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**AUTOMOTIVE
ELECTRICAL
&
ELECTRONICS**

(VOL 1)

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PREFACE

This e-book namely AUTOMOTIVE ELECTRICAL AND ELECTRONICS explain about the basic concepts and application of automotive electrical and electronic systems. the topic cover is Introduction to Electrical Circuits, Inductor, Capacitor and Alternating Current Circuits, Basic Principles of Electromagnetism and Electronic Principles.

Students will learn the fundamental concepts of electricity, electrical circuits, principles of magnetism, tools and test equipment, automotive electrical systems and circuits as well as comfort and safety.

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This topic explain about the basic principle of electric circuits and its connections. The learning outcome for this chapter are the students should be able to explain clearly basic electrical quantities, types of electrical circuits, electrical power, electrical energy and solve related problems.

BASIC ELECTRICAL QUANTITIES

- ◆ **Electromotive force (EMF)**
The electrical force which sets the electric charge in motion.
Examples of source which producing electric energy are battery and generator
Symbol : E
Unit : Volt (V)
- ◆ **Charge**
Consist of positive charge and negative charge. The quantity of charge is known as coulomb.
Symbol : Q
Unit : Coulomb (C)
- ◆ **Current**
Current is the flow of electrons. The current is said to flow from a positively charges body to the negatively charges body.
Symbol : I
Unit : Ampere (A)
- ◆ **Potential energy (Voltage)**
The difference of potential developed between two point in electric circuit.
Symbol : V
Unit : Volt (V)

FACTORS THAT AFFECT THE RESISTANCE OF THE CONDUCTOR MATERIALS

Material (resistivity- ρ)

$$R \propto \rho$$

Some materials like metals are better conductors of electricity and offer less resistance to the flow of current. Non-metals have poor conductivity. Conductivity of charge in metals is mainly due to the free electrons in the outer orbits of metals.

Length

$$R \propto \ell$$

Resistance is directly proportional to the length of the wire. More the length of the wire, longer is the distance to be covered by the electrons and hence charge thereby reducing current and increasing resistance.

Cross-sectional area

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

Resistance is inversely proportional to the area of cross-section of the wire. More the cross-sectional area, easier it is for the electrons and hence charge to flow and hence more current and less resistance.

Temperature

$$R \propto T$$

Higher temperature results in higher resistance. Higher the temperature, faster will be the oscillations of the ions in the conductor and the moving electrons will have to undergo more number of collisions per unit length of the wire, thereby reducing time between successive collisions and reducing drift velocity of the electrons which results in less current and higher resistance.

Formula

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

EXERCISE

Calculate the resistance of the aluminium with 1.5 km length, 10 mm diameter and 0.025×10^{-6} Ohm.m resistivity.

TYPES OF ELECTRICAL CIRCUITS

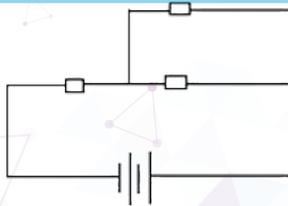
Simple circuits

A closed connection allow the perfect current flow. The current can flow from the supplier and back to the supplier again. It must consist of voltage supplier (V), electric current (I) and resistance (R).



Complex circuits

Various combination of both series and parallel circuit are often found in electric circuit. Both of formula for series and parallel circuit will be using in calculation.



Open circuits

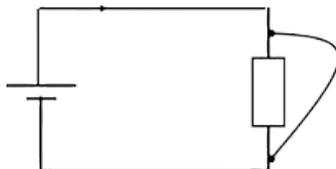
A circuit does not have one of three item. The flow current is unperfected.

The circuit have broken current path so that there is no current. This considered to have infinite resistance.



Short circuits

In short circuit, the maximum amount of current is by passed to earth through a shunt. Shunt is a very low resistance path for the conduction of current.



CIRCUIT MEASURING TOOL

Voltmeters

The voltmeter is a device that can measure the voltage across a circuit element. Since voltage is the difference in potential between two points in circuit, the voltmeter must also fulfill two requirements. The voltmeter must be placed in parallel with the element whose voltage it is measuring. The voltmeter should draw no current away from the element whose voltage it is measuring.



Ammeters

The ammeter is a device to measure the current flowing through the element in the circuit. This device is connected in series with the element; the ammeter should not restrict the flow of current.



Ohmmeters

The ohmmeter is a device that when connected across a circuit element, can measure the resistance of the element. It must be placed in parallel with the element to be measured.



OHM'S LAW

It states that the current in a complete circuit is directly proportional to the potential difference when the resistance, temperature and all other physical conditions are kept constant.

FORMULA

$$V=IR$$

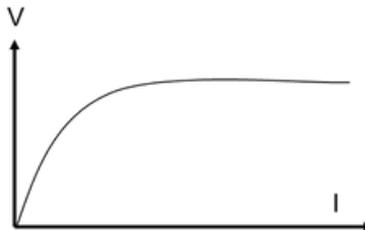
TYPES OF RESISTANCE

Linear resistance

If the resistance value is kept constant and voltage value is doubled, so the current is double



Non-linear resistance



QUESTION

Use Ohm Law to find the current value if the resistance is $12\ \Omega$ and the supply voltage is 14V . If the resistance has been changed to $12\ \text{k}\Omega$, find new current.

SOLUTION

Been given, $V = 14\text{V}$

i) $R = 12\ \Omega$,

Based on Ohm's Law, $V = IR$

$$I = V/R = 14/12 = 1.16\text{A}$$

ii) $R = 12\ \text{k}\Omega$,

$$I = V/R = 14/12 \times 10^3 = 1.16 \times 10^{-3} = 1.16\text{mA}$$

EXERCISE

Calculate the resistance of the conductor with $1.5\ \text{m}$ length, $1.6\ \text{m}^2$ cross section area and $16.3\ \mu\text{Wm}$ resistivity.

ELECTRICAL POWER

It was a product of voltage and current of a circuit as called electrical power. It is the rate of doing work.

Symbol : P

Unit : Watt (W)

$$P = IV$$

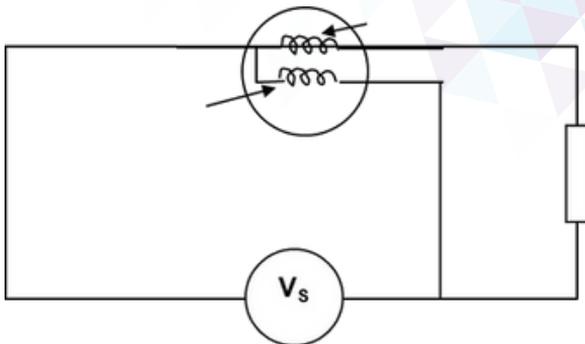
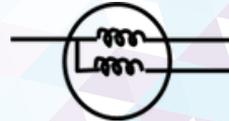
From the Ohm's Law, $V=IR$ and $I=V/R$

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

POWER MEASURING TOOL

Wattmeter

To measure a power value. There are two types of coil, -Voltage coil- parallel connected -Current coil- series connected Symbol : W



ELECTRICAL ENERGY

The quantity of electrical power consumed/generated in a definite line.

Symbol : T or E

Unit : kilowatt (kwh) or kilojoules (kj)

1 Joule = 1 Watt second

$$T = Pt$$

$$T = VI t$$

$$T = I^2 R t$$

$$T = \frac{V^2}{R} t$$

wheres;

T-electrical energy (kWj)

P- power (W)

t - times (s)

V- voltage (V)

I-current (A)

R- resistance (Ω)

EXAMPLE

A bread maker taking 6A current from 235V supply for 20 minutes.

Calculate ,

i. Power used

ii. Energy absorbed in kj

SOLUTION

Given: I = 6 A , V = 235V dan t = 20 x 60 = 1200s

i. P = IV = (6)(235) = 1410W

ii. T = Pt = (1410)(1200) = 1692000W = 1692kWj = 1080 kj

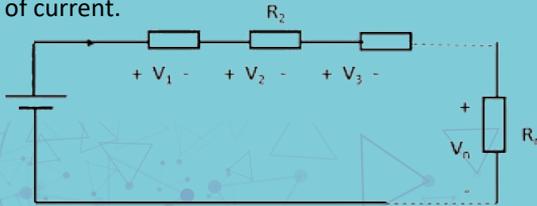
PROPERTIES OF BASIC CIRCUIT

There are two types of circuit

1. Series circuit
2. Parallel circuit

SERIES CIRCUIT

A series circuit is that which has one and only one path for the conduction of current.



SERIES CIRCUIT PROPERTIES

Total resistance, R_T
 $R_T = R_1 + R_2 + R_3 + \dots + R_n$

Total current, I_T
 $I_T = I_1 = I_2 = I_3 = \dots = I_n$

Total voltage, V_T
 $V_T = V_1 + V_2 + V_3 + \dots + V_n$

Voltage will drop at each of resistance. ($V_n = I_n R_n$)

VOLTAGE DIVIDER RULE

Voltage divider law is to determine the voltage value for each resistor in series circuit.

By ohm's law, the voltage drop across any of resistors can be written $V_X = I R_X$ (where $x = 1, 2$ or 3)

The current equal to the total voltage divided by the total resistance:
 $I = V_T / R_T$ ($R = R_1 + R_2 + R_3$)

Substituting V_T / R_T for I in the equation $V_X = I R_X$

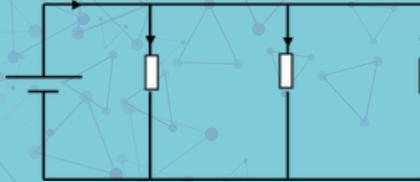
Hence, $V_X = (V_T / R_T) R_X$

$V_X = (R_X / R_T) V_T$

PARALLEL CIRCUIT

A parallel circuit is that in which all the component are connected across a single source of supply.

That means there is more than one current path between two point and the voltage between those two point also appears across each of the branches.



PARALLEL CIRCUIT PROPERTIES

Total resistance, R_T

$$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \dots + 1/R_n$$

Total current, I_T

$$I_T = I_1 + I_2 + I_3 + \dots + I_n$$

Total voltage, V_T

$$V_T = V_1 = V_2 = V_3 = \dots = V_n$$

CURRENT DIVIDER LAW

This current divider law use to determine the value of current in parallel circuit

By Ohm's Law,

Current for each resistance, $I_X = V_T / R_X$ ($X=1,2,3,..n$)

Total voltage $V_T = I_T R_T$

Combine those two equation.

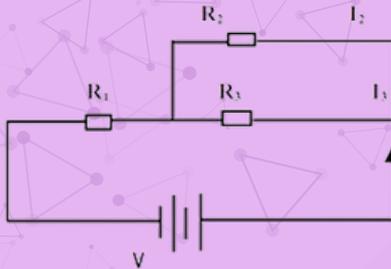
$$I_X = (I_T R_T) / R_X$$

$$I_X = (R_T / R_X) I_T$$

EXAMPLE

According to the circuit, given $R_1=10\Omega$, $R_2=20\Omega$, $R_3=15\Omega$ & power supply $V=120V$. Determine :-

- Total resistance, R_T
- Total current, I_T
- Second current, I_2 & Third current, I_3



SOLUTION

- a) Total resistance, R_T

$$R_{23} = \frac{R_2 R_3}{R_2 + R_3} = \frac{(20)(15)}{20 + 15} = 8.57\Omega$$

- b). Total current, I_T

$$I_T = \frac{V}{R_T} = \frac{120}{18.57} = 6.46 \text{ A}$$

- c). Current

$$I_2 = \left(\frac{R_3}{R_2 + R_3} \right) I_T = \left(\frac{15}{20 + 15} \right) 6.46 = 2.77 \text{ A}$$

$$I_3 = I_T - I_2 = (6.46 - 2.77) = 3.69 \text{ A}$$

2

INDUCTORS, CAPACITORS AND ALTERNATING CURRENT CIRCUITS

This chapter is explaining about the inductors, capacitors and AC circuits. The learning outcome for this chapter are the students should be able to apply correctly the basic principles of inductors, capacitors and AC circuits that contains R, L and C to solve problems.

There are two types of inductor which is often used in electronic circuits: fixed type and variable type. The symbol for inductor is as shows below:

- (a) Fixed type inductor
- (b) variable type inductor

Inductor symbol and unit

Inductor symbol , L

Inductor unit, Henry (H)

INDUCTANCE

There are two types of inductance:

- a)Self Inductance (L)
- b)Mutual Inductance (M)

Self Inductance, $L = N \frac{d\phi}{di}$

L = Self Inductance

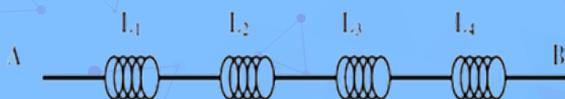
N = Number of turns

$\frac{d\phi}{dt}$ = flux change against time

$\frac{di}{dt}$ = current change against time

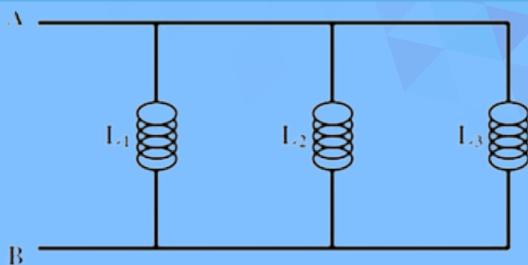
INDUCTOR CIRCUIT ANALYSIS

Series Inductors



$$L_T = L_1 + L_2 + L_3 + L_4$$

Parallel Inductors



$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

INDUCTANCE REACTANCE, XL

$$X_L = 2\pi fL$$

X_L = Inductance Reactance (Ω)

f = Frequency (Hz)

L = Inductor (Henry)

ENERGY IN INDUCTOR

$$E = \frac{1}{2} LI^2$$

CAPACITOR

Capacitor is an electrical device which is capable of storing electrical energy. Unit is Farad (F) and symbol is C. The quantity and duration of energy can be saved depends on the capacitance of the capacitor. Electrical energy stored in the capacitor is in a form of charge. A plate will has a negative charge (-ve) and the other plate is positive charge (+ve).

Capacitor symbol and unit

Capacitor symbol, C Capacitor unit, Farad (F)

Capacitor symbol schematic



CAPACITANCE

Capacitance, (Farad) = $\frac{\text{Cas(Coulomb)}}{\text{Voltage(Volt)}}$

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

Three (3) factors affecting the value of the capacitance of a capacitor:

Area of the Plate, A

The Distance Between Two Plates, d

Permeability,

CAPACITOR CIRCUIT ANALYSIS

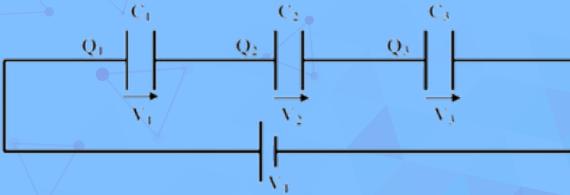
There are 3 types of circuit analysis in capacitor:

Series

Parallel

Combination of series and parallel

SERIES CAPACITORS



Total capacitance

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

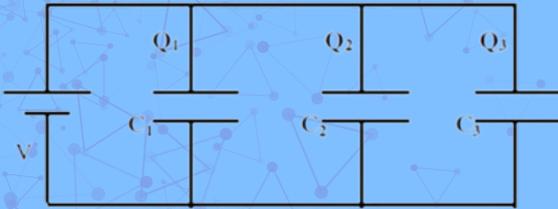
Charge in series

$$Q_1 = Q_2 = Q_3 = Q_T, \text{ where } Q_T = C_T V_T$$

Voltage drop

$$V_{C1} = \frac{Q_T}{C_1}, \quad V_{C2} = \frac{Q_T}{C_2}, \quad \text{where } V_{C3} = \frac{Q_T}{C_3}$$

PARALLEL CAPACITORS



Total capacitance

$$C_T = C_1 + C_2 + C_3$$

Voltage drop

$$V_{C1} = V_{C2} = V_{C3} = V_T$$

Charge in parallel

$$Q_{C1} = C_1 V_T, \quad Q_{C2} = C_2 V_T \quad \text{and} \quad Q_{C3} = C_3 V_T$$

Capacitance reactance, X_C

$$X_C = \frac{1}{\omega C}, \quad \text{where} \quad \omega = 2\pi f$$

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

C = Capacitance (F)

f = Frequency (Hz)

ω = angular velocity (rads⁻¹)

2π = constant

Energy in capacitor

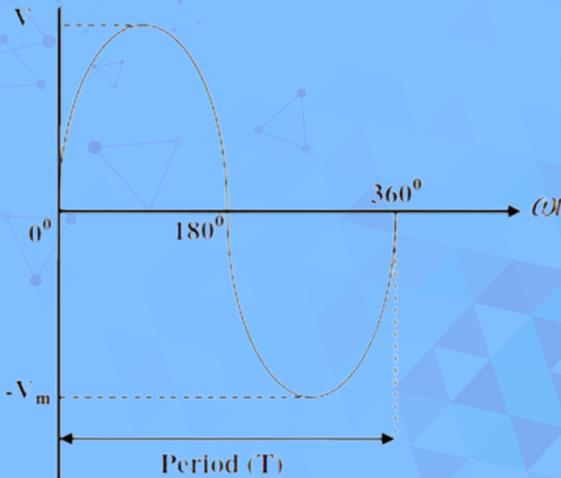
$$E = \frac{1}{2} QV$$
$$E = \frac{1}{2} CV^2$$
$$E = \frac{1}{2} \left(\frac{Q^2}{C} \right)$$

ALTERNATING CURRENT (AC)

Alternating voltage can be generated in 2 ways:

1. Conductors cut the magnetic flux which is stationary and the conductor is moving
2. Magnetic flux cut the conductor where the flux is moving and the conductor is stationary

ALTERNATING CURRENT WAVEFORM



$$v(t) = v_m \sin \omega t$$

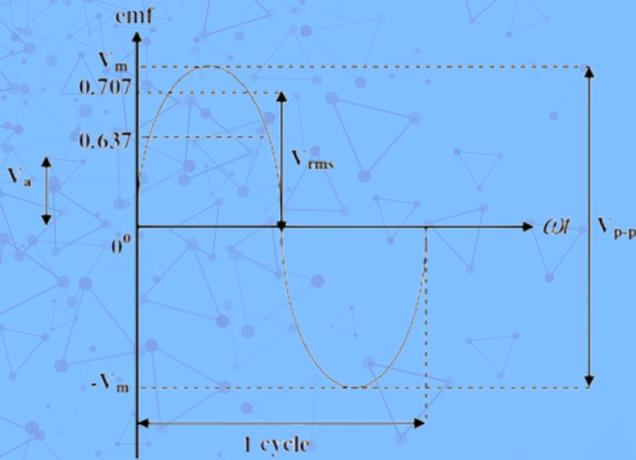
$v(t)$ = Instantaneous voltage (volt)

v_m = Maximum/peak voltage (volt)

ωt = Phase angle against time (rad/degree)

$$T = \frac{2\pi}{\omega} \text{ (second)}$$

TERM IN AC WAVEFORM



Peak voltage,

$$V_P = V_m$$

Peak to peak voltage,

$$V_{PP} = 2V_m$$

Average voltage,

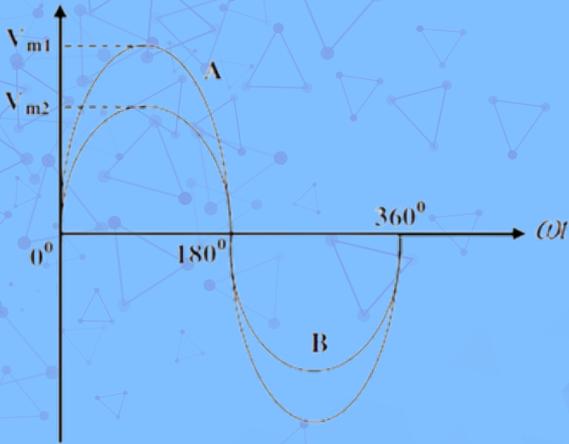
$$V_a = 0.637 V_m$$

Root mean square voltage,

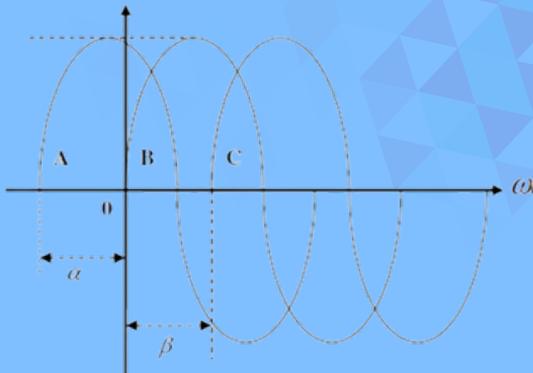
$$V_{rms} = 0.707 V_m$$

TYPES OF AC WAVEFORM

In Phase Waveform



Different Phase Waveform

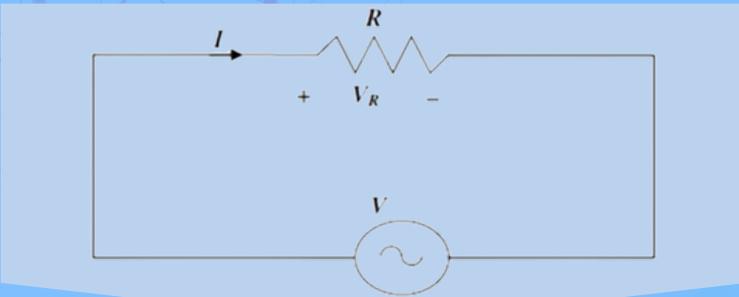


Basic types of AC Circuit

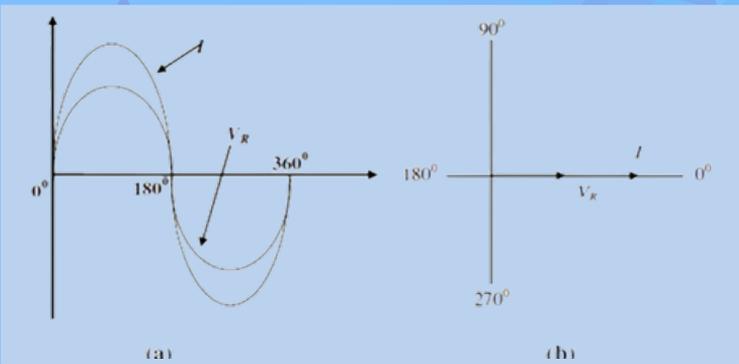
There are 3 basic types of AC circuit:

1. Purely Resistance
2. Purely Inductance
3. Purely Capacitance

Purely Resistance



Purely Resistance Circuit

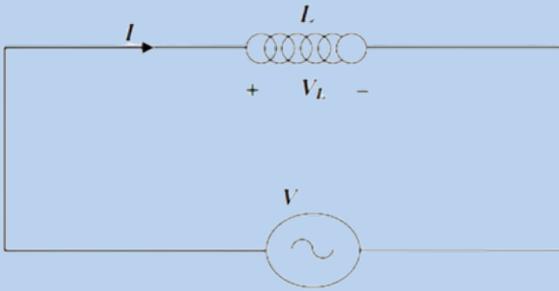


Purely Resistance

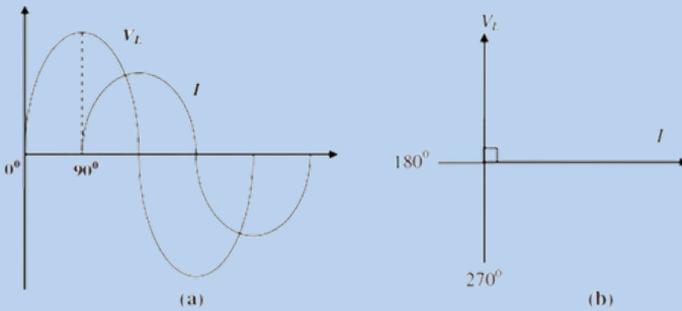
(a) Waveform

(b) Vector Diagram

Purely Inductance



Purely Inductance Circuit

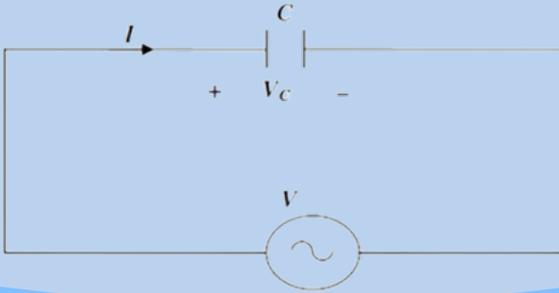


Purely Inductance

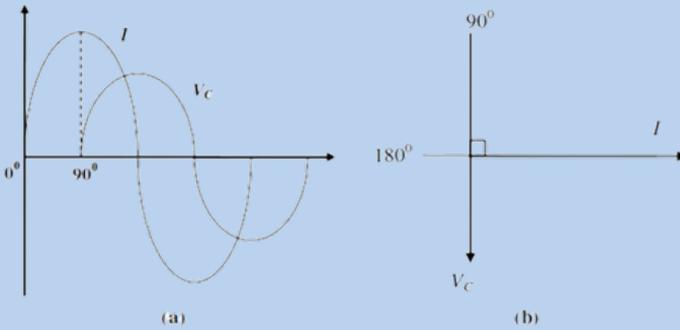
(a) Waveform

(b) Vector Diagram

Purely Capacitance



Purely Capacitance Circuit

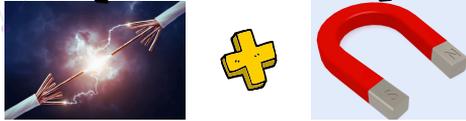


Purely Capacitance

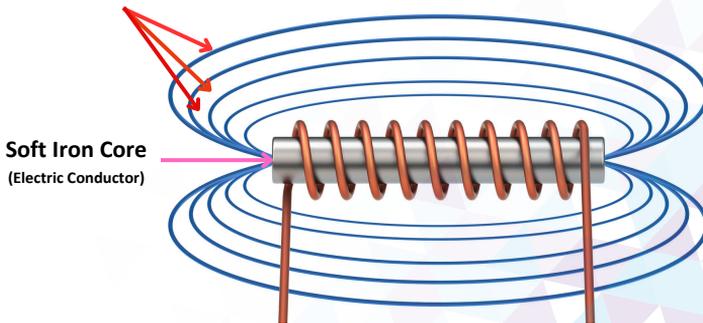
(a) Waveform

(b) Vector Diagram

WHAT IS ELECTROMAGNET?



Magnetic Flux



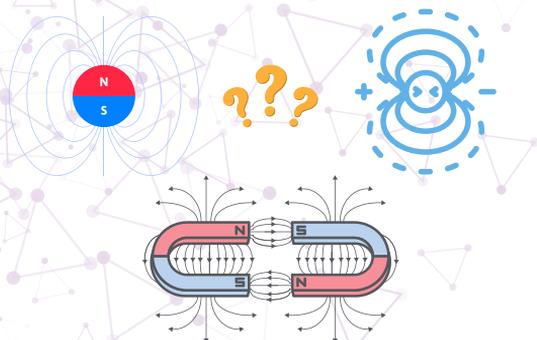
Soft Iron Core
(Electric Conductor)

- An electromagnet is a type of magnet created by passing an electric current through a coil of wire.
- When the current flows through the wire, it generates a magnetic field around the coil, effectively turning the coil into a magnet.

Advantages of soft iron core:

- The conductor becomes magnetized easily when current is applied to it.
- It becomes easy to demagnetize the conductor after the current is removed from the electrical circuit.

SO HOW ABOUT DIRECTION OF MAGNETIC FIELD LINES?



Magnetic field lines form closed loops and point from the **north pole to the south pole** outside the magnet

CHARACTERISTIC OF FLUX

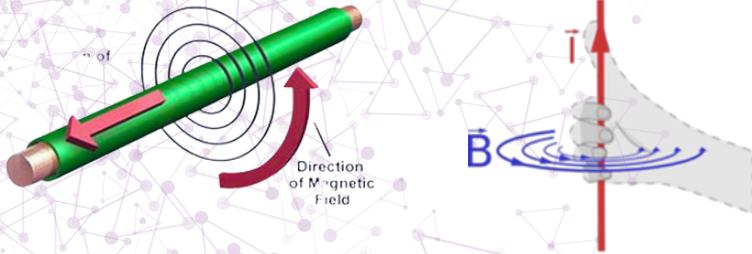
- Form a close loop
- Do not cross each others
- Exit from north pole into south pole
- Have tension a long a flux line to shorten the distance of the flux line

FACTORS THAT AFFECT THE ELECTROMAGNETIC FIELD STRENGTH

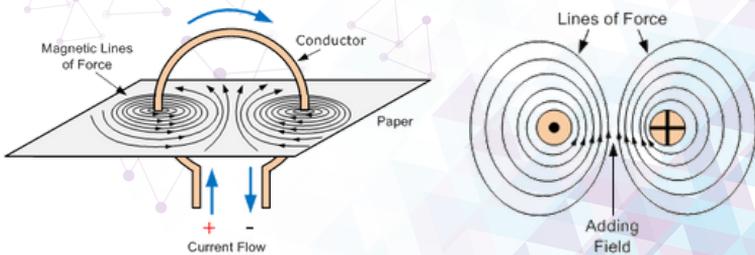
The strength of the magnetic field of an electromagnet increases when:

- (a) The current is increased
- (b) The number of turns is increased
- (c) The turns of the wire are pushed closer together so that the length of the solenoid becomes shorter
- (d) A soft iron core is placed into the solenoid

LET'S SEE HOW TO DETERMINE MAGNETIC FIELD DIRECTION IN SINGLE CONDUCTOR.



CURRENT FLOW IN TWO CONDUCTOR



The resulting interaction between the two like fields produces a mechanical force between the two conductors as they try to repel away from each other.

In an electrical machine, this repelling of these two magnetic fields produces motion.

ELECTROMAGNETIC INDUCTION

When a conductor is moved across a magnetic field to cut through the flux, an electromagnetic force (e.m.f.) is produced in the conductor.

This effect is known as electromagnetic induction which will cause induced current.

Two laws of electromagnetic induction:

Faraday's law

1) it is a relative movement of the magnetic flux and the conductor then causes an e.m.f. Thus, the current is induced in the conductor. Induced e.m.f. on the conductor could be produced by two methods i.e. flux cuts conductor or conductor cuts flux.

For Faraday's Law simulation, students can visit at:

https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_en.html

Lenz's law

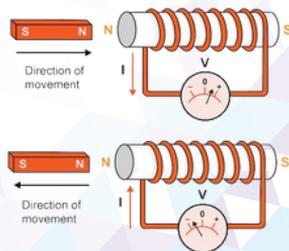
1) The direction of an induced e.m.f. is always such that it tends to set up a current opposing the motion or the change of flux responsible for inducing that e.m.f.

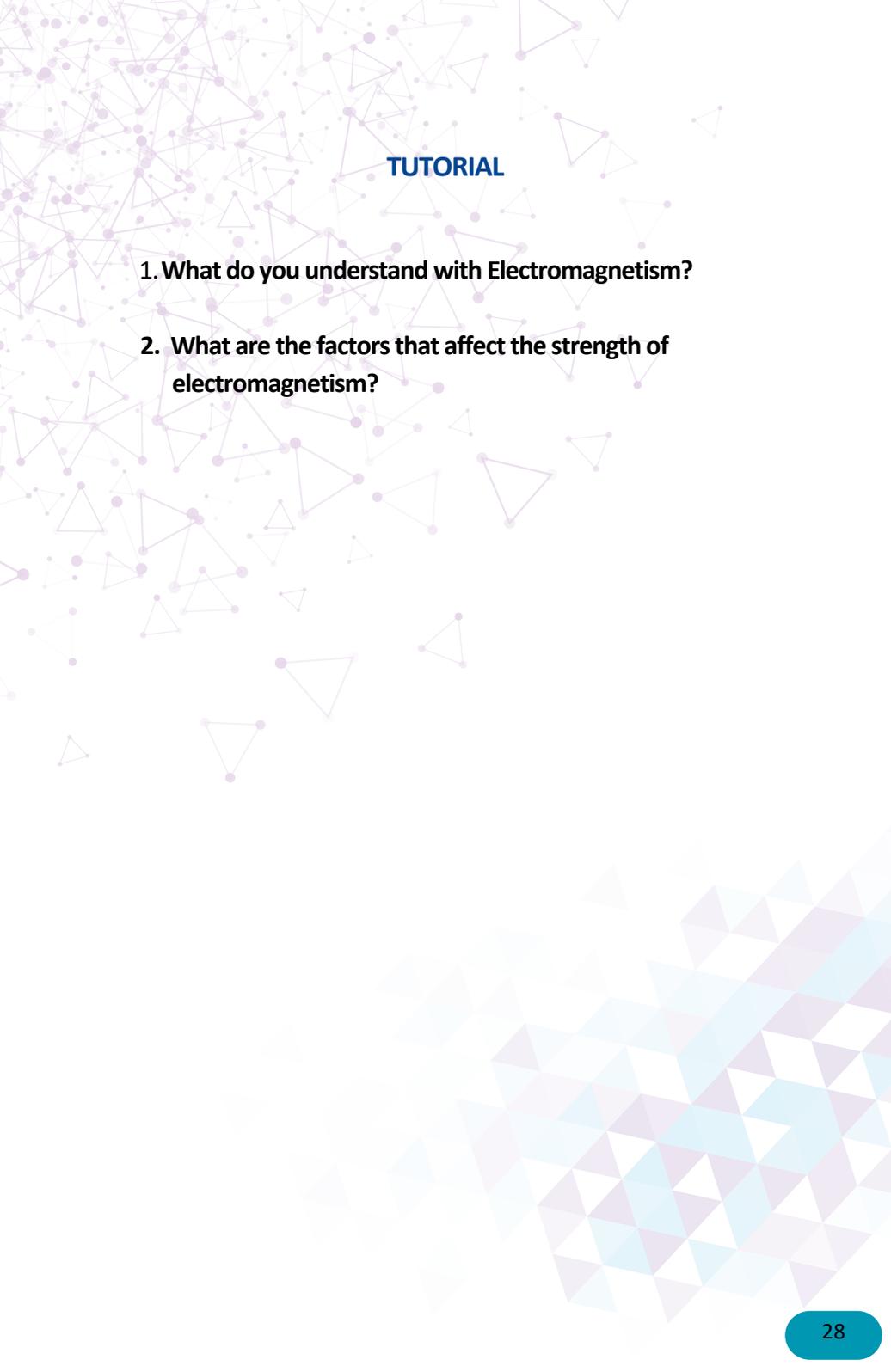
MOVING IN:

- Magnet is pushed to the coil Induced e.m.f that produces current in an anti-clockwise direction will be produced
- The left side of the coil will become a north pole
- The magnet will be repelled by the coil

MOVING OUT:

- The magnet is pulled away from the coil
- Induced e.m.f that produces current in a clockwise direction will be produced
- The left side of the coil will become a south pole
- The magnet will be attracted by the coil





TUTORIAL

- 1. What do you understand with Electromagnetism?**
- 2. What are the factors that affect the strength of electromagnetism?**

Electronics deals with electrical circuit that involve active electrical component such as vacuum tube, transistors, diodes and integrated circuits.

The nonlinear behaviour of active components and their ability to control electron flows makes amplification of weak signals possible and electronics is widely used in information processing, telecommunications and signal processing

The ability of electronic devices to act as switches makes digital information processing possible.

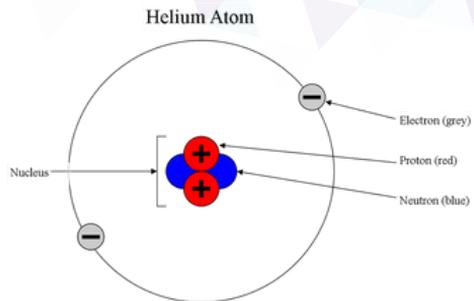
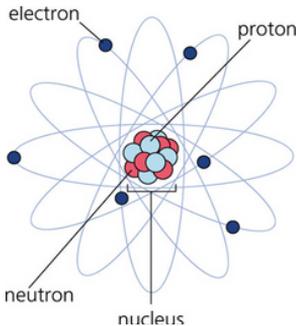
▽ SUBATOMIC PARTICLES

The negatively-charged electron has a mass equal to $\frac{1}{1836}$ of that of a hydrogen atom.

The remainder of the hydrogen atom's mass comes from the positively charged proton.

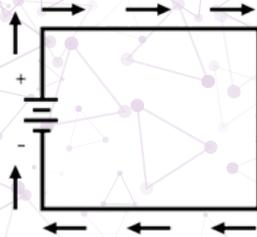
The atomic number of an element is the number of protons in its nucleus. Neutrons are neutral particles having a mass slightly greater than that of the proton.

The study of subatomic particles, atoms, and molecules, and their structure and interactions, requires quantum mechanics.



CONVENTIONAL FLOW

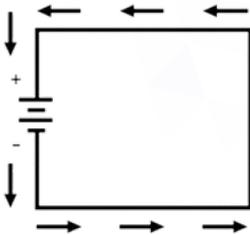
Conventional Flow Notation



Electric charge moves from the positive (surplus) side of the battery to the negative (deficiency) side.

ELECTRON FLOW

Electron Flow Notation



Electron charge moves from the negative (surplus) side of the battery to the positive (deficiency) side.

FACTORS DETERMINE THE LEVEL OF RESISTANCE

All conductors show some opposition to electrical current. This opposition to the current is called resistance.

There are several factors that affect the resistance of a conductor;

- **material** - eg copper, has lower resistance than steel
- **length** - longer wires have greater resistance
- **thickness** - smaller diameter wires have greater resistance
- **temperature** - heating a wire increases its resistance

The two main ways of increasing the current in an electrical circuit are by increasing the voltage or by decreasing the resistance.

THE OPERATION

PRINCIPLE OF THE ELECTRONIC COMPONENTS

- Diodes
- Resistors
- Resistor Ratings
- Variable Resistors
- Thermistors
- Transistors
- Transformer

DIODE

A diode is an electrical device allowing current to move through it in one direction with far greater ease than in the other.

A diode is a two-terminal device, having two active electrodes, between which it allows the transfer of current in one direction only.

Diodes are known for their unidirectional current property, wherein, the electric current is allowed to flow in one direction.

Diodes are used for the purpose of rectifying waveforms and can be used within power supplies or within radio detectors.

Diodes transmit electric currents in one direction, however, the manner in which they do so can vary.

Some of the different types are:

Light Emitting Diode (LED): this diode permits the transfer of electric current between the electrodes, and light is produced. When the diode is switched on or forward-biased, the electrons recombine with the holes and release energy in the form of light. The color of light depends on the energy gap of the semiconductor.

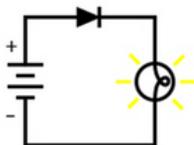
Schottky Diodes: These diodes feature lower forward voltage drop as compared to ordinary silicon PN junction diodes. The voltage drop maybe somewhere between 0.15 and 0.4 volts at low currents, as compared to the 0.6 volts for a silicon diode.

Zener diode: This type of diode provides a stable reference voltage, thus is a very useful type and is used in vast quantities. The diode runs in reverse bias and breaks down on the arrival of a certain voltage. A stable voltage is produced, if the current through the resistor is limited. In power supplies, these diodes are widely used to provide a reference voltage.

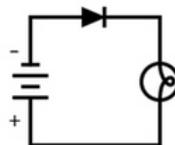
Photodiode: Photodiodes are used to detect light and feature wide, transparent junctions. Generally, these diodes operate in reverse bias, wherein even small amounts of current flow, resulting from the light, can be detected with ease. Photodiodes can also be used to generate electricity, used as solar cells, and even in photometry.



Diode Operation



Current Permitted



Current Prohibited

RESISTOR

Resistors are the most commonly used component in electronics and their purpose is to create specified values of current and voltage in a circuit.

The symbol for a resistor is shown in the following diagram (upper: American symbol, lower: European symbol).

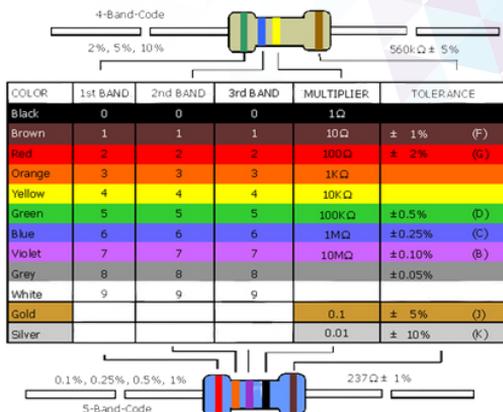


The unit for measuring resistance is the OHM.

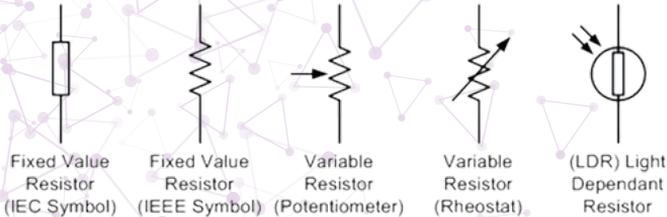
Higher resistance values are represented by "k" (kilo-ohms) and M (mega ohms)
The resistance value is marked on the resistor body. Most resistors have 4 bands.

The first two bands provide the numbers for the resistance and the third band provides the number of zeros.

The fourth band indicates tolerance. Tolerance values of 5%, 2%, and 1% are most commonly available.



THERE ARE BASICALLY TWO TYPES OF RESISTORS. □-FIXED RESISTORS & VARIABLE RESISTORS



THERMISTOR

A thermistor is a resistance thermometer or a resistor whose resistance is dependent on temperature. The term is a combination of “thermal” and “resistor”

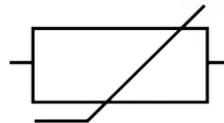
There are two types of thermistors:

Negative Temperature Coefficient (NTC) with an NTC thermistor, when the temperature increases, resistance decreases. Conversely, when temperature decreases, resistance increases. This type of thermistor is used the most.

A **Positive Temperature Coefficient (PTC)** thermistor works a little differently. When temperature increases, the resistance increases, and when temperature decreases, resistance decreases. This type of thermistor is generally used as a fuse.

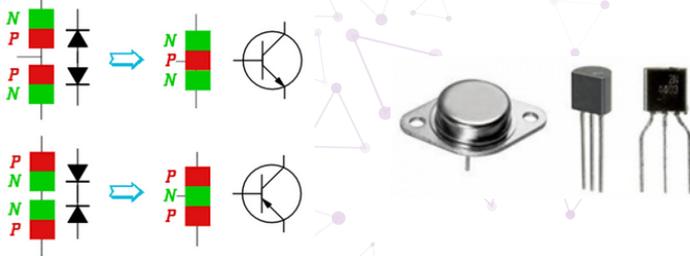


US & Japan



Europe

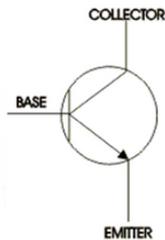
TRANSISTOR



Transistors can be regarded as a type of switch, as can many electronic components.

They are central to electronics and there are two main types; NPN and PNP. Most circuits tend to use NPN.

There are hundreds of transistors which work at different voltages but all of them fall into these two categories.



Transistors are manufactured in different shapes but they have three leads (legs).

The BASE - which is the lead responsible for activating the transistor

The COLLECTOR - which is the positive lead.

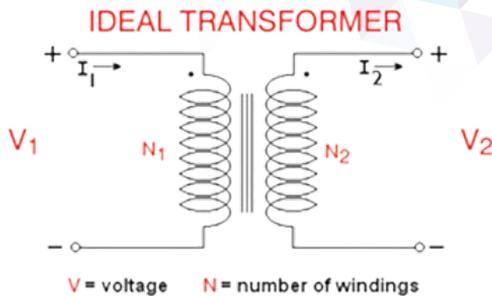
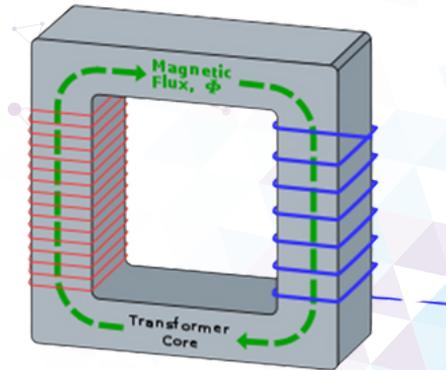
The EMITTER - which is the negative lead.

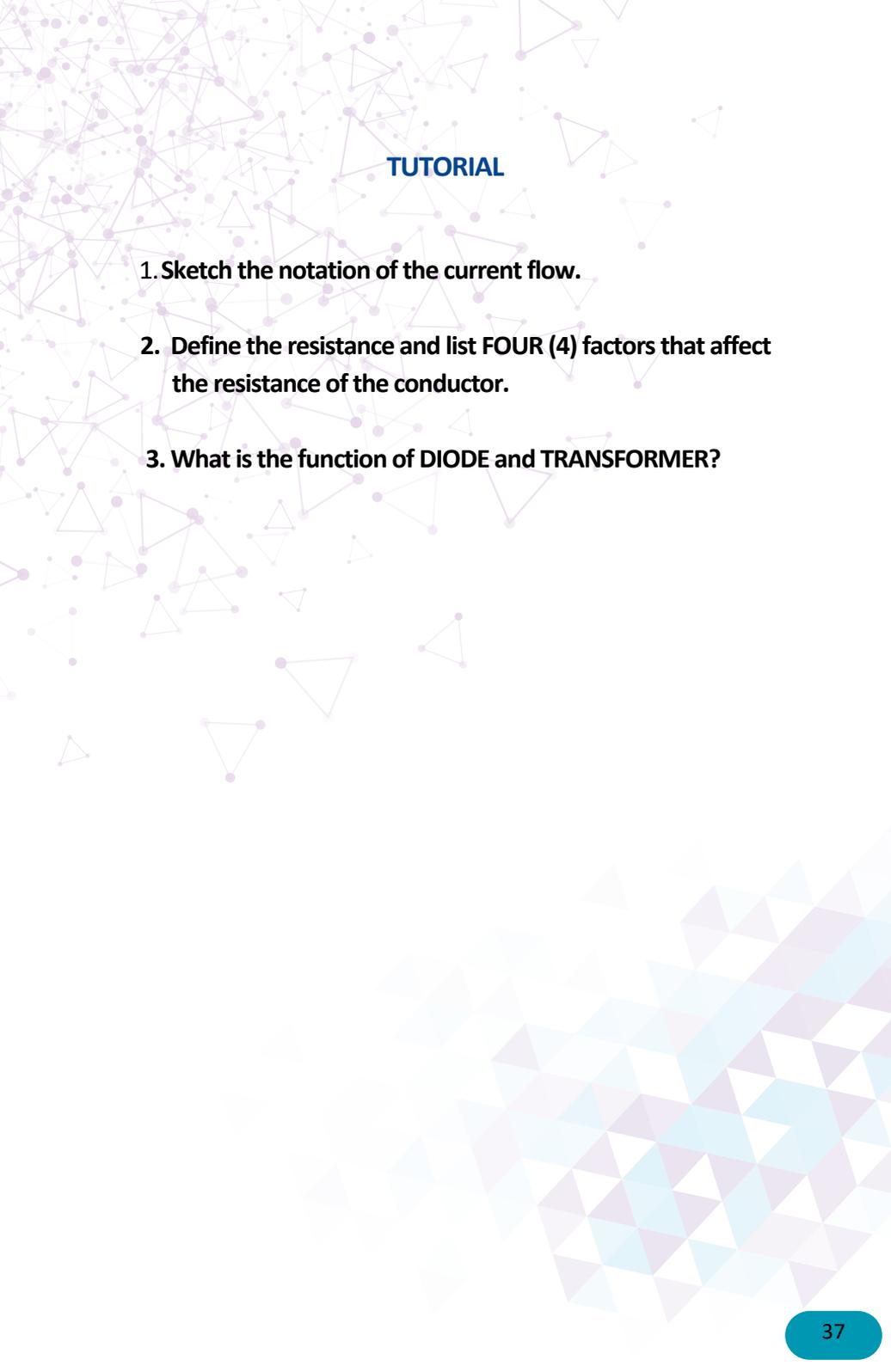
TRANSFORMER

A transformer is a device that changes an electrical voltage or current from one level to another. (In radio frequency applications, it is used to couple the RF electronic circuits.)

Transformers are used to:

- Convert high voltage alternating current (AC) to desired low voltage alternating current (AC). Such transformers are called step-down transformers.
- Convert low voltage alternating current (AC) to desired high voltage alternating current (AC). Such transformers are called step-up transformers.
- Electrically separating one part of the circuit (or any other electrical system) from the other part, termed as 'electrical isolation'. Such transformers are called isolation transformers.





TUTORIAL

1. Sketch the notation of the current flow.
2. Define the resistance and list FOUR (4) factors that affect the resistance of the conductor.
3. What is the function of DIODE and TRANSFORMER?

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