Colour Code		**International Colour Code**	
1. Live wire	Red	1.Live wire	Brown or Black
2.Neural wire	Black	2. Neural wire	Blue
3. Earth wire	Bore or Green	3.Earth wire	Green/Yellow

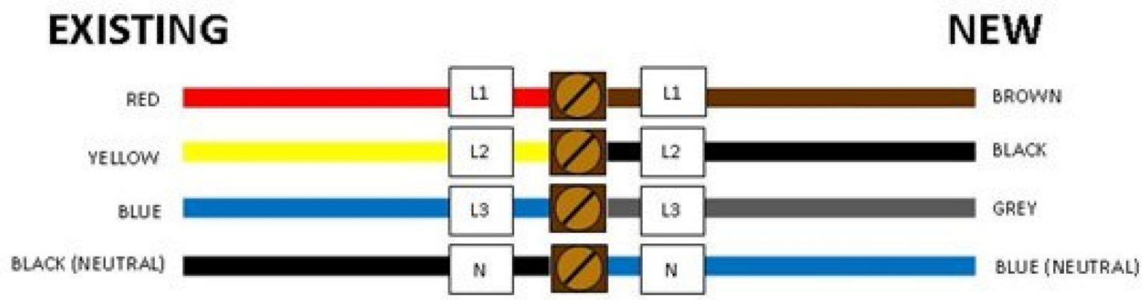
Three phases

Under National Colour Code		**International Colour Code**	
1. Line 1 or phase 1	Red	1. Line1 or phase 1	Brown
2. Line 1 or phase 1	White or Yellow	2. Line 1 or phase 1	Black
3.Line 1 or phase 1	Blue	3. Line1 or phase 1	Black
4. Neutral	Black	4 .Neutral	Blue
5. Earth wire	Bore	5.Earth wire	Green/Yellow

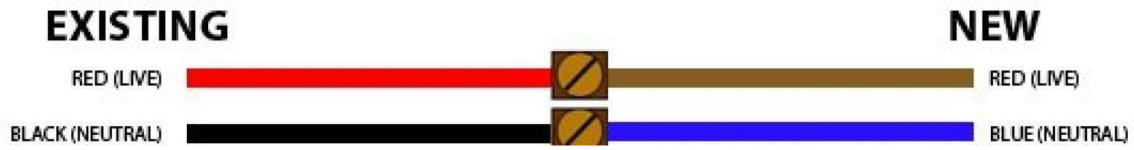
Using the wrong colour codes will make you less safe because you are at a greater risk of shock. Your home is less safe, too, because improperly connected wires may cause a fire.

Being aware of electrical wire colours is valuable, too, since the electrical code requires that certain wires (neutral and ground) follow a standard colour coding pattern.

Colour-coded electrical wires help you with future projects and make them easier to accomplish since you don't have to figure out the purpose of each wire. Each wire's purpose is labelled for you.

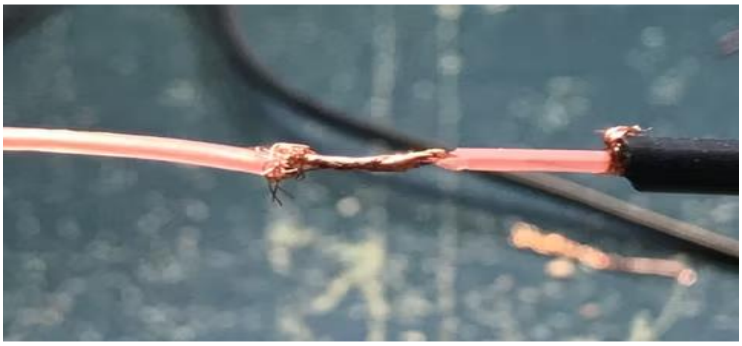


Domestic



5. Wire/cable connection techniques

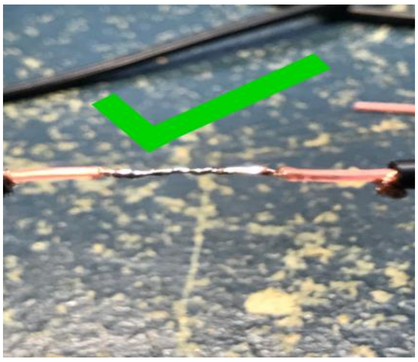
1. Twist and Tape



For any project where you need a temporary fix, or a project that will be largely stationary, a simple twist of wires wrapped in electrical tape can do the trick. While this is in no way as viable as other methods on this list, it can certainly do in a pinch!

The benefits of a simple twist and tape maneuver are mainly economical – there are no tools required, outside of a roll of electrical tape. Due to the nature of the connection, this can be very easily redone or reinforced later; as a result, this is a great solution for prototyping a build before committing to a more permanent splice.

2. Soldering



The natural progression from twist and tape soldering provides you with a secure, electrically sound, and budget-friendly method of joining two wires. The tradeoff for this is twofold – the cost of admittance with the purchase of a quality soldering iron, and the learning curve associated with proper soldering practices. That said, the soldering iron is to electronics as the wing is to the airplane – you won't get very far without it.

There are a couple of key things to keep in mind when splicing wires via soldering: how to identify a solid solder joint, and how to go about making one.

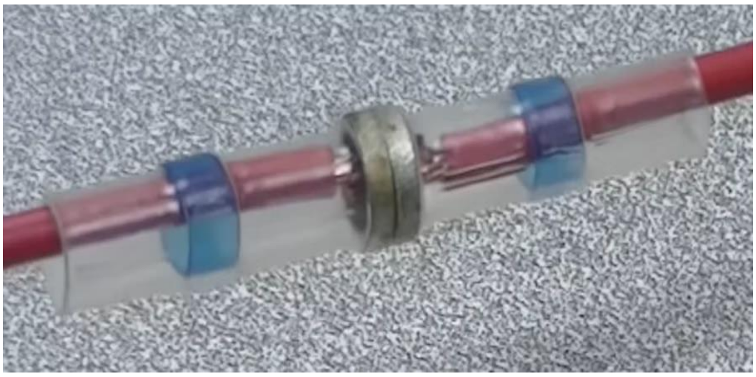
Firstly, take a good look at the solder joint – a proper connection will be shiny and smooth, as opposed to a grotesque blob of solder on two wires. We want shiny and smooth, not lumpy and grey:

On top of that, the solder joint should be solid - give it a good tug! If it pulls apart, that could be a weak point in your project – best to find that out before putting everything else into place.

For best soldering results when splicing wires, follow these guidelines:

1. Twist the wire securely – test with a tug.
2. Apply flux to the twisted pair. This helps with proper heat distribution and ensures smooth flow of solder.
3. Tin your iron with a little bit of solder, so it has a shiny coating.
4. Heat the twisted pair from below and apply solder from above. Let the solder melt and flow down through the wires. This will help to avoid globules of solder and make connection throughout.

3. Heat Shrink Butt Connector



Combining the reliability of a solder joint with the ease of use of twist and tape, the heat shrink butt connector is an easy and clean way of splicing wires together. While a soldering iron is not required, you do still need a heat source of some sort. According to the manufacturers of these connectors, a heat gun is the way to go.

To use these connectors, simply slip the tube onto one end of your splice, twist the wires together, and position the connector over the twisted pair. Once sufficient heat is applied, the solder joint will melt, combining the wires. Simultaneously, the heat shrink wrapper will contract, providing a tidy and contained solder solution.

The main downside of these connectors is cost – not only do you need a dedicated heat gun, but the connectors themselves cost far more than the equivalent solder and heat shrink that they consist of. Still, it is a quick and clean solution

4. Crimp Butt Connector

For something with the strength of solder but none of the heat, a crimped connection is the way to go. Requiring only a crimping tool and the proper connectors, crimping provides a super solid splice with minimal cost of entry.

In essence, crimping squishes the wires together into a connection piece; the intense pressure and friction delivered by the crimping tool provides a gas-tight connection, which helps to prevent corrosion of the wires. Crimped connections are extremely mechanically strong, and very resistant to mechanical stresses, making them an ideal splice for a project that will be on the move, or out in the weather.

The downside to such a mechanically strong connection is that they are non-reversible. Unlike a solder joint, which could be melted and redone if need be, a crimped connection is one and done.

6. Wire/cable labelling and termination techniques

What is a cable marker ?

Simply put, cable markers are symbols or labels used to identify cables, wires, bundles, and conduits. They carry a variety of important details, including conductor colour value, date installed, type of cable, voltage rating, and parent/child device combination. In addition, cable markers can also provide crucial contact information for the owner, making it easy to get in touch if there are any questions or concerns.

Cable markers are available in a large variety of designs, colours, and sizes to suit any need. Common types of cable markers include dot matrix ribbons, dot matrix labels, laser sheets, laser labels, pre-printed tape markers, and self-laminating labels. They can also be constructed from different materials depending on the application, including nylon, metalized polyester, plain polyester, cloth, vinyl, or steel.

Why do cables need to be labelled?

Some of the advantages of labelling cables include:

- **Keeping track of different cables:** Proper cable labelling allows for easy identification of specific cables in a fibre network or cabling system, preventing individuals from tampering with particular cables and consequently limiting the risk of downtime.
- **Eliminate guesswork, thereby saving time:** You will save time and energy trying

to identify and fix a problem when you can easily locate it. When you need to add or remove a wire from a pool of cables, it is a much simpler process when all of them are neatly labelled than having to search through an unlabelled mass of cables. This is especially important in time-sensitive situations.

- **Prevent costly mistakes:** Mislabelling or failing to label cables could result in connecting the wrong devices, which could cause expensive damage.
- **Organise your space:** A well-labelled space is a more organised space. This is not only aesthetically pleasing but can also help you find things more easily.
- **Clarity:** Cable labelling is also crucial for new employees to enable them to understand the cable/fibre network long after the cables have been installed. If a network administrator quits or personnel changes occur in an organisation, new technicians can easily get familiar with the cable network or the network system using the labelled cables. This consequently allows for simpler troubleshooting and maintenance procedures, which also saves time and costs of repairs and expansions.
- **Compliance:** Correctly labelling cables ensures audit compliance and quality assurance. In many cases, cables must be labelled according to specific standards to ensure safety and interoperability. Each industry might have its own given requirements for labelling. This can include things like the size and type of font to be used, as well as the specific information that needs to be included on the cables.
- **Easy identification:** Labelling infrastructure components also reduces the cost of ownership by allowing for comprehensive identification in dynamic management and administration systems.

Material Used in Cable Labelling and Possible Application Area

Labels are made using different materials, each with specific qualities. Common materials used in cable labelling and possible application area include:

- **Polyolefin**– Polyolefins are synthetic polymers consisting of olefinic monomers. Polyethene and polypropylene are the most common forms of polyolefins with widespread applications in different industries. Polyolefin makers are legible in wet environments, non-toxic, durable, heat-resistant and can withstand most kinds of chemical erosion. As such, they are best for use in harsh industrial environments.
- **Vinyl**– Vinyl is a broad class of polymers derived from vinyl monomers. Vinyl cable markers are flexible and provide remarkable oil and dirt resistance. They are ideal for non-flat sub-surfaces.
- **Nylon**– Nylon is a popular synthetic material with a wide range of applications ranging from apparel, consumer goods, industries and more. Nylon cable labels are perfect for curved surfaces as they are both flexible and incredibly strong. What’s more, nylon markers provide excellent resistance against chemicals and

extreme temperature ranges.

- **Steel**– Steel is a strong and durable metal that is often used in cable labelling. Steel labels can withstand harsh industrial environments, including corrosion, acids, heat, cold, chemicals, etc. They are also ideal for outdoor applications and allow for easy attachment with cable ties.
- **Paper**-Paper labels are mostly used for indoor cable labelling, and although paper labels are not as durable as some of the other options, they can still last a long time if they are used correctly. Paper labels are best for short-term use and should not be used in places where they can get wet or damaged easily, i.e. indoors. However, one of the advantages of paper labels is that they are less expensive than other options.

Points to Remember

Definition of:

a) **Wiring: Electrical wiring** refers to the system of conductors, cables, and devices used to carry electrical power from the source to various electrical devices and equipment within a building, structure, or electrical system.

b) **Electrical cable:**are a type of electrical conductor used to transmit electrical power, signals, or data from one point to another

The Components of an Electrical Cable: Electrical cables consist of various components designed to protect and transmit electrical power or signals. The specific components of an electrical cable can vary depending on the cable's type and intended use.

- **Types of wire/cables**

The three wires used to carry electricity from one place to another are:

1) Live wire (L): The live wire has an insulation that is red in color, it carries high voltage and brings in the current.
2) Neutral wire (N): The insulation of the neutral wire is black in color and provides a return path for the current to flow in. It has zero potential.
3) Earth wire (E): The insulation of the earth wire is green in color. It has no charge.

The Criteria to be considered while Selecting Cables are:

A. Cable Type
B. Voltage Rating
C. Environmental Conditions
D. Cable Length
E. Cable Size
F. Flexibility
G. Cost and Budget

Practical Activity 2.4.2: Connection of wires

Task:

1: Referring to previous activities (2.4.1) you are requested to perform the given task. The task should be done **individually**.

i. When installing an ICT lab room, the owner asked the installer to use radial circuit connection. To do perfect connection in junction boxes, the owner wishes to connect wires in this manner:

For live wire must uses soldering and heat shrink butt connector methods

For neutral wire uses crimp butt connector method

For ground wire uses twist and tape method

As installer you are asked to draw a circuit of three outlets connected in a radial circuit.

To do the connection of wires as required in the task and label the circuit-coloured wires

2: List out procedures and formulas to be used to perform the given tasks (2.4.2).

3: Referring to procedures and instructions provided on task 2, Perform the given tasks (a and b)

4: Present your work to the trainer and whole class.

5: Read key reading 2.4.2 and ask clarification where necessary Perform the task provided in application of learning 2.4

Key readings 2.4.2 Connection of wires

- **There are Steps of wire stripping:** Prepare Your Work Area, Select the Right Wire Stripper, Inspect the Wire, Determine the Stripping Length, Adjust the Wire Stripper, Position the Wire

Wire/cable labelling and termination techniques

The purpose of labels is **to facilitate the identification of electrical wires wherever this is required**

Procedures for termination of conductor or cable

Safety is very important at work. A little carelessness may result in large injuries.

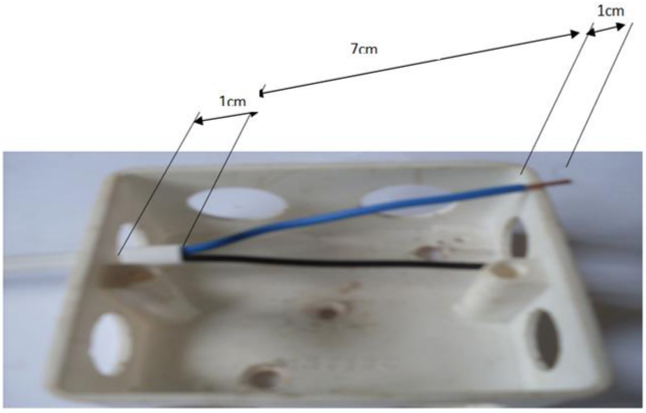
- Do not use improper tools in cable end termination process
- Do not make a wrong termination like excess or extended conductor.

Cable end termination requires considerable practice to produce a good work. In this unit, you will become familiar with termination of cable inside the square box.

- Make sure that the square box is very well fixed.
- The part of wire inside the box should equal to 8 cm
- Stripped wire for connection should be 1cm

Following the dimensions:

- Cut and remove the outer insulation
- Strip as per dimension.



Points to Remember

- **Wire/cable connection techniques**

The purpose of labels is **to facilitate the identification of electrical wires wherever this is required**

- **Techniques of cables/wires connection**

1. Twist and Tape
2. Soldering
3. Heat Shrink Butt Connector
4. Crimp Butt Connector

Application of learning 2.4.

The G company has the domestic appliances to be used in washing and ironing clothes. He wants to install sockets outlets for a washing machine and electrical iron in a given room.

As an electrician you have to provide types of wires to be used depending on size and colour code.

Also to connect the sockets outlets used to plug washing machines and electrical iron by using different methods used to connect wires.

After finishing, label the wires and sockets outlets to their designed roles.

Indicative content 2.5: Installation of Different Types of Switches

Duration: 8

Theoretical Activity 2.5.1: Description of difference types of switches

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of different types of switches.

i. Explain manual switches used in electrical installation

ii. Describe the automatic switches and detectors used in electrical installation

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 2.5.1**

Key readings 2.5.1.: Description of difference types of switches

- **Description of different types of switches**

Detector: A **detector** is an instrument which is used to discover that something is present somewhere, or to measure how much of something there is.

Sensor: A *sensor* is a device that measures physical input from its environment and converts it into data that can be interpreted by either a human or a machine.

Switch: In electrical engineering, a **switch** is an electrical component that can disconnect or connect the conducting path in an electrical circuit, interrupting the electric current or diverting it from one conductor to another.

The most familiar form of switch is a manually operated electromechanical device with one or more sets of electrical contacts, which are connected to external circuits. Each set of contacts can be in one of two states: either "closed" meaning the contacts are touching and electricity can flow between them, or "open", meaning the contacts are separated and the switch is non-conducting. The mechanism actuating the transition between these two states (open or closed) is usually (there are other types of actions) either an "*alternate action*" (flip the switch for continuous "on" or "off") or "*momentary*" (push for "on" and release for "off") type.

Contact terminology

Triple-pole single-throw (TPST or 3PST) knife switch used to short the windings of a 3-phase wind turbine for braking purposes. Here the switch is shown in the open position.

In electronics, switches are classified according to the arrangement of their contacts. A pair of contacts is said to be "*closed*" when current can flow from one to the other.

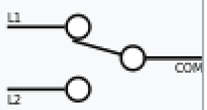
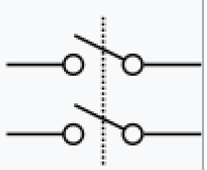
When the contacts are separated by an insulating air gap, they are said to be "*open*", and no current can flow between them at normal voltages. The terms "*make*" for closure of contacts and "*break*" for opening of contacts are also widely used.

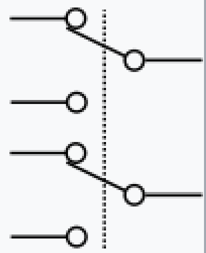
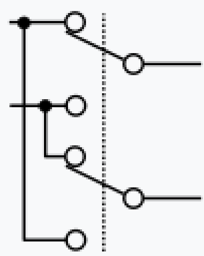
The terms **pole** and **throw** are also used to describe switch contact variations. The number of "*poles*" is the number of electrically separate switches which are controlled by a single physical actuator. For example, a "*2-pole*" switch has two separate, parallel sets of contacts that open and close in unison via the same mechanism. The number of "*throws*" is the number of separate wiring path choices other than "open" that the switch can adopt for each pole. A single-throw switch has one pair of contacts that can either be closed or open. A double-throw switch has a contact that can be connected to either of two other contacts, a triple-throw has a contact which can be connected to one of three other contacts, etc.

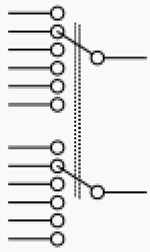
In a switch where the contacts remain in one state unless actuated, such as a push-button switch, the contacts can either be **normally open** (abbreviated "**N.O.**" or "**NO**") until closed by operation of the switch, or **normally closed** ("**N.C.**" or "**NC**") and opened by the switch action. A switch with both types of contact is called a *changeover switch* or *double-throw switch*. These may be "**make-before-break**" ("**MBB**" or shorting) which momentarily connects both circuits, or may be "**break-before-make**" ("**BBM**" or non-shorting) which interrupts one circuit before closing the other.

These terms have given rise to abbreviations for the types of switch which are used in the electronics industry such as "*single-pole, single-throw*" (SPST) (the simplest type, "on or off") or "*single-pole, double-throw*" (SPDT), connecting either of two terminals to the common terminal.

Electronics specification and abbreviation	Expansion of abbreviation	British mains wiring name	American electrical wiring name	Description	Symbol
SPST	Single pole, single throw	One-way	Two-way	A simple on-off switch: The two terminals are either connected together or disconnected from each other. An example is a light switch.	
SPST-NO Form A	Single pole, single throw,			A simple on-off switch. The two terminals are normally	

	normally open			disconnected (open) and are closed when the switch is activated. An example is a pushbutton switch.	
SPST-NC Form B	Single pole, single throw, normally closed			A simple on-off switch. The two terminals are normally connected together (closed) and are open when the switch is activated. An example is a pushbutton switch.	
SPDT Form C	Single pole, double throw	Two-way	Three-way	A simple break-before-make changeover switch: C (COM, Common) is connected either to L1 or to L2.	
SPCO SPTT, c.o.	Single pole changeover *or* single pole, centre off *or* single pole, triple throw			Similar to *SPDT*. Some suppliers use *SPCO/SPTT* for switches with a stable off position in the centre and *SPDT* for those without.	
DPST	Double pole, single throw	Double pole	Double pole	Equivalent to two *SPST* switches controlled by a single mechanism.	

DPDT	Double pole, double throw			Equivalent to two *SPDT* switches controlled by a single mechanism.	
DPCO	Double pole changeover *or* double pole, centre off			Schematically equivalent to DPDT. Some suppliers use DPCO for switches with a stable center position and *DPDT* for those without. A DPDT/DPCO switch with a center position can be "off" in the center, not connected to either L1 or L2, or "on", connected to both L1 and L2 at the same time. The positions of such switches are commonly referenced as "on-off-on" and "on-on-on" respectively.	
		Intermediate switch	Four-way switch	*DPDT* switch internally wired for polarity-reversal applications: only four rather than six wires are brought outside the switch housing.	

2P6T	Two pole, six throw			Changeover switch with a COM (Common), which can connect to L1, L2, L3, L4, L5, or L6; with a second switch (2P, two pole) controlled by a single mechanism.	

1. **Manual switches**

Manual Switch: a switch is an electrical component that can disconnect or connect the conducting path in an electrical circuit, interrupting the electric current or diverting it from one conductor to another.

SPST (Single Pole Single Throw)

An SPST switch is a basic ON and OFF switch that consists of one input contact and one output contact. This switch is commonly used in homes for lighting circuits, small load appliances, computers, and similar electronic devices. SPST switches can power a single circuit by either making (ON) or breaking (OFF) the load.

SPDT (Single Pole Double Throw)

The SPDT switch has three terminals: one is the input contact (pole) and the remaining two are output contacts (throw), hence the name Single Pole Double Throw. Also commonly called a selector switch, the SPDT consists of two ON positions and one OFF position and can supply current or signal to two loops. So the switch is used as a changeover to connect the input between two choices of outputs in most circuits.

DPST (Double Pole Single Throw)

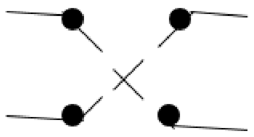
The DPST is basically like two SPSTs in one that can operate simultaneously and is controlled by a single lever. A DPST switch consists of four terminals: two input contacts and two output contacts. Also, the output contacts may be either normally open or normally closed configurations. A DPST switch is commonly used for controlling two different circuits at a time.

DPDT (Double Pole Double Throw)

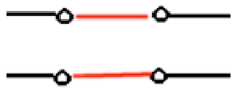
The DPDT is like two separate SPDT configurations operating at the same time. It’s basically a dual ON/OFF switch consisting of two ON positions. The DPDT switch consists of six terminals: two input terminals (poles) with two terminals for each pole for a total of four output terminals (throw). When operating a DPDT switch, the two input contacts are connected to one set of output contacts in one position, then connected to the other set of output contacts in another position.

INTERMEDIATE SWITCH CIRCUITS

An intermediate switch is used in conjunction with two way switches in order to provide control of a lamp or lamps from three or more positions.
It is installed in long corridors with several doors and long halls.



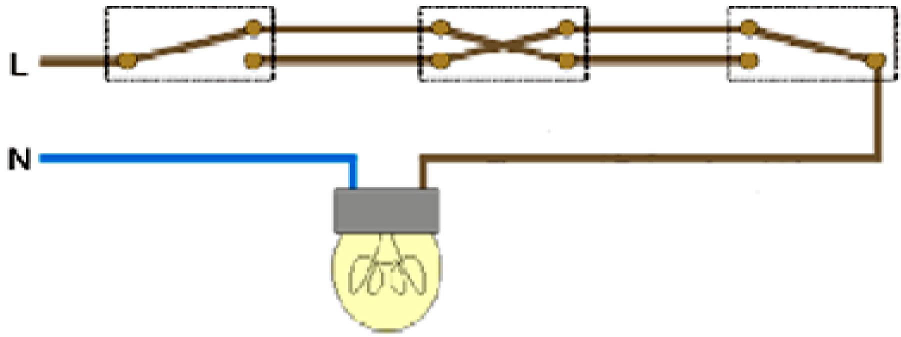
1^{st}



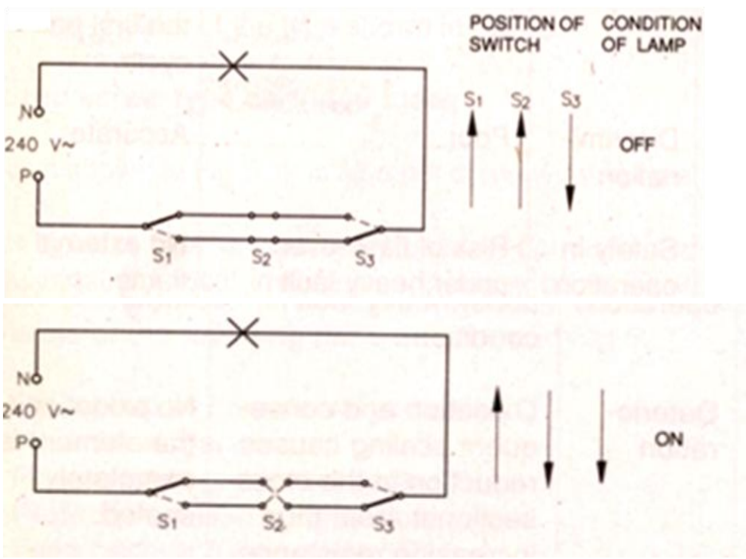
2^{nd}

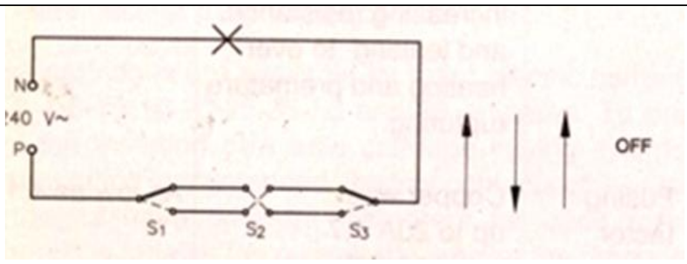
An intermediate switch has two positions:

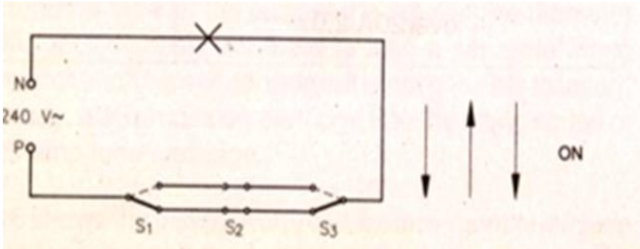
- In the **first position**, the contacts are connected straight through as shown in the figure above and therefore the switch has no effect.
- In **position two**, the switch cross connects the contacts on the left with the contacts on the right, in an "X" connection as shown in the figure below.



If more than three switching locations are required, it is simply necessary to add in extra intermediate type at these locations.
The circuit made must illustrate the following four possible states:







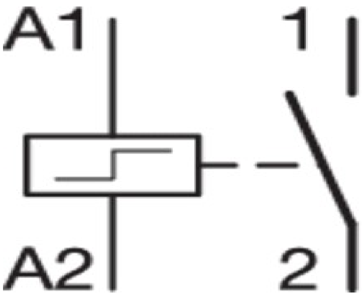
2. AUTOMATIC SWITCHES AND DETECTORS

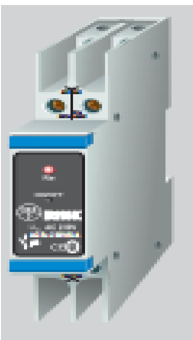
IMPULSE (MEMORY)SWITCH

Impulse switch is a form of latching relay that transfers the contacts with each pulse. Many impulse relays are made up of a magnetic latch relay and a solid state steering circuit that, upon application of power, determines which position the relay is in and energises the opposite coil. The contacts transfer and hold that position when power is removed. When reenergized, the contacts transfer again and hold that position, and so on. In order to

transfer the contacts, one simply provides a single unidirectional pulse. There is no need to redirect the control pulse or reverse the polarity.

This type of switch is applicable for switching of electric circuits up to 16 A by an impulse command. It has the ability to control the lighting circuits from more places in a corridor, on stairs, in the whole house.





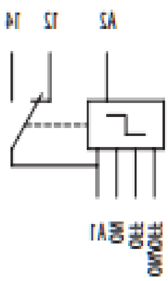


Image of impulse switch **Circuit diagram**

The advantages of using impulse switch over the combination of intermediate switches and two ways switches:

1. It saves crossbar switches
2. The lighting can be controlled by push-buttons instead of a combination of crossbar and three-way switches.
3. It saves conductors
4. It is possible to use smaller cross-sections for the control circuit than for power circuit
5. It brings higher comfort of control; for example it is possible to switch off all lights when leaving the house „
6. The position of the brake-make contact can only be changed by an impulse applied to the following inputs (supply voltage failures have no effect)

TIMER SWITCH

An electric switch that can be set to operate an appliance such as a light or an oven at a particular time is called a **timer switch.**

In any situation where lighting is required for certain hours of the day or week a basic time switch will provide this control. Time switches are available as 24 Hour or 7 Day models.

Analogue and **Digita**l versions are readily available.

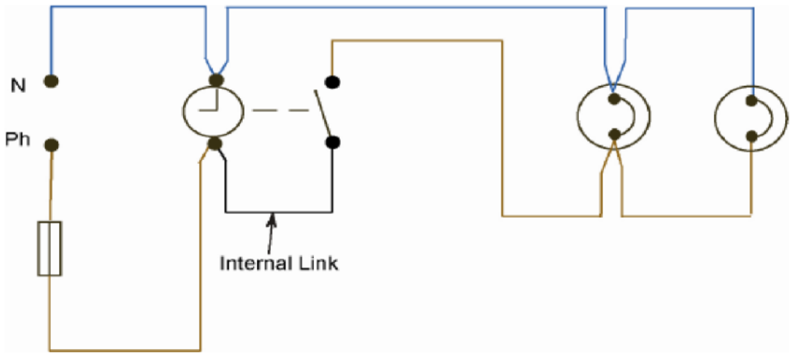
Analogue time switch

Digital time switch

An analogue time switch consists of a suitably rated electrical switch operated by a cam. The movement of this cam is provided by a train of gears driven by a small electric motor. The timing is accurate as the motor speed is governed by the frequency of the supply. The dial on a 24 Hour version rotates once every 24 Hours. The dial on a 7 Day version rotates once every 7 days.

A 24 Hour model will provide the same operation every day. A 7 Day model will provide the same operation every week, allowing for different switching times each day of the week. Some allow for only two "on" / "off" operations per day / week while others allow for much more.

They are often used to provide outside lighting for houses, shops, factories etc. Check the manufacturer's instructions on setting the time switch. Time switches are great for indoor or outdoor lighting, small outdoor pond pumps, swimming pool pumps, and other devices that need to be turned on and off throughout the day.



It may be labeled in different ways. It is however a simple two way switch with an "OFF" position. It allows for the time switch load to be **permanently off**, **permanently on** or **timed**. An indicator light is another useful feature as it gives clear indication that the supply is on the load. It is connected across the outgoing supply from the time switch.

Note. Remember that any load supplied via a time switch may be powered up unexpectedly.

Typical Specifications

Voltage Rating 230 Volts AC 50Hz.
Current Rating 16 Amps Resistive
4 Amps Inductive
Switching Operations 24 Hour 48 on / off
7 Day 96 on / off
Min. Switching Period 24 Hour 30 Minutes 7 Day 105 Minutes

PHOTO-ELECTRIC SWITCH

A photo-electric switch controls outdoor lighting on and off automatically. It consists of a light-sensitive element that registers the brilliance of the ambient light. A switch is activated when daily light reaches the pre-set level. Brief changes in light caused by clouds, car lights, lighting etc will not activate the switch, since there is built-in time delay. Day/night switches have the advantage over time switches in that they react to the light level, not the time. This means that day/night switches always switch on the lighting when it is needed, and at the same lux level, regardless of whether it is winter or summer.

High sensitivity photo-electric switch

Proximity switch

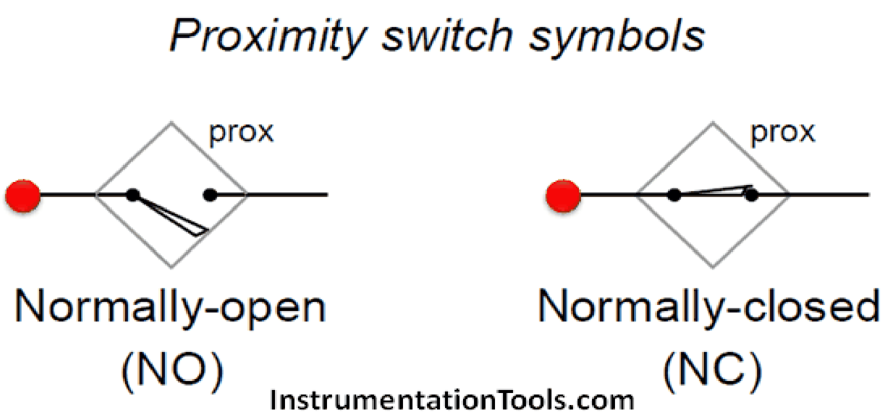
A proximity switch is one detecting the proximity (closeness) of some object. By definition, these switches are non-contact sensors, using magnetic, electric, or optical means to sense the proximity of objects.

A proximity switch will be in its "normal" status when it is distant from any detectable object.

Being non-contact in nature, proximity switches are often used instead of direct-contact limit switches for the same purpose of detecting the position of a machine part, with the advantage of never wearing out over time due to repeated physical contact.

Most proximity switches are active in design. That is, they incorporate a powered electronic circuit to sense the proximity of an object. Inductive proximity switches sense the presence of metallic objects through the use of a high-frequency magnetic field. Capacitive proximity switches sense the presence of non-metallic objects through the use of a high-frequency electric field. Optical proximity switches detect the interruption of a light beam by an object. Ultrasonic proximity switches sense the presence of dense matter by the reflection of sound waves.

The schematic diagram symbol for a proximity switch with mechanical contacts is the same as for a mechanical limit switch, except the switch symbol is enclosed by a diamond shape, indicating a powered (active) device:



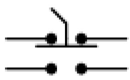
AC CAPACITIVE proximity switch

A basic proximity sensor is used to sense the presence of objects or materials. What differentiates them from other sensors is that they don't make physical contact with the object being sensed, and hence they're also known as non-contact sensors. One of the most common sensor types is the capacitive proximity sensor. As the name suggests, capacitive proximity sensors operate by noting a change in the capacitance read by the sensor. A typical capacitor consists of two conductive elements (sometimes called plates) separated by some kind of insulating material that can be one of many different types including ceramic, plastic, paper, or other materials.

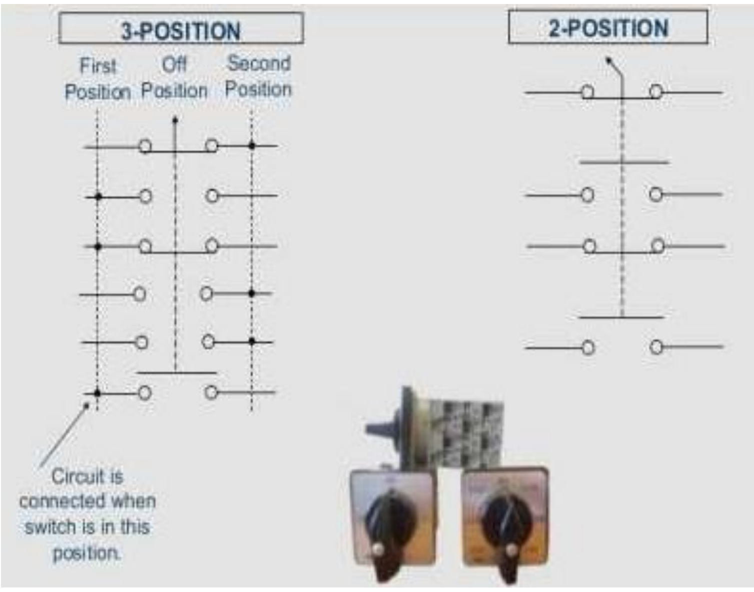
AC INDUCTIVE proximity switch

Inductive proximity sensors detect the presence of metallic objects. Their operating principle is based on a coil and high frequency oscillator that creates a field in the close surroundings of the sensing surface. The presence of metal in the operating area causes a change in the oscillation amplitude. This change is identified by a threshold circuit, which changes the output of the sensor. The operating distance of the sensor depends on the coil's size as well as the target's shape, size and material

Selector switch



Selector switches are actuated with a rotary knob or lever of some sort to select one of two or more positions. Like the toggle switch, selector switches can either rest in any of their positions or contain spring-return mechanisms for momentary operation.



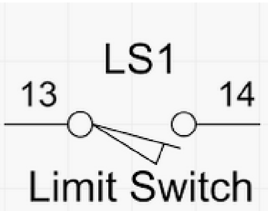
LIMIT SWITCH

A limit switch is an electromechanical device operated by a physical force applied to it

by an object.
Limit switches are used to detect the presence or absence of an object.
These switches were originally used to define the limit of travel of an object, and as a result, they were named Limit Switch.

The limit switch then regulates the electrical circuit that controls the machine and its moving parts. These switches can be used as pilot devices for magnetic starter control circuits, allowing them to start, stop, slow down, or accelerate the functions of an electric motor.

Symbol



Application of limit switch

Limit Switch Applications. Limit switches are controlled by the motion of a mechanical part or presence of an object. Once a limit has been reached the device will operate the contacts to make or break an electrical connection. Limit switches are used in a variety of diverse applications in numerous industries.

Key Card switch

These switches control electrical circuits by simply inserting or removing the guest's access card into the device.

Key Card Switches are generally used in hotels and high end condominiums. After check-in verification in hotels, the front desk personnel will give the guest a key card to his/her assigned room. Upon getting into the assigned room and inserting the key card in a key card slot by the main door of the room, all the lights and other controlled circuits will automatically turn on. Upon leaving the room, guests remove the key card and the lights and other controlled circuits will turn off after a standby delay of a few seconds. This is to ensure that the guest/s have safely exited the room before the power turns off. Aside from the aesthetically appealing design, hospitality establishments install key card switches to help reduce energy costs. This is because all lighting, heating and power (aside from the refrigerator) circuits only become operational once the card is inserted in the key card slot.

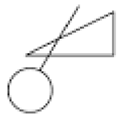
Types of key cards

There are several common **types of key cards** including barcode, magnetic stripe, smart **card**, NFC **card**, RFID **key cards** and even mechanical hole card.

Dimmer switch

A light dimmer is a kind of switch that can raise and lower the brightness of a light. Dimmer switches work with incandescent bulbs, halogen light bulbs, compact fluorescent light bulbs (CFLs) and some LED light bulbs (light-emitting diodes).

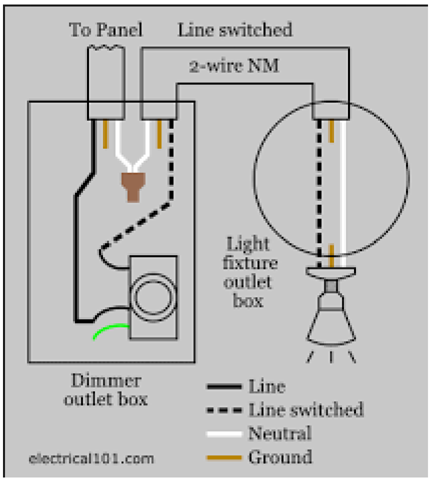
Symbol



Application

Applications for Light **Dimmer Switches**. ... An effective way to quickly change the mood of a room is by **dimming** or brightening the lights with a **dimmer switch**. A softer light results in a more comforting, relaxing atmosphere. Brighter lighting is more suitable for normal room **use** and reading.

Circuit diagram



Types of dimmer switch

1. Resistive dimmers
2.Inductive dimmers
3. Fluorescent dimmers

1. Resistive dimmers

Early **dimmer switches** had a pretty straightforward solution to adjusting **light** levels -- a variable **resistor**. ... When you put a **resistor** in a series circuit, the **resistor's** energy consumption causes a voltage drop in the circuit, decreasing the energy available to other loads (the **light** bulb, for example)

2. Inductive dimmers

Typically, the **dimmer** circuit includes an **inductor** choke, a length of wire wrapped around an iron core, and an additional interference capacitor. Both devices can temporarily store electrical charge and release it later. ... The autotransformer dims the lights by stepping down the voltage flowing to the light circuit

3. Compact Fluorescents dimmers

Compact **fluorescents** refer to a **fluorescent** lamp that has its size reduced either by being coiled or folded to produce the effect of a long tube in a small space.

DETECTORS

Detector Switches are used to "detect" internal mechanical movements and convert human manual operations to electronic signals.

Electrical smoke detector

What is a smoke detector and how does it work?

How **they work**: Ionization-type **smoke alarms** have a small amount of radioactive material (between two electrically charged plates, which ionises the air and causes current to flow between the plates. When **smoke** enters the chamber, it disrupts the flow of ions, thus reducing the flow of current and activating the **alarm**.

Ionisation: change atoms/molecules into charged molecules/atoms.

An optical smoke alarm (also called photo-electric smoke alarm) works using the light scatter principle. The alarm contains a pulsed Infra-red LED which pulses a beam of light into the sensor chamber every 10 seconds to check for smoke particles.

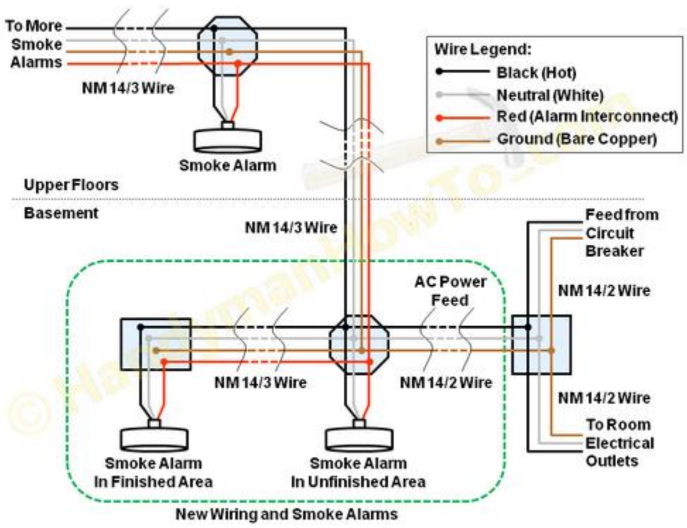
Application

Sensitive **alarms** can be used to detect, and thus deter, smoking in areas where it is banned. **Smoke detectors** in large commercial, industrial, and residential buildings are usually powered by a central **fire** alarm system, which is powered by the building power with a battery backup.

The five types of smoke detector.

- Ionisation **smoke detector**. An Ionization **smoke detector** consists of the following main components.
- Photo-**electric smoke detector**.
- Projected beam **smoke detector**.
- Aspirating **smoke detector**.
- Video **smoke detection**

Electrical diagram of smoke detector



Moisture Sensor

Working Principle of Moisture Sensor. The Soil Moisture Sensor uses capacitance to measure dielectric permittivity of the surrounding medium. ... The sensor creates a voltage proportional to the dielectric permittivity, and therefore the water content of the soil.

Function of electrical moisture sensor

Soil resistivity: Measuring how strongly the soil resists the flow of electricity between two electrodes can be used to determine the soil moisture content. Galvanic cell: The amount of water present can be determined based on the voltage the soil produces because water acts as an electrolyte and produces electricity.

Function

is used for remote sensing in hydrology and agriculture. Portable probe instruments can be used by farmers or gardeners.

Electrical temperature sensor

Working principle of temperature sensor

A simple temperature sensor is a device, to measure the temperature through an electrical signal it requires a thermocouple or RTD (Resistance Temperature Detectors). The thermocouple is prepared by two dissimilar metals which generate the electrical voltage indirectly proportional to change the temperature.

Function

A simple temperature sensor is a device, to measure the temperature through an electrical signal it requires a thermocouple or RTD (Resistance Temperature Detectors). The thermocouple is prepared by two dissimilar metals which generate the electrical voltage indirectly proportional to change the temperature

Application

In industrial automation, the Temperature Sensor is used to measure the temperature. The temperature sensor uses the converter to convert the temperature value to an electrical value.

Practical Activity 2.5.2: Installation of different types of switches

Task:

1: Referring to previous activities **(2.1.1, 2.1.2 and 2.5.1)** you are requested to perform the given task. The task should be done **individually**.

i. As an electrician you are asked to Control a lamp in three locations using two ways and an intermediate switch. Also Control a lamp in three locations by using impulse switch and push buttons. Set a timer switch so that a lamp can be on from 7pm up to 5am and after sensing movement of someone it activates a dimmer switch to vary the light of the lamp.

Refer to **Practical Activity 2.1.2,** You are asked to install the given circuit circuits

2. Draw the electrical circuit diagram to be used to perform the given tasks (1.5.2).

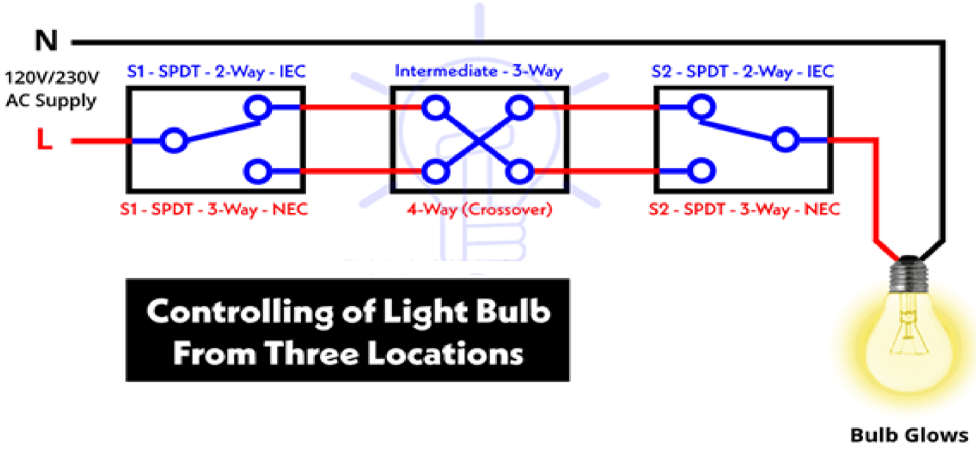
3: Referring to the previous task2, Perform the given tasks

4: Present your work to the trainer and whole class.

5: Read key reading **2.5.2** and ask clarification where necessary Perform the task provided in application of learning **2.5**

Key readings 2.5.2 Installation of different types of switches

A. Controlling a Lamp from Three Locations Using Two-Way Switches and an Intermediate Switch



This setup uses two-way (SPDT) switches and an intermediate switch (also known as a crossover switch) to control a single lamp from three locations. It's common in staircases or large rooms with multiple entrances.

Components Needed:

- Two **SPDT (Single Pole Double Throw) switches** (two-way switches).
- One **Intermediate (crossover) switch**.
- A **lamp** (load).
- Appropriate **wiring**.

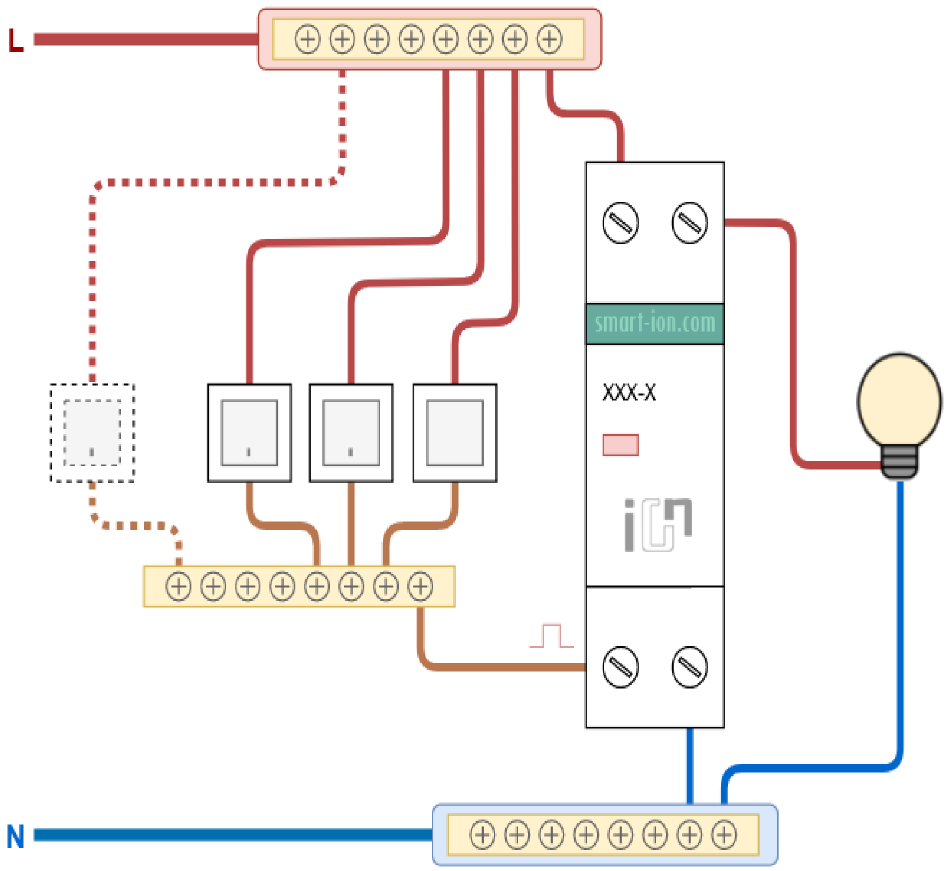
Step-by-Step Installation:

1. **Power Off**: Ensure the power is off before beginning the installation.
2. **Identify Switches**:
   - The two SPDT switches will be installed at the first and last positions.
   - The intermediate switch will be installed between them.
3. **Wiring the SPDT Switches**:
   - Connect the **line (live)** wire from the power source to the **common terminal** of the first SPDT switch.
   - The **common terminal** of the second SPDT switch will be connected to the lamp's live terminal.
4. **Wiring the Intermediate Switch**:

- Connect the two traveler wires from the first SPDT switch to two terminals of the intermediate switch.
- Connect the other two terminals of the intermediate switch to the traveler terminals of the second SPDT switch.

5. **Complete the Circuit**:
6. Connect the neutral wire from the power source directly to the neutral terminal of the lamp.
7. Ground all components for safety.
8. **Test**: After wiring, restore power and test the switches. You should be able to turn the lamp on or off from any of the three locations.

B. Controlling a Lamp in Three Locations Using an Impulse Relay and Push Buttons



Impulse relays allow control of a lamp from multiple locations using push buttons instead of standard toggle switches. Every time a push button is pressed, the state of the relay changes (ON/OFF).

Components Needed:

C. An **Impulse relay**.
D. Three **push buttons**.
E. A **lamp**.
F. Appropriate **wiring**.

Step-by-Step Installation:

G. **Power Off**: Ensure the power is off before beginning the installation.

H. **Install the Impulse Relay**:

  a. Mount the impulse relay inside the electrical distribution board (or another appropriate enclosure).

  b. Connect the **live wire** from the power source to the **input terminal** of the relay.

I. **Wiring the Push Buttons**:

J. Wire the three push buttons in parallel.

K. Connect the parallel output of the push buttons to the **trigger terminal** of the impulse relay.

L. **Connecting the Lamp**:

  a. Connect the **output terminal** of the impulse relay to the **live terminal** of the lamp.

  b. Connect the **neutral wire** of the lamp directly to the neutral terminal of the power supply.

M. **Grounding**: Ensure the relay and push buttons are grounded properly.

N. **Test**: Once the wiring is complete, turn on the power and test each push button. Each press should toggle the lamp between ON and OFF.

C. Setting a Timer Switch to Control a Lamp from 7 PM to 5 AM, and Activating a Dimmer with Motion Detection

This task requires a timer switch for automatic control based on time and a motion sensor to trigger a dimmer for variable lighting when someone is detected.

Components Needed:

- A **timer switch**.
- A **motion sensor**.
- A **dimmer switch**.
- A **lamp**.
- Appropriate **wiring**.

Step-by-Step Installation:

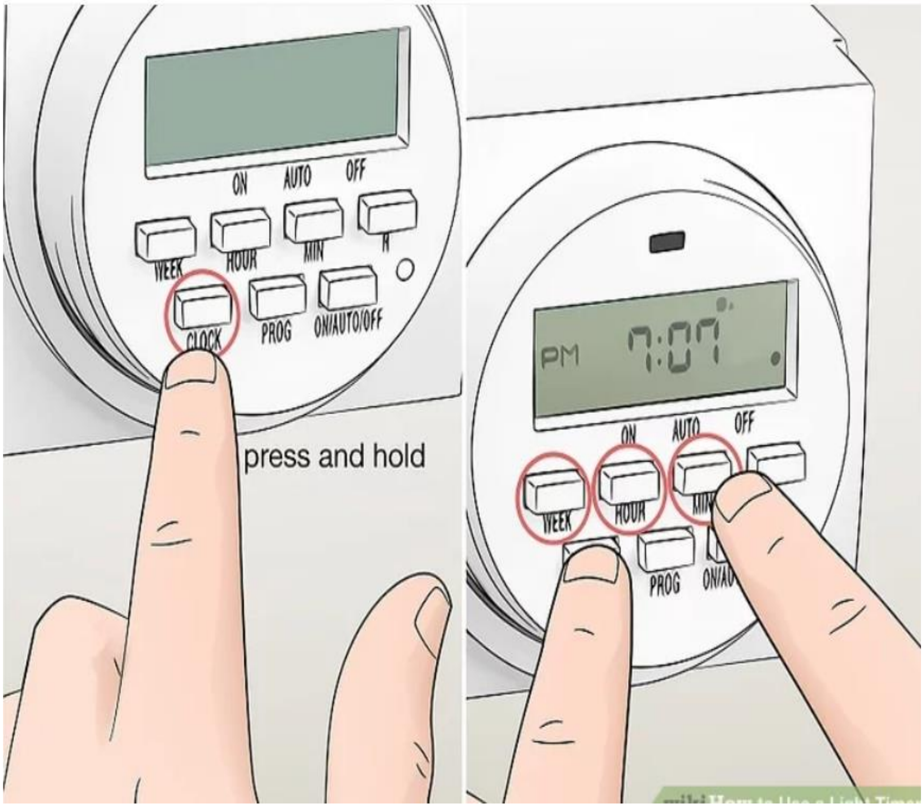
1. **Power Off**: Before installing, ensure the power is off.
2. **Install the Timer Switch**:
   - Mount the timer switch in a convenient location.
   - Wire the **live terminal** from the power source to the input of the timer switch.
   - Set the timer switch to turn ON the lamp at **7 PM** and OFF at **5 AM**.

   Step to set up timer:

a) **Set the day and time by holding down "CLOCK" and using the timer's buttons.** Digital light timers are usually square or rectangular and have 6-8 labelled buttons and a digital display on the front. Press and hold the button labelled “CLOCK,” then press the “HOUR,” “MIN,” and “WEEK” buttons to change the current day and time on the digital display. Release the “clock” button when you are finished.

The exact buttons and process for changing the settings on your digital light timer may vary depending on the make and model. Check the owner’s manual for your specific timer if it has different buttons than the ones listed in these instructions.

The majority of digital light timers work similarly and have the same kinds of buttons, though the buttons might be labelled differently. Refer to the instructions for your specific model if it looks different.[2]



b) **Press the “PROG” button and use the timer’s buttons to set a turn-on time.** Hit “PROG” once and press the “HOUR” and “MIN” buttons to set the time at which you want your light to turn on. Press the “WEEK” button to choose which day or days of the week you want the light to turn on at the designated time.

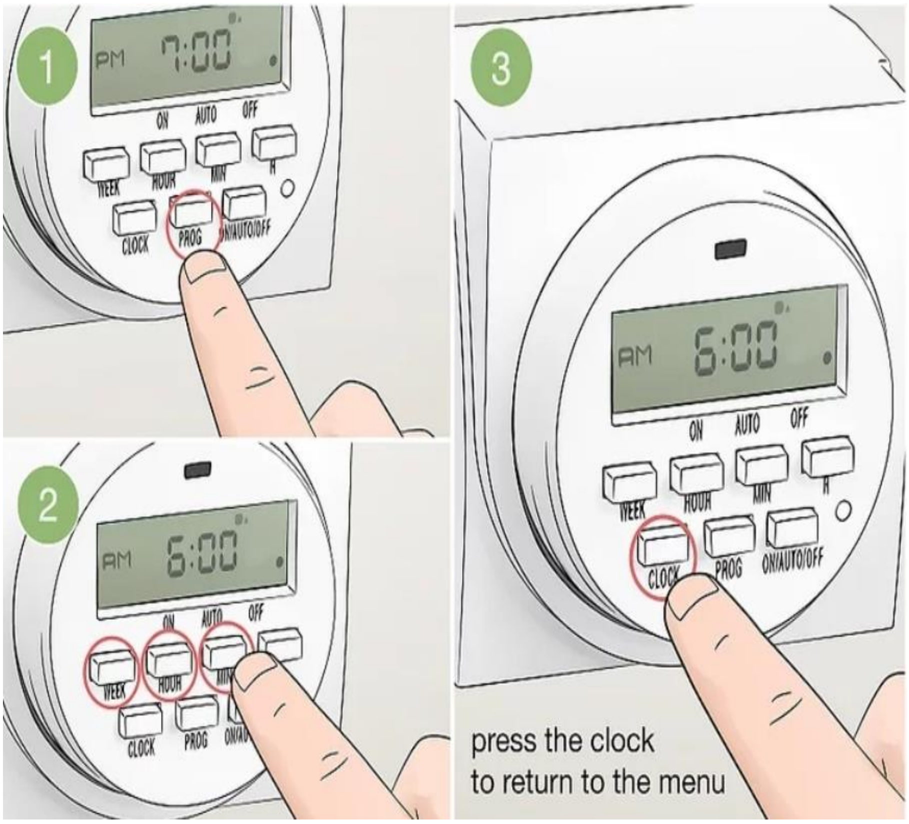
You can keep pressing the “WEEK” button to schedule the on and off times for different combinations of days, which are displayed at the top of the screen. For example, you could set the timer to turn your light on and off every day of the week, one specific day of the week, Monday through Friday, or only on the weekends.

c)

Press “PROG” again and use the timer’s buttons to set a turn-off time. Set the turn-off time using the “HOUR” and “MIN” buttons and choose the day or days of the week with the “WEEK” button. Click the “CLOCK” button when you’re done to return to the main display.

For example, if you set the light to turn on at 9:00 PM on Friday and Saturday nights, you could schedule it to turn off at 6:00 AM on Saturday and Sunday mornings.

Tip: Digital light timers typically let you program more than 1 set of on/off times. You can keep pressing “PROG” to cycle through the different programmed schedules. That way, you can make the light turn on and off at different times on different days of the week or at multiple times throughout the same day.



d)

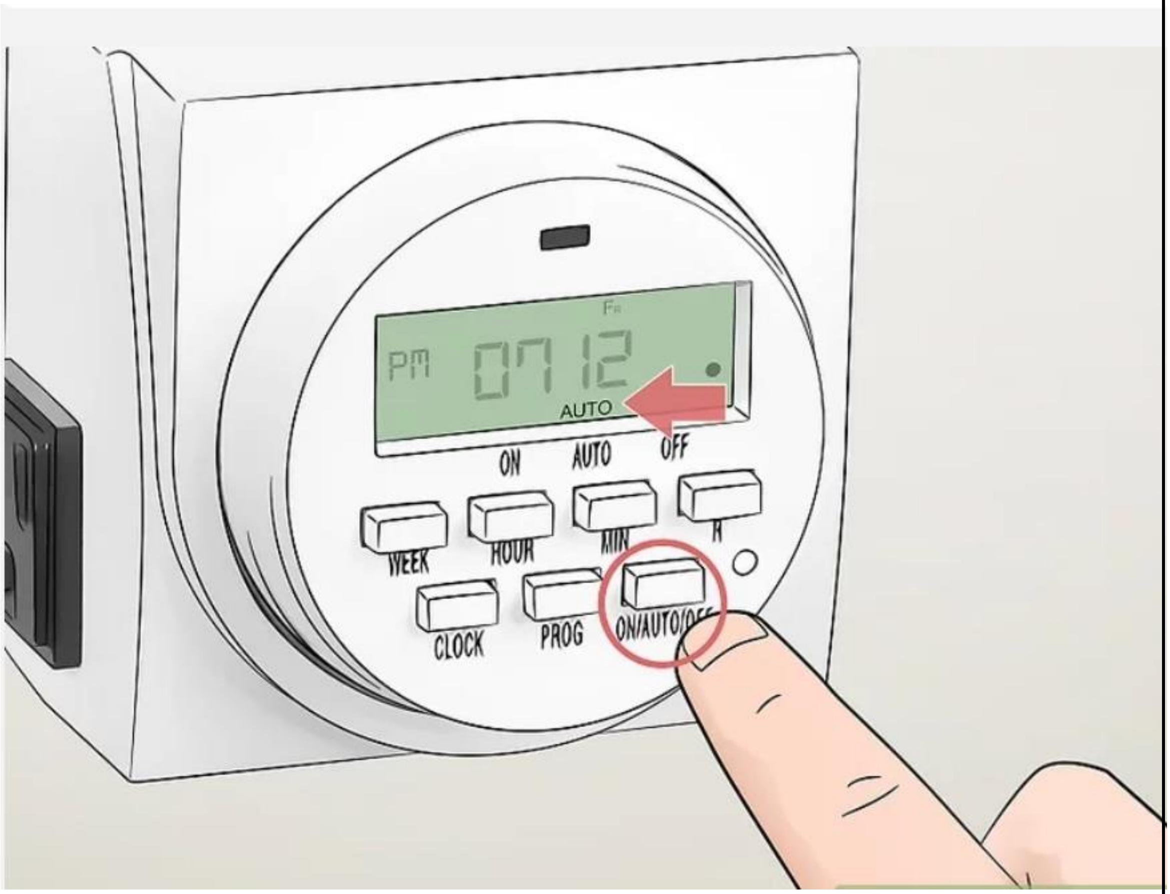
Clear any programmed schedule by holding down the "R" button. Press "PROG" until you get to the timer schedule that you want to clear. Click and hold the "R" button until the display screen goes blank to start over on that programmed schedule.

There is also usually an inset circular button just below the "R" button that you can press and hold with a skinny object, such as a paper clip, to reset the whole timer to factory settings.

e)

Click the "ON/AUTO/OFF" button until the display shows "AUTO." The display will show that the timer is "OFF" by default, which means that no power will be supplied through the timer's outlets to your light. Press the "ON/AUTO/OFF" button until the display shows "AUTO," which means that the timer will switch your light on and off as scheduled.

- The "ON" setting will make it so the timer supplies constant power through it's outlets, meaning that you can turn lights plugged into it on and off as normal and the timer won't turn them on and off according to the scheduled times.



3. **Connect the Timer to the Lamp**:

- Wire the output of the timer switch to the **live terminal** of the lamp. This controls when the lamp is powered based on the timer settings.
- The neutral wire from the power source goes directly to the lamp's neutral terminal.

4. **Install the Motion Sensor**:

- Mount the motion sensor in a suitable location where it can detect movement.
- Wire the motion sensor so that it powers the **dimmer switch** when movement is detected.
- The **live wire** should be connected to the motion sensor's input, and the output should go to the dimmer's input.

5. **Connect the Dimmer Switch**:

- The dimmer switch is connected between the motion sensor's output and the lamp.
- This allows the dimmer to control the lamp's brightness once the motion sensor is triggered.
- Ensure the dimmer is set to adjust the brightness as needed.

6. **Test the Timer and Motion Sensor**:

- Set the timer for 7 PM to 5 AM.

Test the motion sensor by walking into its detection range after 7 PM to see if the dimmer is triggered to adjust the lamp's brightness.

Points to Remember

- ➔ **Manual Switch: a switch** is an electrical component that can disconnect or connect the conducting path in an electrical circuit, interrupting the electric current or diverting it from one conductor to another.
- ➔ **Sensor:** A *sensor* is a device that measures physical input from its environment and converts it into data that can be interpreted by either a human or a machine
- ➔ **Detector:** A **detector** is an instrument which is used to discover that something is present somewhere, or to measure how much of something there is.

- **The examples of manual switches are:**
    1. SPST (Single Pole Single Throw)
    2. SPDT (Single Pole Double Throw)
    3. DPST (Double Pole Single Throw)
    4. DPDT (Double Pole Double Throw)
- **Automatic switches are:**

1. Impulse (memory)switch

Impulse switch is a form of latching relay that transfers the contacts with each pulse.

2. Timer switch

An electric switch that can be set to operate an appliance such as a light or an oven at a particular time is called a timer **switch.**

3. Photo-electric switch

A photo-electric switch controls outdoor lighting on and off automatically.

4. Proximity switch

A basic proximity sensor is used to sense the presence of objects or materials. A proximity switch is one detecting the proximity (closeness) of some object.

5. Selector switch

Selector switches are actuated with a rotary knob or lever of some sort to select one of two or more positions.

6. A limit switch

A limit switch is an electromechanical device operated by a physical force applied to it by an object.

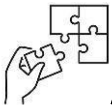
7. Dimmer switch

A light dimmer is a kind of switch that can raise and lower the brightness of a light.

8. Key Card switch

These switches control electrical circuits by simply inserting or removing the guest's access card into the device.

- ➔ The switch can be operated manually or automatically.
- ➔ The different switches can be combined together to perform a given task
- ➔ The sensors are used as automatic switches after the detection of the quantity to be sensed.



Application of learning 2.5

The school of KZX wants to install different switches in this manner to secure and control the working schedule as the follow:

- Lighting system of two lamps controlled in three locations
- Gate lighting controlled by timer switch from 6pm to 6am
- Motion sensor around ICT lab activated at 10pm to 5 am
- Impulse switch with dimmer switch to control lamp in projector room

As an electrician, draw the required circuits and install the given situation on the boards.

Indicative content 2.6: Installation of different types of power socket outlets

Duration: 4

Theoretical Activity 2.6.1: Description of difference types of power socket outlets

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of different types of power sockets outlets.

i. **What do you understand by an electrical power socket?**

ii. **State the types of power socket**.

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 2.6.1.**

5: In addition, ask questions where necessary.

Key readings 2.6.1.: Description of difference types of power socket outlets

- **Power Socket outlet**

Introduction

Electrical power outlets (also known as outlets, electrical sockets, plugs, and wall plugs) allow electrical equipment to connect to the electrical grid. The electrical grid provides alternating current to the outlet. There are two primary types of outlets: domestic and industrial.

Electrical socket outlet is a device that allows electrical appliances to connect to the electrical grid and receive electricity. It consists of two or more metal contacts that are housed in a protective casing. When an appliance plug is inserted into the socket, the metal contacts connect with the corresponding contacts on the plug, completing the electrical circuit and allowing electricity to flow to the appliance.

If not all electrical outlets in your home look the same, it’s because there are many different types of electrical outlets. Each type has unique characteristics and features. What works for the bedroom may not be the best for your bathroom counters and vice versa.

Types of Electrical Outlets

1. 15A, 120 Volt Outlets

These are the most common in older homes and come in two versions:

- Two-pronged outlets feature two long connection slots and provide an ungrounded connection.
- The three-pronged version adds a ground pin and an extra vertical slot to help prevent electric shock from loose wiring.

These are also the cheapest types of electrical outlets on the market and easy to install or replace. At the same time, these can also be prime candidates for an upgrade in the near future. For improved safety and efficiency, it can be a prudent idea to choose more modern alternatives on this list.

2. 20A, 125 Volt Outlets

These electrical outlets support a larger power draw than the previous type. Building codes recommend installing 20A outlets for some appliances, such as large kitchen gadgets, that need more power to function. You can tell these apart from the 15A version by looking for a small horizontal slot alongside the vertical ground slot. These may even be a perfect fit for some washing machines, dishwashers, and space heaters.

Best for: Larger appliances that require more power.

3. 20A, 250 Volt Outlets

Large appliances like air conditioners, air compressors, and hobby shop equipment need even higher levels of power. For such uses, this is the type of electrical outlet to choose. Before installing these 20A, 250-volt outlets, you will need the proper circuit in place. 250-volt outlets need a double-pole circuit breaker installed in your main panel, a job best left to an electrician. Look at the power specifications of the appliance that you plan to use and choose accordingly. Some appliances such as wall ovens and electric dryers might need even more power than these outlets can provide. For these types of cases, you might want to take a look at 30A or 50A outlets.

Best for: Large appliances with very high power draw and hobby shop equipment.

4. Tamper-Resistant Receptacles

Building codes in most places have now made it mandatory to use tamper-resistant outlets in new construction. These types of electrical outlets utilise a built-in physical barrier to prevent the entry of foreign objects. The internal shutters open only when you insert a two-pronged or grounded plug. If you have children at home, this can be a safe choice. Even if children try tampering with these outlets by putting something other than a plug in, there is no shock hazard.

Best for: Safe use at homes with children.

5. GFCI Outlets

Ground Fault Circuit Interrupter (GFCI) outlets are best suited for places close to water. Indoors, this includes spaces like bathrooms, kitchens, basements, crawlspaces, and laundry areas. You can also use GFCI outlets outdoors.

These outlets constantly track the current flow and trip (or cut off power) upon sensing a spike or leap in the current. The interrupter circuit immediately kicks in the moment it detects a dangerous power surge. For outlets near water, a power surge may indicate direct contact with water and the consequent electric shock hazard, like, for example, if you accidentally drop a live hair dryer into your bathtub when it’s full of water. You can easily identify them by looking for “TEST” and “RESET” buttons in

different colors on the façade.
Best for: Preventing electrical hazards in areas close to water.

6. AFCI Outlets

Some electrical faults create heat through arcing. Arcing happens in loose contact points in your electrical system where the electricity jumps between connections. The telltale signs are usually sparks or a buzzing sound. This can create an extraordinary amount of heat. Overheating appliances, hammering a nail through a wire by accident, or rodents chewing on wires can all trigger this risk. When arcing occurs, the Arc Fault Circuit Interrupter (AFCI) outlets detect it, and the integrated breaker deactivates the outlet. You can install these in bedrooms and other sleeping areas through a special circuit breaker in your main panel. This is an important safety precaution for areas in your home where you might not always be awake and fully alert. This is also an exceptional option for kitchens and laundry areas.
Best for: Preventing electrical hazards in bedrooms and other sleeping areas, kitchens, and laundry areas.

7. Switched Outlets

If there are appliances or lights you want to keep plugged in all the time even when they aren't running, consider switched outlets. The unit integrates a socket and a connected switch. Use the switch to control the power to a connected appliance without removing the plug from the outlet. (You do not need a fresh electrical box or any extra wiring to install these.)
Best for: Appliances or lights that you want to keep plugged in always.

8. USB Outlets

Devices that charge via USB are common in households today. If you have found yourself frustrated looking for free USB ports or charging bricks, USB wall outlets may be the solution. These give you one or more USB sockets directly on your wall, often sharing a plate with other two- or three-pronged outlets. Just plug in your cables directly into the wall to recharge your smartphone, tablet, or other USB device.
Best for: Powering devices that charge via USB.

9. Smart Outlets

Modern, innovative smart outlets feature built-in mechanisms for monitoring power usage. They can also switch on or off following a program or schedule. For things you want to run on a set schedule, like lawn sprinklers or drip coffee makers, smart outlets can be great. They can also prevent power leakage and help make your home more energy-efficient.
Many smart outlets also feature remote control using Wi-Fi, Zigbee, or Z Wave protocols. You can operate and track these remotely with your phone or through voice assistants. Hands-free operation is also possible through Google Home and Amazon Echo smart speakers.
Best for: Energy-efficient homes and people who want to implement home

automation.

Practical Activity 2.6.2: Installation of different types of switches

Task:

1: Referring to previous activity (2.6.1) you are requested to perform the given task. The task should be done individually.

i. Install the ring circuits of four power socket outlets

ii. Install the radial circuit of five power sockets outlets

2: Draw electrical diagram to be used to perform the given tasks (2.6.2).

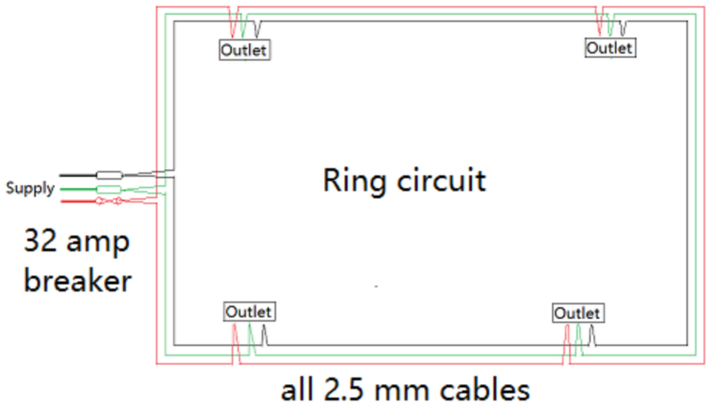
3: Referring to drawing provided from task 2, Perform the given task.

4: Present your work to the trainer and whole class.

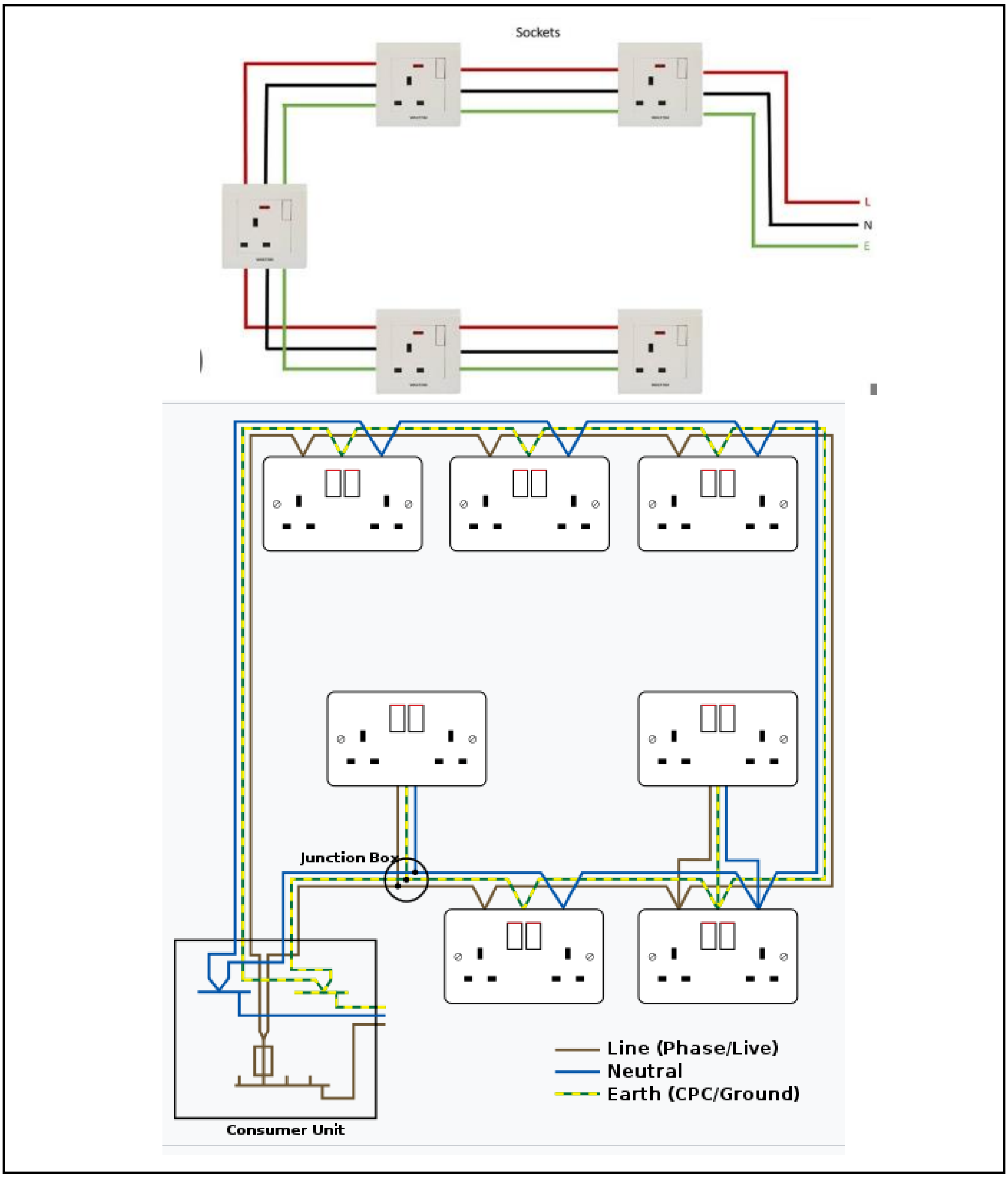
5: Read key reading **2.6.2** and ask clarification where necessary Perform the task provided in application of learning **2.6**

Key readings 2.6.2: Installation of different types of switches

Ring circuits of four power socket outlets:



Radial circuit of five power sockets outlets:



Points to Remember

- **Electrical outlets** allow electrical equipment to connect to the electrical grid. The electrical grid provides alternating current to the outlet.
- **Types of Electrical Outlet are,** 15A, k8 120 Volt Outlets, 20A, 125 Volt Outlets, 20A, 250 Volt Outlets, Tamper-Resistant Receptacles, GFCI Outlets, Switched Outlets, USB Outlets, Smart Outlets.
- There are two types of installation of socket outlets:
  - ✓ Ring circuit installation
  - ✓ Radial circuit installation

Application of learning 2.6

Mr Emmanuel wants to start a business of charging phones. Now he wants to install a system of seven power socket outlets using ring circuit that will help him in that activity. As an installer you are required to draw the circuit and install it.

Indicative content 2.7: Installation of Different electrical lighting circuit

Duration: 8

Theoretical Activity 2.7.1: Description of different electrical lighting circuit

1: In small groups, you are requested to answer the following questions related to the description of different electrical lighting circuit.

- **i. Define**
  - **i. Lighting circuit**
  - **ii. Electric lighting**
- **ii. List out the types of lighting circuit**

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key readings **2.7.1**.

5: In addition, ask questions where necessary.

Key readings 2.7.1.: Description of different electrical lighting circuit

Lighting circuit: wiring that provides power to electric lights.

Electrical lighting: An electric light is a light produced by the use of electricity. Electric light sources may be of the incandescent, fluorescent, gas discharge,

What is the use of a lighting circuit?

The lighting circuit is used for running low power rating devices like bulbs, tube lights, tv etc which draws small current.

What size wire is used for lighting?

2.5mm2 is commonly used for behind sockets, while 1.5mm2 is most often used for lights (depending on how many lights you have in a circuit).

Components of lighting circuit

Every circuit is comprised of three major components:

1. a conductive "path," such as wire;
2. a "source" of electrical power, such as a battery or household wall outlet, and,
3. a "load" that needs electrical power to operate, such as a lamp.

There are also two optional components that can be included in an electrical circuit. These are control devices and protective devices. Control and protective devices, however, are not required for a circuit to function. They are optional.

Circuits are made up of two distinct elements:

- active elements, which are defined as the sources of electrical energy,
- and passive elements, which carry or use the electrical energy for some specific reason.

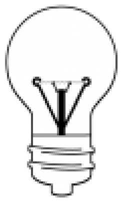
Types of lighting circuit

Lighting circuits are wired in two different ways, using either junction-boxes or loop-in ceiling roses. These days, the loop-in system predominates - though individual circuits often combine the two for the most economical use of cable. Unlike power circuits, lighting circuits are always of the radial type.

Types of electrical lighting

There are four main types of lights, or light bulbs, currently available on the market: Incandescent, CFL, or compact fluorescent lamp, Halogen and LED, or light emitting diodes.

Incandescent light bulb

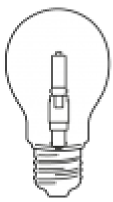


An incandescent light bulb is the traditional style of globe, and is the most commonly used option over the last 100 years or so. They are not that efficient to run though, compared to newer styles on the market, and incandescent light bulbs are also pretty pricey to run. A phase out of this kind of globe started in 2009.

CFL light bulb

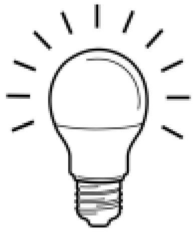
A CFL light bulb is also known as a compact fluorescent lamp, and is a relatively cost effective and energy efficient option when compared to both incandescent and halogen light bulbs. It is noted however that small amounts of mercury are contained in the bulbs.

Halogen light bulb



Halogen light bulbs work in a similar way to incandescent globes, however they contain halogen gas (which makes them more energy efficient). They also run for longer periods than incandescent bulbs.

LED light bulb



LED light bulbs, also known as light emitting diodes, are the most cost effective and energy efficient lighting options on the market.

How do they work?

Each light type works slightly differently, depending on its internal structure:

- **Incandescent Light Bulb**: Firstly, an incandescent light bulb works by sending an electric current though the tungsten filament (the little wire you see in a globe) until it heats up. It glows brighter and brighter the hotter it gets, which is known as lumens, and the energy levels rise too. More energy = more wasted energy though.
- **CFL Light Bulb:** A CFL light bulb, and fluorescent tubes, use an identical method to create light. An electric charge is created in a tube filled with mercury vapour, with the charge exciting the vapour. When the vapour is excited, it lets off UV light which then excites the phosphor lining of the tube. Excited phosphor = light!
- **Halogen Light Bulb:** A halogen light bulb operates in the same way that an incandescent one does, but the globe contains halogen gas. This gas speeds up the entire process, meaning they are both more cost effective and more energy efficient than their incandescent counterparts… and they last longer too!
- **LED Light Bulb:** Finally, an LED globe works differently to all other options. An electric charge is sent through solid material, which engages the electrons within it and encourages them to move faster and faster. This movement creates light and generates less heat, making them both energy efficient and cost effective.

What are the advantages and disadvantages?

Each light types have positives and negatives associated with them, just like anything. A few of the major points are listed below,

Incandescent Light Bulbs

Advantages

- Most common light bulb for 100+ years.
- Simple and cheap to manufacture.
- Cheap to buy.
- Best suited to small areas.
- Made with non-toxic materials.

Disadvantages

- Inefficient to run, as most electrical energy is converted into heat (not light).

- Don’t last very long.
- Not good to light large areas.
- Generally phased out except for speciality uses e.g. oven lights.

CFL Light Bulbs

Advantages

- More energy efficient than incandescent and halogens.
- More cost effective than incandescent and halogens.
- Generate very little heat.
- Highly versatile.
- Can work with dimmers.

Disadvantages

- Cold temperature sensitive.
- Don’t last very long.
- Not recommended for fixtures that are enclosed.
- Longer warm up time.

Halogen Light Bulbs

Advantages

- More energy efficient than incandescent.
- More cost effective than incandescent.
- Quite cheap to buy.
- Clear crisp light.
- Compact size.

Disadvantages

- Inefficient to run.
- Don’t last very long.
- Run hotter than incandescent.
- May require a low voltage transformer.

LED Light Bulbs

Advantages

- Most cost-effective option.
- Most energy efficient option.
- Last for long period of time.
- Generate little to no heat.
- Small in size.

Disadvantages

- Can be voltage sensitive.
- More expensive than other options.
- Depend heavily on the temperature around them to perform properly.

Do not give spherical light distribution (not overly advisable for larger areas)

Practical Activity 2.7.2: Installation of electrical lighting circuits

Task:

1: Referring to previous activity (2.7.1) you are requested to perform the given task. The task should be done individually.

i. A house owner wants to install a house as follow:

- Dining room must have variable light because it can be used when reading books and entertainment when there is a party and the lamps are controlled in three locations.
- Room that can be given light and temperature increase by the lamps controlled in two locations.
- Other room where we need colored light controlled in one position.

You are asked to install the switch used to vary light and select the lamps to be used, choose the lamps to produce light and heat at once; also lamps of color.

2: Draw electrical diagram to be used to perform the given tasks (2.7.2).

3: Referring to drawing provided from task 2, Perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading 2.7.2 and ask clarification where necessary Perform the task provided in application of learning 2.7

Key readings 2.7.2: Installation of electrical lighting circuits

Steps for installing an electrical circuit

1. Planning and Preparation:

- Determine the purpose and location of the circuit: What will the circuit be used for (lighting, outlets, etc.) and where will it be installed?
- Consult the National Electrical Code (NEC): Always follow the latest NEC guidelines for safety and proper installation.
- Obtain necessary permits: Depending on your location, you may need to obtain permits for electrical work.
- Gather tools and materials: You will need various tools like screwdrivers, wire cutters/strippers, a drill, and a level. Materials like wire, conduit (optional), boxes, outlets, and a circuit breaker will also be needed.

2. Turn off the power:

- Locate the main breaker panel and switch off the main breaker to completely cut power to the area where you'll be working.
- Double-check for any remaining power using a voltage tester.

3. Run the wires:

- Choose the appropriate wire gauge based on the circuit's amperage and length (consult the NEC for specific requirements).
- Decide on the wiring method: conduit for concealed wiring or cable for exposed wiring (e.g., in basements).
- Run the wires from the breaker panel to the desired location, ensuring they are protected from damage.
- If using conduit, pull the wires through the conduit after installation.

4. Install boxes and devices:

- Install electrical boxes at the desired locations for outlets, switches, and fixtures.
- Make sure the boxes are securely mounted and level.
- Install the outlets, switches, and fixtures according to the manufacturer's instructions.

5. Connect the wires:

- Make sure all connections are tight and secure using wire nuts or other approved methods.
- Follow the correct color coding for hot (black), neutral (white), and ground (bare copper or green) wires.
- Double-check all connections for accuracy.

6. Install the circuit breaker:

- Install the appropriate circuit breaker in the breaker panel for your circuit's amperage rating.
- Connect the wires from the circuit to the breaker terminals according to the panel's labelling.

7. Test the circuit:

- Before turning on the power, thoroughly test the circuit for any errors or problems using a voltage tester.
- Once confirmed safe, turn on the main breaker and test the circuit's functionality.

8. Finalise and inspect:

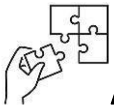
- Securely fasten all wires and boxes using appropriate covers and plates.
- Label the circuit breaker for future reference.

Conduct a final visual inspection to ensure everything is installed correctly and safely

Points to Remember

- **Steps for installing an electrical circuit**
    1. Planning and Preparation
    2. Turn off the power
    3. Run the wires
    4. Install boxes and devices

5. Connect the wires
6. Install the circuit breaker
7. Test the circuit
8. Finalise and inspect



Application of learning 2.7.

XYZ hospital would like to install an electrical lighting system as follow:

1. The living room comprises two fluorescent lamps controlled by two different locations
2. The bedroom comprises one incandescent lamp and two outlet sockets. The lamp is controlled from two different positions.
3. The bathroom comprises one fluorescent lamp and one socket outlet. The lamp is controlled by a bipolar switch.
4. The corridor comprises two fluorescent lamps by controlled by 3 gang two-way switch

And also it would like to install an electrical security lighting system.

5. This security system will be installed by the help of four lamps which will be commanded automatically:

- The first two incandescent lamps will be located in the garden to provide outdoor lighting and it will be controlled by a photo control switch which will turn on any time darkness appears.
- The second two LEDs lamps will be located on the office veranda, and will be controlled by a digital time switch. The lamp will be switched ON from 6:00 pm to 5:30 am.

As technician, you are asked to:

1. Draw the wiring diagram of this installation circuit**.**
2. Install the required installation.

Indicative content 2.8: Installation of protection devices and systems

Duration: 3

Theoretical Activity 2.8.1: Description of protection devices and systems .

Tasks:

1: In small groups, you are requested to answer the following questions related to the of description of resonant circuits.

i. What do you understand by overcurrent protection devices?

ii. Identify the main characteristics of residual current devices

iii. What is a Surge protection device and give its characteristics?

iv. Explain the types of earthing and bonding

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key readings 2.8.1.

5: In addition, ask questions where necessary.

Key readings 2.8.1.: Description of protection devices and systems

Definition of terms:

Protection device: Protective devices are devices that are used to safeguard equipment, machinery, components, and devices in electrical and electronic circuits from short circuit, over current, and ground fault.

Circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit.

Overcurrent: In an electric power system, overcurrent or excess current is a situation where a larger than intended electric current exists through a conductor, leading to excessive generation of heat, and the risk of fire or damage to equipment.

- **Fuse**: Is an electrical component designed to protect electrical circuits by safely opening the circuit under abnormally high current loads.

Earth: The conductive mass of the earth, whose electrical potential at any point is conventionally taken as zero.

Earthing: Is the connection of the exposed conductive parts of an electrical installation to the main protective earthing terminal of the installation.

Grounding: Is the process of electrically connecting any metallic object to the earth by the way of an earth electrode system.

Bonding: Is the linking together of the exposed or extraneous metal parts of an electrical installation for the purpose of safety.

Exposed Conductive parts: Are the metal work of the electrical installation: the conduits, trunking, metal boxes and equipment that make up the electrical installation.

Extraneous conductive parts: Are the other metal parts which do not form a part of the electrical installation; the structural steelwork of the building, gas, water and central heating pipes and radiators.

1. OVERCURRENT PROTECTIVE DEVICES

1.1. CIRCUIT BREAKER

Circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit.

Its basic function is to interrupt current flow after a fault is detected. Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.

Circuit breakers are made in varying sizes, from small devices that protect low-current circuits or individual household appliance, up to large switchgear designed to protect high voltage circuits feeding an entire city.

The generic function of a circuit breaker, RCD or a fuse, as an automatic means of removing power from a faulty system is often abbreviated as OCPD (Overcurrent Protection Device).

Miniature Circuit Breakers (MCBs)

Introduction to Miniature Circuit Breakers

All fuses need to be replaced with MCB for better safety and control when they have done their job in the past. Unlike a fuse, an MCB operates as an automatic switch that opens in the event of excessive current flowing through the circuit and once the circuit returns to normal, it can be reclosed without any manual replacement. MCBs are used primarily as an alternative to the fuse switch in most of the circuits. A wide variety of MCBs have been in use nowadays with breaking capacity of 10KA to 16 KA, in all areas of domestic, commercial and industrial applications as a reliable means of protection

An **MCB or miniature circuit breaker** is an electromagnetic device that embodies complete enclosure in a moulded insulating material. The main function of an MCB is to switch the circuit, i.e., to open the circuit (which has been connected to it) automatically when the current passing through it (MCB) exceeds the value for which it is set. It can be manually switched ON and OFF as similar to normal switch if necessary.

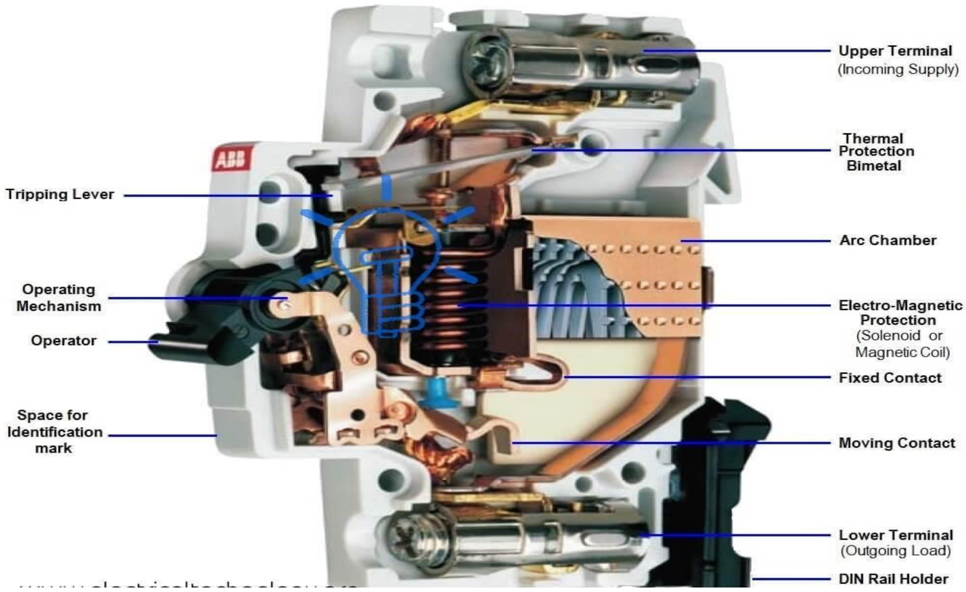
MCBs are time delay tripping devices, to which the magnitude of overcurrent controls the operating time. This means, these get operated whenever overloads exist long enough to create a danger to the circuit being protected. Therefore, MCBs doesn’t respond to transient loads such as switches surges and **motor starting currents.**

Generally, these are designed to operate at less than 2.5 milliseconds during short circuit faults and 2 seconds to 2 minutes in case of overloads.

Construction of MCB

An MCB embodies a complete enclosure in a moulded insulating material. This provides mechanically strong and insulated housing. The switching system consists of a fixed and a moving contact to which incoming and outgoing wires are connected. The metal or current carrying parts are made up of electrolytic copper or silver alloy depending on the rating of circuit

Circuit breaker.



As the contacts are separated in the event of an overload or short circuit situation, an electric arc is formed. All modern MCBs are designed to handle arc interruption process where arc energy extraction and its cooling are provided by metallic arc splitter plates. These plates are held in a proper position by an insulating material. Also, arc runner is provided to force the arc that is produced between the main contacts.

The operating mechanism consists of both magnetic tripping and thermal tripping arrangements.

Working & Operation of MCB

Under normal working conditions, MCB operates as a switch (manual one) to make the circuit ON or OFF. Under overload or short circuit condition, it automatically operates or trips so that current interruption takes place in the load circuit. The visual indication of this trip can be observed by automatic movement of the operating knob to OFF position. This automatic operation MCB can be obtained in two ways as we have seen in MCB construction; those are magnetic tripping and thermal tripping.

Under overload conditions, the current through the bimetal causes it to raise the temperature of it. The heat generated within the bimetal itself is enough to cause deflection due to thermal expansion of metals. This deflection further releases the trip latch and hence contacts get separated. In some MCBs, the magnetic field generated by the coil causes a pull on the bimetal such that deflection activates the tripping mechanism.

Under short circuit or heavy overload conditions, magnetic tripping arrangement comes into the picture. Under normal working conditions, the slug is held in a position by a light spring because the magnetic field generated by the coil is not sufficient to attract the latch. When a fault current flows, the magnetic field generated by the coil is sufficient to overcome the spring force holding the slug in position. And hence slug moves and then actuate the tripping mechanism.

A combination of both magnetic and thermal tripping mechanisms are implemented in most MCBs. In both magnetic and thermal tripping operations, an arc is formed when the contacts start separating. This arc is then forced into arc splitter plates via arc runner. These arc splitter plates are also called arc chutes where arc is formed into a series of arcs and at the same time energy extracted and cools it. Hence this arrangement achieves the arc extinction.

Types of Miniature Circuit Breakers (MCB’s)

MCBs are classified into three major types according to their instantaneous tripping currents. They are

1. ***Type B MCB***
2. ***Type C MCB***
3. ***Type D MCB***

Type B MCB

This type of MCB will trip instantly at a rate of three to five times its rated current. These are normally used for resistive or small inductive loads where switching surges are very small. Therefore, these are suitable for residential or light commercial installations.

Type C MCB

This type of MCB will trip instantly at a rate of five to ten times its rated current. These are normally used for high inductive loads where switching surges are high such as small motors and fluorescent lighting. In such cases, type C MCBs are preferred to handle higher values of short circuit currents. Therefore, these are suitable for highly inductive commercial and industrial installations.

Type D MCB

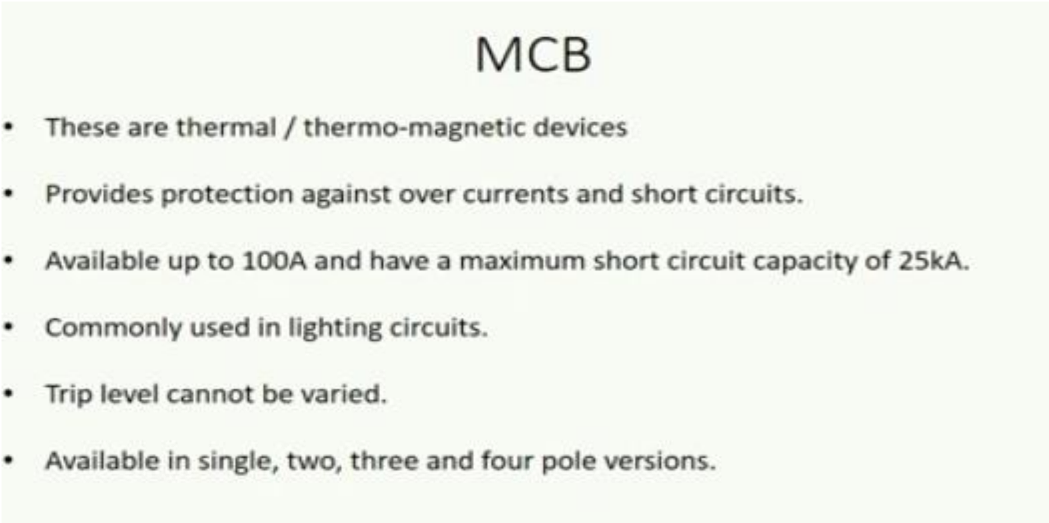
This type of MCB will trip instantly at a rate of ten to twenty-five times its rated current. These are normally used for very high inductive loads where high inrush current is very frequent. These are suitable for specific industrial and commercial applications. The common examples of such applications include x-ray machines, UPS systems, industrial welding equipment, large winding motors, etc.

The above three types of MCBs provide protection within one tenth of a sec. The minimum and maximum trip currents of these MCBs are given in a tabular form below, where Ir is the rated current of the MCB. MCBs can also be classified based on number of poles such as single pole, double pole, triple pole and four pole MCBs.

MCB Type	Minimum Trip Current	Maximum Trip Current
Type B	3 Ir	5 Ir
Type C	5 Ir	10 Ir
Type D	10 Ir	20 Ir

Type	Tripping Current	Operating Time
Type B	3 To 5 time full load current	0.04 To 13 Sec
Type C	5 To 10 times full load current	0.04 To 5 Sec
Type D	10 To 20 times full load current	0.04 To 3 Sec

Characteristics



Advantages of Miniature Circuit Breaker

- Faulty circuit is easily identified
- Supply is quickly restored
- Multiple units are available
- They have factory set operating characteristics
- The circuit protection is difficult to interfere with.
- The supply may be safely restored by an unskilled operator

Disadvantages of Miniature Circuit Breaker

- ❖ Have mechanical moving parts
- ❖ Need for regular testing to ensure satisfactory operation
- ❖ Expensive
- ❖ Characteristics affected by ambient temperature.

MCCB (Moulded Case Circuit Breaker)


Simply, these are electrical protection gadgets that can be used with a wide range of voltages. MCCBs, as they are commonly known, have adjustable trip settings and can hold as much as 2,500 amps in current ratings. They are also used with frequencies that are 50 and 60 Hz and have the following 3 functions:

- They offer protection in case of electrical faults by immediately interrupting a current that is extremely high due to a line fault or a short circuit.

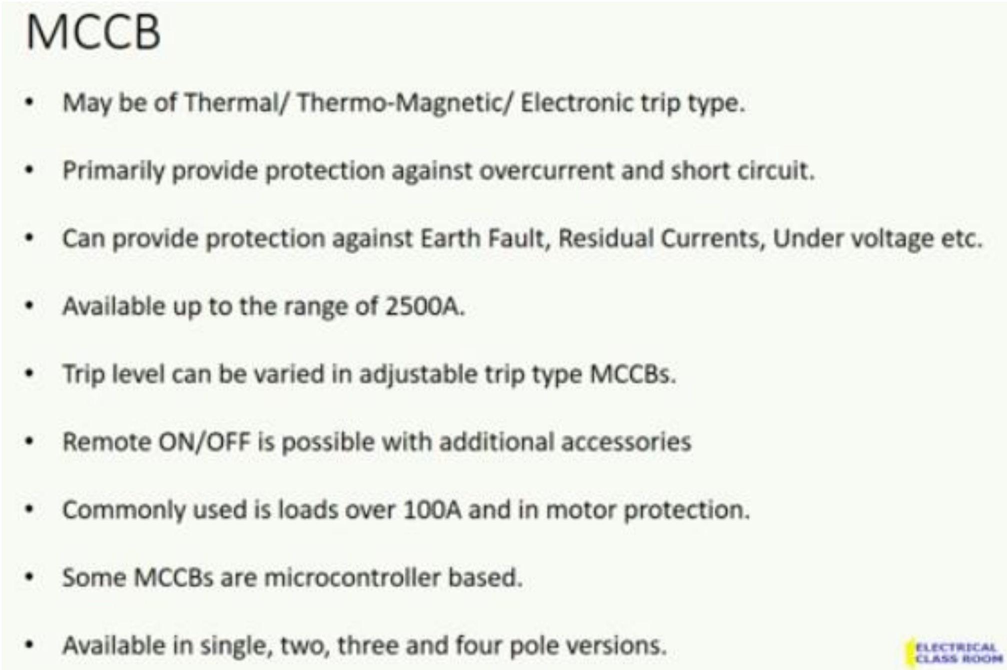
- They protect in the event of an overload where the current is higher than the rated value and lasts a longer time than normal.
- The on and off function can be used to switch the circuit on or off for repairs and replacements.

Various MCCB Circuit Breakers Based on Applications

Due to the fact that they can handle especially high currents, molded case circuit breakers are often used with applications that are heavy duty. Some of these uses are as follows:

- **Protecting Generators**
  They usually produce hundreds of amps in output and require expensive gen-sets. MCCBs, which can handle the current ratings, provide the protection needed.
- **Protecting Electric Feeders**
  If you are using feeder circuits to distribute electric current, they can carry hundreds of amps. In some instances, you may also have additional circuits that will need trip settings. MCCBs come in handy in both the situations.
- **Welding Machines**
  It is possible to have some welding applications that draw very high currents thus needing MCCBs since miniature circuit breakers cannot handle the high currents.
- **Protecting Capacitor Banks**
  These are used to correct power factors in industrial and commercial electrical systems. If the currents they draw are very high, MCCB protection becomes a necessity to reduce currents.
- **Protecting Motors**
  Electric motors also need to be adequately protected and MCCBs do this work very well. Inrush current may need to be adjusted, providing the necessary overload protection without tripping.
- **Adjustable trip settings for applications with low currents**
  MCCBs, even though they are known to be used with high current applications, can also be used with low current ones. They provide adjustable trip settings.

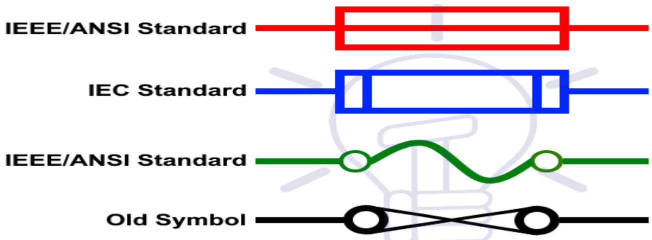
Characteristics of MCCBs



1.2 ELECTRICAL FUSE

In electronics and electrical engineering, a fuse is a type of low resistance resistor that acts as a sacrificial device to provide over current protection, of either the load or source circuit.

It's essential component is: **a metal wire or strip that** melts when too much current flows through it, interrupting the circuit that it connects.



Different Symbols of Fuse

Excessive current is caused by:

- Short circuits
- overloading
- mismatched loads
- Devices failure

Fuses can be used as alternatives to circuit breakers.

A fuse interrupts an excessive current so that further damage by overheating or fire is prevented. Wiring regulations often define a maximum fuse current rating for particular circuits.

Overcurrent protection devices are essential in electrical systems to:

- limit threats to human life and
- Limit property damage.

A fuse consists of a metal strip or wire fuse element, of small cross-section compared to the circuit conductors, mounted between a pair of electrical terminals, and (usually) enclosed by a non-combustible housing. The fuse is arranged in series to carry all the current passing through the protected circuit. The resistance of the element generates heat due to the current flow

OPERATION

For a normal current the heat produced does not cause the element to attain a high temperature. If too high a current flow, the element rises to a higher temperature and either directly melts, or else melts a soldered joint within the fuse, opening the circuit.

The fuse element is made of:

zinc, copper, silver, aluminium, or alloys to provide stable and predictable characteristics. The fuse ideally would carry its rated current indefinitely and melt quickly on a small excess.

The fuse element may be surrounded by air, or by materials intended to speed the quenching of the arc. Silica sand or non-conducting liquids may be used.

Parameters

- Rated current (In)
- Speed
- Breaking capacity
- Rated voltage
- Voltage drop
- Temperature rating

Rated current (In)

A maximum current that the fuse can continuously conduct without interrupting the circuit.

Speed

The speed at which a fuse blows depends on how much current flows through it and the material of which the fuse is made. The operating time is not a fixed interval, but decreases as the current increases.

Breaking capacity

The breaking capacity is the maximum current that can safely be interrupted by the fuse. Generally, this should be higher than the prospective short circuit current. Miniature fuses may have an interrupting rating only 10 times their rated current.

Rated voltage

Voltage rating of the fuse must be equal to or, greater than, what would become the open-circuit voltage. For example, a glass tube fuse rated at 32 volts would not reliably interrupt current from a voltage source of 120 or 230V. If a 32V fuse attempts to interrupt the 120 or 230 V source, an arc may result.

Voltage drop

A voltage drop across the fuse is usually provided by its manufacturer. There is a direct relationship between a fuse's cold resistance and its voltage drop value.

Temperature rating

Ambient temperature will change a fuse's operational parameters. A fuse rated for 1 A at 25 °C may conduct up to 10% or 20% more current at −40 °C and may open at 80% of its rated value at 100 °C. Operating values will vary with each fuse family and are provided in manufacturer data sheets.

Markings

A sample of the many markings that can be found on a fuse, Most fuses are marked on the body or end caps with markings that indicate their ratings.

- Ampere rating of the fuse.
- Voltage rating of the fuse.
- Time-current characteristic; i.e. fuse speed.
- Approvals by national and international standards agencies.
- Manufacturer/part number/series.
- Interrupting rating (Breaking capacity)
- Packages and materials

FUSE CAPACITY

Fuse wire rating (A)	Cu Wire diameter (mm)
3	0.15
5	0.20
10	0.35
15	0.50
20	0.60
25	0.75
30	0.85
45	1.25
60	1.53
80	1.8
100	2.0

How to Select Proper Rating Size of Fuse?

While selecting the proper fuse and its rated size for electrical appliances is based on different factors and environments. but the following basic formula shows that **how to choose the right size of fuse**?

Fuse Rating = (Power / Voltage) x 1.25

For example, you have to find the right size of fuse for a 10A two pin socket.

(1000W / 230V) x 1.25 = **5.4A**

In the above example, 1kW is the power rating which can be controlled through the 2 pin socket and the main supply voltage is single phase 230V AC (120V AC in US).

But you should go for the max i.e. 6A fuse rating instead of 5.4A for safe and reliable operation of the circuit.

The selection of a fuse can be done by calculating the fuse rating by using the above formula.

- Choose the fuse.
- Write down the voltage (volts) and power (watts) of the appliance.
- Calculate the fuse rating.

After the result, use the maximum fuse rating. For instance, if the calculated fuse rating is the maximum fuse rating. For example, if the calculated fuse rating is 7.689 amps, you can use an 8 amp fuse.

CLASSIFICATION OF FUSES

Fuses can be classified as "**One Time Only Fuse**", "**Resettable Fuse**", "**Current limiting and non – current limiting fuses**" based on the usage for different applications.

One time use fuses contain a metallic wire, which burns out, when an over current, overload or mismatched load connect event occurs, the user has to manually replace these fuses, switch fuses are cheap and widely used in almost all the electronics and electrical systems.

On the other hand, the **Resettable fuse** automatically reset after the operation when fault occurs at the system.

In the **Current limiting fuse**, they produce high resistance for a very short period while the non – current limiting fuse produces an arc in case of high current flow to interrupt and limit the current in a related and connected circuit.

Types of Fuses and Applications

In the field of electronics or electrical, a fuse is an essential device used in various electrical circuits which gives the protection from the overcurrent.

It comprises a strip or a metal wire that dissolves when the heavy flow of current supplies through it. Once this device has functioned in an open circuit, it ought to be rewired or changed based on the type of fuse.

A fuse is an automatic disconnection of supply which is frequently shortened to ADS. The alternative of the fuse is a stabiliser or circuit breaker, but they have many different characteristics.

Why do we require Fuse?

These are used to prevent the home appliances from high current or overload damage.

If we use a fuse in the homes, the electrical faults cannot happen in the wiring and it doesn't damage the appliance s from the fire of wire burning.

When the fuse gets broken or damaged, then an abrupt sparkle happens which may direct to damage your home appliances. That is the reason we require different types of fuses to guard our home-appliances against damage.

Different Types of Fuses

The fuses are classified into several types based on the application namely **AC type fuse** and **DC type fuse**. Again, these fuses are classified into several types. The following diagram illustrates the electrical fuse types chart based on the AC fuse and DC fuse.

DC Fuses

DC fuses are available superior in size, and DC supply has a stable value over 0 volts. So, it is tough to remove and deactivate the circuit. There will be a chance of generation of an electric Arc between dissolved wires. To conquer this, electrodes located at better distances. For this reason, the size of DC fuse gets amplified.

SMD Fuses (Surface Mount Fuse), Chip , Radial, and Lead Fuses

SMD Fuses (Surface Mont Device and the name derived from SMT = Surface Mount Technology) are chip types of fuses (also known as electronic fuse) are used in DC power applications like Hard Drive, DVD players, Camera, cell phones etc where space playing an important role because SMD fuses are very tinny in size and hard to replace as well.

Below are some additional types of SMD Fuses and Leaded fuses.

- Slow – Blow Chip Fuses
- Fast Acting Chip Fuses
- Very Fast Acting Chip Fuses
- Pulse Tolerant Chip Fuses
- High Current Rated Chip Fuses
- Telecom Fuses
- Through-hole styles fuses
- Radial Fuse
- Lead Fuse
- Axial Fuse

SMD Fuse and Axial fuse

Rewirable Fuses

The most famous kit-kat fuse (also known as **rewire able** fuse) is mostly used in industries and home electrical wiring for small current applications in Low Voltage (LV) systems.

Rewirable fuse contains 2 basic parts. The inner fuse element as fuse carrier made of tinned copper, Aluminium, Lead etc and the base made of porcelain having the IN and OUT terminals which used to be in series with the circuit to protect.

The main advantage of a rewirable fuse is that It can be rewired easily in case it is blown due to short circuit or over current which melts the fuse elements. Simple, put another wire of fuse elements with the same rating as before.

Thermal Fuses

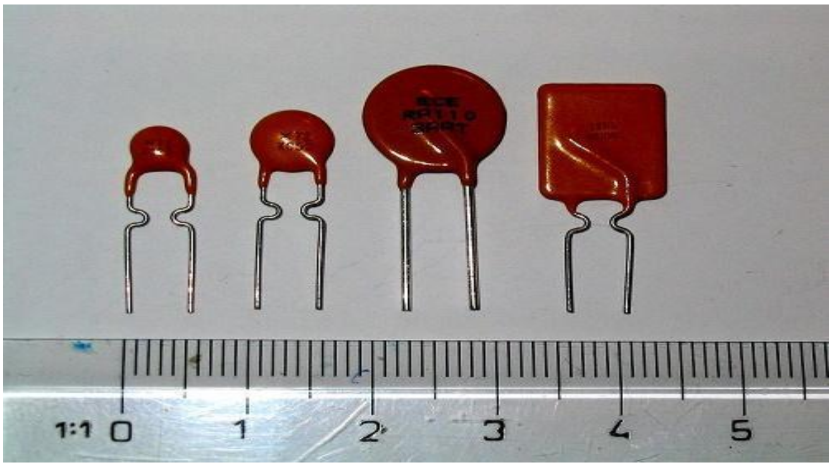
As mentioned above, a thermal fuse is a onetime used only fuse. They are temperature sensitive fuse and the fuse element is made of temperature sensitive alloy. They are known as Thermal Cut-outs (TCO) or thermal Links.

In a thermal fuse, the fuse element holds a mechanical spring contact which is normally closed. When high currents due to over current and short circuit flow through the elements of the fuse, the fuse elements melt down which lead to release the spring mechanism and prevent the arc and fire and protect the connected circuit.

Resettable Fuses

Resettable fuse is a device, which can be used multiple times without replacing it. They open the circuit, when an over current event occurs and after some specific time they connect the circuit again. Polymeric positive temperature coefficient device (PPTC, commonly known as a resettable fuse, poly-switch or poly-fuse) is a passive electronic component used to protect against short current faults in electronic circuits.

Application of resettable fuses is overcome where manually replacing fuses is difficult or almost impossible, e.g. fuse in the nuclear system or in the aerospace system.



Resettable Fuses |Image Credit: Wikipedia

Uses and Applications of Fuses

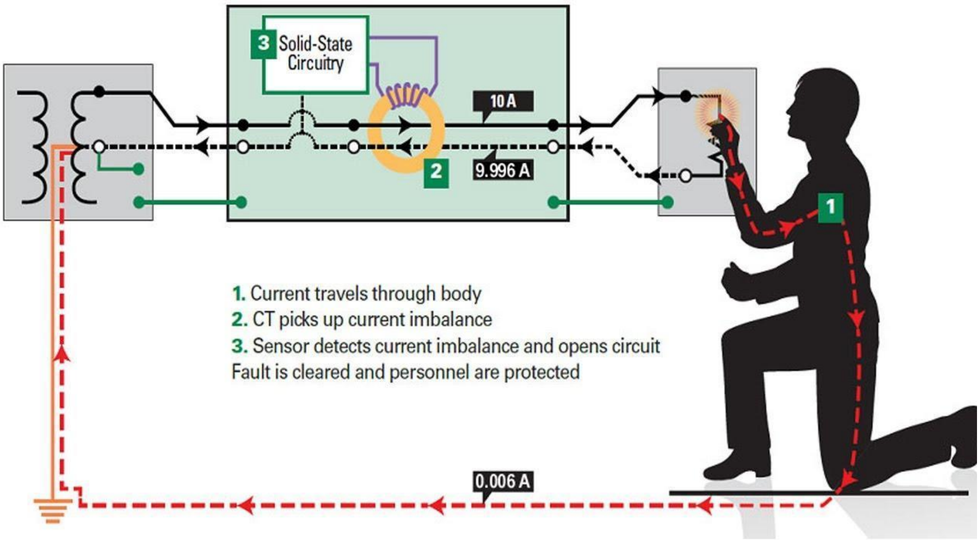
Different types of Electrical and Electronic Fuses can be used in all types of electrical and electronic systems and applications including:

- Motors & Transformers
- Air-conditions
- Home distribution boards
- General electrical appliances and devices
- Laptops
- Cell phones
- Game systems
- Printers
- Digital cameras
- DVD players
- Portable Electronics
- LCD monitors
- Scanners
- Battery packs
- Hard disk drives
- Power convertors

2. **RESIDUAL CURRENT DEVICE**

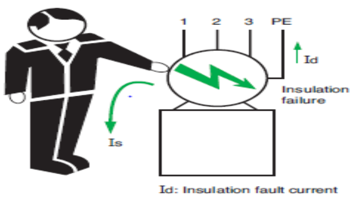
A residual current device (RCD), or residual current circuit breaker (RCCB), is an electrical wiring device that disconnects a circuit whenever it detects that the electric current is not balanced between the phase ("hot") conductor and the neutral conductor. Such unbalance is sometimes caused by current leakage through the body of a person who is grounded and accidentally touching the energized part of the circuit. "Indirect contact"," direct contact" electric shock.

1. **Direct contact**

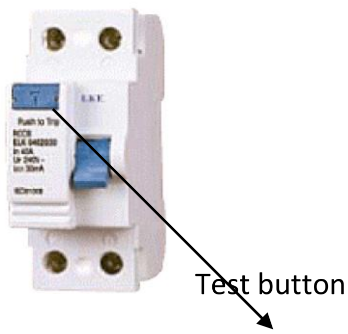


2. Indirect contact

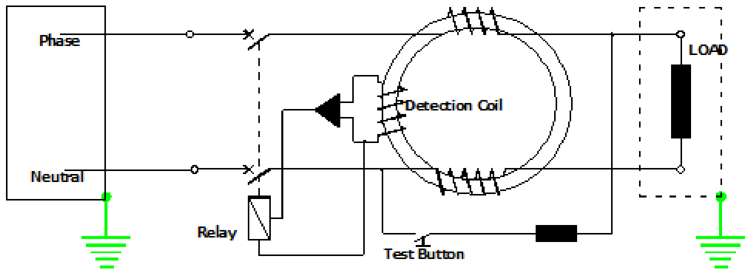
An indirect contact refers to a person coming into contact with an exposed conductive-part such as the metallic enclosures of electrical appliances, the metallic conduit, trunking or cable tray which is not normally alive, but has become alive accidentally (due
to insulation failure or some other cause).



Operation principle of RCD



Single Phase RCD



RCDs operate by measuring the current balance between two conductors using a differential current transformer. The device will open its contacts when it detects a difference in current between the line conductor and the neutral conductor. The supply and return currents must sum to zero, otherwise there is a leakage of current to somewhere else (to earth/ground, or to another circuit, etc.).

Residual current detection is complementary to over-current detection. Residual current detection cannot provide protection for overload or short-circuit currents.

Characteristics

- **Phase (line) and Neutral** both wires connected through RCD.
- It trips the circuit when there is earth fault current.
- The amount of current flowing through the phase (line) should return through neutral.
- It detects by RCD any mismatch between two currents flowing through phase and neutral detected by -RCD and trips the circuit within 30 Milliseconds.
- If a house has an earth system connected to an earth rod and not the main incoming cable, then it must have all circuits protected by an RCD (because might not be able to get enough fault current to trip a MCB)
- RCDs are an extremely effective form of shock protection

The most widely used are 30 mA (milliamp) and 100 mA devices. A current flow of 30 mA (or 0.03 amps) is sufficiently small that it makes it very difficult to receive a dangerous shock. Even 100 mA is a relatively small figure when compared to the current that may flow in an earth fault without such protection (hundreds of amps)

A 300/500 mA RCCB may be used where only fire protection is required. eg., on lighting circuits, where the risk of electric shock is small.

Limitation of RCCB

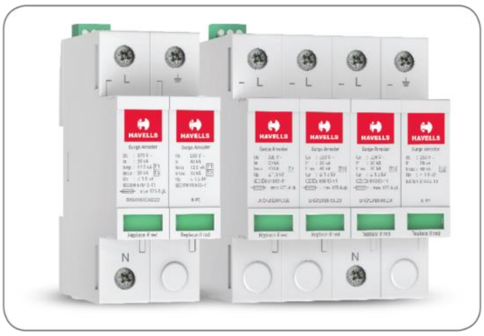
- **RCDs don't offer protection against current overloads**: RCDs detect an imbalance in the live and neutral currents. A current overload, however large, cannot be detected. It is a frequent cause of problems with novices to replace an MCB in a fuse box with an RCD.
- **RCD will not protect against a socket outlet being wired with its live and neutral terminals** the wrong way round.

- **RCD will not protect against the overheating** that results when conductors are not properly screwed into their terminals.
- **RCD will not protect against live-neutral shocks**, because the current in the live and neutral is balanced. So if you touch live and neutral conductors at the same time (e.g., both terminals of a light fitting), you may still get a nasty shock.
- **Nuisance tripping of RCCB:** Sudden changes in electrical load can cause a small, brief current flow to earth, especially in old appliances.

3. SURGE PROTECTION DEVICE

Surge Protection Devices (SPD) is used for electric power supply networks, telephone networks, and communication and automatic control buses

The Surge Protection Device (SPD) is a component of the electrical installation protection system.



This device is connected in parallel on the power supply circuit of the loads that it has to protect. It can also be used at all levels of the power supply network. This is the most commonly used and most efficient type of overvoltage protection.

SPD is designed to limit transient overvoltage of atmospheric origin and divert current waves to earth, so as to limit the amplitude of this overvoltage to a value that is not hazardous for the electrical installation and electric switchgear and control gear.

SPD eliminates overvoltage

- In common mode, between phase and neutral or earth;
- In differential mode, between phase and neutral.

In the event of an overvoltage exceeding the operating threshold, the SPD conducts the energy to earth, in common mode;

- distributes the energy to the other live conductors, in differential mode.

The three types of SPD

Type 1 SPD

The Type 1 SPD is recommended in the specific case of service-sector and industrial buildings, protected by a lightning protection system or a meshed cage.

It protects electrical installations against direct lightning strokes. It can discharge the back-current from lightning spreading from the earth conductor to the network conductors.

Type 1 SPD is characterised by a 10/350 µs current wave.

Type 2 SPD

The Type 2 SPD is the main protection system for all low voltage electrical installations. Installed in each electrical switchboard, it prevents the spread of overvoltages in the electrical installations and protects the loads.

Type 2 SPD is characterised by an 8/20 µs current wave.

Type 3 SPD

These SPDs have a low discharge capacity. They must therefore mandatorily be installed as a supplement to Type 2 SPD and in the vicinity of sensitive loads.

Type 3 SPD is characterised by a combination of voltage waves (1.2/50 µs) and current waves (8/20 µs).

Common characteristics

- **Uc**: Maximum continuous operating voltage.
- This is the A.C. or D.C. voltage above which the SPD becomes active. This value is chosen according to the rated voltage and the system earthing arrangement.
- **Up**: Voltage protection level (at In)

  This is the maximum voltage across the terminals of the SPD when it is active. This voltage is reached when the current flowing in the SPD is equal to In. The voltage protection level chosen must be below the overvoltage withstand capability of the loads. In the event of lightning strokes, the voltage across the terminals of the SPD generally remains less than Up.
- **In**: Nominal discharge current

  This is the peak value of a current of 8/20 µs waveform that the SPD is capable of discharging minimum 19 times

4. EARTHING AND BONDING

The earthing system, sometimes simply called 'earthing', is the total set of measures used to connect an electrically conductive part to earth. The earthing system is an essential part of power networks at both high- and low-voltage levels. A good earthing system is required for (AIMS OF EARTHING):

- Protection of buildings and installations against lightning
- Safety of human and animal life by limiting touch and step voltages to safe values
- Electromagnetic compatibility (EMC) i.e. limitation of electromagnetic disturbances
- Correct operation of the electricity supply network and to ensure good power quality.

All these functions are provided by a single earthing system that has to be designed to fulfill all the requirements.

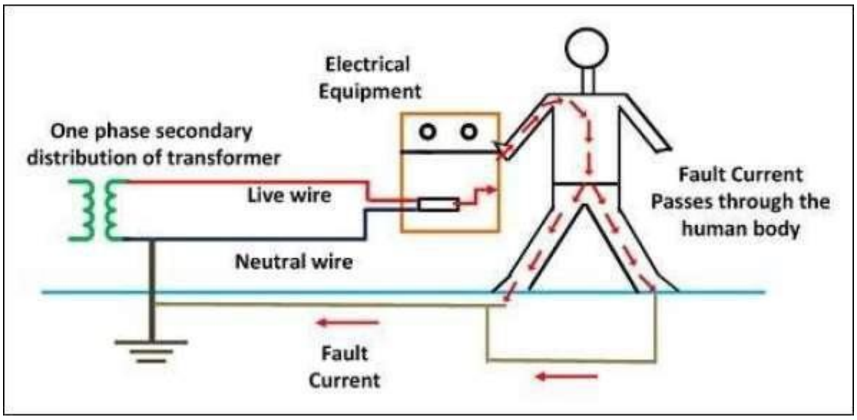
Explanation

We will now understand the need of earthing considering the following conditions –

A) Normal Condition

Earthing of a system is done in the installation to connect the respective parts with electrical conductors or electrodes. The electrode is placed near the soil or below the ground level, which has flat iron riser under the ground. The noncurrent-carrying parts are connected with the flat iron.

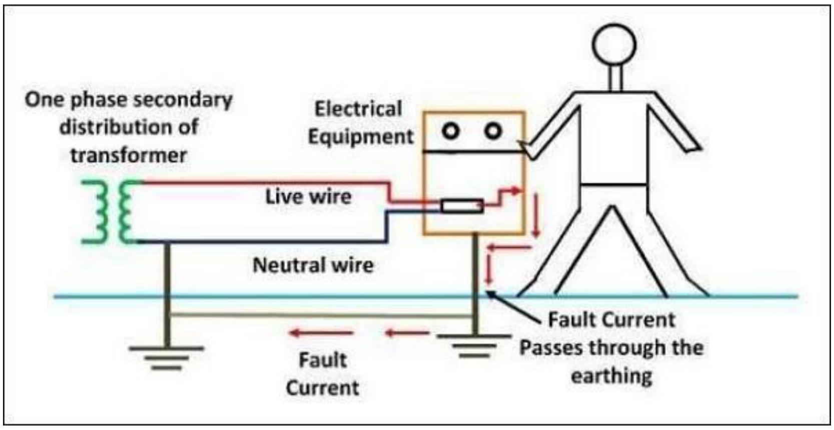
The following figure shows the **flow of fault current without earthing system** –



B) Fault Condition

In a fault condition, the fault current flows from the equipment to the earth through the earthing system. Thus, the apparatus is protected from short circuit or fault current. At the fault time, the voltage of the electrode increases and equals to the resistance of the electrode and the ground fault.

The following figure shows the **flow of fault current with an earthing system**



Danger in an unearthed system

- Leakage of electric current in any equipment will be able to cause a severe shock to the person accidentally coming in contact, even such person may die
- Large and tall buildings will be destroyed within a few moments by atmospheric electricity.
- The line voltage will not stand stable in absence of neutral being earthed.

Effect of electric current on human body

A current of 20mA causes the nerves to shrink**,** and a current of 50mA causes burning sensation. The effect of 100mA current is dangerous which may even cause death.
AC is more dangerous in comparison to DC, because AC affects the nerves of the body more rapidly. Hence 1000 Volts AC is more dangerous than 1000 Volts DC

ADVANTAGES OF EARTHING

For efficient/effective operation of any power system, it is very much essential to connect the neutral to suitable earth connection. The following are the few advantages:

- Reduced operation & Maintenance cost
- Reduction in magnitude of transient over voltages.
- Improved lightning protection.
- Simplification of ground fault location.
- Improved system and equipment fault protection.
- Improved service reliability
- Greater safety for personnel & equipment
- Prompt and consistent operation of protective devices during earth fault.

The disadvantages of earthing

The two important disadvantages are:
1. - Cost: the provision of a complete system of protective conductors, earth electrodes, etc. are very expensive.
2. - Possible safety hazard: It has been argued that complete isolation from earth will prevent shock due to indirect contact because there is no path for the shock current to return to the circuit if the supply earth connection is not made.

Measurement of Earth resistance

The earth resistance of an earthing system can be measured in the following two ways:

- Potential drop method
- Earth tester method

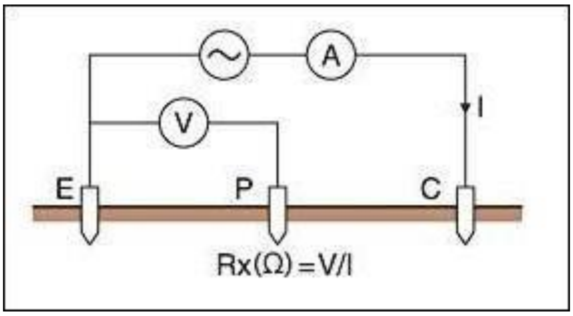
Potential drop method

In this method, the potential between the earth points and an auxiliary earth electrode measured by passing a defined amount of current through them.
The ground resistance of an electrode is measured by the fall of potential method. The total set up is shows in the figure given below, where -

E is the earth electrode under test
P & C are two auxiliary electrodes placed at a suitable distance from E
I is the amount of current that passes between E and C

V is the measured voltage between E and P

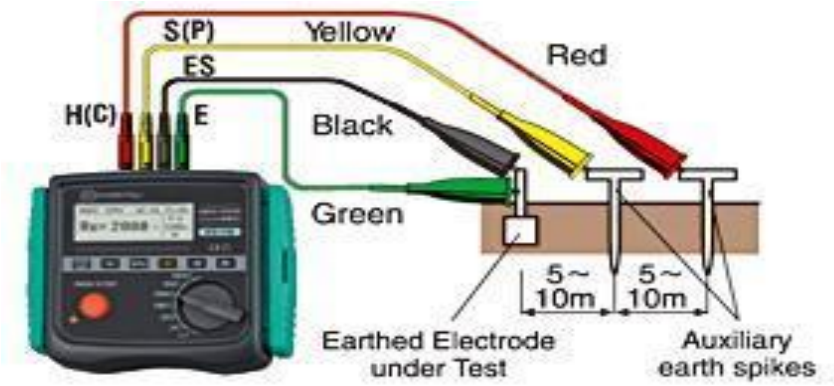
The following figure shows the setup to measure ground resistance –



There is no appreciable effect on the resistance of E, if C is at an adequate distance from E. As the current into electrode P is very small, the electrode also has a negligible effect on resistance. Now varying the distance of electrode P from E, the resistance is measured.

Earth tester method

In this method, earth tester equipment is used for measuring the earth resistance. It has three terminals C, P and E. Terminal E is connected to the earth electrode under testing. Terminal P and C are connected to two auxiliary or temporary earth



Methods of reducing earth resistance

Factors influencing earth resistance

The resistance of earth system depends upon the following factors:

- Condition of soil.
- Temperature of soil.
- Moisture content of soil.
- Size and spacing of earth electrodes
- Depth, at which the electrode is embedded.
- Material of conductor.
- Quality of coal, dust, charcoal and salt in the earth electrode pit.
- No. of electrodes connected in parallel.

Lesser is the earth resistance, better will be the earthing. The resistance of an earthing system can be reduced in the following manners:

By pouring water

The earth resistance can be reduced by pouring water in the pipe of the earthing system. Especially during the summer season, an earthing may require water due to the loss of its dampness.

By increasing the plate area

The earth resistance may also be reduced by using large size copper plates. A large size plate will have more area in contact with the damp earth, thus it will reduce the earth resistance.

By increasing the depth of the electrode

The depth of the damp bed of earth varies in accordance with the season. Therefore, by increasing the depth, the earth electrode will remain in contact with the damp earth as required, therefore, the resistance will be reduced.

By connecting many earth electrodes in parallel

The earth resistance can be reduced by connecting a number of separately installed earth electrodes in parallel.

In this way by connecting more earth electrodes in parallel, the earth resistance can be reduced, further.

Earth Rod Types

- Stainless Steel Earth Rods
- Galvanised Steel Earth Rods
- Copper bond Threaded Earth Rods
- Solid Copper Earth Rods

Copper is the optimal choice of earth electrode material and underground conductor – **solid copper** is recommended for high fault current installations whereas **copper bonded** rods are usually installed for smaller sections.

Copper bonded steel core earth rods are the most specified due to electrical and mechanical strength, resistance to corrosion as comparatively lower cost compared to **solid copper** or **stainless steel** types – the lowest cost galvanised rods for usually installed non-critical, short-term or temporary earthing requirements.

Copper bonded rods and electrodes are suitable for deep driving into most ground conditions and provide a low resistance path to ground.

Soil resistivity tests should be conducted prior to installing the earth rods to ensure acceptable soil resistivity readings – to reduce resistivity additional rods can be driven into the ground to increase density.

Different types of electrodes

- Ufer Ground or Concrete
- Ufer Ground or Building Foundations
- Encased Electrodes
- Concrete Encased Electrode
- Electrolytic Electrode
- Ground plate

- Driven rod

BONDING

Electrical bonding is the practice of connecting all exposed metallic items not designed to carry electricity in an area by using a protective bonding conductor and aims to protect people who may touch two separate metal parts from electric shock in case of an electrical fault. It reduces the voltage that might have been

Practical Activity 2.8.2: Installing overcurrent protective devices

Task:

1: Referring on the theoretical activity 2.8.1 you are requested to install the protection system of the domestic electrical installation described below, by the help of overcurrent protection devices.

Mr KAZUBWENGE would like to install an electrical lighting and system and power sockets in her house of living room, bedroom and the bathroom as follow:

- The living room comprises two fluorescent lamps controlled by two different locations
- The bedroom comprises one incandescent lamp and two socket outlets. The lamp is controlled from two different positions.
- The bathroom comprises one fluorescent lamp and one socket outlet. The lamp is controlled by a bipolar switch.

Note that the:

- Lamps and socket outlets will be protected separately
- Lamps and socket outlets are earthed
- Installation should provide reserve space for future extension of protective devices

Task:

i. Draw a wiring diagram of the described installation that shows appropriate protection.

ii. By the help of overcurrent protective device, Install the circuit and its protection system of this electrical installation.

2: Follow the instructions and technics provided in the key reading and perform the task.

3: Present your final product to your classmates.

4: Read key reading **2.8.2** for more information about the steps of installing overcurrent protective devices.

Key readings 2.8.2 Installing overcurrent protective devices

1.Steps for installing a circuit breaker

1.1 Turn Off Power: Locate the main breaker panel and turn off the power to the circuit where you'll be installing the circuit breaker. Verify that the power is off using a voltage tester.

1.2 Remove Cover: Remove the cover from the breaker panel.

1.3 Identify the Busbar: Locate the busbar in the panel, which is a thick, metal bar that carries electricity to the various circuits.

1.4 Prepare the Circuit: If the circuit already has a breaker, remove it and disconnect the wires from its terminals.

1.5 Connect the Wires: Connect the wires from the circuit to the terminals of the new circuit breaker. Ensure that the wires are properly stripped and securely fastened.

1.6 Secure the Breaker: Snap the new circuit breaker into place in the panel.

1.7 Test the Circuit: Turn on the main breaker and test the circuit to ensure that the new breaker is working properly. Use a voltage tester to verify that power is restored to the circuit.

1.8 Replace the Cover: Replace the cover of the breaker panel.

Steps to Install a Fuse

1. **Safety First:**
   - **De-energize the circuit:** Always turn off the power to the circuit you'll be working on to prevent electrical shock. Use a voltage tester to confirm the circuit is dead.
2. **Locate the Fuse Box:**
   - **Identify the panel:** Find the fuse box or breaker panel in your home or building.
3. **Identify the Fuse:**
   - **Match the rating:** Determine the correct fuse rating (amperage) for the circuit you're working on. This information is usually found on the fuse itself or the circuit breaker panel.
4. **Remove the Old Fuse:**
   - **Use a fuse puller:** If the fuse is difficult to remove, use a fuse puller to safely extract it.
5. **Insert the New Fuse:**
   - **Match the orientation:** Ensure the new fuse is inserted correctly, with the flat side facing the fuse puller.
   - **Snap it in place:** Press the fuse firmly into the socket until it clicks into place.
6. **Test the Circuit:**

- **Turn on the power:** Once the new fuse is installed, turn on the power to the circuit.
- **Check for functionality:** Verify that the devices connected to the circuit are working properly.

Practical Activity 2.8.3: Installing Residual current devices and Surge protection devices

Task:

1: Referring on the theoretical activity 2.8.1 you are requested to install the residual current device and Surge protection device to improve protection of domestic electrical circuit installed in practical activity 2.8.2.

2: Follow the instructions and technics provided in the key reading 2.8.1 and perform the task.

3: Present your final product to your classmates.

4: Read key reading **2.8.3** for more information about the steps of installing residual current and Surge protection devices.

Key readings 2.8.3 Installing Residual current devices and Surge protection devices

Steps to Install a Residual Current Device (RCD)

Note: Always consult local electrical codes and regulations, and seek guidance from a qualified electrician, especially when working with live electrical systems.

1. **Safety First:**
   - **De-energize the circuit:** Turn off the power to the circuit where you'll be installing the RCD. Use a voltage tester to confirm the circuit is dead.
2. **Identify the Location:**
   - **Determine the appropriate location:** Decide where you want to install the RCD. It's often recommended to install RCDs in areas with high moisture or where electrical equipment is exposed to water, such as bathrooms, kitchens, or outdoor outlets.
3. **Prepare the Circuit:**
   - **Disconnect devices:** Remove any devices or appliances connected to the circuit.
4. **Remove the Existing Outlet or Switch:**
   - **Use a wire stripper:** Carefully remove the wires from the existing outlet or switch.

5. **Install the RCD:**

- **Mount the RCD:** Securely mount the RCD to the electrical box using appropriate fasteners.
- **Connect the wires:** Connect the incoming power wires (line, neutral, and ground) to the RCD according to the manufacturer's instructions.
- **Connect the outgoing wires:** Connect the wires leading to the outlets or switches to the RCD.

6. **Test the RCD:**

- **Use a test button:** Press the test button on the RCD to ensure it's functioning correctly. The RCD should trip, indicating it's working.
- **Reset the RCD:** After testing, reset the RCD.

7. **Reconnect Devices:**

- **Plug devices back in:** Once the RCD is tested and reset, you can plug your devices back into the outlets.

8. **Verify Functionality:**

- **Test devices:** Ensure that the devices connected to the RCD are working properly

Steps of installing SPD

Procedure:

1. **Safety First:**
   - **De-energize the circuit:** Turn off the power to the circuit where you'll be installing the SPD. Use a voltage tester to confirm the circuit is dead.
2. **Identify the Location:**
   - **Choose a suitable location:** Select a location for the SPD near the equipment you want to protect. This will minimize the length of the surge protection cable.
3. **Prepare the SPD:**
   - **Remove protective cover:** If necessary, remove the protective cover from the SPD.
4. **Connect the SPD:**
   - **Identify terminals:** Locate the input and output terminals on the SPD.
   - **Connect input wires:** Connect the incoming power wires (line, neutral, and ground) to the input terminals of the SPD.
   - **Connect output wires:** Connect the wires leading to the equipment you're protecting to the output terminals of the SPD.
   - **Secure connections:** Tighten the wire nuts or screws to ensure secure connections.
5. **Test the SPD:**
   - **Use a surge tester:** If available, use a surge tester to verify that the SPD

is functioning correctly. Follow the manufacturer's instructions for testing.

6. **Energize the Circuit:**
   - **Turn on the power:** Once you've verified that the SPD is working properly, you can re-energize the circuit.
7. **Document the Installation:**
   - **Create a record:** Document the installation, including the type of SPD, its location, and any specific testing results. This information can be helpful for future reference and maintenance.

Practical Activity 2.8.4: Installing earthing system of domestic electrical circuit

Task:

1: Referring to the theoretical activity 2.8.1 you are requested to install the earthing system of domestic electrical circuit installed in practical activity 2.8.2.

2: Follow the instructions and technics provided in the key reading 2.8.1 and perform the task.

3: Present your final product to your classmates.

4: Read key reading **2.8.4** for more information about the steps of installing earthing system of domestic electrical circuit.

Key readings 2.8.4 Installing earthing system of domestic electrical circuit

Steps of installing earthing system

The installation of an earthing (grounding) system in a domestic electrical circuit is crucial for safety. It helps prevent electric shock by providing a path for fault current to flow safely into the ground. Below are the general **steps followed to install an earthing system** in a domestic electrical circuit:

1. Select the Type of Earthing System

- **Types of Earthing**: Common methods include plate earthing, pipe earthing, and rod earthing.
- **Material**: Choose the appropriate earthing material, such as galvanized iron (GI) or copper, based on the installation requirements.

2. Dig an Earth Pit

- **Location**: Choose a location away from the building foundation, water pipes, and electrical wiring.
- **Pit Dimensions**: Dig a pit of around 1.5 to 3 meters deep (depending on soil

conditions and local regulations).

- **Soil Treatment**: Use salt and charcoal to improve soil conductivity, especially in dry or high-resistance soil.

3. Install the Earth Electrode

- **Plate Earthing**: Install a copper or GI plate (about 60 cm × 60 cm) vertically at the bottom of the pit.
- **Pipe Earthing**: Insert a GI or copper pipe (about 2.5–3 meters in length) vertically into the pit.
- **Rod Earthing**: Drive a copper or steel rod into the ground.

4. Connect the Earthing Lead to the Electrode

- **Earthing Lead**: Use a GI strip or copper wire to connect the electrode to the main earthing terminal of the house.
- **Connection Method**: Bolt the earthing strip securely to the earthing electrode using clamps or nuts and bolts to ensure good electrical conductivity.
- **Protect the Connection**: Cover the connection point with waterproofing materials like bitumen to prevent corrosion.

5. Fill the Pit

- **Layering**: Fill the pit with alternate layers of charcoal, salt, and soil to maintain low resistance and improve the conductivity of the soil.
- **Covering**: Backfill the pit with the soil removed earlier, compacting it to ensure a solid structure.

6. Connect the Earth Electrode to the Distribution Board

- **Earthing Busbar**: Connect the earthing wire to the earthing terminal or busbar in the electrical distribution board.
- **Main Earthing Conductor**: Ensure that the main earthing conductor is securely connected to the metallic parts of electrical installations (such as the main switchboard, metal casings of electrical devices, etc.).

7. Testing the Earthing System

- **Earth Resistance Test**: Use an earth resistance tester to measure the earth resistance value. It should typically be below 2 ohms in domestic installations (depending on local regulations).
- **Continuity Test**: Perform a continuity test to ensure the connection between the earth electrode and the electrical system is intact.

8. Label the Earth Pit (Optional)

- **Identification**: For future maintenance, label the earthing system clearly, especially the earth pit location, so it can be easily identified later.

9. Maintenance of the Earthing System

- Regularly check and test the earthing system to ensure its efficiency and safety.

Over time, factors like corrosion or soil conditions may affect the earthing system's effectiveness.

Points to Remember

- **Protection device:** Protective devices are devices that are used to safeguard equipment, machinery, components, and devices in electrical and electronic circuits from short circuit, over current, and ground fault.
- **Circuit** breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit.
- Circuit breakers are of different types (MCB, MCCB, RCD, SPD, ELCB)
- **Fuse**: Is an electrical component designed to protect electrical circuits by safely opening the circuit(melts) under abnormally high current loads.
- Fuses are of different types (enclosed and semi enclosed; rewirelabe and dc or ac fuses)
- **Earth**: The conductive mass of the earth, whose electrical potential at any point is conventionally taken as zero.
- **To install a circuit breaker**, begin by turning off the main power and verifying with a voltage tester. Remove the panel cover, locate the busbar, and disconnect the wires from the old breaker if needed. Attach the wires securely to the new breaker, snap it into position, and test the circuit by turning the power back on. Finally, replace the panel cover. **For fuse installation,** turn off the power and locate the fuse box. Identify the correct fuse rating, remove the old fuse using a fuse puller if necessary, insert the new fuse, and test the circuit after restoring power.
- **To install a Residual Current Device (RCD),** begin by turning off the power and verifying the circuit is de-energized. Choose a suitable location, typically in moisture-prone areas like bathrooms or kitchens, and disconnect any connected devices. Remove the existing outlet or switch, and mount the RCD in the electrical box. Connect the incoming and outgoing wires as instructed by the manufacturer. Test the RCD to ensure it trips and resets properly, then reconnect the devices and verify that everything is functioning correctly.
- **To install a Surge Protective Device (SPD),** first ensure safety by turning off and confirming the power is de-energized. Identify an optimal location near the equipment for protection, minimizing cable length. Prepare the SPD by removing any cover and connect the incoming power wires to the input terminals and outgoing wires to the output terminals, securing all connections. Test the SPD with a surge tester if available to verify functionality. Once confirmed, restore power to the circuit and document the installation, including the SPD type, location, and testing results for future reference.

- **To install an earthing system**, first select the type of system (plate, pipe, or rod) and appropriate materials (galvanized iron or copper). Then, dig a pit about 1.5 to 3 meters deep, away from foundations, and improve soil conductivity with salt and charcoal. Install the earth electrode by placing a copper or GI plate, pipe, or rod at the bottom. Connect the electrode to the main earthing terminal using a copper or GI wire. Fill the pit with layers of soil, salt, and charcoal, and compact it. Finally, connect the electrode to the distribution board, test the system for low resistance (below 2 ohms), and maintain it regularly to ensure continued effectiveness.

Application of learning 2.8.

XYZ Company Ltd has a building of 12mx10m of length and width located in Nyagatare district, Karangazi sector where thunders are frequent. The building has 5rooms, 2 bathrooms 1 living room and 1 dining room without protection means. It is equipped with:

- 4 fluorescent lamps of 40W, 220V, 50Hz each
- 5 down lights of 26W, 220W, 50Hz each
- 1 freezer of 300W, 220V, 50Hz,
- 2 fridges of 200W,220V, 50Hz,
- Radio 25w 220v 50Hz
- and T.V 70w 220V 50Hz

Each room has 2 socket outlets whereby freezer and fridges are connected in the corner of dinning room. TV and radio are connected living room.

You as Electrician installer, you are called upon to install the power protection system of the above mentioned building following the following requirement specifications:

- Lamps and socket outlets will be protected separately
- Each room will be protected separately
- Lamps and socket outlets are earthed
- The building should be protected by the lightning arrestor.

All materials, tools and equipment's are provided. The task must be completed in 6 hours.

Indicative content 2.9: Installations of electric bells

Duration: 2

Theoretical Activity 2.9.1: Installations of electric bells

Tasks:

1: In small groups, you are requested to answer the following questions related to the of description of electrical bells.

i. **What do you understand is an electrical bell?**

ii. **Explain its working principle**

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key **readings 2.9.1.**

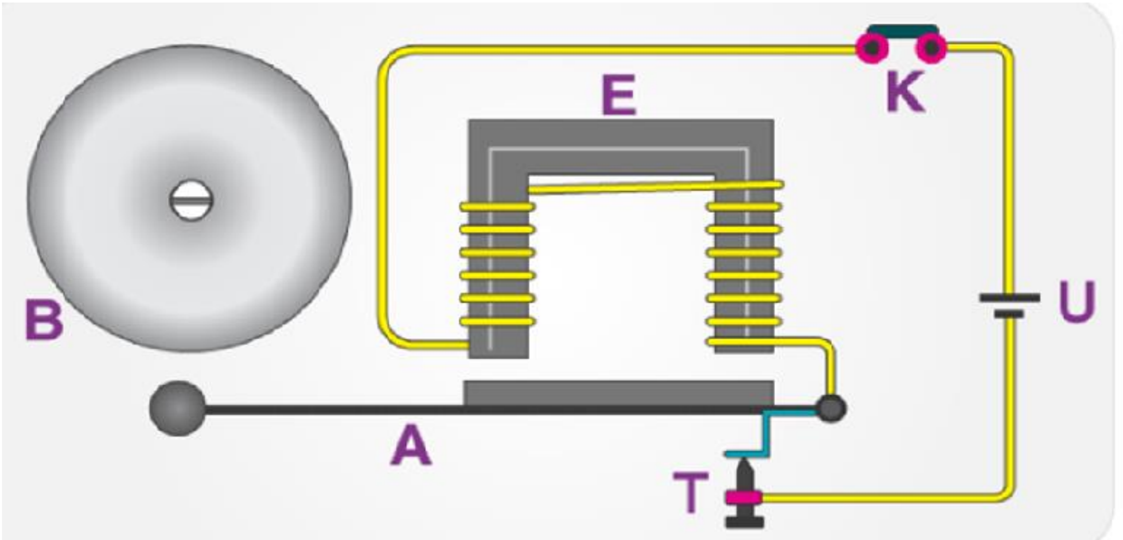
5: In addition, ask questions where necessary.

Key readings 2.9.1.: Installations of electric bells

Electric bell is an electromechanical device used for producing clamouring, ringing or buzzing noise when an electric current is passed through it. It consists of an insulated copper wire having many turns which are wound over a core made of ferromagnetic material. When a current is passed through the windings, the magnetic flux linked with them increases, increasing the magnetic field strength of the ferromagnetic core. When the electric current stops, the magnetic flux also stops. This is a classic use of electromagnets. Electromagnets are advantageous in comparison to permanent magnets, since the intensity of the magnetic field can be controlled by changing the electric current passed through it.

Construction and working of an electric bell

Electric bell primarily consists of a round shaped gong (B), a hammer (which strikes against the gong), and an electromagnet (E). The gong and hammer (A) are made of metal in order to produce a long ringing noise when struck with. The soft iron strip and the screw (T) are together known as the armature. When the user activates the switch, the electric current flows through the windings and makes the core behave like an electromagnet. When this electromagnet comes in contact with the armature, it triggers the hammer to strike against the gong. Later, the armature loses contact with the electrical magnet, the circuit is now broken and the ringing stops for a moment. The armature and the hammer return to their original positions. When this happens, the circuit becomes complete again, the current starts flowing. The process keeps repeating until the user releases the switch (K) and the current stops flowing–thereby demagnetizing the magnet. This type of bell is known as an interrupter bell– they are usually operated on 5 to 24 V AC.



1. When you press the push button, the circuit is completed, and current flows through the electromagnet coil.
2. The iron core in the electromagnet becomes magnetised and attracts the armature.
3. As the armature moves towards the electromagnet, it pulls away from the contact screw, breaking the circuit.
4. With the circuit broken, the electromagnet loses its magnetism, and the spring pulls the armature back to its resting position.
5. In its resting position, the armature touches the contact screw again, completing the circuit.
6. Steps 2-5 repeat rapidly, causing the armature to vibrate and strike the bell repeatedly, producing the ringing sound.

Types of electric bells

- Interrupter bells-This type of bells are used in households–their construction is explained above.
- Single stroke bells-They are used in railway stations. They produce a loud sound only once when struck with the hammer.
- Telephones-Telephones make use of a polarized bell, which usually operate on 60-105 Volts.
- Buzzers-Their working principle is similar to that of the interrupter bell.

Practical Activity 2.9.2: Installation of an electrical bell

Task:

1: Referring to previous activity (2.9.1) you are requested to perform the given task. The task should be done individually.

i. The owner of the house needs an electrician to install an electrical system alert of One bell controlled by a push button from the gate.

   a. Make the installation it as the owner's need

2: Draw electrical diagram to be used to perform the given tasks (2.9.2).

3: Referring to drawing provided from task 2, Perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading **2.9.2** and ask clarification where necessary Perform the task provided in application of learning **2.9**

Key readings 2.9.2 Installation of an electrical bell

Procedures to install an electrical bell

1: Mount at the right height

2: Remove the gong

3: Wire the fire alarm bell

4: Mount the bell to the outlet box or back box

5: Reattach the gong

6: Test the bell

Points to Remember

- **An electric bell** is an electromechanical device used for producing clamouring, ringing or buzzing noise when an electric current is passed through it.
- **Working principle**

1. When you press the push button, the circuit is completed, and current flows through the electromagnet coil.
2. The iron core in the electromagnet becomes magnetised and attracts the armature.
3. As the armature moves towards the electromagnet, it pulls away from the contact screw, breaking the circuit.
4. With the circuit broken, the electromagnet loses its magnetism, and the spring pulls the armature back to its resting position.
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Procedures to install an electrical bell

1. Mount at the right height
2. Remove the gong
3. Wire the fire alarm bell
4. Mount the bell to the outlet box or back box
5. Reattach the gong
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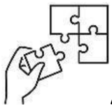


Application of learning 2.9

Mr Don has a building of 12mx10m of length and width located in Kayonza District, Mukarange Sector where this house has 4 gates. So he wants an electrician to install a bell controlled at every gate (using an impulse switch). As an electrician you are asked to draw the circuit and install it.

Indicative content 2.10: Testing techniques of electrical installations

Duration: 2

Theoretical Activity 2.10.1: Description of testing techniques of electrical installations

Tasks:

1: In small groups, you are requested to answer the following questions related to the of description of testing techniques of electrical installations.

Explain how to measure a continuity test.

i. Current measurement

ii. Voltage measurement

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key readings **2.10.1.**

5: In addition, ask questions where necessary.

Key readings 2.10.1.: Description of testing techniques of electrical installations

Definition of terms:

Continuity: is the presence of a complete path for current flow.

Current: is the rate at which electrons flow past a point in a complete electrical circuit.

Voltage is the pressure from an electrical circuit's power source that pushes charged electrons (current) through a conducting loop, enabling them to do work such as illuminating a light.

An ***electrical test*** is an evaluation of the parametric, functional, or timing performance of a component when electrical power is applied

Electrical measuring instruments are all the devices used to measure the magnitude of an electric current with different objectives.

Electrical measurements are the methods, devices and calculations used to measure electrical quantities.

1. Continuity Testing

Continuity is the presence of a complete path for current flow. A closed switch that is operational, for example, has continuity.

A continuity test is a quick check to see if a circuit is open or closed. Only a closed, complete circuit (one that is switched ON) has continuity.

During a continuity test, a digital multimeter sends a small current through the circuit to measure resistance in the circuit.

A meter with a continuity beeper briefly sounds off when it detects a closed circuit. The level of resistance needed to trigger the beeper varies by meter, but most will indicate continuity with a measurement between 0-50 ohms.

The audio signal speeds the measuring process since technicians do not have to look at the meter during testing.

Continuity testing determines:

- If a fuse is good or blown.
- If conductors are open or shorted.
- If switches are operating properly.
- If circuit paths are clear (accomplished by circuit or conductor tracing).

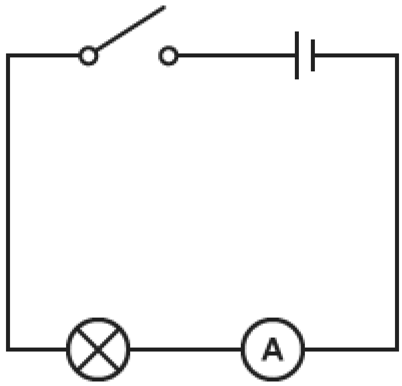
Continuity testing should be attempted only when voltage is NOT present in the circuit being tested.

Continuity testing safety

Always unplug the device or turn off the main circuit breaker before attempting a continuity test. Ensure that all capacitors are safely discharged.

If voltage contact is made while in continuity, most meters provide overload protection in ohms up to the meter's voltage rating. For most Fluke instruments, that is 1000 V ac.

2. Current Measurement



The ammeter is in series with the lamp

Measuring current

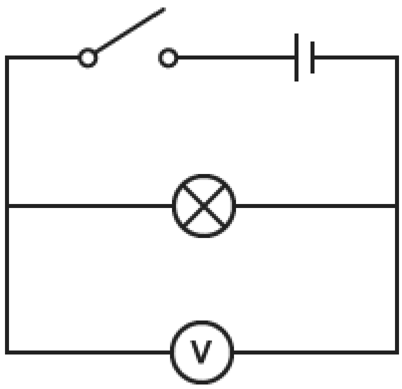
Current is measured in **amperes**. Amperes is often abbreviated to **amps** or **A**. The current flowing through a component in a circuit is measured using an ammeter. The ammeter can be placed anywhere in the circuit. Remember that the current is the same in all parts of a series circuit.

The ammeter must be connected in series with the component – remember, in a series circuit, electrical devices are placed one after the other in a continuous line in the circuit between the positive and negative poles of the battery.

3. Voltage Measurement

A voltage (or potential difference) across an electrical component, such as a lamp, is needed to make a current flow through it. Cells or batteries often provide the voltage needed.

Voltage is measured in **volts**, often abbreviated to **V**.



The voltmeter is in parallel with the lamp

The voltage across a component in a circuit is measured using a voltmeter.

The voltmeter must be connected **in parallel** with the component.

❖ **The testing techniques of electrical installations**

key testing techniques for electrical installations:

Visual Inspection:

- Conduct a thorough visual inspection of the installation. Look for any visible signs of damage, loose connections, or irregularities. Check that the components are installed correctly and that there are no exposed wires.

Continuity Testing:

- Verify the continuity of electrical conductors using a multimeter or continuity tester. This ensures that there are no breaks in the conductors, which could lead to open circuits.

Insulation Resistance Testing:

- Measure the insulation resistance between conductors and between conductors and earth. This test helps identify any insulation breakdown or deterioration. Insulation resistance testing is crucial to prevent short circuits and ensure electrical safety.

Earth (Ground) Resistance Testing:

- Measure the resistance between the electrical installation's grounding system and the earth. Low earth resistance is essential for proper grounding and helps prevent electric shock hazards.

Polarity Testing:

- Verify the correct polarity of the electrical installation, ensuring that live and neutral conductors are correctly connected. Incorrect polarity can lead to equipment malfunction and safety hazards.

Load Testing:

- Apply the maximum expected load to the electrical installation to ensure that it can handle the demand. This is particularly important for critical systems to prevent overloading and to verify that protective devices operate as intended.

Functional Testing:

- Test the functionality of all electrical components, switches, outlets, and other devices within the installation. Ensure that they operate correctly and safely.

Practical Activity 2.10.2: Test electrical installations

Task:

1: Referring to previous activity (2.10.1) you are requested to perform the given task. The task should be done **individually**.

Mr **Sebuhoro** would like to install an electrical lighting system in her house of living room, bedroom and the bathroom as follow:

- The living room comprises two fluorescent lamps controlled by two different locations
- The bedroom comprises one incandescent lamp and two outlet sockets. The lamp is controlled from two different positions.

- The bathroom comprises one Incandescent lamp and one socket outlet. The lamp is controlled by a bipolar switch.

Note that the:

- Lamps and socket outlets will be protected
- Lamps and socket outlets are earthed

After finishing the installation process, you are required:

- To test continuity
- To test short circuit

2: Draw electrical diagram to be used to perform the given tasks (2.10.2).

3: Referring to drawing provided from task 2, Perform the given task.

4: Present your work to the trainer and whole class.

5: Read key reading **2.10.2** and ask clarification where necessary Perform the task provided in application of learning **2.10**

Key readings 2.10.2: Test electrical installations

A multimeter is a measurement tool that can come in very handy for troubleshooting electrical or electronics projects.

Its parts include:

1. Probes: A DMM has two probes — one red and one black. Each has a plug and a metal strip used to connect your DMM to the electronic components you are measuring.
2. Dial: The dial is used to select the measuring entity. These entities vary based on the type of DMM used.
3. Display: The display shows a digital reading of the measuring entity and displays negative (-) sign.
4. Slots: The slots are used to connect two probes (different multimeters have a different slot configuration for the RED probe)

PROCEDURE TO CONNECT MULTIMETER

1. Gather your tools:

- Multimeter: Make sure you have the correct multimeter for the job you're doing. For basic home electrical work, a digital multimeter with voltage, current, and resistance measurement capabilities is sufficient.
- Probes: These are the test leads that connect the multimeter to the circuit you're testing. Most multimeters come with red and black probes, with the red probe typically used for the positive side of the circuit and the black probe for the negative side.
- Safety gear: Depending on the circuit you're working with, you may need to wear safety glasses and gloves to protect yourself from electrical shock.

2. Set the multimeter dial:

- Identify the dial or function selector on your multimeter. This dial allows you to choose the type of measurement you want to make (voltage, current, resistance, etc.) and the range of the measurement.
- Refer to your multimeter's manual for specific instructions on setting the dial for the desired measurement and range.

3. Connect the probes:

- Insert the black probe plug into the jack labeled "COM" or "common." This is the negative input for most measurements.
- Insert the red probe plug into the jack labeled for the specific measurement you're making. For example, for measuring DC voltage, the jack might be labeled "V-" or "DCV."

4. Touch the probes to the circuit:

- Touch the probe tips to the two points in the circuit you want to measure. Be sure to maintain proper polarity, with the red probe on the positive side and the black probe on the negative side.
- If you're measuring current, you may need to break the circuit and connect the probes in series with the component you're testing.

5. Read the measurement:

- The measured value will be displayed on the multimeter's screen.

This is the additional tips for connecting a multimeter safely and effectively:

- Always turn off the power to the circuit before you start testing.
- Double-check that you have the correct settings on the multimeter dial before touching the probes to the circuit.
- Don't overload the multimeter by measuring a current or voltage that is too high for its range.
- Keep the probe tips clean and sharp for good contact.
- Store the multimeter in a safe place when not in use.

Performing a Continuity Test

A continuity test checks whether two points of measurements are electrically connected or not. If both points are connected, then a beep generates, indicating continuity between two points.

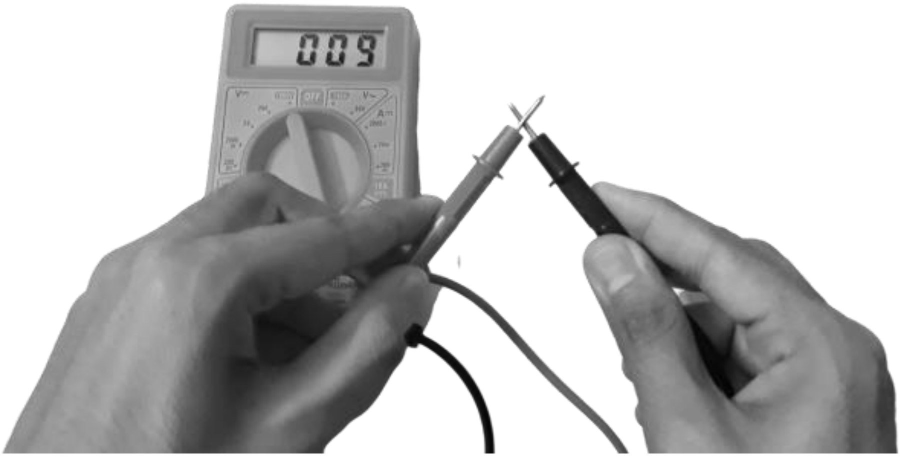
For a simple continuity test measurement, connect both red and black probes with each other.

Steps:

1. Set the multimeter to continuity mode. Look for a symbol that resembles a speaker or diode on the dial. This mode usually beeps or lights up an indicator when there is continuity.
2. Touch the probe tips together. This completes the circuit within the multimeter

itself and should trigger the continuity beep or indicator. This confirms that the multimeter and probes are working correctly.

3. Touch the probe tips to the two points in the circuit you want to test. Make sure to touch bare metal or the ends of exposed wires.
4. Observe the multimeter. If there is continuity, the multimeter will beep or light up the indicator. If there is no continuity, the multimeter will remain silent or the indicator will be off.



The continuity test checks for resistance between two points. If the resistance is less than a few ohms (Ω), it passes the continuity test and displays a small resistance value. If the resistance is large or there is no connection between the two points, it won't pass the continuity test and displays 0L.

This test can be used for various purposes. It can be used to trace tracks on PCBs or check whether two or more electrical or electronic components are connected or not.

Performing a Short Circuit Test using a Multimeter

A short circuit occurs when an unintended electrical connection forms between two points in a circuit, typically bypassing some or all of the intended current path. This can cause various problems, like overheating, component damage, and even fires. Fortunately, you can use a multimeter to identify and isolate short circuits.

Here's what you'll need:

- Multimeter: A digital multimeter is preferred for its ease of use and accuracy.
- Probes: The red and black test leads that come with the multimeter.
- Safety gear: Safety glasses and gloves are recommended when working with electrical circuits.

Steps:

1. Safety first! Turn off the power to the circuit you're testing before proceeding. This is crucial to avoid electrical shock.
2. Set the multimeter to resistance mode. Look for the Ω symbol on the dial. Some multimeters may have a dedicated "continuity" mode with a beeper, which can also be used for short circuit testing, but resistance mode provides more information.

3. Choose a high resistance range. Start with a high resistance range (e.g., 10MΩ) to avoid overloading the multimeter if there's no short circuit. You can always decrease the range later if needed.

Multimeter dial set to resistance mode

4. Identify the suspected short circuit points. Based on your understanding of the circuit or any visible signs of damage, identify the points you suspect might be connected unintentionally.
5. Touch the probe tips to the two points. Make sure the probes make good contact with bare metal or exposed wire ends.
6. Observe the multimeter reading.
    - High resistance reading (close to the selected range): This indicates no short circuit. The circuit is open as expected between those points.
    - Low resistance reading (close to 0 Ω): This suggests a strong possibility of a short circuit. The value might not be exactly 0 due to some internal resistance in the circuit itself.
7. Repeat the test for other suspected points. If you didn't find a short circuit in the first attempt, continue testing other points you suspect might be connected unintentionally.

Points to Remember

- The testing techniques of electrical installations are, Visual Inspection, Continuity Testing, Insulation Resistance Testing, Earth (Ground) Resistance Testing, Polarity Testing, Load Testing, Functional Testing

- Procedure to connect multimeter
  1. Set the multimeter dial
  2. Connect the probes
  3. Touch the probes to the circuit
  4. Read the measurement

Application of learning 2.10

XYZ hospital would like to install an electrical lighting system as follow:

- The living room comprises two fluorescent lamps controlled by two different locations
- The bedroom comprises one incandescent lamp and two outlet sockets. The lamp is controlled from two different positions.
- The corridor comprises two fluorescent lamps by controlled by two-way switch

And also it would like to install an electrical security lighting system. This security system will be installed by the help of four lamps which will be commanded automatically:

The first two incandescent lamps will be located in the garden to provide outdoor lighting and it will be controlled by a photo control switch which will turn on any time darkness appears.

The second two LEDs lamps will be located on the office veranda, and will be controlled by a digital time switch. The lamp will be switched ON from 6:00 pm to 6:00 am.

The installation is to be protected.

As technician, After installation processes you are asked to:

- Perform short circuit test and continuity test

Learning outcome 2 end assessment

Written assessment

1. Match the statement in column A with the statement in column B

Answers	Column A	Column B
1....	1) Resistance	Kelvin(K)
2.......	2) Ohm's law	is defined as the work accomplished when a unit positive electric charge is moved from one point nother.
3.......	3) Luminous intensity	meters per second squared
4........	4) Current	The flow of electric current is subject to friction pposition, and is the property of a conductor that ts current.
5.......	5) An insulator	Joules
6......	6) Acceleration	is a material having a low resistance which ws electric current to flow in it. All metals are ductors
7......	7) Thermodynamic temperature	is the reciprocal of resistance
8.....	8) Potential erence	Watt
9.....	9) A conductor	is the rate of movement of charge
10....	10) Energy	Candela(cd)
		is a material having a high resistance which does allow electric current to flow in it
		The current I flowing in a circuit is directly portional to the applied voltage V and inversely portional to the resistance R, provided the perature remains constant.

2. **Fill in the following sentences with a suitable term**.
   The area around a magnet is called the ………………… and it is in this area that the effects of the ………………. Produced by the magnet can be detected. The magnetic flux density is calculated using the following formula……………….and expressed in ………….In vacuum (in free space) the Permeability of free space is equal to
3. List any four(4) causes of fire in electrical installation
   Answer:
   Loose connections
   Overloaded circuits
   Wrongly rated fuses

Damaged insulation.

4. **Read the following statement, and Answer by True or False**
   a) Electrical Load is the part or component in a circuit that only converts electricity into light
   b) Resistive loads is the load that resist current flow linearly and cause heat and light
   c) Inductive loads resist *changes* in current and as such, when you measure the current, it leads the voltage
   d) Capacitive loads are for many purposes, the opposite of inductive loads. They resist *changes* in voltage, and as you'd expect, the voltage lags the current
   e) The important thing to remember about inductive loads is that they have *two* types of power, apparent power and reactive power
   f) A capacitor is two conductive surfaces separated by an insulator, which store charge
   g) The conductor cross section plays a very significant role. The smaller it is, the smaller the electrical resistance of the conductor
   h) Current carrying capacity of a cable is defined as the amperage a conductor can carry before melting either the conductor or the insulation.
   i) AC power plugs and sockets connect electric equipment to the direct current (DC) power supply in buildings and at other sites
   j) A lighting control system creates the ability for all of a home’s lighting to be controlled together

5.

A) There are many factors which will limit the amount of current that can be passed through a wire. These major determining factors are:

i) Conductor Size
ii) Conductor Number
iii)Installation Conductors
iv)Ambient Temperature
v) all above are correct
vi) None of above

B) Cable size is selected as follows, Except:

a) Physical properties of the conductor (tensile strength, voltage drop, conductivity, weight)
b) Cable is calculated on current capacity
c) Voltage drop is calculated (and cable size increased if necessary)
d) Fault level withstand is calculated (and cable size increased if necessary)

C) The voltage sensing system for ELCB has a lot of disadvantages, which include, Except:

i. Wire break in the fault to load section or Earth to ground section will results, a failure in operation of ELCB, and user may get severe electric shock, during Earth fault

ii. They are less sensitive to fault conditions, and therefore have fewer nuisance trips

iii. Requirement of an additional third wire from the load to the ELCB.

iv. Separate devices cannot be grounded individually.

v. The voltage-operated ELCB are the requirement for a second connection

D) For the following statements, which one is not the characteristics of Miniature Circuit Breaker (Select one or more)

a. Provides protection against over currents and short circuits
b. Trip level can be varied
c. Commonly used in lighting circuits
d. These are thermal /thermo-magnetic/ Electronic trip level
e. Available up to 100A and have a maximum short circuit capacity of 25kA

6. Give three (3) types of fuses
7. Differentiate a fuse from circuit breaker
8. Write down the main function of the following equipment:

a) Gloves**:**
b) Goggles:
c) Helmet:
d) Eye protection:
e) Safety shoes:

9. Write in full word the following term:

a) SPD:
b) ELCB:
c) MCB:
c) RCBO:
d) MCCB:

10. Sketch the symbol of:

a) Fuse
b) Pull cord switch
c) Push button
d) Circuit breaker
e) Bipolar switch
f) Timmer switch
g) Impulse switch
h) Photocontrol

Practical assessment

XY BETTER SERVICE Ltd is a new company located in GATSIBO District, GATSIBO Sector. This company have assigned different electrical installation tasks to his group of electricians for houses installation. One of those houses is located at EASTERN province, KAYONZA district. The owner needs an electrician to lay electrical conduit and install electrical lighting control system, alarm and power sockets as follow:

- The kitchen comprises one LED lamp and two single phase outlet sockets. The lamp is controlled from two different positions.
- The living room comprises two incandescent lamps controlled by impulse switch from three different positions and thermostat temperature control switch which controls an electric fan and comprises power circuit consisting of two earthed socket outlets
- The bedroom comprises two lamps and one outlet socket. Bed room's lamp controlled by 2 gang 2-way switch (Use a pull switch)
- The bathroom comprises one lamp and one socket outlet both controlled by a bipolar switch.
- The corridor comprises two fluorescent lamps controlled from three different positions.
- Outdoor lighting system consisting of two lamps automatically switched ON and OFF by means of motion sensor.
- One bell controlled from the gate and also comprises two lamps controlled by a twilight switch.
- Changeover by means of contactors to connect REG main grid to the backup generator

Note that:

- ✓ The installation should be protected against overload and short-circuit. The protection should be done by circuit breakers (MCBs and RCD) and the entire installation should be grounded.
- ✓ Test the continuity and short circuit should be done
- ✓ Tools, material and equipment are provided.

As electrical technician, you are assigned to:

- ➢ Draw the wiring diagram for the installation to be extended
- ➢ Perform domestic electrical installation in accordance with the wiring

The duration of the work is 6 hours.

All Resources are available

Tools: Pliers, screwdrivers, drill machines

Equipment: Circuit breakers, impulse switch, switches, lamps, socket outlets, sensor switches

Material/Consumable: Wires, insulator tape, papers, switch boxes, junction boxes, conduits

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Learning Outcome 3: Prepare technical report and invoice

Indicative contents
3.1. Identification of main parts of technical report **3.2. Prepare technical report** **3.3. Cost estimation techniques** **3.4. Generating invoice (proforma, invoice)**

Key Competencies for Learning Outcome 3: Prepare technical report and invoice

Knowledge	Skills	Attitudes
• Identification of main parts of technical report • Description of Cost estimation techniques	• Generating invoice (proforma, invoice) • Preparing technical report • Preparing Cost estimation techniques	• Having an innovative spirit • Having Creativity • Having Critical thinking • Having Teamwork • Having Problem Solving • Being Patience

Duration: 6 hrs

Learning outcome 3 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify properly the main parts of technical report in line with the reporting procedures.
2. Prepare correctly technical report according to the work to be done
3. Describe clearly Cost estimation techniques according to the work to be done
4. Generate effectively the invoice (proforma, invoice) according to the work to be done

Resources

Equipment	Tools	Materials
• Computer (Desktop or Laptop), • Printer	• Calculator	• Papers, • Flash disk, • Pens

Indicative content 3.1: Identification of main parts of a technical report

Duration: 1 hr

Theoretical Activity 3.1.1: Identification of technical report

Tasks:

1: In small groups, you are requested to answer the following questions related to the of technical report.

- **i. Define a technical report**
- **ii. Identify main parts of a technical report**
- **iii. What is the Importance's of Writing a Technical Report?**

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key readings **3.1.1.**

5: In addition, ask questions where necessary

Key readings 3.1.1.: Identification of technical report

Description of technical report

1. Definition of Technical report

"A technical report is a document written by a researcher detailing the results of a project and submitted to the sponsor of that project."

In the field of electricity and electrical engineering, technical reports are essential for ensuring safety, compliance, quality, and effective communication. They serve as a means to capture, analyse, and communicate information, making them a valuable tool for professionals in the industry.

Main purpose of technical report

The main purpose of an Engineering technical report is to present a solution to a problem in order to prompt action. Technical reports provide a record of your developing expertise and are a legal record of your work and decision making.

Major characteristics of report writing

Precision

In a good report, the report writer is very clear about the exact and definite purpose of writing the report. This central purpose directs the investigation, analysis, recommendations, and others. The precision of a report provides unity to the report and makes it a valuable document for best usage.

Accuracy of Facts

Information contained in a report must be based on accurate facts. Since decisions are based on report information, inaccurate information or statistics will lead to a wrong decision. It will hamper ensuring the achievement of the organisational goal.

Relevancy

The facts presented in a report should be accurate and relevant. Irrelevant facts make a report confusing and likely to be misleading.

Simple Language

Simplicity is the best for anything. It is just another essential feature of a good report. A good report is written in simple language, avoiding vague and unclear words. The writer's emotion or goal should not influence the report's language. The message of a good report should be self-explanatory. A good reporter should use simple sentences instead of complex sentences in the narration of facts.

Conciseness

A good report should be concise, but it does not mean that a report can never belong. Rather it means that a report transmits maximum information with minimum words. It avoids unnecessary detail and includes everything significant and necessary to present proper information.

Grammatical

A good report is free from errors. Any faulty construction of a sentence may change its meaning in the reader's mind and potentially make it confusing or ambiguous.

Recommendation

Recommendations usually affect the reader's mind. Therefore, if recommendations are made at the end of a report, they should be impartial and objective and come to a logical conclusion for investigation and analysis.

a. Clarity

Clarity depends on the proper arrangement of facts. A good report is absolutely clear. The reporter should clarify their purpose, define their sources, state their findings, and make a necessary recommendation. A report must be clear to understand to ensure effective communication throughout.

b. Presentation

The presentation of a report is also a factor that should be considered for a good report. The structure, content, language, typing, and presentation style of a good report should be attractive to make a clear impression in the mind of its reader.

c. Complete Information

A good report shows important information. Most of this information is analyzed as the basis of importance. The report should not contain useless or vague information.

Importance of Writing a Technical Report

1. Efficient communication

Technical reports are used by technicians to convey pertinent information to upper management or clients. This information is then used to make crucial decisions that would impact the company in the future.

2. Evidence for your work

Most of the technical work is backed by software.

So, if you're a technician, your technical report acts as the sole evidence of your work. It shows the steps you took for the technical works and glorifies your efforts for a better evaluation.

3. Organises the data

A technical report is a concise, factual piece of information that is aligned and designed in a standard manner. It is the one place where all the data of a project is written in a compact manner that is easily understandable by a reader.

4. Tool for evaluation of your work

Professors and supervisors mainly evaluate your research project based on the technical write-up for it. If your report is accurate, clear, and comprehensible, you will surely bag a good grade.

The main parts of a technical report

a) Introduction

The material which you are about to present in the main body of the report must be set in context depending on the type of project/report or issue handled. This section gives the reader the necessary background information and leads straight into the report itself. A typical introduction can include the following content:

- Main aim/s, objective/s and scope (the parameters) of the report
- identify the importance of the current project for technical issue,
- an overview of the report's sections
- method(s) of approach
- indications of scope and limitations of the study
- outline of material presented in the rest of the report.

b) Body

This will include all the main content of the report like what task was at hand, what were the findings about the faults, what methodology was used to find the findings/results, comparison and discussion of the results. This is usually the longest and most important part in the structure of the report so the material must be presented logically to make it is easy to read. It is divided into numbered and headed sections. These sections separate the different main ideas in a logical order.

c) Conclusion & recommendations

i) Conclusion

It answers the questions raised by the original research problem or objectives of the study. The conclusions should be a condensed version of the intervening sections giving the key findings of the work. No new scientific argument should be presented here - everything should have already been discussed in the "Discussion".

- reference to original aim(s) and objective(s) of report,
- limitations and advantages of the findings,
- objective opinion, evaluation or judgement of the evidence

The conclusion must arise from the evidence discussed in the body of the report. It should not, therefore, subjectively tell the reader what to do, this job is performed by the recommendations section.

ii) Recommendations

In some reports recommendations are also required along with conclusions. The recommendations should emerge from the conclusions of the report. Recommendations tell the reader what to do: what decision to make, what course of action to take, what solution is superior or what further work needs to be undertaken. The recommendations section should never contain any new evidence and should arise from the information presented in the body and conclusion sections.

Recommendations in the technical report structure should be feasible and appropriate to the problem; for example, their cost should be realistic to the budget and they should be ethical. They should be as concrete and specific as possible; they should be read as a list of things the client should do. They can be written in descriptive as well as bullets form, whatever is desired. Let your reader know why you are recommending an action by supplying the reasons for your decision drawn from the conclusions of the report

Points to Remember

- **A technical report is** a document written by a researcher detailing the results of a project and submitted to the sponsor of that project.
- **The main parts of a technical report**

  a) Introduction

  b) Body

  c) Conclusion & recommendations

- **Importance of Writing a Technical Report**

  1. Efficient communication

  2. Evidence for your work

  3. Organizes the data

  4. Tool for evaluation of your work safely.

Indicative content 3.2: Preparation of technical reports

Duration: 1 hr

Practical Activity 3.2.1: Preparation of technical reports

Task:

1: Referring to previous activities (3.1.1 and 3.1.2) you are requested to perform the given task. The task should be done individually.

i. Refer to the Practical Activity (2.7.2) you are asked to make the technical report of the given tasks.

2: List out procedures to perform the given tasks (3.1.1)

3: Referring to procedures and formulas provided on task 2, Perform the given tasks (a and b)

4: Present your work to the trainer and whole class.

5: Read key reading **3.2.1** and ask clarification where necessary Perform the task provided in application of learning 3.2

Key readings 3.2.1 : Preparation of technical reports

- **Preparation of technical reports**

Technical reports usually require a title page. To know what to include, follow the conventions required in your subject. A technical report summary (or abstract) should include a brief overview of your investigation, outcomes and recommendations.

Engineers need to be good writers too—and technical reports prove it! A good technical report presents data and analysis on a specified topic in a clear, highly-organized, and effective manner. Before you begin writing, define your message and audience, and make an outline. Then, write the main body of the report and surround it with the other necessary sections, according to your chosen layout.

Planning Your Report

Establish the message you want to convey through the report. You've done your research and collected your data, so now it's time to ask yourself what it all means.

How will you define the problem or topic you are addressing, and what conclusions can you draw based on the data and evidence?

- For instance, you may want to convey the message that a new technique for extracting a particular chemical compound is both safer and more cost-effective.
- The best technical reports remain clear and focused throughout—they have a specific purpose and convey the information in a logical order.
- Work with advisors, supervisors, or colleagues to fine-tune the message and/or goal of your report. These can vary widely depending on whether the report is being produced for academic, business, or other purposes.

Define your audience before you begin writing. Who will be reading your report—fellow researchers, corporate executives, the general public, or someone else? It's imperative that your report is written in such a way that its data and findings can be easily understood by its intended audience.

- If others in your field will be reading the report, it can be more "technical" in language and detail. In many cases, though, technical reports are intended for those outside of your particular discipline. If so, cut back on the jargon for non-expert readers.
- Consider having a non-expert friend look over your report throughout the process to give you feedback on its accessibility to a broad audience.

Create an outline to follow while you write. Technical reports are usually very structured, often with clearly-labelled and numbered sections. Therefore, it's fairly straightforward to draw up an outline that identifies each major element of the report.

- Determine which particular sections your report must or may have. Consult the person or organisation to whom you'll be submitting the report for any layout requirements.

Writing the Main Body of the Report

Create a thorough but focused introduction to the report. The introduction to a technical report lays out the main problem or issue your paper addresses, and how you go about addressing it in the report. It should indicate to the reader why the issue at hand is important, and clearly establish the objectives for your report.

- In most cases, the introduction will likely be 1-3 paragraphs in length.
- The end of the introduction should clearly state what the report “does.” It might do so by way of a direct statement (“This report analyzes…”), or by providing a series of questions (which may in some cases be bulleted or numbered) to be addressed.

Provide background information and/or a literature review in the next section. Right after the intake, delve into the basic circumstances surrounding the topic at hand—a quick history of the problem and its relevance today, for instance. If it has been a topic of sustained debate within your field, you might also walk readers through important examples of past work on the subject.

- Essentially, you want readers who may be new to the subject matter to feel like they have at least a rudimentary grasp of it after reading this section.

Follow up with a clear and detailed project description. In this section, you basically tell your reader what it is you actually did to tackle the problem or issue at hand. Tell them what type of testing or analysis you did, using what methods and equipment, and any other relevant details.

- If, for instance, your report is focused on a particular experiment, be specific on the way it was conceived, set up, and conducted.
- This is sometimes called a “methods” section, since you are describing the methods used to conduct your research.

Present your data and describe what it all means in the next sections. You’ve now reached the heart of a technical report, in which you clearly lay out and contextualise the data you’ve gathered. In most cases, you’ll need to provide numerous figures and tables to present the actual data. Don’t rely exclusively on them, though—use text to put the findings into a context that is appropriate for your intended audience.

- It can be hard to determine how much data to present. Giving too little can significantly weaken your analysis and the overall report. Giving too much, however, can drown the reader in a sea of tables and figures. Make sure you provide all essential data, and err on the side of providing a bit too much unless otherwise instructed.

- Present your data in a logical order, so that each table or figure leads into the next one.

Round out the report with a conclusion that bookends your introduction. In a technical report, your introduction should raise the "big" questions and your conclusion should provide your answers. If, for instance, you listed several specific questions in your intro, answer them specifically in the conclusion. Otherwise, use it to pull together your findings into a clear, convincing statement.

Be as bold in your conclusions as your data and analysis permits you to be. Don't use terms like "might," "perhaps," "could," and so forth—write something like, "The data shows that…" However, don't draw conclusions that aren't supported by your data.

Points to Remember

- **While Planning/ preparing Your Report:**
  - ✓ Establish the message you want to convey through the report.
  - ✓ Define your audience before you begin writing
  - ✓ Create an outline to follow while you write.
  - ✓ Create a thorough but focused introduction to the report
  - ✓ Provide background information and/or a literature review in the next section.
  - ✓ Follow up with a clear and detailed project description.
  - ✓ Present your data and describe what it all means in the next sections.
  - ✓ Round out the report with a conclusion that bookends your introduction

Application of learning 3.2.

Referring to the Practical Assessment at the end of learning outcome 2 you are asked to prepare a technical report of the given tasks.

Indicative content 3.3: Cost estimation techniques

Duration: 2

Theoretical Activity 3.3.1: Introduction to cost estimation techniques.

Tasks:

1: In small groups, you are requested to answer the following questions related to the of description of application of cost estimation techniques.

- **i. Define cost estimation used by electricians**
- **ii. What is the purpose of estimating and costing?**
- **iii. What are the Cost estimation techniques?**

2: Provide the answer for the asked questions and write them on papers.

3: Present the findings/answers to the whole class

4: For more clarification, read the key readings **3.3.1.**

5: In addition, ask questions where necessary.

Key readings 3.3.1.: Introduction to cost estimation techniques

- **Introduction to Cost estimation techniques**

Definition of Cost Estimation

Electrical estimation and costing are the process of determining the cost of an electrical project based on the materials, labour, and equipment needed to complete it. This typically includes analysing the project scope, identifying necessary materials and equipment, and estimating the amount of time and labour required to complete the project. The final cost estimate is then used to budget for and manage the project. There are two general methods of creating accurate electrical estimates: computer software or manual calculations.

Cost Estimating is an art by which we can get an approximation of the material, investment involved and the time to be taken for the completion of an electrical project.

Purpose of Estimating & Costing:

- It is necessary to know the necessary material and the cost to be incurred before starting the project.

- To ensure all the materials required for the execution of the project.
- To avoid the misuse of money.
- To save time required for completion of the project.
- To complete the project uninterruptedly.

Cost estimation techniques
(Guides on how to estimate the cost of electrical installation**)**

Estimating the cost of electrical installation for a project, whether it's a residential, commercial, or industrial application, involves several steps and considerations. Here's a general guide on how to estimate the cost of electrical installation:

1. Scope Definition:

Clearly define the scope of the electrical installation project. This includes identifying the type of building or facility, the electrical requirements, and any specific electrical systems or components needed.

2. Drawings and Plans:

Obtain electrical drawings, blueprints, or plans for the project, if available. These documents will provide valuable information about the layout and requirements of the electrical system.

3. Material and Equipment List:

Create a detailed list of all the electrical materials, components, and equipment required for the project. This should include items such as wiring, conduits, switches, outlets, circuit breakers, panels, lighting fixtures, and any specialised equipment.

4. Labour Costs:

Estimate the labour costs, including the number of electricians needed and the hours required for installation. Consider factors like local labour rates and any union agreements that may apply.

5. Site Conditions:

Assess the site conditions, including the complexity of the installation, accessibility, and any unique challenges (e.g., working at heights, confined spaces, hazardous environments).

6. Permit and Inspection Fees:

Account for any fees associated with obtaining electrical permits and scheduling inspections. These costs can vary depending on your location.

7. Travel and Accommodation (if applicable):

If the project is in a different location, consider travel and accommodation costs for your team.

8. Review and Documentation:

Document the cost estimate in a clear and organised manner, including all calculations and assumptions made during the estimation process.

9. Present the Estimate:

Present the cost estimate to the client or project stakeholders. Ensure that they understand the breakdown of costs and the basis for the estimate.

It's important to keep in mind that electrical installation costs can vary significantly depending on factors such as location, project size, complexity, and specific requirements. Therefore, it's crucial to conduct a thorough and accurate estimation process to provide an appropriate budget and avoid unexpected cost overruns during the project. Additionally, it's recommended to regularly update the estimate as more information becomes available throughout the project's lifecycle.

Practical Activity 3.3.2: Apply Cost estimation techniques

Task:

1: Referring to previous activities (3.2.1) you are requested to perform the given task. The task should be done individually.

i. Refer to the Practical Activity (2.7.2) you are asked to make the cost estimation of the given tasks.

2: List out procedures to perform the given tasks (3.2.2)

3: Referring to procedures and formulas provided on task 2, Perform the given tasks (a and b)

4: Present your work to the trainer and whole class.

5: Read key reading **3.3.2** and ask clarification where necessary Perform the task provided in application of learning **3.3**

Key readings 3.3.2 Apply Cost estimation techniques

- **Apply Cost estimation techniques**

The steps follow while doing Cost estimation:

- Define Scope
- Drawings and Plans
- Material and Equipment List
- Labour Costs
- Site Conditions
- Permit and Inspection Fees
- Travel and Accommodation (if applicable)
- Review and Documentation
- Present the Estimate

. Electrical estimation and costing is the process of determining the cost of an electrical project based on the materials, labour, and equipment needed to complete it.

. Purpose of Estimating & Costing:

- It is necessary to know the necessary material and the cost to be incurred before starting the project.
- To ensure all the materials required for the execution of the project.
- To avoid the misuse of money.
- To save time required for completion of the project.
- To complete the project uninterruptedly.

The steps follow while doing Cost estimation :

- Define Scope
- Drawings and Plans
- Material and Equipment List
- Labour Costs
- Site Conditions
- Permit and Inspection Fees
- Travel and Accommodation (if applicable)
- Review and Documentation
- Present the Estimate

Points to Remember

- **Electrical estimation and costing** is the process of determining the cost of an electrical project based on the materials, labor, and equipment needed to complete it.
- **Some purposes of Estimating & Costing are,** It is necessary to know the necessary material and the cost to be incurred before starting the project, To ensure all the materials required for the execution of the project, To avoid the misuse of money and To save time required for completion of the project.
- **The steps follow while doing Cost estimation:**
    - Define Scope
    - Drawings and Plans
    - Material and Equipment List
    - Labour Costs
    - Site Conditions
    - Permit and Inspection Fees
    - Travel and Accommodation (if applicable)
    - Review and Documentation
    - Present the Estimate

Application of learning 3.3.

Referring to the Practical Assessment at the end of learning outcome 2 you are asked to do cost estimation of the given tasks.

Indicative content 3.4: Generating invoice (proforma invoice)

Duration: 2

Theoretical Activity 3.4.1: Description of invoice (proforma)

Tasks:

1: In small groups, you are requested to answer the following questions related to the description of invoice (proforma invoice)

i. **Define invoice**

ii. **What is proforma?**

iii. **Describe the elements of the invoice?**

2: Provide the answer for the asked questions and write them on papers/Flip charts.

3: Present the findings/answers to the whole class

4: For more clarification, read the key readings **3.4.1.**

5: In addition, ask questions where necessary.

Key readings 3.4.1.: Description of invoice (proforma)

- **Description to invoice (proforma, invoice)**

Definition of terms

a) Proforma

A proforma invoice is a preliminary invoice that is sent to a buyer before a sale is confirmed. This invoice highlights the deliverables from the seller's end such as the goods or services to be delivered, their prices, shipping information, and delivery date. After reviewing the proforma invoice, the buyer gives the green light to the seller. The seller proceeds to send a sales invoice and starts working on their part of the deal—manufacturing the products or providing the service.

When a proforma invoice is issued?

A proforma invoice is issued when a seller has discussed the preliminaries of a sale with the buyer but cannot proceed to send an official invoice since the final details of the deal aren't confirmed by the buyer yet. A proforma invoice can be issued to let the buyer know what exactly to expect from the seller.

A pro forma invoice is a preliminary bill of sale sent to buyers in advance of a shipment or delivery of goods. The invoice will typically describe the purchased items and other important information, such as the shipping weight and transport charges. Pro forma invoices often come into play with international transactions, especially for customs purposes on imports.

A pro-forma invoice is a binding agreement, although the terms of sale are subject to change.

Why do businesses use proforma invoice?

A proforma invoice is used:

- To let the buyer know what to expect from the supplier and to invite negotiation
- To show the supplier's willingness to offer the goods and services at the discussed price, on the promised date
- To acknowledge the buyer's acknowledgment and intent to pay
- To streamline the quote-to-cash process
- To act as a quote for internal purchase approval protocols for the buyer
- To save processing time and costs

On the other hand, a proforma invoice is not a legal agreement since it's only a draft. A proforma invoice is also not a document requesting a payment.

However, the following fields are typically included in a proforma invoice:

1. The document title 'Proforma Invoice'
2. Buyer's details such as the company name, billing address, and shipping address
3. Seller's details such as the company name and address
4. Payment terms
5. Invoice creation date
6. Invoice expiration date
7. Description of the goods or services
8. The prices of the goods and services
9. Quantity of the goods and services
10. Discounts
11. Taxes
12. Total

b) Invoice

Definition of invoice

An invoice is a commercial document that records a transaction between a seller and a buyer. It serves as a formal request for payment for goods or services provided.

Invoices typically include specific details related to the transaction and are used for accounting, financial record-keeping, and tax purposes.

Other terms:

- An invoice is a document that maintains a record of a transaction between a buyer and seller, such as a paper receipt from a store or an online record from an e-tailer.
- Invoices are a critical element of accounting internal controls and audits.
- Charges found on an invoice must be approved by the responsible management personnel.
- Invoices generally outline payment terms, unit costs, shipping, handling, and any other terms outlined during the transaction.

Types of invoices

- ✓ a paper receipt,
- ✓ a bill of sale,
- ✓ a debit note,
- ✓ a sales invoice,
- ✓ an online electronic record.

Is an Invoice a Bill or Receipt?

An invoice is generally used to document products or services sold and delivered to a customer, so it is a bill. A receipt is a document that shows payment was received.

Creating an Invoice: Step by Step

If you want to create a professional invoice that stands up to audits and streamlines the payment process, consider the following steps:

1) Use Clear Language

Customers should always know that they're receiving an invoice. Simply adding the word "invoice" will prompt buyers to take the document seriously and pay on time, as the label makes it stand out from other documents in the pile. In some cases, it's the law to include clear language.

2) Professionalism

Make sure the document looks professional. This includes matching fonts, accurate calculations, and branding in the proper places. If you're not sure how to create the format for an invoice, there are hundreds of free invoice templates online.

3) Contact Information

This includes the information from both the buyer and the seller. The invoicing process should always include the following:

- Your company's name, address, and contact information
- The customer's name, address, and contact
- Any specific names or addresses for the accounts payable department

4) Describe the Goods and Services

This doesn't need to be long, but it should include enough information so the customer can easily identify what they are paying for. Make sure to include quantities and amounts, as this can be an area of invoice dispute that leads to delayed payments.

Here's a quick checklist of what to include in your product/services section:

- The date any service was completed
- A description of services/products that specifies the unit level
- Total number of units and rate
- Total amount due
- Any applicable tax

5) Adding Dates

Make sure you add all essential dates as well. This includes:

- The date the invoice was created
- The date the goods/services were provided

The invoice data should always be at the top. The date the goods/services were provided can be in the description.

6) Calculating What is Due

This is the most important part of the invoice. In addition to the costs of individual goods and services, you must put the total amount owed. If you've agreed to an early payment discount with the customer, this should also be noted on the invoice and subtracted from the cost. If it's applicable, include the VAT amount too.

7) Mention the Payment Terms

Payment terms are agreed upon with the customer during the initial contract period. However, the payment terms should be noted on the invoice as well. If you expect to be paid within a certain time period, remind people by stating that clearly.

The more information included on an invoice, the easier it is for a customer to pay you. This helps maintain positive cash flow and strengthens business relationships.

What should an invoice include?

The specific things to be added to your invoices depend on the industry you are in, region-specific regulations, and the type of work you do.

Here are the key elements you'll find on a typical invoice:

Header Information:

Seller's Business Name and Contact Information: This includes the seller's name, address, phone number, and email.

Buyer's Business Name and Contact Information: The buyer's name, address, phone number, and email.

Invoice Date: The date on which the invoice is issued.

Invoice Number: A unique identifier for the invoice, often used for tracking and reference.

Payment Information:

Payment Due Date: The date by which the buyer is expected to make payment.

Payment Methods: Details on how the buyer can make the payment, including bank account information or payment portal links.

Payment Terms: Specific payment terms and conditions, such as late payment fees or discounts for early payment.

Itemised List of Goods or Services:

Description of Goods/Services: A detailed list of the products or services provided, often including a brief description, quantity, and unit price.

Quantity: The number of units or items sold.

Unit Price: The price of one unit or item.

Subtotal: The total amount for each line item (quantity multiplied by unit price).

Total Amount: The sum of all subtotals.

Taxes and Fees:

Sales Tax or Value Added Tax (VAT): If applicable, the invoice may include taxes based on local tax laws.

Other Fees: Any additional fees, such as shipping costs or handling charges.

Grand Total: The total amount to be paid, including taxes and fees.

Additional Information: Purchase Order (PO) Number: If the transaction is associated with a purchase order, the PO number is often included for reference.

Terms and Conditions: Any specific terms or conditions related to the sale or payment.

Notes or Messages: Space for additional information, such as special instructions, messages, or acknowledgments.

Company Logo and Branding: Some invoices include the seller's company logo and branding for a professional appearance.

Payment Instructions: Clear instructions on how the buyer should remit payment, such as a mailing address or bank details.

Invoices are used for both business-to-business and business-to-consumer transactions. They provide a formal record of the transaction and help both parties maintain accurate financial records. In addition to their accounting and payment function, invoices also serve as legal documents that can be used to resolve disputes or for tax reporting and compliance.

Practical Activity 3.4.2: Generating invoice (proforma invoice)

Task:

1: Trainer provide tasks

Referring to the Practical learning on Indicative content 2.7.2 you are asked to generate an invoice for the given tasks.

2: Trainer provide instructions regarding to the task

3: Preparation and selection of materials, tools and equipment depending on the given task

4: Trainer demonstrates and explain to the trainees how the work is done

5: Asks learners to imitate what the trainer did

6: Trainer guidance, monitor and gives explanation if necessary

7: Announces the end time for the task

8: Trainer uses checklist to assess the performed trainee's task and asks learners to read the key readings **3.4.2**

Key readings 3.4.2 Generating invoice (proforma invoice)

A proforma invoice is a preliminary invoice that is sent to a buyer before a sale is confirmed.

An invoice is a commercial document that records a transaction between a seller and a buyer.

Types of invoices

- ✓ A paper receipt,
- ✓ A bill of sale,
- ✓ A debit note,
- ✓ A sales invoice,
- ✓ An online electronic record.

The key elements you'll find on a typical invoice:

- Header Information
- Payment Information
- Itemised List of Goods or Services
- Taxes and Fees
- Additional Information
- Payment Instructions

Points to Remember

- **A proforma invoice** is a preliminary invoice that is sent to a buyer before a sale is confirmed.
- **An invoice** is a commercial document that records a transaction between a seller and a buyer.
- **Types of invoices**
    - A paper receipt,
    - A bill of sale,
    - A debit note,
    - A sales invoice,
    - An online electronic record.
- **The key elements you'll find on a typical invoice:**
    - Header Information
    - Payment Information
    - Itemized List of Goods or Services
    - Taxes and Fees
    - Additional Information
    - Payment Instructions

Application of learning 3.4.

Referring to the Practical Assessment at the end of learning outcome 2 you are asked to do cost estimation and prepare an invoice of the given tasks.

Learning outcome 3 end assessment

Theoretical assessment

1. Define a technical report.
2. Discuss the main parts of a technical report.
3. What is an invoice?
4. Identify the types of invoices.
5. Differentiate an invoice from a proforma invoice.

Practical assessment

Read the scenario given below and answer the given questions:

Zylker Bottles, a bottle manufacturing company, gets a request for 500 plastic bottles. The price of each bottle is $8. They can prepare a proforma invoice that contains the rate of each plastic bottle, any applicable discounts or taxes, the total price, the estimated delivery date, and more. After Zylker Bottles has finished manufacturing 500 plastic bottles, they need to collect the payment from the buyer before they ship the goods. Zylker Bottles can send an invoice that contains the total money owed to them along with their bank details so that the buyer can make the payment.

Read the scenario given above and make both proforma and an invoice that should be sent to the client of the company!

References

1. James D. Johannes (1995),2ndEdition, Cost estimator's reference manual.
2. John E. Traister, Dale C. Brickner (2004). Electrician's Exam Preparation Guide: Based on the 2005 NEC. Craftsman Book Company, 2004. ISBN 1-57218-152-4 p.269.
3. Jump up^ Bureau of Labor Statistics, U.S. Department of Labor, Occupational Outlook Handbook, 2014-15 Edition, Drafters. accessed: 2 December 2014

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