Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

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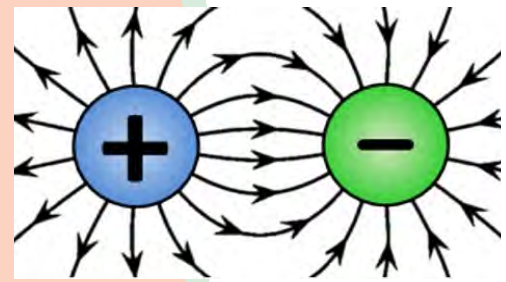
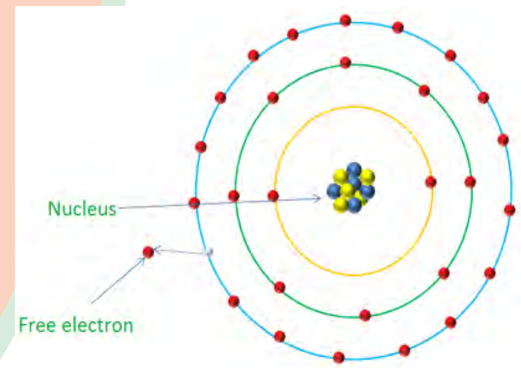
Computer Engineering

9

Fundamentals of Electro-System





Technical and Vocational Stream
Learning Resource Material

Fundamentals of Electro-System

(Grade 9)

Computer Engineering

Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

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Preface

The curriculum and curricular materials have been developed and revised on a regular basis with the aim of making education objective-oriented, practical, relevant and job oriented. It is necessary to instill the feelings of nationalism, national integrity and democratic spirit in students and equip them with morality, discipline, self-reliance, creativity and thoughtfulness. It is essential to develop linguistic and mathematical skills, knowledge of science, information and communication technology, environment, health and population and life skills in students. It is also necessary to bring the feeling of preserving and promoting arts and aesthetics, humanistic norms, values and ideals. It has become the need of the present time to make them aware of respect for ethnicity, gender, disabilities, languages, religions, cultures, regional diversity, human rights and social values to make them capable of playing the role of responsible citizens with applied technical and vocational knowledge and skills. This learning resource material for computer engineering has been developed in line with the Secondary Level computer engineering Curriculum with an aim to facilitate the students in their study and learning on the subject by incorporating the recommendations and feedback obtained from various schools, workshops, seminars and interaction programs attended by teachers, students, parents and concerned stakeholders.

In bringing out the learning resource material in this form, the contribution of the Director General of CDC Mr. Yubaraj Paudel and members of the subject committee Dr. Baburam Dawadi, Dr. Sarbim Sayami, Mrs. Bibha Sthapit, Mrs. Trimandir Prajapati is highly acknowledged. This learning resource material is compiled and prepared by Mr. Bimal Thapa, Mr, Rajendra Rokaya, Mr. Suresh Shakya. The subject matter of this material is edited by Mr. Badrinath Timsina and Mr. Khilanath Dhamala. Similarly, the language is edited by Mr. Binod Raj Bhatta. CDC extends sincere thanks to all those who have contributed to developing this material in this form.

This learning resource material contains a wide coverage of subject matters and sample exercises which will help the learners to achieve the competencies and learning outcomes set in the curriculum. Each chapter in the material clearly and concisely deals with the subject matters required for the accomplishment of the learning outcomes. The Curriculum Development Centre always welcomes creative and constructive feedback for the further improvement of the material.

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Sanothimi, Bhaktapur

Table of Content

Guidelines to Teachers

A. Facilitation Methods

The goal of this course is to combine the theoretical and practical aspects of the contents needed for the subject. The nature of contents included in this course demands the use of practical or learner focused facilitation processes. Therefore, the practical side of the facilitation process has been focused much. The instructor is expected to design and conduct a variety of practical methods, strategies or techniques which encourage students engage in the process of reflection, sharing, collaboration, exploration and innovation new ideas or learning. For this, the following teaching methods, strategies or techniques are suggested to adopt as per the course content nature and context.

Brainstorming

Brainstorming is a technique of teaching which is creative thinking process. In this technique, students freely speak or share their ideas on a given topic. The instructor does not judge students' ideas as being right or wrong, but rather encourages them to think and speak creatively and innovatively. In brainstorming time, the instructor expects students to generate their tentative and rough ideas on a given topic which are not judgmental. It is, therefore, brainstorming is free-wheeling, non-judgmental and unstructured in nature. Students or participants are encouraged to freely express their ideas throughout the brainstorming time. Whiteboard and other visual aids can be used to help organize the ideas as they are developed. Following the brainstorming session, concepts are examined and ranked in order of importance, opening the door for more development and execution. Brainstorming is an effective technique for problem-solving, invention, and decision-making because it taps into the group's combined knowledge and creative ideas.

Demonstration

Demonstration is a practical method of teaching in which the instructor shows or demonstrates the actions, materials, or processes. While demonstrating something the students in the class see, observe, discuss and share ideas on a given topic. Most importantly, abstract and complicated concepts can be presented into visible form through demonstration. Visualization bridges the gap between abstract ideas and concrete manifestations by utilizing the innate human ability to think visually. This enables students to make better decisions, develop their creative potential, and obtain deeper insights across a variety of subject areas.

Peer Discussion

Peer conversation is a cooperative process where students converse with their peers to exchange viewpoints, share ideas, and jointly investigate subjects that are relevant or of mutual interest. Peer discussion is an effective teaching strategy used in the classroom to encourage critical thinking, active learning, and knowledge development. Peer discussions encourage students to express their ideas clearly, listen to opposing points of view, and participate in debate or dialogue, all of which contribute to a deeper comprehension and memory of the course material. Peer discussions also help participants develop critical communication and teamwork skills by teaching them how to effectively articulate their views, persuasively defend their positions, and constructively respond to criticism.

Peer conversation is essential for professional growth and community building outside of the classroom because it allows practitioners to share best practices, work together, and solve problems as a group. In addition to expanding their knowledge horizon and deepening their understanding, peer discussions help students build lasting relationships and a feeling of community within their peer networks.

Group Work

Group work is a technique of teaching where more than two students or participants work together to complete a task, solve a problem or discuss on a given topic collaboratively. Group work is also a cooperative working process where students join and share their perspectives, abilities, and knowledge to take on challenging job or project. Group work in academic contexts promotes active learning, peer teaching, and the development of collaboration and communication skills. Group work helps individuals to do more together than they might individually do or achieve.

Gallery Walk

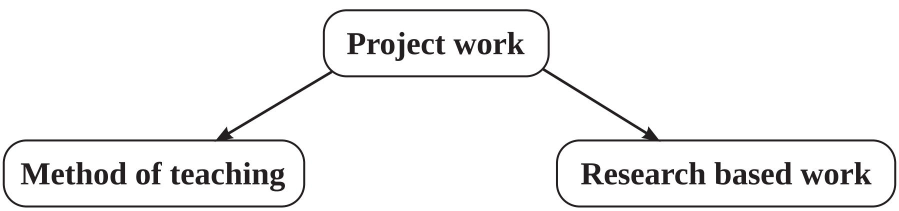
Gallery walk is a critical thinking strategy. It creates interactive learning environment in the classroom. It offers participants or students a structured way to observe exhibition or presentation and also provides opportunity to share ideas. It promotes peer-to-peer or group-to-group engagement by encouraging participants to observe, evaluate and comment on each other’s work or ideas. Students who engage in this process improve their communication and critical thinking abilities in addition to their comprehension of the subject matter, which leads to a deeper and more sophisticated investigation of the subjects at hand.

Interaction

The dynamic sharing of ideas, knowledge, and experiences between people or things is referred to as interaction, and it frequently takes place in social, academic, or professional settings. It includes a broad range of activities such as dialogue, collaboration or team work, negotiation, problem solving, etc. Mutual understanding, knowledge sharing, and interpersonal relationships are all facilitated by effective interaction. Interaction is essential for building relationships, encouraging learning, and stimulating creativity in both in-person and virtual contexts. Students can broaden their viewpoints, hone their abilities, and jointly achieve solutions to difficult problems by actively interacting with others.

Project Work

Project work is a special kind of work that consists of a problematic situation which requires systematic investigation to explore innovative ideas and solutions. Project work can be used in two senses. First, it is a method of teaching in regular class. The next is: it is a research work that requires planned investigation to explore something new. This concept can be presented in the following figure.



Project work entails individuals or teams working together to achieve particular educational objectives. It consists of a number of organized tasks, activities, and deliverables. The end product is important for project work. Generally, project work will be carried out in three stages. They are:

- Planning
- Investigation
- Reporting

B. Instructional Materials

Instructional materials are the tools and resources that teachers use to help students. These resources/materials engage students, strengthen learning, and improve conceptual comprehension while supporting the educational goals of a course or program. Different learning styles and preferences can be accommodated by the variety of instructional resources available. Here are a few examples of typical educational resource types:

- Daily used materials
- Related Pictures
- Reference books
- **Slides and Presentation:** PowerPoint slides, keynote presentations, or other visual aids that help convey information in a visually appealing and organized manner.
- **Audiovisual Materials:** Videos, animations, podcasts, and other multimedia resources that bring concepts to life and cater to auditory and visual learners.
- **Online Resources:** Websites, online articles, e-books, and other web-based materials that can be accessed for further reading and research.

Maps, Charts, and Graphs: Visual representations that help learners understand relationships, patterns, and trends in different subjects.

Real-life Examples and Case Studies: Stories, examples, or case studies that illustrate the practical application of theoretical concepts and principles.

C. Assessment

Formative Test

Classroom discussions: Engage students in discussions to assess their understanding of concepts.

Quizzes and polls: Use short quizzes or polls to check comprehension during or after a lesson.

Homework exercises: Assign tasks that provide ongoing feedback on individual progress.

Peer review: Have students review and provide feedback on each other's work.

Summative Test

Exams: Conduct comprehensive exams at the end of a unit or semester.

Final projects: Assign projects that demonstrate overall understanding of the subject.

Peer Assessment

Group projects: Evaluate individual contributions within a group project.

Peer feedback forms: Provide structured forms for students to assess their peers.

Classroom presentations: Have students assess each other's presentations.

Objective Test

Multiple-choice tests: Use multiple-choice questions to assess knowledge.

True/False questions: Assess factual understanding with true/false questions.

Matching exercises: Evaluate associations between concepts or terms.

Portfolio Assessment

Compilation of work: Collect and assess a variety of student work samples.

Reflection statements: Ask students to write reflective statements about their work.

Showcase events: Organize events where students present their portfolios to peers or instructors.

Observational Assessment

Classroom observations: Observe students' behavior and engagement during class.

Performance observations: Assess practical skills through direct observation.

Field trips: Evaluate students' ability to apply knowledge in real-world settings.

Abbreviations

μ: Magnetic Permeability

μ0: Permeability of Free Space

μF: Microfarad

μr: Relative Permeability

A: Ampere

AC: Alternating Current

ADC: Analog-to-Digital Converter

AGM: Absorbent Glass Mat (type of lead-acid battery)

Ah: Ampere-hour

B: Magnetic Field

B: Magnetic Flux Density

BH Curve: Magnetic Hysteresis Curve

BJT: Bipolar Junction Transistor

BMS: Battery Management System

C: Capacitance

C: Coulomb

CEM: Computational Electromagnetics

CGS: Centimeter-Gram-Second (system of units)

CMOS: Complementary Metal-Oxide-Semiconductor

Coulomb (C): Unit of electric charge, named after Charles-Augustin de Coulomb

CT: Current Transformer

DAC: Digital-to-Analog Converter

DC: Direct Current

DOD: Depth of Discharge

DOL: Direct On-Line (starter for motors)

E: Electric Field

E: Electric field strength

E: Energy

EHV: Extra High Voltage

EM: Electromagnetic

EMF: Electromotive Force

Eo (ε0): Permittivity of free space (vacuum permittivity)

EPCOS: A brand name, often used to refer to capacitors from EPCOS AG (now part of TDK Corporation)

ESR: Equivalent Series Resistance

F: Farad

Farad (F): Unit of Capacitance

FFT: Fast Fourier Transform

G: Conductance

Gauss (G): Unit of Magnetic Flux Density

Gauss: Unit of magnetic flux density, sometimes used in electrostatics contexts

GFCI: Ground Fault Circuit Interrupter

GND: Ground

H: Henry

H: Magnetic Field Strength

Henry (H): Unit of Inductance

HF: High Frequency

HV: High Voltage

Hz: Hertz (unit of frequency)

I: Current

I2C: Inter-Integrated Circuit

IC: Integrated Circuit

IRMS: Current Root Mean Square

J: Joule (unit of energy)

k: Coulomb's constant (approximately 8.99 x 10^9 N m^2/C^2)

kV: Kilovolt (1 kV = 10^3 V)

kVA: Kilovolt-Ampere (1 kVA = 10^3 VA)

kW: Kilowatt (1 kW = 10^3 watts)

L: Inductance

LCD: Liquid Crystal Display

LCR: Inductance (L), Capacitance (C), Resistance (R)

LED: Light Emitting Diode

LF: Low Frequency

Li-ion: Lithium-Ion

Lorentz Force: The force on a charged particle due to electromagnetic fields

LV: Low Voltage

mA: Milliampere (1 mA = 10^-3 A)

mAh: Milliampere-hour

Maxwell (Mx): Unit of Magnetic Flux

MCB: Miniature Circuit Breaker

MLCC: Multi-Layer Ceramic Capacitor

MMF: Magnetomotive Force

MOSFET: Metal-Oxide-Semiconductor Field-Effect Transistor

MRI: Magnetic Resonance Imaging

MW: Megawatt (1 MW = 10^6 watts)

mΩ: Milliohm (1 mΩ = 10^-3 Ω)

nF: Nanofarad

nH: Nanohenry (1 nH = 10^-9 H)

NiCd: Nickel-Cadmium

NiMH: Nickel-Metal Hydride

NMR: Nuclear Magnetic Resonance

NPN: Negative-Positive-Negative (type of BJT)

Ohm (Ω): Unit of electrical resistance

P: Power

Pb-acid: Lead-Acid

PCB: Printed Circuit Board

PE: Polyethylene (type of dielectric material)

PET: Polyethylene Terephthalate (type of dielectric material)

pF: Picofarad

PF: Power Factor

PFC: Power Factor Correction

PID: Proportional-Integral-Derivative (controller)

PLC: Programmable Logic Controller

PNP: Positive-Negative-Positive (type of BJT)

PP: Polypropylene (type of dielectric material)

PSU: Power Supply Unit

PT: Potential Transformer

PWM: Pulse Width Modulation

Q: Charge

R: Resistance

RC: Resistive-Capacitive (type of AC circuit)

RCD: Residual Current Device

RF: Radio Frequency

RL: Resistive-Inductive (type of AC circuit)

RLC: Resistive-Inductive-Capacitive (circuit)

RMS: Root Mean Square

S: Siemens (unit of conductance)

SCR: Silicon Controlled Rectifier

SI: International System of Units (Système International d'Unités)

Siemens (S): Unit of electrical conductance

SMD: Surface-Mount Device

SMPS: Switched-Mode Power Supply

SOC: State of Charge

SOH: State of Health

SPI: Serial Peripheral Interface

t: Time

TAN δ: Loss Tangent (or Dissipation Factor)

Tesla (T): Unit of magnetic flux density

THD: Total Harmonic Distortion

TTL: Transistor-Transistor Logic

UHF: Ultra High Frequency

UPS: Uninterruptible Power Supply

V: Electric potential or voltage

V: Volt (unit of electric potential)

V: Voltage

VA: Volt-Ampere (unit of apparent power)

VAC: Volts Alternating Current

VAR: Volt-Ampere Reactive (unit of reactive power)

VCC: Voltage Common Collector (positive supply voltage)

VDC: Volts Direct Current

VFD: Variable Frequency Drive

VHF: Very High Frequency

VLF: Very Low Frequency

VRMS: Voltage Root Mean Square

W: Watt

Weber (Wb): Unit of magnetic flux

Wh: Watt-hour

X7R: A type of ceramic dielectric material specification

μC: Microcoulomb (1 μC = 10^-6 C)

μF: Microfarad (1 μF = 10^-6 F)

Ω: Ohm (unit of electrical resistance)

- **Security:** An operating system provides security features like protection against unauthorized access, file encryption of sensitive data, firewalls, and antivirus software. It also provides features like backup and recovery to ensure data availability in case of data loss or system failure.
- **Updates and patches:** Operating systems regularly receive updates and patches to fix bugs, improve performance and add new features. These updates are important to keep the system secure and up to date.

Elaboration of Content

Electrostatics, a branch of physics, studies static electric fields produced by charges. It's used in photocopiers, paint spraying, computer peripherals, and agricultural activities like plant spraying and seed sorting. Greek philosopher Thales discovered that amber, a yellow resin, attracts lighter objects like paper when rubbed against wool. Dr. Gilbert later demonstrated that materials like glass, plastic, and nylon also attract lighter objects, derived from the Greek word 'electron'.

1.1 Introduction to Electricity

Electricity is the flow of electric charge, typically carried by electrons, and is a fundamental force that powers much of our modern world. At the atomic level, electrons orbit the nucleus of atoms, and when subjected to certain conditions, they can be made to move from one atom to another, creating an electric current. Voltage represents the potential energy per unit charge available to move electrons, while current is the flow of electric charge through a conductor. Resistance opposes this flow, and Ohm's Law describes the relationship between voltage, current, and resistance. Electric circuits provide a pathway for electrons to flow, comprising a power source, conductive pathways, and various components.

1.2 History of Electricity

Before electricity generation, houses used kerosene lamps, iceboxes, and wood-burning stoves. Benjamin Franklin's kite experiment sparked the discovery of electricity, which led to the invention of the electric light bulb, transforming outdoor lighting into indoor lighting and modern inventions like electric cars and Li-Fi technology. The history of electricity spans millennia, from ancient Greek observations to scientific discoveries by Michael Faraday and Alessandro Volta. Early civilizations experimented with lightning and static electricity, while the scientific method led to key milestones like Franklin's kite experiment and Volta's voltaic pile. Today, electricity is a cornerstone of modern civilization, driving innovation and shaping the world. Tesla's electric car series revolutionizes driving with long travel distances, smooth rides, and free recharge at charging stations, utilizing electricity in unprecedented ways. Tesla is also beginning to make electricity storage feasible and cost-effective for the average family home.

1.3 Types of Electricity

There are two main ways to categorize electricity: by its flow and by its source.

Based on Flow

Dynamic Electricity

Dynamic electricity is the lifeblood of our technological world. It's the continuous flow of energetic electrons, not a static buildup. Imagine a river of these tiny charges coursing through wires, propelled by a voltage (pressure) and encountering resistance (friction) along the way. This current (flow rate) is what truly powers our devices, from lighting up a room to running complex machinery. It's all thanks to a dynamic dance of electrons, constantly on the move!

Static Electricity

Static electricity is the fleeting party crasher of the electrical world. Unlike its dynamic cousin, it's a temporary buildup of electric charges on an object's surface, often due to friction. Think of it like rubbing balloons together, creating an imbalance. This imbalance seeks to discharge, causing that surprising zap from a doorknob or a dazzling lightning strike. It's a momentary spark, not a continuous flow, making it more of an occasional nuisance than the workhorse that powers our devices.

Difference Between Static and Dynamic Electricity

Static Electricity	Dynamic Electricity
The electricity which is built up on the surface of the substance is known as static electricity.	The dynamic or current electricity is because of the flow of electrons.

It induces because of the movement of the negative charges from one object to another	It is because of the movement of the electrons.
It develops both in the conductor and insulator.	It develops only in the conductor.
It cannot induce the magnetic field.	It induces a magnetic field.
It has existed for a short time.	It has existed for a long time.
Lightning strokes, develop by rubbing the balloons on hair, etc.	The current electricity is used for running the fan, light, TV, etc.

Method of Electrification

When a plastic comb is brought near to the pieces of paper, it does not attract the paper. But when it is brought nearer after rubbing or combing the hair, it attracts the paper. Similarly when a glass rod rubbed with silk cloth is brought nearer to the pieces of paper, the glass rod will also attract the pieces of paper. From these, it can be said that the attracting capacity is developed in the body due to friction. When the body produces a charge on it, it is said to be electrically charged or electrified. The process of producing the charge on a body is called electrification. Sometimes, a crackling sound is heard in the electrification caused by friction. It can be felt when we take out sweaters in a dark room. These crackling sounds are due to the electric sparks.

Note: Charge is produced on a body due to the movement of electrons from one to another. It is denoted by 'Q' and measured in terms of Coulombs (C). Some other smaller units of charge can be shown as,

$$1 \text{ micro coulombs (mC)} = \frac{1}{1000} C = 10^{-3} C$$

$$1 \text{micro coulombs } (\mu C) = \frac{1}{1000000} C = 10^{-6} C$$

$$1 \text{ nano coulombs (nC)} = \frac{1}{10^9} C = 10^{-9} C$$

$$1 \text{ pico coulombs (pC)} = \frac{1}{10^{12}} C = 10^{-12} C$$

The negative charge is developed when an atom or a substance gains or takes an electron. The positive charge is developed when an atom or a substance loses or gives electrons.

Activity:

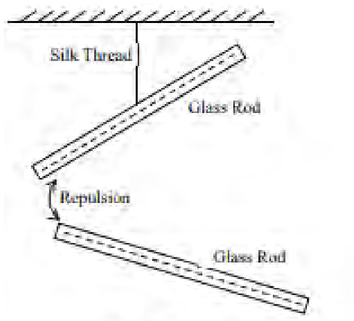


Fig (i)

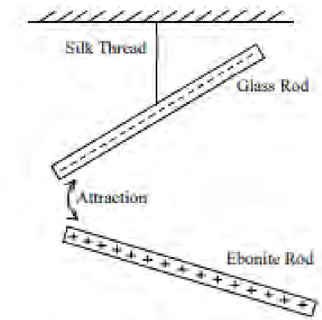


Fig (ii)

In Figure (i), a glass rod is rubbed with silk cloth and is hung with the help of silk thread. When another glass rod again rubbed with silk cloth is brought nearer to it, it is found that they repel each other. Likewise, in Figure (ii), a glass rod is rubbed with silk cloth and is hanged with the help of silk thread. Instead as in Figure (i), when an ebonite rod rubbed with fur is brought nearer to the glass rod, it is found that the two glass rods attract each other. From the above activity, it is clear that the same charges (like charges) repel each other and opposite charges (unlike charges) attract each other.

Based on Source

- **Direct Current (DC):** This type of electricity has a constant flow in one direction, like the current from a battery. It powers many electronic devices like laptops and smartphones.
- **Alternating Current (AC):** This type of electricity constantly reverses direction, going back and forth at a specific frequency (usually 50 or 60 Hz). It is the type of electricity delivered to our homes and businesses for powering appliances and lights.

1.4 Application and Uses of Electricity

Electricity, a form of energy, powers machines, computers, communications, lighting, and heating equipment. It has transformed our surroundings, making life simpler and more enjoyable, and has applications in every aspect of our lives. Here's a glimpse into its diverse uses:

Powering Our Homes and Businesses

Electricity powers lighting, appliances, heating, cooling, entertainment, industry, manufacturing, and automation. It powers appliances like refrigerators and washing machines, provides year-round comfort, and powers electronics like TVs and gaming consoles. Electric motors power assembly lines, robots, and heavy machinery in factories.

Transportation and Infrastructure

Electric vehicles, public transportation systems, and communication infrastructure are all contributing to a reduction in fossil fuel reliance and improved environmental sustainability.

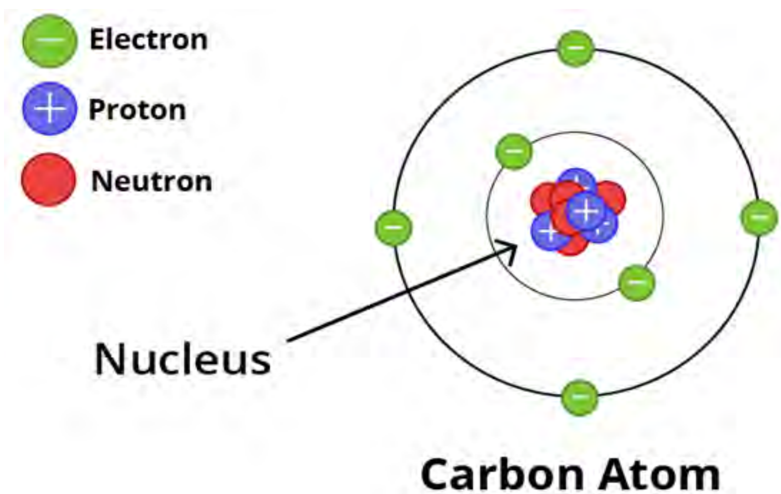
Beyond Daily Life

Electricity powers medical equipment, scientific research, and space exploration, enabling lifesaving machines, diagnostic tools, and advancements in scientific experiments and advancements.

1.5 Introduction to Atom and its Components (Electron, Proton, Neutron)

Atom

Atoms are the fundamental building blocks of matter, consisting of a nucleus with neutral neutrons and protons and a cloud of negatively charged electrons. Their characteristics, such as mass, charge, and chemical behavior, are determined by their electrons. Understanding atoms is crucial for comprehending matter's structure and interactions.



The basic structure of the atom

Electron

Electrons, a subatomic particle with a rest mass of 9.109 x 10 -31 kilograms, orbit the atom's nucleus and are charged negatively. Together with protons and neutrons, they determine atom behavior and chemical characteristics. Electrons are lighter than protons and can be transferred, acquired, or lost through interactions.

Proton

Positively charged and heavier than an electron, a proton is a particle. A proton has a mass of 1.672 × 10-27 kilograms. An atom's nucleus contains one or more protons. The symbol for a proton is p+. At 1.602 × 10-19 Coulombs (C), it is charged. Proton and electron charges are equal, but they have different polarity.

Neutron

Neutron has no electric charge. The mass of a neutron is slightly higher than that of a proton. The mass of a neutron is 1.675×10^{-27} Kilograms. The nucleus of every atom consists of at least one neutron. It is denoted by N.

1.6 Introduction to Atomic Number, Atomic Weight, free Electrons, and Electric Charge

Atomic Number

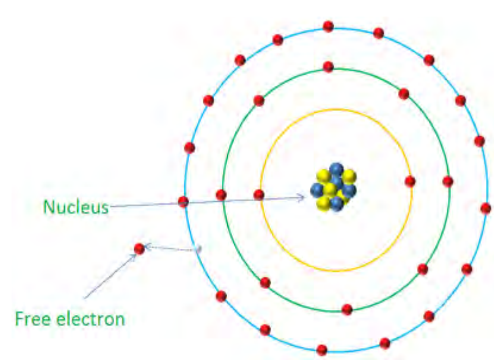
The number of protons or number of electrons contained in an atom is known as its atomic number. i.e Atomic number = No. of protons or No. of electrons contained in an atom For eg, the number of protons and electrons in oxygen is 8, hence its atomic number is 8.

Atomic Weight

The sum of the total number of protons and several neutrons contained in an atom is known as its atomic weight. i.e. Atomic weight = No. of protons + No. of neutrons For eg, the number of protons and neutrons contained in oxygen is 8 and 8 resp., hence its atomic weight is 16. Electronic Configuration: The scientific and systematic arrangement of electrons in different orbits of an atom is known as electronic configuration.

Free Electrons

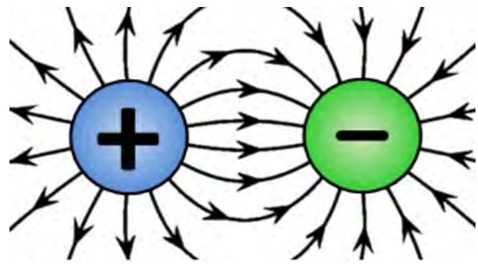
Free electrons are electrons that are not bound to an atomic nucleus and are therefore able to move independently within a material. In solid materials, particularly metals, some electrons are not tightly bound to individual atoms but rather move relatively freely throughout the material. These electrons are responsible for various electrical and thermal properties of



Free Electron

metals, such as electrical conductivity and heat conduction. Free electrons are a fundamental concept in understanding the behavior of materials in fields such as solid-state physics and electronics. Materials that contain free electrons will conduct electric current. Materials that do not contain free electrons do not conduct electric current.

Electric Charge



Electric charge

Electric charge is a fundamental property of matter that describes the fundamental unit of electric interactions, with electrons carrying a negative charge and protons carrying an equal positive charge. Charged particles exert forces on each other through electromagnetic force, which can be attractive or repulsive depending on the charges involved. The SI unit of electric charge is the coulomb (C), and charged objects can interact through processes like electrostatic induction and conduction. Conservation of electric charge states that the total electric charge in an isolated system remains constant over time, a principle fundamental to understanding electrical phenomena ranging from the behavior of individual particles to the operation of complex electrical circuits.

The two types of electric charges are: Positive and Negative, commonly carried by charge carriers protons and electrons. Examples of the types of charges are subatomic particles or the particles of matter:

- protons are positively charged
- electrons are negatively charged
- neutrons have zero charge

1.7 Introduction to Coulomb's law and its Derivation

Coulomb's law was published by Charles Augustin de Coulomb, the French physicist. The Coulomb's law was critical in the development of the theory of electromagnetism. The particles in the universe, as well as our environment, remain in a balanced form only because of the forces of attraction; this renders one of the practical applications of Coulomb's law.

Coulomb's Law, a fundamental principle in electrostatics, describes the attraction or repulsion between two point charges, forming the basis of electrical interactions and crucial in various electricity applications.

The Essence of the Law

Coulomb's Law states that the magnitude of the electrostatic force (F) between two point charges (q1 and q2) is directly proportional to the product of their magnitudes and inversely proportional to the square of the distance (r) separating them. We can express this mathematically as:

F = k * (q1 * q2) / r^2

Here, k is a constant of proportionality known as **Coulomb's constant**. Its value depends on the chosen system of units. In the International System of Units (SI), k = 8.99 x 10^9 N·m^2/C^2.

Understanding the Proportionalities

- **Direct proportion to the product of charges:** If either charge (q1 or q2) is doubled, the force between them also doubles. Likewise, halving either charge halves the force.

Inverse proportion to the square of the distance: The force between charges decreases by a factor of four when the distance between them is doubled, as the force decreases rapidly with increasing separation.

Derivation of Coulomb's Law (Optional): Coulomb's Law, derived from mathematical concepts from calculus and vector analysis, is based on experimental observations and reasoning, providing a basic understanding.

Experimental Evidence: Charles-Augustin de Coulomb's early experiments demonstrated that the force between charged objects was influenced by their charge magnitude and distance.

Inverse Square Law Analogy: The inverse square relationship with distance is similar to the behavior of light intensity or gravitational attraction, where the effect weakens with increasing distance squared.

Let us consider two charges, 'q_1' and 'q_2'; separated by a distance 'r.' The force of attraction or repulsion is 'F';

$F \propto q_1 q_2$ ....(i)

$F \propto \mathbf{1/r^2}$........................(ii)

Combining equations (i) and (ii) we get:

$F \propto q_1 q_2 / r^2$

$F = k\, q_1 q_2 / r^2$

In the above equation, $k = 1/4\pi\varepsilon_0$. ε_0 describes the permittivity of a vacuum. The value of k is nearly $9 \times 10^9\ Nm^2/C^2$; if we consider the value of ε_0 in SI units as $8.854 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

This theory also describes that like charges repel each other and opposite charges attract each other.

Coulomb's Law and Point Charges

It's important to note that Coulomb's Law strictly applies to point charges – hypothetical objects with negligible size compared to the separation distance. In real-world scenarios, charges are distributed over a certain volume. However, for many practical applications, we can treat charged objects as point charges if the distance between them is much larger than their size.

Coulomb's Law: A Powerful Tool

By understanding Coulomb's Law, we can:

a. Predict the force between charged objects in various configurations.

b. Explain the behavior of charged particles in electric fields.

c. Analyze the interactions between atoms and molecules involving electron distribution.

d. Formulate the basis for more complex electrical phenomena like capacitance and electric fields.

Coulomb's Law is a cornerstone of electrostatics, paving the way for further exploration and advancements in electrical science and technology.

Numerical Examples

1. Two positive charges of 5μC and 4μC are placed 0.1 m apart. Calculate the repulsive force between them. [$\in_0 = 8.854 \times 10^{-12} C^2 N^{-1} m^{-2}$]

   Solution,

   Value of one change (q_1) = 5μC

   $= 5 \times 10^{-6}$ C

   Value of another charge (q_2) = 4μC

   $= 4 \times 10^{-6}$ C

Distance between two charges (r) = 0.1 m

The permittivity of vacuum ($\in_0$) = $8.854 \times 10^{-12} C^2 N^{-1} m^{-2}$

The force between charges (F) =?

Now, $F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$

or, $F = \frac{9\times10^9\times5\times10^{-6}\times4\times10^{-6}}{(0.1)^2}$ $[\because \frac{1}{4\pi\epsilon_0} = 9\times10^9]$

or, F = 18N

$\therefore$ The repulsive force between two charges is 18N.

2. **The positive charges of 4 μC and 6 μC experience a repulsive force of 20 N. Calculate the distance between two charges. [∈0 =8.854×10-12C2N-1m-2]**

Value of one charge (q_1) =4 μC= 4×10^{-6}C

Value of another charge (q_2) = 6μC = 6×10^{-6}C

The force between two charges (F) = 20N

Distance between two charges (r) =?

Now,

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$

or, $20 = \frac{9\times10^9\times4\times10^{-6}\times6\times10^{-6}}{r^2}$

or, $20\times r^2 = 0.216$

or, $r^2 = \frac{0.216}{20}$

or, $r^2 = 0.0108$

or, $r = \sqrt{0.0108}$

or, r = 0.104 m

$\therefore$ The distance between the two charges is 0.104m.

A computer needs memory for holding data and instructions permanently or temporarily. Computer memory is the electronic holding place for the instructions and data. It is the place where information or instructions are stored for immediate use. Memory is one of the basic functions of a computer, because without it, a computer would not be able to function properly. Memory is also used by a computer's operating system, hardware and software.

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1.8 Introduction to an Electric Field, Potential and Potential Difference

Introduction to the Electric Field

An electric field is an invisible force field caused by an electric charge. It is an alteration in the space (air or vacuum) around the charge. It results in an **electric force** that is felt by electric charges when placed close to one another. A static electric field is created when the charges are stationary, and the corresponding force is known as electrostatic force. The electric field is a vector quantity having both magnitude and direction.

Electric lines of force represent the strength and direction of an electric field, drawn around a charge. When a positive charge is near a negative charge, the lines exit and terminate into the negative charge, indicating the direction of the field.

The flux of an electric field is defined as the number of field lines passing through a certain area in space. The area can represent a regular or irregular surface through which the lines pass. Mathematically, it is the dot product of the electric field *E* and the area vector *A*. The symbol ø denotes flux.

$$\varphi = E.A$$

If E and A make an angle θ, then the equation is given by,

$$\varphi = EA \cos \theta$$

The strength of the electric field in the space surrounding a source charge is known as the **electric field intensity**. An electric field is defined as the electric force experienced by a unit charge.

The following equation gives the electric field vector:

$$E = F/q$$

Numerical Problems

1. An electric force of 8 N is acting on the charge 3 μC at any point. Determine the

electric field at that point.

Solution,

Force (F) = 8 N

Charge (q) = 3 μC = 3×10^{-6}C

Electric Field (*E)* =*?*

Now

$E = F/q$ = 8 N/3 μC = 2.67×10^{6} N/C

2. **A small charge, q = 4 μC, is found in a uniform electric field E = 3.6 N/C. What is the force on the charge?**

Solution,

Charge (q) = 4 μC = 4×10^{-6}C

Electric Field (*E)* = 3.6 N/C

Force (F) =?

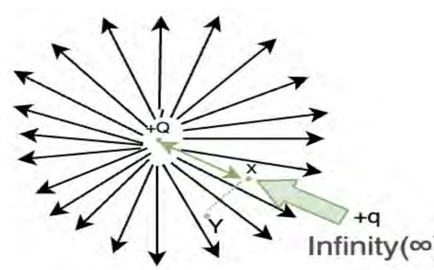
Now,

$F = qE = 4\ \mu C \times 3.6\ N/C = 4 \times 10^{-6}C \times 3.6\ N/C$

$= 14.4 \times 10^{-6}$N.

Introduction to Electric Potential

Electric Potential is the amount of labor required per unit charge to move that charge from infinity to a location in the electrostatic field against the field force. Voltage, sometimes known as volts, is the SI unit for electric potential or electric potential difference. Electric potential is a scalar quantity.



Electric Potential

The figure illustrates the task of bringing a unit charge (+q) from infinity to a point inside the electric field against the field, as the electrostatic force is against the charge.

- If the work is done to move the charge from infinity to point X, it will be called an Electric potential at X (Vx).
- If the work is done to move the charge from infinity to point Y, It will be called an Electric potential at Y (Vy).
- If the work is done to move the charge from X to Y, it will be called the potential

difference between x and y (Vxy).

Formula for Electric Potential

Electric Potential/ Voltage = Work Done (W) / Unit Charge(q)

SI unit for Electric Potential:

V = W/q = Joules/ coulomb (Volt)

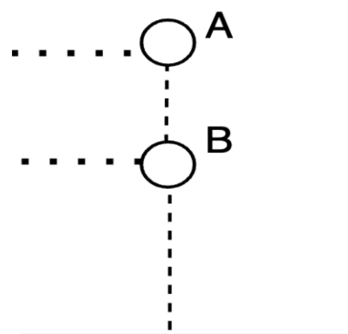
Therefore, the SI unit for Electric Potential is Volts or Voltage.

1 Volt = 1 Joule/ 1 coulomb

1 Volt can be defined as 1 joule of work done to move 1 coulomb of charge.

Introduction to Electric Potential Difference

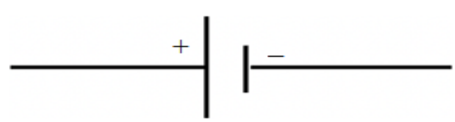
Imagine a ball at some height, there will be some energy in the ball called Potential energy. If the ball is dropped from point A to B, the ball will fall from a higher gravitational potential to a lower one, then there will be a difference in both energies. The electrical potential difference is analogical to this concept.



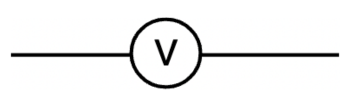
The energy possessed by electric charges is known as electrical energy. A charge with higher potential will have more potential energy and the charge with lesser potential will have less potential energy. The current always moves from higher potential to lower potential. The difference in these energies per unit charge is known as the electric potential difference.

To create electricity and the flow of current, a potential difference is always required which is maintained by a battery.

The longer side represents the higher potential (+ve terminal) and the shorter side represents the lower potential (-ve terminal).



The electric potential difference is measured by a Voltmeter which is applied parallel to the instrument whose Voltage is to be measured.



It is the work done per unit charge to move a unit charge from one point to another in an electric field. Electric potential difference is usually referred to as Voltage difference.

Formula for Electric Potential Difference

$V_{xy} = V_x - V_y = [W_x - W_y]/q$

The SI unit of electrical potential difference is the same as the electric potential, i.e.; Voltage or Volts.

Numerical Examples

1. **What is the Potential difference of a charge of 10mC is moved from infinity to point A in the Electric field, the work done in this process is 20 Joules.**

Solution

W = 20 joules

Charge (q) = 10mC

$= 10\times10^{-3}$C

= 0.01C

Potential difference (V) =?

Now,

V = W/q

$= 20/10\times10^{-3}$

= 2kV

= 2000V

Therefore, the potential difference of a charge is 2000 volts.

2. **A Charge of 50mC is moved from one point to another (from A to B) The voltage at A is 50kV and the Voltage at B is 30kV, Find the Work done by the charge.**

Solution

Potential difference (V_{AB}) = $V_A - V_B$

= 50kV- 30kV

= 20kV

= (20×1000) V

= 20000V

Charge (q)

= 50mC

$= 50\times10^{-3}$C

Work done (W) =?

Now,

Work done = V× q

= 20000V × 50×10^{-3}C

= 100 Joules

1.9 Electric Energy, Voltage, and its Unit

Electrical energy is the energy derived from the electric potential energy or kinetic energy of the charged particles. In general, it is referred to as the energy that has been converted from electric potential energy. We can define electrical energy as the energy generated by the movement of electrons from one point to another. The movement of charged particles along/through a medium constitutes current or electricity.

Electrical Energy Formula

A cell has two terminals – a negative and a positive terminal. The negative terminal has an excess of electrons whereas the positive terminal has a deficiency of electrons. Let us take the positive terminal as A and the electrical potential at A is given by V(A). Similarly, the negative terminal is B and the electrical potential at B is given by V(B). Electric current flows from A to B, and thus V(A) > V (B).

The potential difference between A and B is given by

$$V = V(A) - V(B) > 0$$

Mathematically, electric current is defined as **the rate of flow of charge through the cross-section of a conductor**.

Thus, it is given by $I = \Delta Q/ \Delta t$ where I is the electric current and ΔQ is the quantity of electric charge flowing through a point in time Δt.

The potential energy of charge Q at A is Q V(A) and at B, it is Q V(B). So the change in the potential energy is given by

ΔUpot = Final potential energy – Initial potential energy

$$= \Delta Q [(V (B) - V (A)] = -\Delta Q V$$

$$= -I V\Delta t \text{ (Since } I = \Delta Q/ \Delta t)$$

If we take the kinetic energy of the system into account, it would also change if the charges inside the conductor moved without collision. This is to keep the total energy of the system unchanged. Thus, by conservation of total energy, we have:

$\Delta K = -\Delta Upot$

Or $\Delta K = I\ V\Delta t > 0$

Thus, in the electric field, if the charges move freely across the conductor, there would be an increase in the kinetic energy as they move.

When the charges collide, the energy gained by them is shared between the atoms. Consequently, the vibration of the atoms increases resulting in the heating up of the conductor. Thus, some amount of energy is dissipated in the form of heat in an actual conductor.

Units of Electrical Energy

The basic unit of electrical energy is the joule or watt-second. An electrical energy is said to be one joule when one ampere of current flows through the circuit for a second when the potential difference of one volt is applied across it. The commercial unit of electrical energy is the kilowatt-hour (kWh) which is also known as the Board of Trade Unit (B.O.T).

1 kWh = $1000 \times 60 \times 60$ watt – second

1 kWh = 36×10^5 Ws or Joules

= 3.6×10^6 Joules

Generally, one kWh is called one unit.

The examples of electrical energy are as follows:

- In a car battery, a chemical reaction results in the formation of an electron which possesses the energy to move in an electric current that provides electrical energy to the circuits in the car.
- Lightning and thunderstorms are examples of electrical energy.
- Electrical energy can be converted into other forms of energy like heat energy, light energy, motion, etc. For example: The motor in the Fan converts electrical energy into mechanical energy. In a bulb, electrical energy is converted into light energy. The heater converts electrical energy into heat energy.

Voltage

Voltage is the force or pressure that is responsible for pushing the charge in a closed-looped conductor in an electrical circuit. The flow of charge is called current. Voltage is denoted by the letter V. Voltage is also known as electric pressure, electric tension, or electric potential difference.

Unit of Voltage

The unit of voltage is volt named after Italian physicist Alessandro Volta who invented the first battery (chemical battery to be more precise).

One volt is defined as "the potential difference between two points that allows a current of 1 ampere through it and dissipates 1 watt of power between these points".

The unit of voltage is the volt, and it is represented by the symbol "V." One volt is defined as one joule of energy per coulomb of charge. The volt is the standard unit for measuring electric potential difference, electromotive force, and voltage in the International System of Units (SI). In equations, voltage is often denoted by the letter "V." For example, Ohm's Law, which relates voltage (V), current (I), and resistance (R), is expressed as V = I * R, where V is the voltage in volts, I is the current in amperes, and R is the resistance in ohms.

In other words, a "one volt" is the potential difference that moves one joule of energy per coulomb charge between two points.

$$1\,\mathbf{V = 1J / C}$$

$$\mathbf{= 1W / A}$$

Where:

V = Voltage in "Volts"

J = Energy in "Joules"

C = Charge in "Columbus"

W = Work done in "Joules"

A = Current in "Ampere"

Exercises

Choose the correct answer from the given alternatives.

1. The mass of an electron is............

   a. 9×10^{-31}kg   b. 1.67×10^{-31}kg

   c. 6.67×10^{-31}kg   d. 9.107×10^{-31}kg

2. Which of the following statements is true?

   a. The mass of an electron is less than that of the proton.

   b. The mass of an electron is equal to the mass of a proton.

   c. The mass of an electron is greater than the mass of a proton.

   d. An electron is a massless particle.

3. The SI unit of potential difference is........

   a. Coulomb   b. Joule   c. Volt   d. Ampere

4. The SI unit of permittivity of vacuum ($\in 0$)is.............

   a. C^2Nm^{-2} b. $C^2N^{-1}\ m^{-2}$ c. $CN^{-1}\ m^{-2}$ d. CNm^2

5. One kilowatt hour is equal to..........

   a. 3×10^6J   b. 36×10^6J   c. 3.6×10^6J   d. 3.6×10^5J

6. Which of the following devices converts electrical energy into mechanical energy?

   a. Fan   b. Iron   c. Heater   d. Television

Write short answer to the following questions.

1. Define static and dynamic electricity.
2. What is atomic weight? How is it calculated?
3. What is electric charge? Write its types.
4. Change one kilowatt hour into Joule.
5. What is electric potential? Write its formula and SI unit.
6. How is static electricity produced?
7. Write any four uses of electricity.

Write long answer to the following questions.

1. Write any three differences between static electricity and dynamic electricity.
2. State Coulomb's law and derive the mathematical expression for it with necessary illustrations.

Project Work

Solve the following Numerical:

1. Calculate the force between two charges of 10μC and 20μC respectively when they are placed 20 cm apart. [∈0 =8.854×10-12C2N-1m-2]
2. Calculate the value of two equal charges if they repel one another with a force of 1N when situated 1m apart in a vacuum. [∈0 =8.854×10-12C2N-1m-2]
3. An electric force of 12N is acting on the charge 4μC. Determine the electric field at that point.
4. What is the force on a charge of 6μC when it is kept in a uniform electric field of 10 N/C?
5. A charge of 9μC is moved from point 'P' to 'Q'. The voltage at 'P' is 100 KV and the voltage at 'Q' is 20 KV. Find the work done by the charge.

Unit 2 Electric Fundamentals

2.1 Introduction to Basic Electric Terms

There are two types of electric charges: positive and negative. Similar charges will repel one another, and opposite charges will attract. Protons and electrons as the fundamental charged particles, and each carries an "elementary charge," which describes its magnitude.

Properties of Electricity

Current

Current is denoted by 'I' and measured in amperes. It is the rate at which charge is flowing from negatively charged material to positively charged material. It is defined as the amount of charge that passes a point in a second. For example, if 3 Coulombs of charge pass a single point in a wire for 2 seconds, there exists a current of 1.5 Amperes (A) in the system.

I = Q/t

Where,

I: Current

Q: Charge

t: Time

Current is measured in units of Ampere. 1 Ampere = 1 coloumb/sec = 6.25 x 10^{18} **electrons per second.**

Voltage

Voltage is denoted by V. It is referred to as "electrical potential difference" or "electro-motive force" which is the difference in the electrical potential energy per unit of charge between two positions in space. It tells us the amount of energy that is required to separate two charged materials some distance. For example, if it requires 9 Joules (J) of energy to separate 3 Coulombs (C) of electrical charge, the resulting electrical potential difference (which is to say voltage) would be 3 Volts (V). Accordingly, the equation for voltage is:

$V = W/Q$

Where

V: Voltage

W: Energy (or Work)

Q: Charge

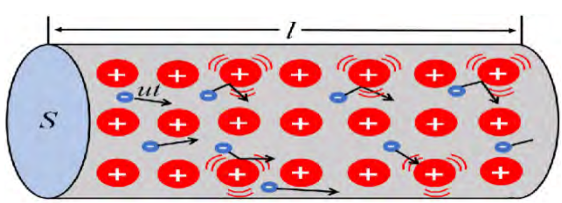
The units of voltage or Volts: 1 Volt = 1 Joule/Coulomb

Resistance

Resistance is the opposition to electrical current in a material. It is the inverse of a material›s ability to conduct electricity. It commands quickly charge will flow through a circuit and total current existence. Metals are good conductors due to low resistance. Wood is a poor conductor due to high resistance. Resistance (R) is measured in ohms (Ω) and depends upon both the type of material and its size. Long wires have more resistance than short wires; thin wires have more resistance than thick wires. R is also temperature-dependent.

2.2 Concept of Movement of Electrons in a Conductor

The flow of electrons through a conductor produces an electrical current in the opposite direction. When some quantity of electric charge transfers from one point of a conductor to another point of the conductor, it indicates an electric current. In the International standard (SI) unit, the electric current is shown by ampere. The electric current is also indicated by Coulomb per second. Calculate the number of electrons that would be equivalent to 1 Coulomb of charge.



movement of electrons

$e = 1.609 \times 10^{-19}$ Coulomb.

That is the charge of an electron is 1.609×10^{-19} Coulomb. Conversely, we can say that 1.609×10^{-19} Coulomb charge is obtained from = 1 electron. Therefore, 1 Coulomb of charge can be obtained from = $(1/1.609) \times \mathbf{10}^{-19}$ electrons.

2.3 Sources of Electricity

Electricity, a fundamental natural phenomenon, is a widely used secondary energy source, produced by converting primary energy sources like coal, natural gas, nuclear, solar, and wind energy into electrical power. It can be converted into mechanical or heat energy. Electricity can be generated from various sources, each with its own set of characteristics, advantages, and challenges.

Hydroelectricity

Hydroelectricity, or hydroelectric power, is a renewable energy source derived from natural forces like gravity or flowing water. It is increasingly popular worldwide, with dams being common sources. The turbine spins a metal shaft, generating an electric current in the coils of wire inside the turbine.

The following is a list of the few power stations in Nepal.

Hydropower	Location	Capacity (MW)	Commissioned	Owner
Upper Tamakoshi Project	Dolakha	456	2021	NEA
Kaligandaki A Hydroelectric Power Station	Syangja	144	2002	NEA
Middle Marsyangdi Hydropower Station	Lamjung	70	2008	NEA
Mai Hydropower Station	Illam	22	2014	Sanima Hydropower
Marsyangdi Hydropower Station	Tanahun	69	1989	NEA
Kulekhani I	Makwanpur	60	1982	NEA

Sunkoshi Small Hydropower Plant	Sindhupalchowk	2.5	2005	Sanima Hydropower
Khimti I Hydropower Plant	Dolkha	60	2000	Himal Power Ltd.
Upper Marsyangdi A Hydroelectric Station	Lamjung Marsyangdi Rural Municipality	50	2016	SSPC, Power China
Bhote Koshi Power Plant (Upper Bhote Koshi)	Sindhupalchowk	45	2001	Bhote Koshi Power Company Private Limited (BKPC)
Kulekhani II	Makwanpur	32	1986	NEA

Hydropower, a renewable energy source, uses water energy from rivers, dams, and tidal movements to generate electricity, making it one of the oldest and most widely used globally.

Basic Mechanism

- **Flowing or Falling Water:** The primary source of energy in hydropower is the kinetic energy of flowing or falling water.
- **Turbines:** Water flow is used to turn turbines, which are connected to generators.
- **Generators:** Turbines drive generators that convert the mechanical energy from the rotating turbines into electrical energy.

Types of Hydropower

a. Run-of-River Hydropower: Run-of-river systems utilize a river's natural flow to generate electricity without a large reservoir, diverting a portion of the river's flow through a canal to turbines.

b. Reservoir Hydropower: Dams store water in reservoirs, which are then released through turbines to generate electricity, providing greater control over power generation for base or peak loads.

c. **Pumped Storage Hydropower:** Pumped storage facilities utilize surplus electricity to pump water from lower reservoirs to upper reservoirs during low demand, and release stored water from upper reservoirs to generate electricity during high demand periods.

Nuclear fission/Fusion

Fusion occurs when light nuclei bond to form a heavier nucleus, with the new atom's mass being less than the original two, releasing energy. Nuclear fusion is the process of merging multiple atomic nuclei to create a single, heavier nucleus, which powers active stars and releases significant energy. This process offers an inexhaustible energy source for future generations, with research in various countries. Nuclear fission and nuclear fusion are two processes involving energy release from atomic nuclei. Nuclear fission involves splitting an atom into smaller nuclei and releasing a large amount of energy. This energy is used in nuclear power plants to generate electricity and is the underlying process in nuclear weapons.

Wind Power or Energy

Wind power is a renewable energy source that converts wind kinetic energy into mechanical or electrical energy. Historically used in windmills, modern commercial turbines generate electricity using rotational energy. Research aims to address challenges in utilizing wind energy for greater global use.

Wind power converts wind kinetic energy into electrical energy, a clean and sustainable renewable energy source, gaining prominence for electricity generation due to its low greenhouse gas emissions.

Wind power is primarily generated by wind turbines, large structures with rotating blades that drive a generator to generate electrical power.

Thermal Power

Thermal power refers to the rapid conversion of heat from fuel into heat, typically used in power plants to generate electricity, with input measured in megawatts thermal. It converts heat energy from fossil fuel combustion or other sources into electrical energy, a crucial component of global electricity production.

Types of Thermal Power

a. **Fossil Fuel-Based Thermal Power:** Coal-fired power plants generate heat, power turbines, generate electricity through high-temperature gases, and oil-fired plants use oil to generate heat and electricity.

b. **Nuclear Thermal Power:** Nuclear power plants convert heat energy into electricity through nuclear reactions, producing steam that drives turbines connected to generators.

c. **Solar Thermal Power:** Solar thermal power plants utilize sunlight to generate heat, with Concentrated Solar Power (CSP) systems focusing sunlight onto a specific area, generating high temperatures and steam for electricity generation.

d. **Geothermal Power:** Geothermal power plants harness Earth's internal heat to generate steam, driving turbines connected to generators, a form of thermal power.

Solar Energy or Solar Power

Solar energy captures the Sun's energy and converts it into electricity, used in homes, streets, businesses, and machines. China, the world's largest generator, has a solar energy capacity of over 130 gigawatts.

Solar energy, derived from the sun's radiation, is a renewable energy source used for electricity and heat generation in residential, commercial, and industrial applications, offering environmental benefits and sustainable production.

There are two primary ways in which solar energy is commonly utilized:

a. **Photovoltaic (PV) Solar Power:** Photovoltaic technology converts sunlight into electricity using solar cells, typically silicon-based, and is widely used in rooftops, solar farms, and power installations for a clean and sustainable electricity generation method.

b. **Solar Thermal Power:** Solar thermal technologies generate heat from sunlight, producing electricity through concentrating solar power (CSP) and solar water heating systems. CSP uses mirrors to focus sunlight, while water heating directly heats water for residential or industrial use.

Advantages of Solar Energy

- Solar energy reduces your monthly power bill
- It provides lucrative tax incentives

- It can be paired with a solar battery
- Solar panels and battery storage are an ideal combination when paired together.
- Solar energy is environmentally-friendly

Disadvantages of Solar Energy

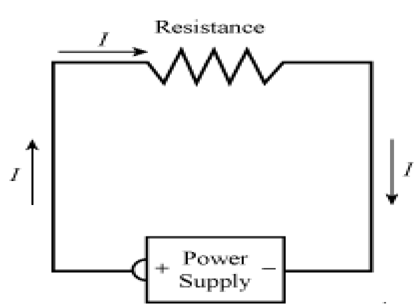
- Initial costs can be high to set up.
- The permitting process can be time-consuming.
- Weather Dependence
- Not every roof will meet the criteria for solar

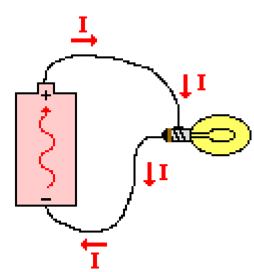
2.4 Conventional Direction of Electric Current and its Uses

The conventional direction of electric current is from positive to negative terminal. Or, in other words, from higher potential to lower potential. Electric current is measured by the number of electrons flowing at a particular point in a conductor or a circuit per unit of time.

$I = Q / t$

Where Q is the charge of electrons flowing through the conductor, t is the time of flow in seconds.





Electric current in the external circuit is directed from the positive to the negative terminal.

There are two theories to explain the direction of the current. One is the theory of conventional current, and the other is the theory of actual current flow. When Benjamin Franklin was studying charges, the structure of an atom and atomic particles were unknown. Hence, he assumed the point of charge accumulation as positive and the point which is deficient of charges as negative. Therefore, the charge is said to flow from positive to negative. This is called conventional current. Or, the direction of current flow from the positive to the negative end of a battery is called the conventional direction of current flow.

Electrons are negatively charged particles and are attracted towards the positive charge. Also, many experiments have revealed that it is free electrons in a conductor that flows. Negatively charged electrons move from the negative terminal to the positive terminal. This is the direction of the actual current flow. Or, the direction of flow of electrons from the negative to the positive end of a battery is called the actual direction of current flow.

The conventional direction of electric current, established before electron discovery, is the positive charge flow from a voltage source to the negative terminal. This convention simplifies circuit analysis and design, aligning with historical conventions before electron discovery.

2.5 Electrical Resistance and its Unit

When an electric current flows through a bulb or any conductor, the conductor offers some obstruction to the current and this obstruction is known as electrical resistance and is denoted by R. Every material has an electrical resistance.

Electrical resistance is a measure of how much a substance opposes the flow of electric current. It is denoted by the symbol "R" and is measured in ohms, represented by the symbol "Ω" (omega). One ohm is defined as the amount of resistance that limits the flow of one ampere of current when one volt of electric potential is applied across it.

According to Ohm's law, there is a relation between the current flowing through a conductor and the potential difference across it. It is given by,

$V \propto I$ $V = IR$

$V = IR$

Where,

V is the potential difference measured across the conductor (in volts)

I am the current through the conductor (in amperes)

R is the constant of proportionality called resistance (in ohms)

The electrical resistance of a circuit is the ratio between the voltage applied to the current flowing through it.

The unit of electrical resistance is ohms (Ω).

1ohm = 1 volt / 1ampere

Electric charge flows more easily through some materials than others. The electrical resistance measures how much the flow of this electric charge is restricted within the circuit.

2.6 Use and Application of Resistance in a Circuit

Different types of resistors work according to the usage range. In this, we can set the resistance value by using a type of feature called a knob. Any changes in a resistance value affect the flow of current inside the circuit. The two main ways of increasing the current in an electrical circuit are by increasing the voltage or by decreasing the resistance. The use of resistors in circuit functions are:

- In controlling the speed of a motor,
- The pitch of a musical tone, and
- The loudness of an amplifier.

Resistance plays a crucial role in electrical circuits, and its applications are diverse. Here are several uses and applications of resistance in a circuit:

- **Voltage Division:** Resistors are commonly used to create voltage dividers in a circuit.
- **Current Limiting:** Resistors are frequently employed to limit the current in a circuit.
- **Heating Elements:** Some electrical devices, such as electric heaters or toasters, use resistive elements to generate heat.
- **Biasing in Transistors:** Resistors are essential in biasing circuits for transistors.
- **Filter Circuits:** Resistors are used in combination with capacitors and inductors to create filter circuits.

2.7 Classification of Objects Based on Resistance

Materials are classified into three main categories based on their electrical conductivity: conductors, semiconductors, and insulators. Conductors allow electric current flow, while semiconductors have electrical conductivity between conductors and insulators. Classifications are determined by factors like conductivity, resistivity, band structure, forbidden gap, band overlap, and current flow.

Objects can be classified based on their resistance into three main categories conductors, insulators, and semiconductors.

Conductor

A conductor is a material or substance that allows the flow of electric current. In conductors, electric charges (usually electrons) can move freely within the material in response to an applied electric field. Conductors have low electrical resistance, which means they offer minimal opposition to the flow of electric current. Gold and silver are excellent conductors, along with certain electrolyte solutions found in certain liquids, and metals like copper and aluminum.

Characteristics of Conductors

Conduc--tors have low electrical resistance due to the presence of free electrons, allowing efficient transmission of electric current. They have high electrical conductivity, like copper and aluminum, and allow free electron movement in response to an electric field. This allows for efficient heat generation due to the material's resistance.

Semiconductor

A semiconductor is a material that has conductivity in-between conductors and insulators. It can block or allow the current flow providing total control over it. They are mostly modified by adding impurities called doping. It modifies its properties like unidirectional current flow amplification or energy conversion etc. The electrical conduction inside semiconductors is due to the movement of electrons & holes. Silicon, germanium, and graphite are some examples of semiconductors.

Characteristics of Semiconductors

- **Moderate Electrical Conductivity:** Semiconductors have electrical conductivity higher than insulators but lower than conductors.
- **Band Gap:** Semiconductors have an energy band gap between the valence band (where electrons are bound to atoms) and the conduction band (where electrons can move freely).
- **Controlled Conductivity:** The conductivity of semiconductors can be increased through a process called doping, where specific impurities are intentionally added to the semiconductor crystal structure.
- **Temperature Sensitivity:** The conductivity of semiconductors is often temperature-dependent. As the temperature increases, the energy of electrons in the crystal lattice also increases, affecting their ability to move through the material.

Silicon and germanium are the most widely used semiconductors in electronic devices.

Silicon, in particular, is the cornerstone of the semiconductor industry and is used in the fabrication of integrated circuits (ICs) and other electronic components. Semiconductors are fundamental to the operation of electronic devices. They are used in the construction of transistors, diodes, integrated circuits, and various semiconductor devices. Semiconductors play a crucial role in computers, smartphones, televisions, electronic sensors, and a wide range of modern electronic systems.

Insulator

An insulator is a material or substance that does not readily allow the flow of electric current. Insulators have high electrical resistance, meaning they strongly resist the movement of electric charges through the material. Unlike conductors, which allow electrons to move freely, insulators have tightly bound electrons that are not easily displaced.

Characteristics of Insulators

- **High Electrical Resistance:** Insulators exhibit high resistance to the flow of electric current.
- **Low Electrical Conductivity:** Insulators have low electrical conductivity, meaning they do not readily conduct electric current.
- **Large Band Gap:** Insulators typically have a large energy band gap between the valence band (where electrons are bound to atoms) and the conduction band (where electrons can move freely).
- **Examples of Insulators:** Common insulating materials include rubber, glass, plastic, wood, ceramics, and dry air.

Differences Between Conductors, Semiconductors and Insulators

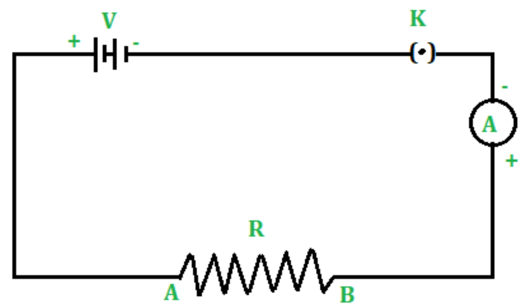
SN	Conductor	Semiconductor	Insulator
1	A conductor is a material that facilitates the flow of charge when applied with a voltage.	A semiconductor is a material with conductivity between the conductor and insulator.	An insulator is a material that prevents the flow of current.
2	The resistance of a conductor increases with an increase in temperature.	The resistance of a semiconductor decreases as the temperature increases.	The resistance of an insulation system is highly high, yet it continues to increase with temperature.

3	It has extremely high conductivity.	It has moderate conductivity.	It possesses no conductivity.
4	The conduction in it is due to the free electrons in metal bonding.	The conduction in it is due to the movement of electrons & holes.	There are no free electrons or holes thus, there is no conduction.
5	A conductor's conduction and valance bands have no or low energy gap, requiring no additional energy for the conduction state.	The band gap of an insulator is larger than that of a conductor, but less than that of an insulator, requiring less energy for the conduction state.	The large band gap in an insulator requires a significant amount of energy, like lightning, to push electrons into the conduction band.
6	The resistivity coefficient is positive.	The resistivity has a negative coefficient.	The material has a negative resistivity coefficient but exhibits a substantial resistance.
7	Some conductors turn into superconductors when supercooled down to absolute zero while others have finite resistance.	The semiconductors turn into insulators at absolute zero.	The insulator's resistance increases when cooled down to absolute zero.
8	Example: Gold, Copper, Silver, Aluminum, etc	Examples: Silicon, Germanium, Selenium, Antimony, Gallium Arsenide (known as semi-insulator), Boron, etc.	Example: Rubber, Glass, Wood, Air, Mica, Plastic, Paper, etc.
9	Metals like iron and copper are used in creating wires and cables that can conduct electricity.	These components are utilized in various electronic devices like cell phones, computers, solar panels, switches, energy converters, and amplifiers.	These devices are utilized to safeguard against high voltages and to prevent electrical shorts between cables in circuits.

2.8 Concept of Factors Affecting the Resistance

Resistance is the property of the material that restricts the flow of electrons. There are five factors affecting resistance which are Temperature, Length of wire, Area of the cross-section of the wire, nature of the material, and shape of the conductor.

The resistance of a wire depends both on the cross-sectional area and length of the wire and on the nature of the material of the wire. Thick wires have less resistance than thin wires. Longer wires have more resistance than short wires. Copper wire has less resistance to thin steel wire of the same size. Electrical resistance also depends on temperature. At a certain temperature and for a particular substance.



The resistance of a conductor is influenced by several factors. The following are the factors on which the resistance of the conductor depends:

- **Material:** Different materials have different resistivities, which is a fundamental property determining how strongly a given material opposes the flow of electric current. Materials with high resistivities, such as rubber or glass, exhibit higher resistance, while conductive materials like copper or aluminum have low resistivity.
- **Length of the Conductor:** The length of the conductor is directly proportional to its resistance. In other words, the longer the conductor, the higher the resistance. This relationship is expressed by the formula: $R \propto L$.
- **Cross-Sectional Area:** The cross-sectional area of the conductor is inversely proportional to its resistance. A larger cross-sectional area allows more space for the electrons to flow, resulting in lower resistance. The relationship is expressed by the formula: $R \propto 1/A$.
- **Temperature:** Temperature has a significant impact on resistance. In general, as the temperature of a conductor increases, its resistance also increases. This relationship is more pronounced in conductors with higher temperature coefficients. However, for semiconductors, resistance tends to decrease with increasing temperature.

Prove that where symbols have their meaning.

Prove that $\rho = \frac{R \times A}{l}$ where symbols have their meaning.

Let,

R = Resistance of a conductor

A = cross-sectional area of conductor

l = length of conductor

The resistance of a conductor is directly proportional to the length of the conductor. i.e. $R \propto l$ ....(i)

The resistance of a conductor is inversely proportional to the cross-sectional area of the conductor. i.e. $R \propto \frac{1}{A}$...........(ii)

Combining relation (i) and (ii) we get,

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

or, $R = \rho \times \frac{l}{A}$

where $'\rho'$ is the proportionality constant called resistivity of the conductor.

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

Resistivity

The resistance of a conductor having a unit area of cross-section per unit length is called resistivity. It is denoted by and its SI unit ism.

The resistivity of a conductor is constant. The resistivity of different conductors is different.

The resistance R of any conductor is given by

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

where σ is called the conductivity of the material and it depends only on the type of the material used and not on its dimension.

The resistivity of a material is equal to the reciprocal of its conductivity.

$$\rho = \frac{1}{\sigma}$$

Now we can rewrite equation (2.18) using equation (2.19)

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

The resistance of a material is directly proportional to the length of the conductor and inversely proportional to the area of a cross section of the conductor. The proportionality constant ρ is called the resistivity of the material.

If l = 1 m and A = 1 m2, then the resistance R = ρ. In other words, the **electrical resistivity of a material is defined as the resistance offered to current flow by a conductor of unit length having a unit area of the cross section.** The SI unit of ρ is ohm-metre (Ω m). Based on the resistivity, materials are classified as conductors, insulators, and semi-conductors. The conductors have the lowest resistivity, insulators have the highest resistivity and semiconductors have a resistivity greater than conductors but less than insulators.

Exercise

Choose the correct answer from the given alternatives.

1. The SI unit of electric current is..............

   a. Watt b. Volt c. Coulomb d. Ampere

2. How many electrons are there in one-ampere current?

   a. 6×10^{6} b. 6.25×10^{18} c. 6.18×10^{18} d. 6.18×10^{25}

3. The capacity of hydropower production in the upper Tamakoshi project is...........

   a. 450 MW b. 456 MW c. 356 MW d. 556 MW

Write short answer to the following questions.

1. What is electric current? Write its mathematical expression.
2. What is one volt? Write the mathematical relation between voltage, work done, and charge.
3. Define electrical resistance. Write its SI unit.
4. Write any three applications of resistance.
5. What are called conductors? Give any two examples of semi-conductor.
6. Write any four factors that affect the resistance of a conductor.
7. Why do long wires have more resistance than short wires?
8. Why thin wire have more resietance than thick wires?

Write long answers to the following questions.

1. Write any four sources of electricity. Describe in brief in any one of them.
2. What is resistivity of a conductor? Derive the relation where symbols have their usual meaning.
3. Write any two advantages and disadvantages of wind power.
4. Write the name of any four hydropower projects in Nepal with their capacity.

Unit 3 Electrical Circuit

3.1 Introduction to Electric Circuit

When the different components such as source, bulb, switch, connecting wires etc are joined together in a particular form, the bulb will glow. It is because, through these components, we have made a path for the electrons to flow. And this flow of electrons is current. When the two ends of the cell are joined with various components through connecting wires, it forms a conduction path for the electrons (charge) to flow from one end of the source to another end. This conducting path is known as an electric circuit.

Hence, the conducting path made for the flow of electrons when two ends of the cells are joined with the help of connecting materials and electrical components is known as an electric circuit.

3.2 Types of Electric Circuits

i) Open circuit

The circuit where there is no flow of current is known as an open circuit. There is a gap or discontinuity in the circuit. So the load connected to the circuit won't work.

ii) Closed Circuit

The circuit where there is the flow of electric current is known as a closed circuit. There is no gap or discontinuity in the circuit. So the load connected to the circuit will work.

iii) Short Circuit

Sometimes the two terminals of the source get connected by mistakenly or accidentally. Such a circuit so formed has very less resistance, so much higher amount of current may flow through it. This may cause damages to the circuit and may cause other electrical hazards as well. Such a circuit is known as a short circuit.

iv) Series Circuit

A circuit consisting of components connected only in series is known as a series circuit. In a series circuit, the current through each of the components is the same, and the voltage across the circuit is the sum of the voltages across each component. For a series circuit to be complete, every device or component must function. If one device or component burns out in a series circuit, the whole circuit will stop functioning.

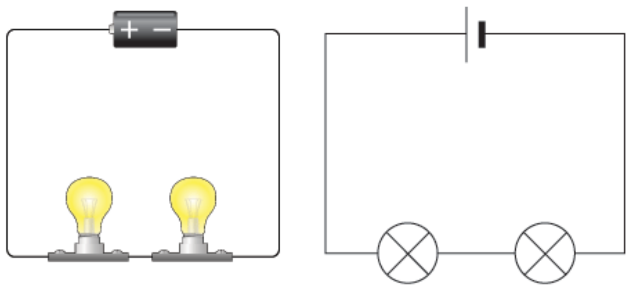


Fig: Series Circuit

v) Parallel Circuit

The circuit in which all the components are connected completely in parallel is known as a parallel circuit. In a parallel circuit, the voltage across each of the components is the same, and the total current is the sum of the currents through each component. In parallel circuits, each device or component has its circuit, so even if one of the devices or components gets damaged, the other will still function.

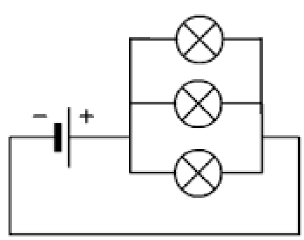


Fig: Parallel Circuit

vi) Mix Circuit

The circuit in which all the components are connected both in series and parallel is known as a mixed circuit.

Symbols used in the circuit.

Conducting Wires	Cell
Battery	Resistor

Capacitor	Inductor
Bulb or load or	Open switch
Closed switch or	Ammeter
Voltmeter	Galvanometer
Connected wires	Non-connected wires or
Rheostat (Variable Resistance)	AC source
DC source	Both AC and DC
Transformer	

Resistance

The flow of electrons through a conductor is called electric current. When the electrons flow through a conductor, they collide with other electrons or atoms or ions contained in the conductor. Due to this there is some obstruction in the flow of electrons through a conductor. The property of a substance to oppose the flow of current through it is known as resistance. It is denoted by 'R' and its SI unit is ohm ' Ω '. The resistance of a conductor can be calculated using the mathematical relation,

$$\text{Resistance} = \frac{\text{Potential difference}}{\textit{Current}}$$

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

Here, if the potential difference V= 1 volt and the current in the conductor is 1 ampere, then the resistance of the conductor becomes 1 ohm.

$$\text{i.e. } 1 \text{ ohm} = \frac{1 volt}{1 amp}$$

Thus, 1 ohm is the resistance of the conductor, when 1 ampere of current flows through a conductor under a potential difference of 1 volt.

Factors Affecting Resistance

The resistance of a conductor depends on the following factors.

i) length of the conductor

ii) Cross–sectional area of conductor

iii) Temperature of the conductor

iv) Nature of conducting material

i) Length of a Conductor

It is found that the resistance of the conductor increases on increasing the length and decreases on decreasing the length of a conductor. So the resistance of a conductor is directly proportional to the length of a conductor.

i.e. $R \propto l$ ....(1)

Thus, when the length of the wire is doubled, the resistance of the wire is also doubled and if the length of the conductor is made half, then the resistance is also halved. So we can conclude that, the resistance for a long wire is more and that for the shorter wire is less.

ii) Cross-Sectional Area of Conductor

The resistance of a conductor is inversely proportional to the cross-sectional area of a conductor.

i.e. $R \propto \frac{1}{A}$ ....(2)

Since the resistance of a wire is inversely related to the cross-sectional area of the conductor, if the cross-sectional area of the wire is doubled, the resistance of the wire will be halved and if the cross-sectional area of the conductor is halved, then the resistance of the conductor will be doubled. So a thicker wire (large diameter) will have more cross-sectional area and thus will have less resistance and the thinner wire (less diameter) will have less cross-sectional area and thus will have more resistance in it.

Similarly, it can also be shown through the calculations that the resistance of the wire is inversely proportional to the square of its diameter. So if the diameter of the wire is doubled, its resistance will become one-fourth$\left(\frac{1}{4}\right)$ and if the diameter of the wire is halved, the resistance of the wire will become 4 times.

iii) Temperature of the Conductor

It is found that the resistance of the conductors increases on increase of the temperature and decreases on lowering the temperature. Thus the resistance of a conductor is dependent on the temperature of the conductor, which is given by,

$$R = R_o(1 + \alpha t)$$

Where R = resistance at a given temperature

Ro=Resistance at 0oC

α = temperature coefficient

t = given temperature

iv) Nature of Conducting Materials

The resistance of the conductor also depends upon the nature of the material of which it is made. Some materials may have high resistance and some may have less resistance. For example, if we take two wires of the same length and the same cross-section of copper and nichrome, then it can be found that the resistance of nichrome will be about 60 times more than that of copper. Thus we can conclude that the resistance of the conductors also depends upon the nature of the materials of the conductor.

Combining (1) and (2)

$$R \;\alpha\; \frac{l}{A}$$

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

where ρ (rho) is the proportionality constant known as the resistivity of a conductor also known as specific resistance.

From this equation, it can be said that for a given conductor having a specific length ‘l’ and cross-sectional area ‘A’, the resistance of the conductor ‘R’ is directly proportional to the resistivity of the material. So if the material of the conductor is changed with another material having double resistivity than the previous, then the resistance of the conductor will also be doubled. Similarly, if it is replaced with the conductor having resistivity half the previous, then the resistance will also be halved.

or, $\frac{RA}{l} = \rho$

If the cross-sectional area (A) = 1 m^2 and the length of the conductor is 1m, then the resistivity of the conductor will be equal to the resistance of the conductor. i.e $R = \rho$.

Thus, the resistivity of the substance can be defined as the resistance of the wire having unit length and unit cross-sectional area. The SI unit of resistivity of the conductor is Ωm.

he resistivity of the material doesn’t depend upon the length and cross-sectional area of the conductor. It only depends upon the temperature and nature of the material used.

3.3 Resistance in Series and Parallel Circuit

Combination of Resistors

The resistors can be to a circuit in the following ways,

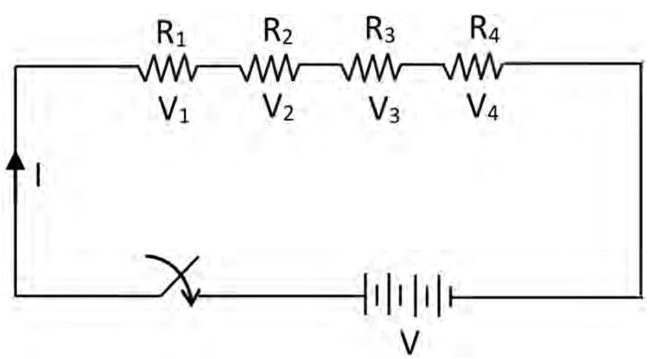
i) Series Combination of Resistor

ii) Parallel Combination of Resistor

iii) Mixed Combination of Resistor

i) Series Combination of Resistor

The combination in which two or more resistors are connected end to end consecutively is known as a series combination of resistors. In a series combination, the equivalent resistance will be always greater than the maximum value of resistance connected to the circuit.



So in general, the resistors are connected in series to increase the value of resistance.

If the resistors R_1, R_2, $R_{3,}$ and R_4 are connected in series, then the equivalent resistance is determined by,

Since in series combination, the same current flows through all the resistors, and the voltage across them will be different and additive, so,

$$V = V_1 + V_2 + V_3 + V_4$$

$$\text{or, } IR_{eq} = IR_1 + IR_2 + IR_3 + IR_4$$

$$\text{or, } IR_{eq} = I (R_1 + R_2 + R_3 + R_4)$$

$$\text{i.e. } R_{eq} = R_1 + R_2 + R_3 + R_4$$

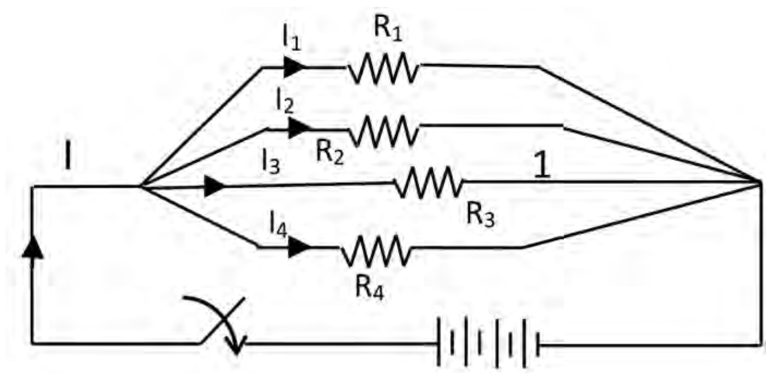
In a series combination of resistors, the equivalent resistance is always greater than the maximum resistance connected to the circuit.

Characteristics

- Resistance is added. i.e. $R_{eq} = R_1 + R_2 + R_3 + R_4$
- The same amount of current flows through all the resistor
- The voltage drop across each resistor will be different.
- The total voltage drop will be additive. i.e. $V = V_1 + V_2 + V_3 + V_4$
- The power is also additive.

ii) Parallel Combination of Resistor

The combination in which two or more resistors are connected between the same two points is known as a parallel combination of resistors. In other words, the combination of resistors in which all the positive terminals of the resistor are connected to one point and all the negative terminals of the resistor at another point is known as a parallel combination of resistors.



If the resistors R_1, R_2, $R_{3,}$ and R_4 are connected in parallel, then the equivalent resistance is determined by,

Since in parallel combination, there will be the same voltage across all the resistors and the current flowing them will be different and additive, so,

$I = I_1 + I_2 + I_3 + I_4$

or, $\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \frac{V}{R_4}$ or, $\frac{V}{R_{eq}} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right)$

i.e. $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$

i.e. $G_{eq} = G_1 + G_2 + G_3 + G_4$ where G = Conductance

In a parallel combination of resistors, the equivalent resistance is always less than the minimum resistance connected to the circuit.

Characteristics

- Conductance is added. i.e. $G_{eq} = G_1 + G_2 + G_3 + G_4$
- The voltage drop across each resistor will be the same.
- Different currents flow through different resistors.
- The total current is additive. i.e. $I = I_1 + I_2 + I_3 + I_4$

Advantages of parallel combinations in domestic wiring:

The arrangement of lights and various electrical appliances in parallel circuits or combinations is used in domestic wiring for the following reasons:

a. Parallel circuits ensure that if one appliance fails, all other appliances continue to function normally, as seen when a bulb in a parallel circuit is damaged.

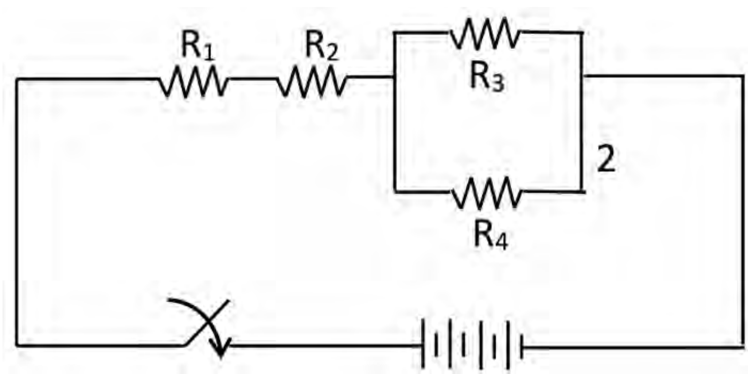
b. Parallel circuits allow each appliance to be controlled independently, like bulbs, without affecting other appliances in the house.

c. Parallel circuits ensure that all appliances operate at the same voltage level, as the voltage across each appliance remains the same as the supply line's voltage.

d. Parallel combination of electrical appliances reduces circuit resistance, allowing more current to flow from the supply, ensuring proper functioning of all connected appliances, including high power rating devices.

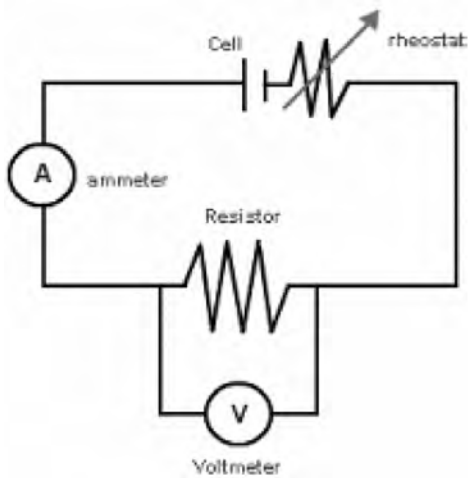
iii) Mixed Combination of Resistors

The combination of resistors consisting of both series and parallel combinations is known as a mixed combination of resistors.

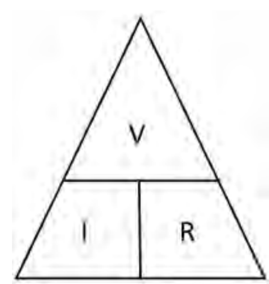


3.4 Ohm's Law

In an electric circuit, the flow of electrons (charge) is maintained by the cell. The higher the potential difference between the two points, the higher is the flow of current. There exists a relation between the current flowing through a conductor and the potential difference (p.d) between two ends of the conductor. This relation is explained by Ohm's law.



It states that "The current flowing through a conductor is directly proportional to the voltage applied across its two ends assuming the physical condition and temperature of conductor to be constant."



i.e. $I \alpha V$

or, $V \alpha I$

or, $V = IR$

Where, R = proportional constant, known as resistance of a conductor.

If V=1 volt and I = 1Ampere, then

R = 1 ohm

Hence, the resistance of conductor is said to be 1Ω . if 1 A current flows through a conductor under a potential difference between two ends of 1 V.

The three letters of Ohm's law can be arranged in the form of triangle as shown in the figure. The value of V or I or R can be found out by covering the letter meant for it and performing simple mathematical calculation as directed by uncovered two letters.

Thus, if we need to calculate V, we have to cover V, then V =IR. Similarly, if we need to calculate I, then $I=\frac{V}{R}$ and $R=\frac{V}{I}$.

Kirchoff's Law

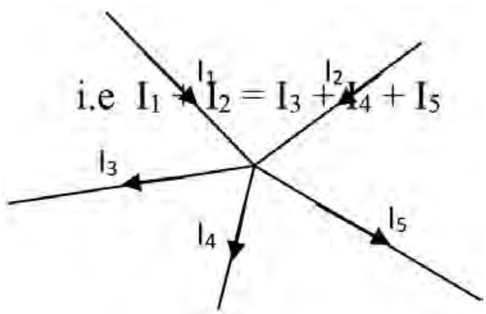
Sometimes the resistors and the voltage source may be connected to the circuit in a very complicated way. So the concept of a combination of resistors and Ohm's law may not be sufficient to solve the problems. In such cases, we apply Kirchoff's law to analyze the circuit. And there are two laws of Kirchoff, namely,

a. Kirchoff's Current Law (KCL)

b. Kirchoff's Voltage Law (KVL)

3.5 Kirchoff's Current Law (KCL)

This law relates the current at the junction points of a circuit. It states that" the algebraic sum of current entering the node and leaving the node is always zero."



Kirchhoff's Current Law (KCL), commonly known as nodal analysis or junction rule, is a fundamental concept in circuit analysis. It basically says that the algebraic sum of currents entering a junction in a closed circuit must equal the algebraic sum of currents exiting the junction. Simply put, the total current flowing into a junction (the point at which wires connect) must match the total current flowing out of that junction.

Consider the junction point in a circuit where many wires meet. KCL states that the current flowing into this point via all incoming wires must be equal to the current flowing out of the junction via all outgoing wires. There is no accumulation or disappearance of current at the junction; it is all about preserving equilibrium.

KCL is a crucial law for analyzing electrical circuits, allowing for the calculation of unknown currents and verifying circuit integrity by ensuring proper design and summation of currents.

3.6 Kirchoff's Voltage Law (KVL)

This law relates the emf and voltage drops in a circuit and it states that the algebraic sum of voltage drop across any loop in a circuit and emf is always equal to zero.

Sign Convention

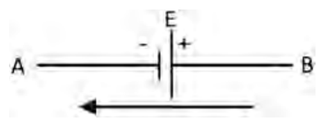
For applying KVL in a circuit, the sign convention is the most important factor. The sign convention for KVL application is given by,

Voltage Source

Move from positive to negative – drop in potential = -ve

Move from negative to positive – rise in potential = +ve

Rise in potential (+E)



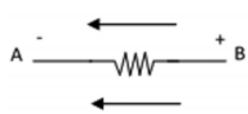
Fall in potential (-E)

Current Source

The same direction of current – Higher potential to lower potential (drop) = -ve

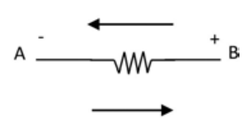
Opposite direction of current – lower potential to higher potential (rise) = +ve

Current



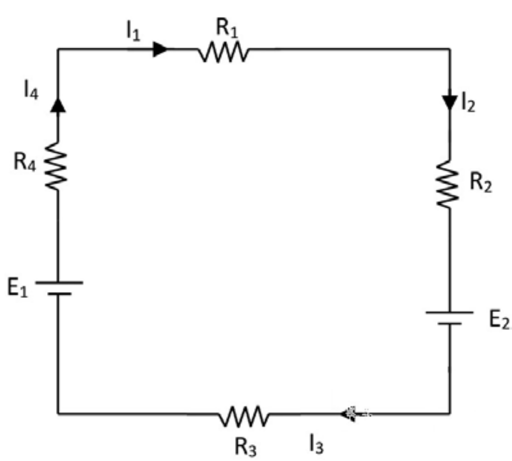
Motion
(Drop in potential-V=-IR)

Current



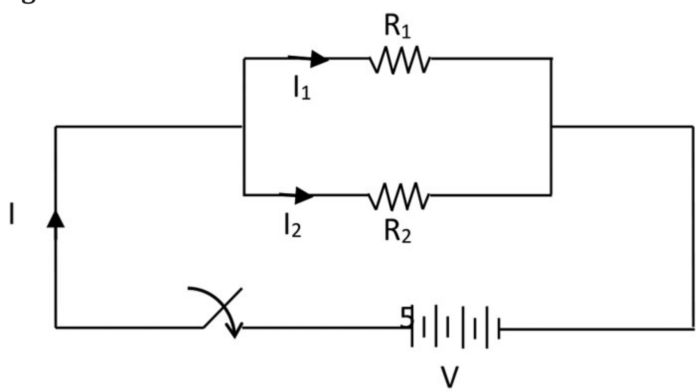
Motion
(Rise in potential +V =+IR)

Application



i.e $-I_4R_4 - I_1R_1 - I_2R_2 - E_2 - I_3R_3 + E_1 = 0$

Current Dividing Rule



As the resistors are connected in parallel, the voltage across R1 and R2 will be the same.

Now, $I = I_1 + I_2$

$$or,\ I = \frac{V}{R_1} + \frac{V}{R_2}$$

$$or,\ I = V\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$or,\ I = V\left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

$$or,\ I\left(\frac{R_1 R_2}{R_1 + R_2}\right) = V$$

And, $$I_1 = \frac{V}{R_1} = \frac{I\left(\frac{R_1 R_2}{R_1 + R_2}\right)}{R_1} = \left(\frac{R_2}{R_1 + R_2}\right) \times I$$

$$I_2 = \frac{V}{R_2} = \frac{I\left(\frac{R_1 R_2}{R_1 + R_2}\right)}{R_2} = \left(\frac{R_1}{R_1 + R_2}\right) \times I$$

Voltage Dividing Rule

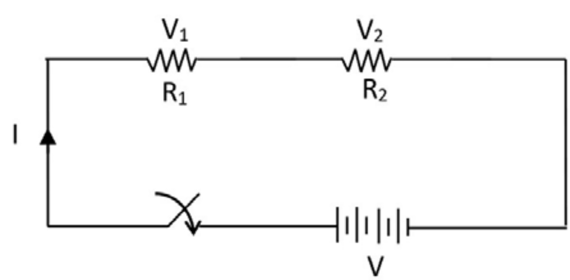
As the resistors are connected in series, the current flowing through them is the same.

Now, $V = V_1 + V_2$

$$or,\ V = R_1 + R_2$$

$$or,\ V = I(R_1 + R_2)$$

$$or,\ I = \frac{V}{(R_1 + R_2)}$$



And,

$$V_1 = I \times R_1 = \frac{V}{(R_1 + R_2)} \times R_1 = \left(\frac{R_1}{R_1 + R_2}\right) \times V$$

$$V_2 = I \times R_2 = \frac{V}{(R_1 + R_2)} \times R_2 = \left(\frac{R_2}{R_1 + R_2}\right) \times V$$

1. **A cell of e.m.f. 6V is connected across a resistor of resistance 15Ω. Find the current.**

Solution

Here, V = 6V

R = 15 Ω

I =?

Now, we have

V =IR

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

or, I = $\frac{6}{15} = 0.4A$

2. **If 6.25 X 10^{19} electrons are flowing through a conductor in one second, find the current flowing through it.**

Solution

No. of electrons = 6.25 X 1019

Now, $\frac{\text{No. of electrons}}{6.25 \times 10^{18}} \quad (\because 1A = 6.25 \times 10^{18}\ electrons)$

Current (I) = $\frac{6.25 \times 10^{19}}{6.25 \times 10^{18}}$

= 10A

3. **In a circuit of resistance 6.2Ω, the current of 3.5A is flowing. Find the potential difference applied across the conductor.**

Solution

Here, R= 6.2Ω

I = 3.5A

Now, we have

V =IR

or, V = 6.2 X 3.5 =21.7 V

4. **Find the current flowing through a conductor of resistance 25Ω, when the**

potential difference between the two terminals of the conductor is 60V.

Solution

Here, V = 60V

R = 25 Ω

I =?

Now, we have

V =IR

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

or, $I = \frac{60}{25} = 2.4A$

5. The potential difference between two points of a conductor carrying a current of 4.2A is 6V. Find the resistance of the conductor.

Solution:

Here, V = 6V

I = 4.2 A

R =?

Now, we have

V = IR

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

or, $R = \frac{6}{4.2} = 1.43\ \Omega$

6. The resistance of a conductor 1 mm2 in cross-section and 20cm long is 0.346Ω. Determine the resistivity of the conductor.

Solution

Cross-sectional area (A) = 1mm2 = 1 X 10-6 m2

Length (l) = 20 cm = 0.2m

Resistance (R) = 0.346 Ω

Now, we have

$$\rho = \frac{RA}{l}$$

$$or,\ \rho = \frac{0.346 \times 1 \times 10^{-6}}{0.2}$$

$$or,\ \rho = 1.73 \times 10^{-6}\ \Omega - m$$

7. The resistances of 5Ω, 10Ω and 14Ω are connected in series and parallel. Find the equivalent resistance in each case.

Solution

$R_1 = 5\Omega$

$R_2 = 10\Omega$

$R_3 = 14\Omega$

Now, for a series combination

Equivalent Resistance (R_{eq}) = $R_1 + R_2 + R_3$

= 5 + 10 + 14

= 29Ω

For parallel combination

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$or,\ \frac{1}{R_{eq}} = \frac{1}{5} + \frac{1}{10} + \frac{1}{14}$$

$$or,\ \frac{1}{R_{eq}} = \frac{14 + 7 + 5}{70}$$

$$or,\ R_{eq} = \frac{70}{26} = 2.69\ \Omega$$

8. Two resistors of resistances 10Ω and 25Ω are connected in (a) series and (b) parallel, with a battery of 12V. Calculate the current flowing in each case.

Solution

R1 = 5Ω

R2 = 10Ω

Now, for a series combination

Equivalent Resistance (Req) = R1 + R2

= 10 + 25

= 35Ω

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

$$\therefore, I = \frac{12}{35} = 0.343A$$

For parallel combination

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\therefore, \frac{1}{R_{eq}} = \frac{1}{10} + \frac{1}{25}$$

$$\therefore, \frac{1}{R_{eq}} = \frac{5+2}{50}$$

$$\therefore, R_{eq} = \frac{50}{7} = 7.143\Omega$$

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

$$\therefore, I = \frac{12}{7.143} = 1.68\ A$$

Tutorials

1. Calculate the amount of work done in moving a charge of 4 coulombs from a point at 220 volts to another point at 230 volts. **[Ans: 40J]**

2. What is the potential difference between the terminals of the battery if 250 joules of work is required to transfer 20 coulombs of charge from one terminal of a battery to the other? **[Ans: 12.5V]**

3. In 10 seconds, a charge of 25 C leaves the battery and 200 J of energy are delivered to an outside circuit as a result.

   (a) What is the p.d. across the battery?

   (b) What current flows from the battery? **[Ans: 8V, 2.5A]**

4. A potential difference of 20 volts is applied across the ends of a resistance of 5 ohms. What current will flow in the resistance? **[Ans: 4A]**

5. A current of 5 amperes flows through a wire whose ends are at a potential difference of 3 volts. Calculate the resistance of the wire. **[Ans: 0.6Ω]**

6. What p.d will be needed to send a current of 6A through an electrical appliance having a resistance of 40 Ω ? **[Ans: 240V]**

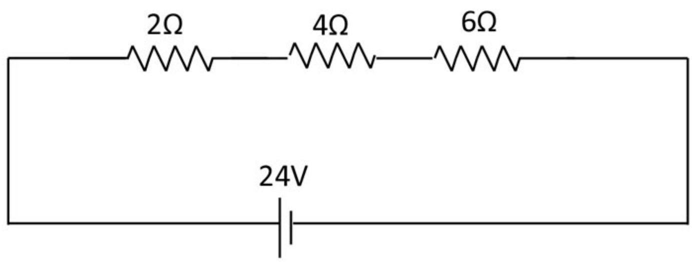
7. Calculate the resistance of 100m length wire having a cross-sectional area of 0,1mm^2. (Given resistivity of wire = 50 X 10^{-8} Ω m)

8. A wire is 1.0 m long, 0.2 mm in diameter and has a resistance of 10Ω. Calculate the resistivity of the material.

9. What will be the resistance of the metal wire of length 2 meters and area of cross section 1.55 X 10^{-6} m^2, if the resistivity of the metal be 2.8 X 10^{-8} Ω m ?

10. Calculate the resistance of the copper wire 1.0 km long and 0.50mm diameter if the resistivity of copper is 1.7 X 10^{-8} Ω m.

11. Find the current flowing in the circuit.

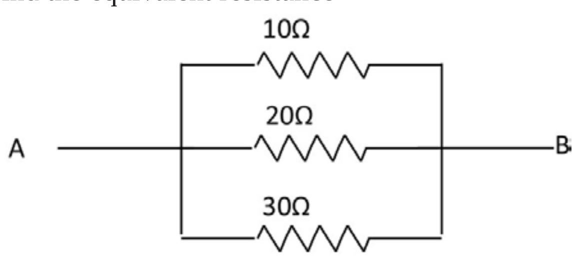


[Ans: 2A]

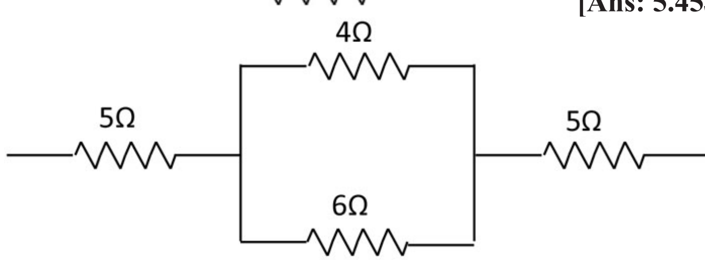
12. If the resistors 4Ω, 8Ω and 12Ω are connected in both series and parallel combination. Find the equivalent resistance in both cases. **[Ans: 24Ω, 2.18Ω]**

13. Two resistors of resistance 6Ω and 12Ω are connected in a) series and b) parallel combination, across a potential of 10V. Calculate the current flowing through the circuit in each case. **[Ans: 0.56A, 2.5A]**

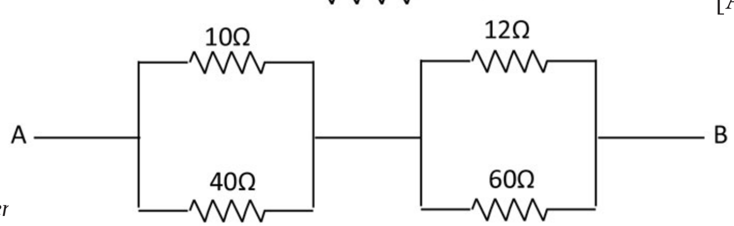
14. Find the equivalent resistance



[Ans: 5.45Ω]

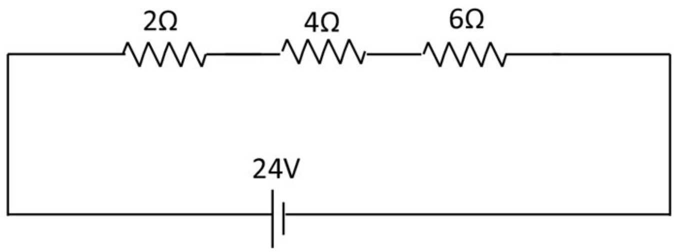


[Ans: 12.4Ω]



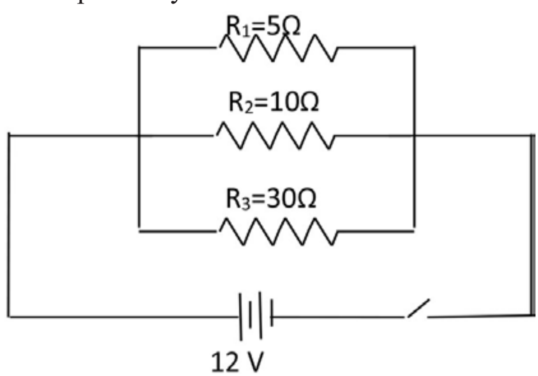
[Ans: 18Ω]

15. Find the voltage across each resistor.



[Ans: 4V, 8V and 12V]

16. In the circuit diagram given below, three resistors R1, R2 and R3 of 5Ω, 10Ω and 30Ω respectively are connected as shown:



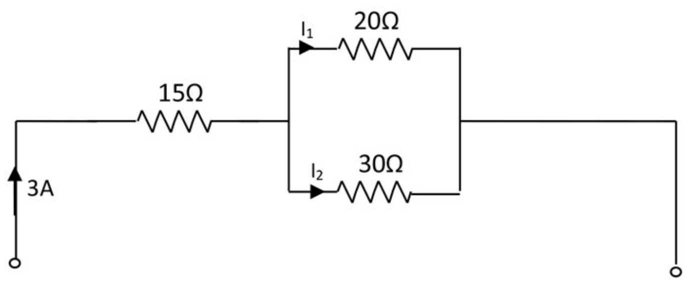
Calculate

a) current through the resistor. **[Ans: 2.4A, 1.2A and 0.4A]**

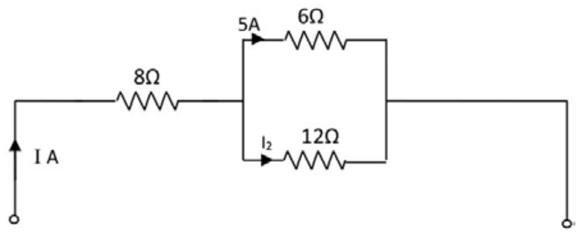
b) total current in the circuit. **[Ans: 4A]**

c) Total resistance in the circuit. **[Ans: 3Ω]**

17. In the given figure, find the current in 20Ω and 30Ω resistor. Also find the total voltage.



18.



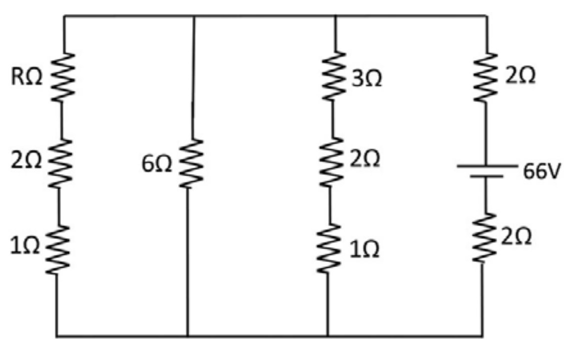
In the circuit given above, find

i) The total current

ii) Current flowing through 12Ω resistor

iii) Total voltage in the circuit.

19. If current flowing through the given circuit is 6A, find the value of unknown resistance R.



Exercise

Choose the correct answer from the given alternatives.

1. What is an electric circuit?
   a. A way to cook food
   b. A path for the electric current to flow
   c. A type of battery
   d. A magnet
2. Which circuit does not allow electricity to flow?
   a. Closed Circuit
   b. Open Circuit
   c. Series Circuit
   d. Parallel Circuit
3. In which type of circuit do all components share the same current?
   a. Series Circuit
   b. Parallel Circuit
   c. Open Circuit
   d. Leakage Circuit
4. What is Ohm's Law?
   a. V = I/R
   b. V = IR
   c. I = V + R
   d. R = V + I
5. In a parallel circuit, the total resistance is:
   a. More than individual resistors
   b. Equal to the largest resistor
   c. Less than the smallest resistor
   d. Same as in series
6. Kirchhoff's Current Law states:
   a. Voltage remains same in all branches
   b. Total current entering a junction equals total current leaving
   c. Resistance is always constant
   d. Electric charge is destroyed
7. Which type of circuit has both series and parallel components?
   a. Open Circuit
   b. Closed Circuit
   c. Leakage Circuit
   d. Mix Circuit

Write short answer to the following questions.

1. What is an electric circuit? Define open circuit.
2. What is a closed circuit? What is a leakage circuit?
3. What does Kirchhoff's Current Law (KCL) state?

Write long answer to the following questions.

1. Explain the different types of electric circuits with examples.
2. State and explain Ohm's Law with one example.
3. What is Kirchhoff's Voltage Law (KVL)? Explain with a simple example.

Unit 4 Electrical Power and Theory

4.1 Introduction to Electrical Power

Electrical power is a fundamental concept in electrical engineering and daily life, referring to the rate at which energy is transferred by an electric circuit. Electrical power is the rate at which electrical energy is moved or converted in an electric circuit, expressed in watts (W). It is determined as the product of voltage (V) and current (I), and it represents how much work electricity can perform in powering gadgets, lighting, heating, and other applications. Electrical power comes in a variety of forms, including active power, which does actual work, and reactive power, which maintains electromagnetic fields. Electrical power, generated from sources such as fossil fuels, nuclear, and renewables, is transported through grids to homes, businesses, and industries, playing an important part in modern life by pushing technological breakthroughs and facilitating daily activities.

4.2 Unit of Electrical Power and its Practical Concept

The rate at which electrical energy is spent or changed into another type of energy, such as heat, light, or mechanical power. It is measured in watts (W).

The basic formula for electrical power in a circuit is:

$P=VI$

where:

- P is the power in watts,
- V is the voltage in volts,
- I is the current in amperes.

Or,

The amount of electrical work done per unit of time is called electric power. Its SI unit is watt.

$$\text{Electric power} = \frac{\text{Electric work done}}{\text{Time taken}}$$

$$\therefore P = \frac{ItV}{t}$$
$$\therefore P = \frac{W}{t}$$
$$\therefore P = IV$$
$$\therefore P = I^2R$$
$$\therefore P = \frac{V^2}{R}$$

Similarly, the electric power can also be expressed as,

$$\text{Electric power} = \frac{\text{Electric energy consumed}}{\text{Time taken}}$$

$$\therefore \text{Electric power (P)} = \frac{\text{Q}}{\text{t}}$$

Electrical Energy Consumption

We have

$$\text{Electric power} = \frac{\text{Electric energy consumed}}{\text{Time taken}}$$

Or, Electric energy consumed = Electrical power X time taken

Now, if P = 1 watt, t = 1 sec

Electric energy = 1 watt X 1 sec

= 1 watt-sec

Hence watt-sec is very smaller unit of electrical energy. So in home and for commercial purposes, we use higher units of it. i.e watt-hour, kilowatt-hour(kwh).

Watt-hour

1 watt-hour = 1 X 60 X 60 watt-sec

= 3600 watt-sec

= 3600J

Kilowatt - hour

1 kilowatt-hour = 1000 X 60 X 60 watt-sec

= 3600000 J

This 1 kilowatt-hour simply can be said as 1 unit electrical energy consumption.

Kilowatt- hour (kwh)

When an electrical appliances of 1000 watt the (1 kw) is used for 1 hour, then the electrical energy consumed is said to be 1 kilowatt-hour (kwh). Simply it is called 1 unit electrical energy consumption.

1 watt electrical power

We have,

$P = I \times V$

$= 1A \times 1V$

$= 1$ watt

If 1 A current is flowing through a conductor under a potential difference of 1 volt, then the power consumed is said to be 1 watt of electrical power.

Similarly,

$$\text{Electric power} = \frac{\text{Electric work done}}{\text{Time taken}}$$

$$ø\ , P = \frac{W}{t}$$

If W = 1 joule and t = 1 sec, then

$$ø\ , P = \frac{1}{1} = 1 watt$$

Thus, if 1 joule of work is done in moving the charge from one point to another within the circuit in 1 second, then the power consumed is said to be 1-watt power.

Note:

If a bulb is rated with 100 watts, it means the bulb can convert 100 J of electrical energy into heat and light energy in 1 second.

Practical Concepts of Electrical Power

a. **Power Rating of Devices:** Every electrical device has a power rating that indicates the amount of power it consumes. Example: A refrigerator might have a power rating of 150 W, meaning it uses 150 watts of power when running.

b. **Energy Consumption:** Electrical energy consumption is often measured in kilowatt-hours (kWh). One kilowatt-hour is the amount of energy consumed by a device that uses one kilowatt of power for one hour. Example: If you use a 100 W light bulb for 10 hours, it consumes $100\ W \times 10\ h = 1{,}000\ Wh = 1\ kWh$

c. **Power and Efficiency:** The efficiency of an electrical device is the ratio of its useful power output to the total power input, expressed as a percentage. Higher efficiency means less power is wasted as heat or other forms of energy. Example: An LED bulb is more efficient than an incandescent bulb because it converts a higher percentage of electrical energy into light.

d. **Load and Demand:** The load on an electrical system refers to the total power consumption of all connected devices.

e. **Electrical Power in Daily Life:** Electrical power is essential for almost all aspects of modern life, from lighting and heating to powering electronic devices and industrial machinery.

4.3 Define Electrical Energy, its Unit, and Applications

Electrical Energy

The energy produced due to the flow of electrons is known as electrical energy. Its SI unit is Joule.

If 'I' current is flowing through a circuit for a time of 't' seconds, then from the definition of potential difference,

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Quantity of charge moved}}$$

Work done = charge X potential difference

= Q X V

i.e W=Q X V ……………(i)

1 J electrical work

We have,

W = Q X V

= 1C X 1V

= 1 J

It is defined as the amount of work done when 1 coulomb of charge is moved under a potential difference of 1 volt.

Similarly,

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

$\therefore Q = I \times t$ …….. (ii)

Substituting the value of 'Q' in (i), we get

W = I X t X V

Thus we can say, that electrical energy depends on current, voltage, and time of flow of current.

Similar, to Ohm's law,

We have,

$V = I \times R$

$\therefore W = I \times t\,(I \times R)$

$= I^2 R t$

Thus, the electrical energy will be converted into heat energy and the electrical energy is said to be consumed by the electric circuit. This is known as the heating effect of current and the heat developed in a circuit is given by the relation,

$H = I^2Rt$

This relation is known as Joule's law of heating. According to it, the heat produced on the conductor is directly proportional to:

i. Square of the magnitude of current flowing through the conductor.

ii. Resistance of a conductor

iii. Time for which the current is passed over to the conductor.

4.4 Numerical

1. **The resistance of the element of the heater is 900Ω and a current of 1.5A is flowing through the circuit. Find the power dissipated in the circuit.**

   Sol^n. Here,

   Resistance (R) = 900Ω

   Current (I) = 1.5 A

   Now.

   Power (P) $= I^2R$

   $= (1.5)^2 \times 900$

   = 2025 watt

2. **An electric heater operates on 220 V and draws a current of 6 A. Calculate the power consumption.**

   Sol^n. Here,

   Voltage (V) = 220V

Current (I) = 6 A

Now.

Power (P) = IV

= 6 X 220

= 1320 watt

3. The current passing through a filament lamp is 2A. If it is connected to a 12 V power supply. Calculate the resistance of the filament and power consumed by the lamp.

Sol[n]. Here,

Voltage supply (V) = 12 V

Current (I) = 2 A

Now. From Ohm law, we have

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

or, $R = \frac{12}{2}$

or, R = 6Ω

And,

Power (P) = IV

= 2 X 12

= 24 watt.

4. A student is using an electrical bulb of 100 watts for 6 hours daily. Find the electrical energy consumed in a month of 30 days.

Soln.

Power of bulb = 100 watt

$= \frac{100}{1000} kw = 0.1 kw$

Time = 6 hrs

Now,

The electrical energy consumed = 0.1 kw X 6 hrs

= 0.6 kw-hrs

And. Total energy consumed in 30 days = 0.6 X 30

= 16 kw-hrs (units)

5. An electric heater of 220V is used on 8A. Find the power consumed by it. Also, find the cost of using the heater for one hour if the rate of electricity is Rs. 6 per unit.

Sol^n. Here,

Voltage(V) = 220V

Current (I) = 8A

Time used = 1 hr

Now.

Power (P) = IV

= 8 X 220

=1760 watt

= 1.76 kw

And,

Electrical energy consumed = 1.76 X 1

= 1.76 kw-hr

∴ Cost = Rs. 1.76 X 6

= Rs. 10.56

6. In a house, 5 bulbs of 60 watts glow for 4 hours a day, an electric press of 750 watts for an hour every day, and 3 electric fans of 150 watts are used for 8 hours a day. Find the total electrical energy consumed in 15 days. Also, calculate the cost of electricity at Rs. 12 per unit.

Sol^n.

Power of bulb = 60 watt

$= \frac{60}{1000} kw = 0.06\ kw$

No. of bulbs = 5

Time = 4 hrs

Now,

Electrical energy consumed = 0.06 kw X 5 X 4 hrs

= 1.2 kw-hrs

Similarly

Power of press = 750 watt

$= \frac{750}{1000} kw$

$= 0.75\ kw$

No. of press = 1

Time = 1 hrs

Now,

Electrical energy consumed = 0.75 kw X 1 X 1 hrs

= 0.75 kw-hrs

And

Power of fan = 150 watt

$= \frac{150}{1000} kw = 0.15\ kw$

No. of fans = 3

Time = 8 hrs

Now,

Electrical energy consumed = 0.15 kw X 3 X 8 hrs

= 3.6 kw-hrs

∴ Total energy consumed in 1 day = 1.2 + 0.75 + 3.6

= 5.55 kw-hrs (units)

And Total energy consumed in 15 days = 5.55 X 15

= 83.25 units

Cost of electricity = Rs. 12 X 83.25

= Rs. 999

7. **In a house, 8 bulbs of 100 watts glow for 5 hrs a day, an electric iron of 800 watts for an hour every day, and 2 electric heaters of 1000 watts for 6 hours a day. Find the cost of electricity for a month of 30 days if the rate of electricity is Rs. 4 per unit.**

Sol^n.

Power of bulb = 100 watt

$= \frac{100}{1000} kw = 0.1 kw$

No. of bulbs = 8

Time = 5 hrs

Now,

The electrical energy consumed = 0.1 kw X 8 X 5 hrs

= 4 kw-hrs

Similarly

Power of press = 800 watt

$= \frac{800}{1000} kw = 0.8 kw$

No. of press = 1

Time = 1 hrs

Now,

Electrical energy consumed = 0.8 kw X 1 X 1 hrs

= 0.8 kw-hrs

And

Power of heater = 1000 watt

$= \frac{1000}{1000} kw$

$= 1 kw$

No. of heater = 2

Time = 6 hrs

Now,

Electrical energy consumed = 1 kw X 2 X 6 hrs

= 12 kw-hrs

∴ Total energy consumed in 1 day = 4 + 0.8 + 12

= 16.8 kw-hrs (units)

And Total energy consumed in 30 days = 16.8 X 30

= 504 units

Cost of electricity = Rs. 4 X 504

= Rs. 2016

Exercise

Choose the correct answer from the given alternatives.

1. What is electrical power?
   - a. The energy used to cook food
   - b. The rate of doing electrical work
   - c. The speed of electric current
   - d. The size of a battery
2. The SI unit of electrical power is............
   - a. Watt
   - b. Volt
   - c. Ohm
   - d. Ampere
3. 1 kilowatt is equal to........
   - a. 100 watts
   - b. 1000 watts
   - c. 10 watts
   - d. 1 watt
4. What is electrical energy?
   - a. The size of a circuit
   - b. The total work done by electric power
   - c. The amount of resistance
   - d. The speed of voltage
5. The unit of electrical energy in electricity bills is:
   - a. Watt
   - b. Kilowatt
   - c. Kilowatt-hour
   - d. Ampere-hour

Write short answer to the following questions.

1. What is electrical power?
2. Write the formula for electrical power.
3. What is the SI unit of electrical power? Define 1 watt of power.
4. What is electrical energy? What is the unit of electrical energy?
5. Write the formula for electrical energy. Give two uses of electrical energy.

Write long answer to the following questions.

1. Explain the concept of electrical power with its unit and formula.
2. Define electrical energy. Write its unit and applications.
3. Differentiate between electrical power and electrical energy

Unit 5 Cell and Capacitor

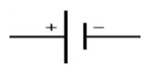
5.1 Introduction to Cell and Battery

Cell

The electrochemical device which can convert stored chemical energy into electrical energy is called a cell. It is the basic unit of the battery. Also, it can be defined as the device in which a potential difference is created between the two electrodes. The two electrodes are called Anode and Cathode and the electrodes are immersed in an electrolyte.

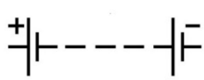
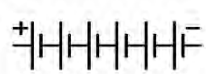
The rate of chemical reaction in the cell depends upon the surface area of the electrodes, temperature, and the load connected across the cell.

The symbol of a cell is.



Battery

The combination of two or more cells in a series or parallel combination is known as a battery. The number of cells in a battery is related to the desired voltage and required current. The symbol of a battery is

 or 

5.2 Types of Cell

The cells may be classified into two general classes:

a. Primary cell

b. Secondary cell

Primary Cell

The cell in which chemical substances produce electromagnetic force (emf) by chemical reaction is known as the primary cell. The chemical action in this cell is not reversible. Since this cell cannot be revived, this cell is called a non-rechargeable cell. After the cell is used, the substances in it become useless.

The commonly used primary cell is as follows:-

a. Voltaic cell

b. Daniel cell

c. Leclanche cell

Voltaic Cell

It consists of a glass container, in which conducting materials (copper and zinc plates), are immersed in an electrolyte (dilute sulphuric acid (i.e. $H_2SO_4 + H_20$)). The chemical action results in the voltage difference between the two materials. This method is called Voltaic cell, after the name of its inventor Alessandro Volta.

The charged conductors in the electrolyte of a cell are called the electrodes or plates of the cell. The zinc plate acts as a positive electrode while the copper plate acts as a negative electrode. When a volt meter is connected across these electrodes, it indicates the presence of emf. When a load is connected across the electrodes, the conventional direction of the current outside the cell is from the positive terminal to the negative terminal of the cell. Inside the cell, the direction of the current is in the opposite direction, that is, from a negative terminal to a positive terminal.

Working principle of Voltaic cell

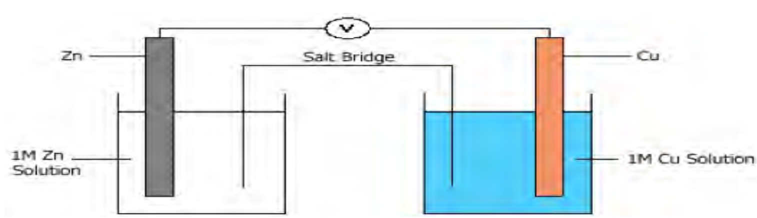


Fig: voltaic cell

Whenever two dissimilar metals are immersed inside an electrolyte solution, the more reactive metal plate will be negatively charged and the less reactive metal will be positively charged. In the case of a simple voltaic cell, the two dissimilar metals are zinc plate and copper plate and the electrolyte is sulphuric acid. Since copper is a less reactive metal than zinc, the zinc plate will get negatively charged and the copper plate will get positively charged. However, this action stops when the potential difference (PD) developed in the cell is 1.08V.

To avoid the cell from local action, the zinc electrode is coated with mercury amalgam.

Daniel Cell

It is a two-fluid cell that is a variant of the simple voltaic cell. This cell comprises an exterior copper vessel. The tank contains a strong solution of copper sulfate (CuSO4), which functions as a depolarizer.

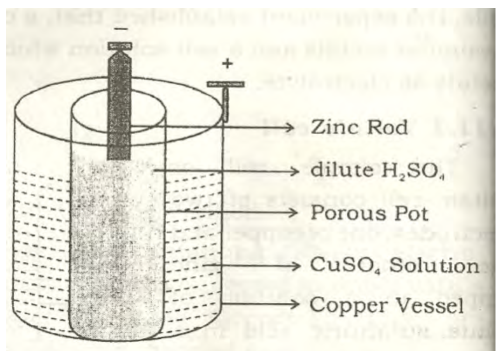


Fig: Daniel Cell

Secondary Cell

The cell in which chemical action is reversible; the electrolytes and electrodes can be restored to the previous state once it is used up is the secondary cell. This cell is first charged from the external source and then it gives electric current storing electric energy in the form of chemicals. It is also called a storage cell because this cell is rechargeable. For example: Lead Acid Cells, nickel, cadmium cells, etc.

Differences between Primary Cell and Secondary Cell

S.N.	Primary Cell	S.N.	Secondary Cell
1	It is a non-rechargeable cell.	1	It is a rechargeable cell.
2	It cannot be recharged once it is discharged.	2	It can be recharged once it is discharged.
3	It has a shorter life.	3	It has a comparatively longer life.

4	It has a lighter weight.	4	It has a heavier weight than a primary cell.
5	It is used for intermittent work with a low current rating.	5	It is used for conditions with a high current rating.
6	For e.g.: Daniel cell, Voltaic cell, Leclanche cell etc.	6	For e.g. Lead acid cell, nickel cadmium cell.

5.3 Series and Parallel connection of a cell

Series connection

Cells are said to be connected in series when the negative terminal of a first cell is connected to the positive terminal of a second cell, and the negative terminal of the second cell is connected to the positive terminal of a third cell, and so on. In a series connection, the individual voltages of the cells add up, but the current capacity of a battery remains constant since the same current passes through all of the cells.

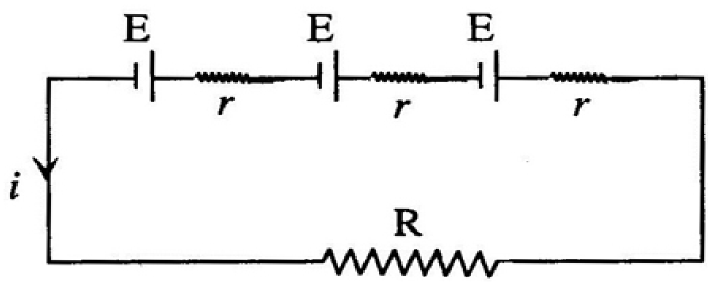


Fig: A series combination of cells

When cells are connected in series, total emf is given by the sum of their emf and the sum of their internal resistances.

Total EMF (E)= $E_1+E_2+E_3$..........E_n

Total internal resistance(r)= $r_1+r_2+r_3$——r_n

If similar cells of emf 'E' and internal resistance 'r' are connected in series, then Total emf(E_t)=nE

Total internal resistance (r_T)= nr

Cells are connected to an external resistance 'R' then current flowing through the current(I)= nE/nr

=E/r

Cells in a Parallel Connection

Cells are said to be in parallel when all the positive terminals are connected at one point and all the negative terminals are connected at another point. When cells are connected in parallel, the available voltage is the same as the voltage supplied by each cell when all of the cells have the same voltage rating. If all of the cells do not have the same voltage rating, the cells of lower voltage will drain current from the cells of higher voltage. In parallel combination, the cells can have different current ratings if they all supply the same voltage.

When similar cells are connected in parallel then

Total Emf(E)= Emf of one cell

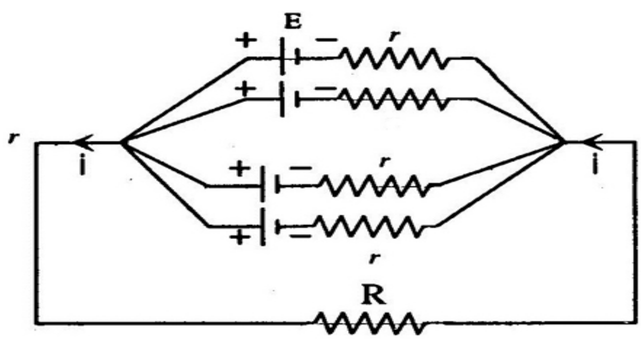


Fig. Parallel connection of cell

The combined internal resistance of the circuit = r/m

If 'R' is the external resistance in the circuit then the current(I) through the circuit is given by

I=E/ (R+r/m)

For maximum current, external resistance should be small as compared to the total resistance.

5.4 Capacitor, Capacitance, and its Units

Capacitor

Capacitor is an electrical device capable of storing charge within its electric field. It consists of two conducting surfaces separated by a layer of insulating substance known as dielectric. The conducting surfaces can be circular, rectangular, spherical, or cylindrical. Capacitance describes a capacitor's ability to store charge inside its electric field. The SI unit is Farad (F).

The smaller units of capacitance are:

1mF (mili)= 10 -3 F

1μF(micro) = 10 -6 F

1 nF(nano) = 10 -9 F

1 pF (pico)= 10 -12 F

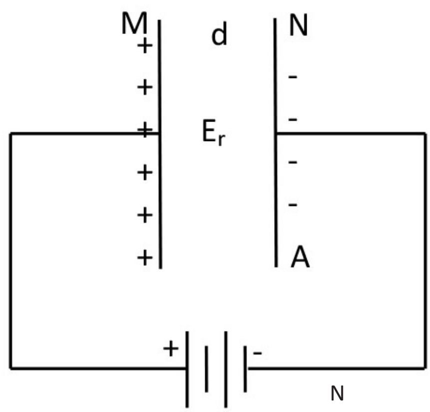
Capacitance can also be defined as the charge required to produce a unit of potential difference between the plates. If the ‘Q’ charge is stored in the plates to produce a potential difference of ‘V’ volts, then

$$\text{Capacitance (C)} = \frac{Q}{V}$$

1 F Capacitance

Capacitance can be defined as the capacitance of the capacitor when 1 coulumb of charge is stored producing a potential difference of 1 V between the plates.

Calculation of capacitance of a parallel plate capacitor



The parallel plate capacitor with plates ‘M’ and ‘N’ each having an area of A is separated by a distance ‘d’.

When the charge +Q is applied to the plate M, the charge starts to store in the dielectric and the electric flux (ψ) is produced in it.

Now,

$$\text{Electric Flux density } (\Delta) = \frac{\text{Electric Flux}}{Area} \quad \text{or, } \Delta = \frac{\psi}{A}$$

$$\text{or, } \Delta = \frac{Q}{A} \text{ ....(i)}$$

Again

$$\text{Electric Field Intensity (E)} = \frac{Voltage}{\text{Distance of separation}}$$

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

Similarly,

$$\Delta = \in E$$

or, $\Delta = \in \frac{V}{d}$ ....(ii)

Equating (i) and (ii), we get

$$\frac{Q}{A} = \in \frac{V}{d}$$

or, $\frac{Q}{V} = \in \frac{A}{d}$

or, $C = \in \frac{A}{d}$, where C is the capacitance of the parallel plate capacitor.

Note:

The capacitance of a parallel plate capacitor can be increased in the following ways,

i) Increasing the area of plates.

ii) Decreasing the distance between the plates.

iii) Using dielectrics with more dielectric values.

Values of dielectric constants for some medium

i) Vacuum – 1 F/m

ii) Air – 1.004 F/m

iii) Mylar – 3 F/m

iv) Paper – 5 F/m

v) Mica – 6 F/m

vi) Glass – (4-18) F/m

vii) Barium Titanate (BaTiO3) – (1500-2000) F/m

viii) Other formulated ceramics – (8000-20000) F/m

5.5 Factors Affecting Capacitance

Several factors influence the capacitance of a capacitor. These factors determine how much charge a capacitor can hold at a particular voltage. Here are the main factors:

a. Capacitance is directly proportional to the surface area (A) of conducting plates. Larger plate surfaces enable more charge to be stored.

b. Capacitance is inversely proportional to the distance (d) between plates. Because the electric field is stronger at shorter distances, capacitance increases.

c. The dielectric substance between the plates influences capacitance via its dielectric constant. A higher dielectric constant increases capacitance.

d. The permittivity of a dielectric material indicates how easily electric field lines can travel through it. Higher permittivity leads to increased capacitance.

e. Capacitance can change with temperature. Some dielectrics have a positive or negative temperature coefficient, which means their permittivity varies with temperature, affecting capacitance.

5.6 Characteristics of Capacitance

The characteristics of capacitance that describe its behavior and properties in diverse settings include the following:

a. Capacitance refers to the ability to store and release electrical energy in the form of an electric field between two conductors.

b. Capacitance is proportional to the electric charge stored and the potential difference applied between the conductors.

c. The capacitance value is determined by the geometry of the conductors (area and separation distance) as well as the dielectric material used between them.

d. Different dielectric materials influence capacitance because their dielectric constant increases the ability to store charge.

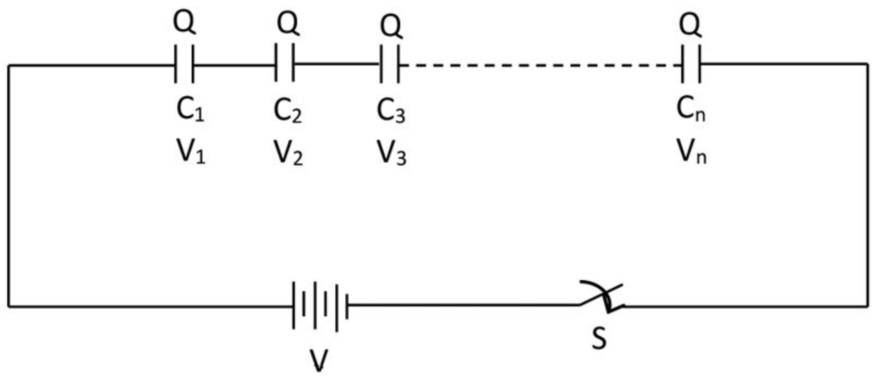
e. Capacitance determines how much energy is stored in the electric field.

5.7 Series and Parallel Plate Capacitors

The capacitors can be connected to a circuit in different ways.

1. Series combination
2. Parallel Combination

1. Series combination of capacitors



Let C_1, C_2, $C_{3.............}$ and C_n be capacitances of the capacitors connected in series to a voltage source of 'V' volts. C_{eq} is the equivalent capacitance of the capacitors connected to the above series circuit. Since the same charge flows through all of them and potential difference will be different and additive.

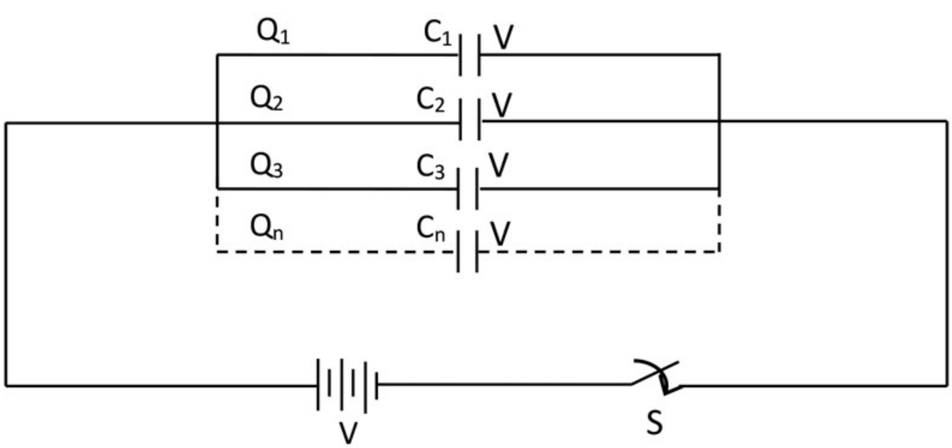
i.e. $V = V_1 + V_2 + V_3 + ... + V_n$

or, $\frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} + ... + \frac{Q}{C_n}$

or, $\frac{Q}{C_{eq}} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}\right)Q$

or, $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$

2. Parallel combination of capacitor



Let C_1, $C_{2,}$ $C_{3\,................}$ and C_n be capacitances of the capacitors connected in parallel across a voltage source of 'V' volts. And C_{eq} is the equivalent capacitance of the capacitors connected to the above parallel circuit. Since in parallel combination, the potential difference across each capacitor will be the same and the charge stored in each of the capacitors will be different and additive.

i.e. $Q = Q_1 + Q_2 + Q_3 + \ldots\ldots\ldots\ldots\ldots\ldots + Q_n$

or, $C_{eq}V = C_1V + C_2V + C_3V + \ldots\ldots\ldots\ldots\ldots\ldots + C_nV$

or, $C_{eq}V = (C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots\ldots\ldots + C_n)\ V$

or $C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots\ldots\ldots\ldots\ldots + C_n$

Tutorials

1. If the capacitors with capacitances 1.5μF, 2 μF, and 3 μF are connected to a circuit, find the maximum and minimum that you can get using these three capacitors.

Sol[n]. Here

$C_1 = 1.5\ \mu F$

$C_2 = 2\ \mu F$

$C_3 = 3\ \mu F$

Now, if they are connected in a series combination

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

$$\text{or, } \frac{1}{C} = \frac{4+3+2}{6}$$

$$= \frac{9}{6}$$

$$\therefore C = 0.67\ \mu F$$

And, if they are connected in parallel combination,

$C = C_1 + C_2 + C_3$

or, $C = 1.5 + 2 + 3$

$$\therefore C = 5.5 \mu F$$

2. Three of the capacitors of capacitances 4 μF, 6 μF, and 8 μF are connected in series across a potential difference of 220 V. Calculate the equivalent capacitance

and the charge.

Sol[n]. Here

$C_1 = 4\ \mu F$

$C_2 = 6\ \mu F$

$C_3 = 8\ \mu F$

Now, if they are connected in series of combination

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

or, $\frac{1}{C} = \frac{1}{4} + \frac{1}{6} + \frac{1}{8}$

$$= \frac{6+4+3}{24}$$

$$= \frac{13}{24}$$

$$\therefore C = \frac{24}{13} = 1.85\ \mu F$$

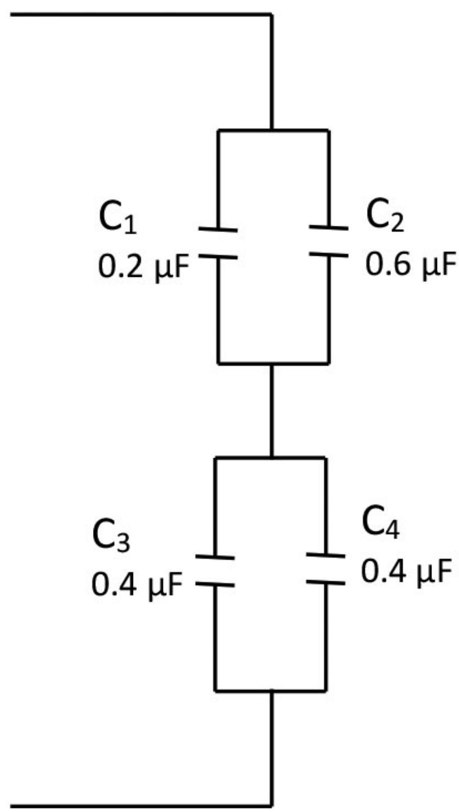
Again, we have

$Q = CV$

or, $Q = 1.85 \times 10^{-6} \times 220$

or, $Q = 4.07 \times 10^{-4}$ C

3. **Find the equivalent capacitance in the given circuit.**



Here,

The capacitors C_1 and C_2 are connected in parallel, so the

equivalent capacitance C_{12} is given by

$C_{12} = C_1 + C_2$

or, $C_{12} = 0.2 + 0.6$

$= 0.8\ \mu F$

Similarly,

The capacitors C_3 and C_4 are also connected in parallel, so the

equivalent capacitance C_{34} is given by

$C_{34} = C_3 + C_4$

or, $C_{34} = 0.4 + 0.4$

$= 0.8\ \mu F$

And, the equivalent capacitances C12 and C34 will be in series, so the equivalent capacitance between them can be calculated as,

$$\frac{1}{C} = \frac{1}{C_{12}} + \frac{1}{C_{34}}$$

or, $\frac{1}{C} = \frac{1}{0.8} + \frac{1}{0.8}$

or, $\frac{1}{C} = \frac{2}{0.8}$

$\therefore C = 0.4\mu F$

Hence the equivalent capacitance is 0.4μF.

4. The capacitors 10μF, 20μF, and 30μF are connected in parallel across a potential difference (p.d) of 6V. Calculate the total charge across the capacitors.

Here,

$C_1 = 10\mu F$

$C_2 = 20\mu F$

$C_3 = 30\mu F$

$\therefore$ Equivalent capacitance (C) $= C_1 + C_2 + C_3$

$= 10 + 20 + 30$

$= 60\ \mu F$

And, Total charge (Q) $= CV$

$= 60 \times 10^{-6} \times 6$

$= 360\ \mu C$

Exercise

Choose the correct answer from the given alternatives.

1. What is a cell?
   - a. A wire
   - b. A device that stores electric energy
   - c. A bulb
   - d. A switch
2. Which cell can be recharged?
   - a. Primary cell
   - b. Secondary cell
   - c. All cells
   - d. Dry cell
3. When cells are connected in series:
   - a. Voltage increases
   - b. Voltage decreases
   - c. Current becomes zero
   - d. Resistance becomes infinite
4. The SI unit of capacitance is:
   - a. Ampere
   - b. Volt
   - c. Farad
   - d. Ohm
5. Which factor does NOT affect capacitance?
   - a. Area of plates
   - b. Distance between plates
   - c. Shape of wire
   - d. Dielectric material

Write short answer to the following questions.

1. What are the components of a cell?
2. Differentiate primary and secondary cells.
3. What is a Daniel cell?
4. Explain the methods of charging cells.

Write long answer to the following questions.

1. Explain the parallel combination of cells with an appropriate diagram.
2. Explain the series connection of cells with an appropriate diagram.
3. Explain how the capacitance of the parallel plate capacitor is increased.

Magnetism and Electromagnetism

Unit 6

6.1 Introduction to Magnet and Magnetism

Magnets have attracted mankind for decades because of their unusual ability to attract and repel specific items. Magnetism is a fundamental force of nature, just like gravity and electricity. It is caused by the movement of electrons, which are tiny charged particles that exist within atoms. In some materials, electrons align in a precise pattern, producing a magnetic field. Each magnet has two distinct poles: north and south. The most basic assumption of magnetism is that like poles repel one another while unlike poles attract one another. This means that the north pole of one magnet repels the north pole of another, while attracting the south pole.

Consider an invisible field around a magnet. This is the magnetic field, or the area where the magnetic force is strongest. We can't see it directly, but we can tell it's there by how it affects other magnets or materials. Iron filings strewn around a magnet will align along the lines of force in the magnetic field, revealing its pattern.

Properties

a) When approached, it can attract magnetic materials.

b) When a magnet is freely hanging, it always rests in the north-south direction.

c) It has two poles: the north pole and the south pole.

d) The magnet's poles cannot be separated.

e) It has the highest attraction capacity at the poles.

f) Like poles repel and unlike poles attract one another.

6.2 Types of Magnet

Magnets are diverse in composition, source of magnetism, and properties, including permanent, alnico, ferrite, rare earth, temporary, electromagnets, superconducting, flexible, and composite types.

Temporary Magnet

Temporary magnets, like iron, steel, and nickel, are materials that exhibit magnetic properties only when exposed to an external magnetic field. They lose their magnetism when the field is removed, making them useful in applications like electromagnets, magnetic clamps, and magnetic sensors for temporary magnetic attraction or manipulation.

Permanent Magnet

Permanent magnets, made from rare earth elements like neodymium, iron, and boron, generate a persistent magnetic field without an external power source. They are used in everyday applications like electric motors, generators, speakers, magnetic separators, and MRI machines due to their stable magnetic fields.

There are four types of permanent magnets

- Ceramic or ferrite
- Alnico
- Samarium Cobalt (SmCo)
- Neodymium Iron Boron (NIB)

6.3 Magnetic and Non-magnetic Materials

In the fascinating world of magnetism, materials can be broadly classified into two categories based on how they interact with magnetic fields: magnetic and non-magnetic.

Magnetic Materials

Magnetic materials are substances that can be magnetized and exert magnetic fields. They are characterized by the alignment of their atomic or molecular magnetic moments, resulting in macroscopic magnetization. Common examples of magnetic materials include iron, nickel, cobalt, and their alloys, as well as certain rare earth materials like neodymium and samarium cobalt. These materials can be attracted to a magnet and can retain their magnetism to varying degrees.

Non-Magnetic Materials

Non-magnetic materials, on the other hand, are substances that are not affected by magnetic fields. They either do not possess magnetic moments or possess them in such a way that they cancel each other out. Examples of non-magnetic materials include plastics, wood, glass, rubber, and ceramics. These materials do not exhibit any attraction or repulsion when brought near a magnet and cannot be magnetized easily.

The magnetic properties of a material arise from the behavior of its atoms. In magnetic materials, the atoms have a permanent magnetic dipole moment, meaning they act like tiny bar magnets. These permanent microscopic magnets tend to align in the same direction in the presence of an external magnetic field, resulting in a net attraction. In non-magnetic materials, the atoms either have no permanent magnetic dipole moment or their alignment is random, leading to a negligible magnetic response.

Application of Magnetic and Non-Magnetic Materials

Magnetic and non-magnetic properties of a substance are used in daily life for ease of working. Magnets help gather pins from pin boxes and separate iron nails from wood shavings in carpentry. Iron nails stick to magnets, while wooden shavings don't.

Difference between magnetic and non-magnetic materials

Magnetic materials	Non-magnetic materials
Magnetic materials are substances that are attracted to a magnet.	Non-magnetic materials are substances that are not attracted to magnets.
Iron, nickel, and cobalt are magnetic substances that attract objects when a magnet is applied to them.	Examples of non-magnetic materials include rubber, plastic, stainless steel, feathers, paper, mica, gold, silver, leather, and other non-magnetic materials.
These can also be magnetized, or magnetic materials can be transformed into magnets.	Modern coins are composed of consistent mixes of several metals that render them non-magnetic.

Activity

Nilshankar Manandhar performs magic for his friends and receives a lot of praise for it. He maintains a steel automobile on his hardwood table. He can move the car without having to push it physically. His buddies are astounded and question how it is possible. What's the secret to his magic?

Nilshankar Manandhar keeps a magnet beneath the table. He can move the automobile on the table without moving it by shifting the magnet beneath it. This practice demonstrates that the force of a magnet can travel through a nonmagnetic substance, such as wood in this case.

What will happen if the table top is made of iron instead of wood?

6.4 Introduction to Magnetic Terminologies

Magnetic field or Magnetic Induction (B)

Magnet or Electromagnet produces a magnetic field. The field where the magnet attracts or repels magnetic materials such as iron, steel, etc. may be defined as a force on a moving charge,

$F = q \times V \times B$

Where

- F = Force,
- V = Speed of Particles,
- B = magnitude of the field.

It is a vector quantity and The SI Unit of magnetic Field is Tesla where 1 Tesla = (Newton x second) / (coulomb x meter) 10,000 Gauss. The Formula for the magnetic field in SI is $B = \mu_\circ (H+M)$ and in CGS is $B = H+4\pi M$.

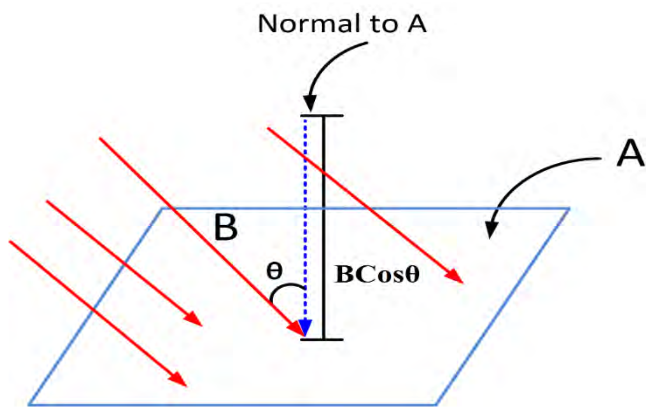
A wire carrying a direct current or permanent magnet produces a magneto-static (Stationary) field and its magnitude and direction remain the same. While, alternating current or Pulsating direct current carrying conductor creates alternating magnetic field which continuously changes, their direction and magnitude.

Magnetic Field Density or Strength

The amount of magnetizing force (how much force it has to magnetize, magnetic materials such as iron, steel, etc) is called magnetic field strength which is denoted by (H). It is inversely proportional to the length of the wire and directly proportional to the current passing through it. The SI unit of Magnetic Field Strength is Ampere/meter (A/m) and it is a vector quantity.

Magnetic Flux (Φ)

The total number of magnetic lines of force produced in a magnetic field is known as magnetic flux. It is denoted by ‘φ ‘ and its SI unit is Weber (Wb). If the magnetic lines of force of a magnet are more, the magnetic flux will also be more hence the stronger magnetic field and vice-versa. The Formula for finding magnetic flux in the SI system is;



$\Phi = B.Ac$

Where

B = magnetic field

Ac = area in m2

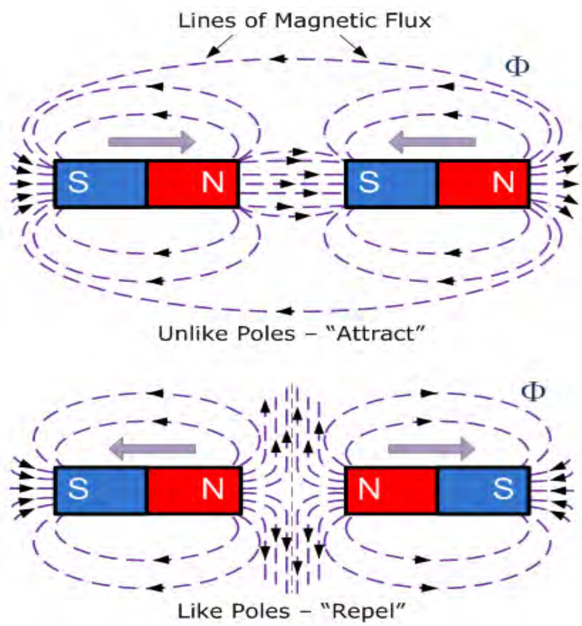
$\Phi = BA\cos\Theta$

Where Θ is the angle between the magnetic field and area.

Lines of Magnetic Flux

Magnetic flux refers to the total number of magnetic lines in a magnetic field. The imaginary North Pole experiences repulsive and attractive forces from the magnet, causing it to move along a specific path. Positioning the pole at different distances may alter its path.

Lines of force represent the paths of the unit north pole in a magnetic field, which can be placed at infinite points. However, visualizing an infinite number of lines is insufficient for scientific calculations. We take the unit of magnetic flux as Weber. If a field has φ Weber flux, it means the field has a total φ number of lines of force. Like the isolated North Pole, the concept of lines of force in a magnetic field is also imaginary. It does not have any physical existence.



Lines of magnetic flux

Properties of Magnetic Flux

Magnetic flux refers to the total number of magnetic lines of force in a field, each a closed loop starting from the North Pole of a magnet and continuing through the field and body of the magnet, with no two lines crossing each other.

Magnetic Flux Density

The total number of magnetic lines of force passing through the unit surface of area 'A' normally (being perpendicular) is known as magnetic flux density. It is denoted by 'B' and its SI unit is Tesla. The magnetic flux density of the field would be,

$$B = \frac{\phi}{A}$$

The SI unit of magnetic flux density by capital letter B is Weber per square meter (Wb/m^2) which is called Tesla (T).

1T= 1 Wb/m^2

6.5 Magnetic Effect of Current and its Application

The magnetic effect of current is a key idea that serves as the foundation for a wide range of modern technology. It essentially asserts that when an electric current travels through a conductor, a magnetic field forms around it. This invisible magnetic field exerts force on other magnets and even currents, allowing for a wide range of applications.

Consider a cable conveying an electric current. The current flows, causing a swirling motion of charged particles (electrons) within the conductor. This passage of charges generates the magnetic field. The strength and shape of the magnetic field depend on several factors:

- **Current Strength:** A stronger current translates to a more intense magnetic field.
- **Shape of Conductor:** Straight wires produce a circular magnetic field around them, while coils of wire (like in electromagnets) create a stronger, more concentrated magnetic field within the coil.

  Right-Hand Rule: The right-hand rule is a useful technique to determine the direction of the magnetic field around a current-carrying conductor by curling your fingers around the wire.

Applications of the Magnetic Effect of Current

This principle forms the foundation for numerous technologies that have revolutionized our lives. Here are some key examples:

- **Electromagnets:** As mentioned earlier, coiling a wire and passing current through it creates a powerful electromagnet. The strength of the magnetic field can be controlled by adjusting the current. Electromagnets are used in:
  a. **Electric motors:** The interaction between a rotating electromagnet and a permanent magnet creates torque, which is the turning force that powers electric motors in appliances, fans, and power tools.
  b. **Generators:** The principle is reversed in generators, where a rotating magnet induces a current in a coil of wire, converting mechanical energy into electrical energy.
  c. **Magnetic levitation trains (Maglev trains):** These trains utilize powerful electromagnets to levitate and propel themselves above a specially designed track.
- **Electric Transformers:** Transformers exploit the magnetic effect of current to change the voltage of an AC (alternating current) electrical signal. This is crucial for efficient power transmission and distribution over long distances.

Electromagnetism

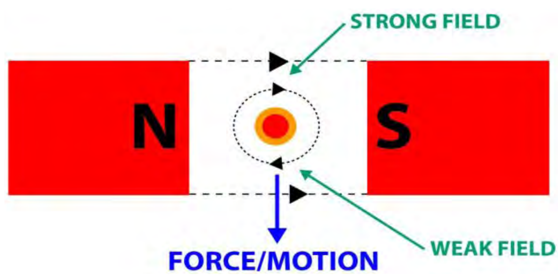
Electromagnetism is the phenomenon of the interaction of the electric current with the magnetic field, as when the electric current generates a magnetic field or when a changing magnetic field generates the electric field. The production of magnetic property (magnetism) in a current-carrying conductor is known as electromagnetism and the magnetic field developed around is known as electromagnetic field.

6.6 Principle of Electromagnetism

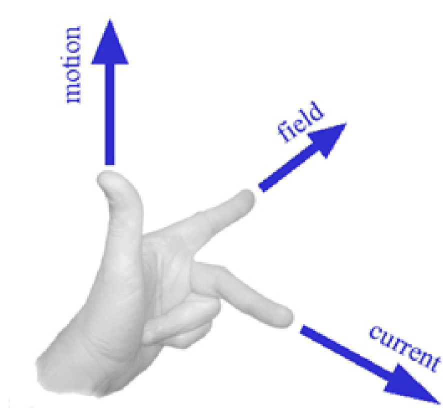
Electromagnetism is a branch of physics that focuses on the interaction between electricity and magnetism. It plays a major role in most objects encountered in daily life. Electromagnetism is the interaction between conductors and fixed magnetic fields.

Motor principle and Fleming's left-hand rule

Whenever a current-carrying conductor lies in a magnetic field, there will be a force set up on that conductor.



The direction of force on a current-carrying conductor can be remembered by using Fleming's left-hand rule.



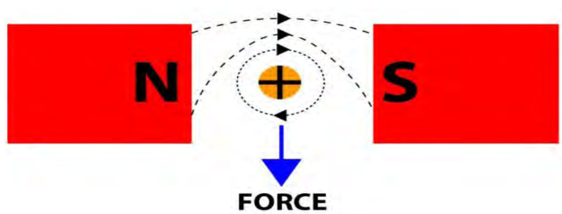
The direction of force on a current-carrying conductor can be remembered by using Fleming's left-hand rule. Fleming's left-hand rule helps remember the direction of motion in an electric motor. When an external magnetic field is applied, the wire experiences a force perpendicular to the field and current direction.

The thumb = the direction of force on the conductor.

The forefinger = the direction of the field flux.

The middle finger = the direction of the current.

In practice, the main field will distort and the conductor will be pushed downwards.



This is because

- Lines of magnetic flux that have the same direction push each other apart.
- Lines of magnetic flux are in a permanent state of contraction.
- Lines of magnetic flux do not cross.

Force is measured in Newton's (**N**). The magnitude of the force depends on the strength of the main field, the strength of the field produced by the current-carrying conductor, and its active length.

The formula to remember for this is:

F = B x **I** x **L**

As an example, a conductor carrying a current of 2A and with an active length of 0.1m lies in a magnetic field with a flux density of 2.5T. The force on the conductor therefore is:

F = B x I x L

F = 2.5 x 2 x 0.1

F= 0.5N

6.7 Faraday's law of Electromagnetic Induction

Faraday’s law of electromagnetic induction, also known as Faraday’s law, is the basic law of electromagnetism which helps us to predict how a magnetic field would interact with an electric circuit to produce an electromotive force (emf). This phenomenon is known as electromagnetic induction.

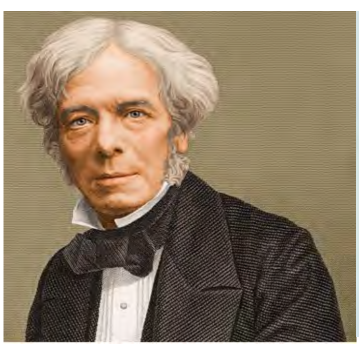
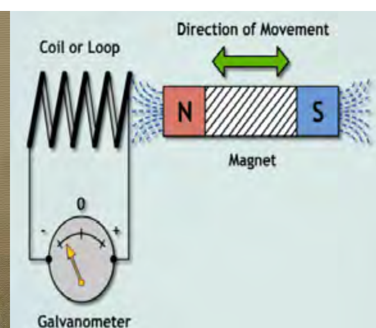
Michael Faraday proposed the laws of electromagnetic induction in the year 1831. Faraday’s law or the law of electromagnetic induction is the observation or results of the experiments conducted by Faraday. He performed three main experiments to discover the phenomenon of electromagnetic induction.

It states that

a) When the magnetic flux linked with the closed circuit changes, an electromotive force (emf) is induced in the circuit.

b) The magnitude of induced emf is directly proportional to the rate of change of magnetic flux.

c) The induced emf lasts in the circuit as long as the change in the magnetic flux continues.

Michael Faraday

Note: The magnitude of induced emf can be increased by the following methods

i) By increasing the strength of the magnet

ii) By decreasing the distance between the poles of the magnet iii) By increasing the speed of the moving conductor.

Exercises

Choose the correct answer from the given alternatives.

1. Which of the following is not the property of a magnet?
   a. Like poles repel and unlike poles attract.
   b. Magnetic poles exist in pairs.
   c. A freely suspended bar magnets point the N-S direction at rest.
   d. Magnet has more force of attraction in the middle than at the end.

2. Which of the following is not a magnetic substance?
   a. Copper   b. Iron   c. Nickel   d. Cobalt

3. The SI unit of magnetic flux density is,
   a. Wbm   b. Wbm^{-2} c. Wbm^{2} d. Wbm^{-1}

4. Electromagnetic induction was discovered by
   a. Lonz   b. Faraday   c. Newton   d. Einstein

Write short answer to the following questions.

1. Electromagnet and Temporary magnet
2. Magnetic and Non-magnetic substances
3. Write Faraday's first and second laws of electromagnetic induction.
4. Write any three ways to change the magnetic field intensity in a closed loop.
5. List applications of magnetism.
6. Differentiate magnetic and non-magnetic materials.
7. How can the strength of the electromagnet be increased?

Write long answer to the following questions.

1. What is a temporary magnet?
2. Define magnetic and non–magnetic substances.
3. What is magnetic flux? Define magnetic flux density.
4. Define electromagnet. What is magnetization?
5. Write any four characteristics of the magnet.

6. Mention any three uses of magnets.
7. Write any four properties of magnetic field lines.
8. What is the magnetic effect of current? Write its application.

Fundamentals of current and phase current

Unit 7

7.1 Introduction to AC and DC

AC Current

An alternating current changes direction and magnitude on a continuous and periodic basis. Generators produce alternating current (AC). Alternating currents are more widely used because they are easier to manage, transmit, and utilize than direct currents. AC current is not the only alternating quantity; voltage can be alternating as well. These signals are most commonly represented as a sinusoidal waveform or sine wave, although they can also be displayed as a square or triangle wave.

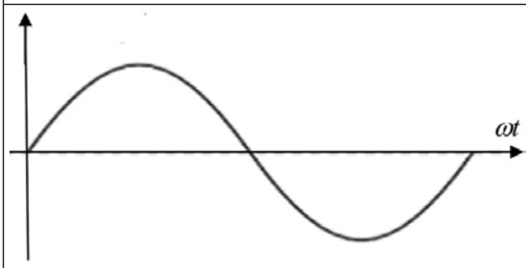
DC Current

DC power systems have only one polarity of voltage or current, and it refers to the voltage or current's constant, zero-frequency, or slowly fluctuating local mean value. i.e. The voltage across a DC voltage source remains constant, as does the current via a DC current source. Direct current (DC) refers to the unidirectional passage of electric charge. Batteries, thermocouples, power supplies, solar cells, and other sources all generate direct current. Electric current flows in a consistent direction, which distinguishes it from alternating current. A rectifier circuit can be used to convert an alternating current supply into direct current. Direct current can also be transformed into alternating current using an inverter or a motor-generator set. Direct current is utilized for charging batteries, powering electronic systems, producing aluminum, and powering railways, while high-voltage direct current transmits power from remote sources or interconnects alternating current power grids.

7.2 Differences Between AC and DC

Comparison of AC and DC signal

AC	DC
The magnitude changes continuously.	The magnitude remains constant.
The direction of ac signal changes periodically	The direction of DC is fixed.
It is produced by AC generators.	It is produced by cells.
It has a certain value of frequency.	The frequency of DC is 0.

AC signals can be easily converted into DC.	Conversion of DC into AC is not simple.
Transmission of AC signal over higher distances is easier.	Transmission of DC signals over higher distances is difficult.
With the same rating, AC is less dangerous than DC.	With the same rating DC is more dangerous than AC.
	

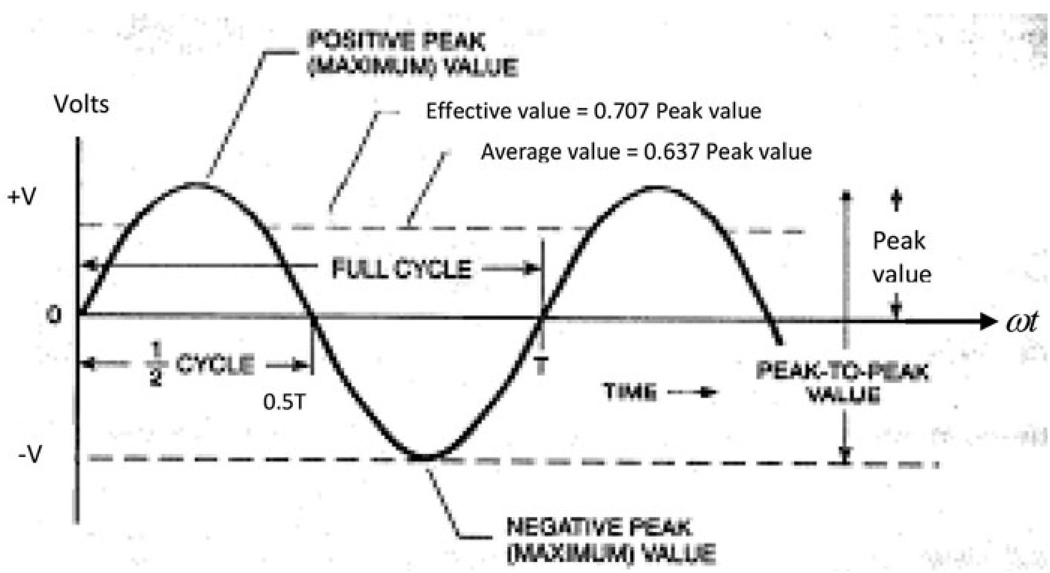
7.3 Define the following terms Frequency, Amplitude, and Time Hrs.

a. Cycle

When the waves move through one positive half-cycle and one negative half-cycle, then the wave is said to have completed one complete cycle.

b. Time period

The time taken by a wave to complete one cycle is known as the time period. It is represented by 'T' and is measured in terms of seconds.



AC signal showing different parameters

c. Frequency

The total number of complete cycles made by a wave in one second is known as frequency. It is represented by 'f' and measured in terms of Hertz (Hz).

The common power frequency in Nepal is 50 Hz i.e. the wave completed 50 complete cycles in 1 second. Likewise in electronics, the frequencies of the signals may vary from zero (DC signal) to kilohertz (kHz), megahertz(MHz) to gigahertz(GHz).

Note:

The relation between time period and frequency of the wave is given by,

Frequency (f) = $\frac{1}{T} Hz$ where T – time period of the wave.

d. Wavelength

The distance covered by a wave while completing one cycle is known as the wavelength of the wave. It is represented by 'λ' and its SI unit is meter. It depends on the velocity of the wave and the relation can be expressed as,

$c = f\lambda$ where c = speed of the wave (m/s)

f = frequency of wave (Hz)

and λ = wavelength of wave (m)

In the case of radio waves transmitting at a speed of 3 X 10^8 m/s, the wavelength of a 60 Hz alternating wave is,

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}}{60} = 5\times10^{6} m$$

e. Amplitude (peak value)

The maximum positive or negative value attained by a wave from its mean position or zero value is known as amplitude. It is denoted by 'A'.

f. Phase

It is given by the amount of time (or angle) that has elapsed since the wave last passed through the positive zero value.

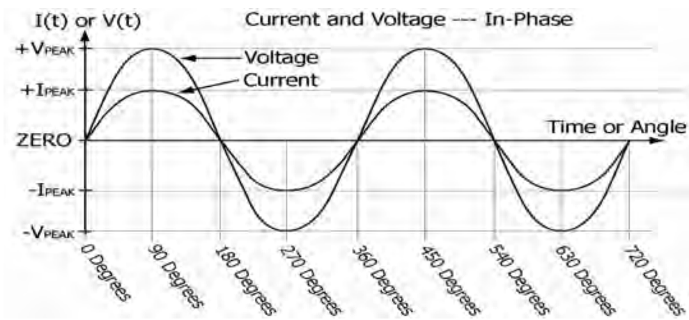
In the figure, the phase angle of the sine wave at point A is seconds $\frac{\pi}{2}^{c}$.

g. **Phase difference**

The difference in time or angle between the two sine waves sine they last passed through their zero values is called the phase difference between two waves.

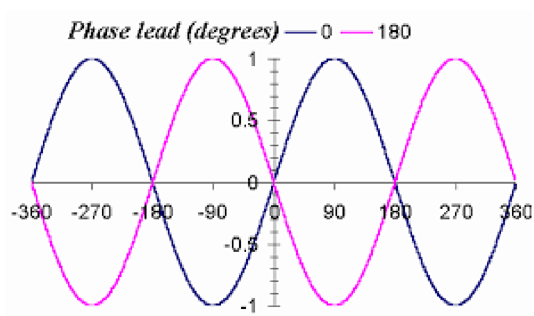
h. **In phase**

When we compare the two sine waves, if they reach the zero value or maximum (either positive or negative) at the same time or phase, then the two waves are said to be in phase. Under this condition, the phase difference between the two waves is 0.



i. **Anti-phase or Out-phase**

In comparing the two waves, if they reach the zero value at the same time but when one of the waves reaches the positive maximum, and the other wave reaches the negative maximum, then the waves are said to be in anti-phase or out-phase. During this condition, the phase difference between the waves is 180°.



Numerical

If an AC signal is given by, i(t) = 300 sin $\left(157t + \frac{\pi}{3}\right)$

Calculate:

a) maximum value of current

b) frequency

c) time period

Solution:

Here, the given expression for AC current is

i(t) = 300 sin $\left(157t + \frac{\pi}{3}\right)$

Comparing with i(t) = Im sin$(\omega t + \phi)$, we get

(i) Im = 300 A

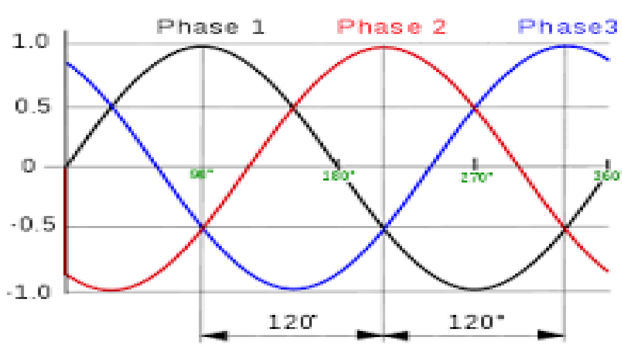
$$(ii)\ \omega = 157$$
$$or,\ 2\pi f = 157$$
$$or,\ f = \frac{157}{2 \times 3.14} = 25\ Hz$$

(iii) Time period (t) = $\frac{1}{f} = \frac{1}{25} = 0.04$ sec

7.4 Difference Between Single-phase and Three-phase System

Polyphase System

A polyphase system is a method of distributing alternating current electrical power. Polyphase systems include three or more energized electrical conductors that carry alternating currents with a distinct phase difference between the voltage waves in each conductor. Polyphase systems are especially effective at transmitting power to electric motors. The most prominent example is the three-phase power system, which is utilized in industrial applications and for power transmission. A significant advantage of three-phase power transmission (which uses three conductors as opposed to two conductors in single-phase power transmission) is that, because the remaining conductors serve as the return path for any single conductor, the power transmitted by a balanced three-phase system is three times that of a single phase transmission while only one extra conductor is required.



The single-phase system is utilized in the majority of applications, however, it may not be appropriate in some areas of electrical engineering, such as power transmission, electromechanical energy conversion, and so on. In the case of power transmission, the single-phase AC circuit does not make use of the appropriate conduction system, and for energy conversion, the single-phase machines provide pulsating torque and operate at a very low power factor, and they may frequently require additional equipment to start. These problems are easily solved with three-phase systems. As a result, three-phase systems are most commonly employed in power applications.

7.5 Uses and Applications of Three-phase Systems

The advantages of a three-phase system over a single-phase system can be listed as follows.

a. Three-phase power distribution requires a lesser amount of copper or aluminum for transferring the same amount of power as compared to single-phase power

b. The output of a phase machine is about 1.5 times that of a single-phase machine of the same size. The 3-ϕ alternator occupies less space for a given size and voltage and costs less than the single-phase machine of the same ratings.

c. In a phase system, the power delivered is almost constant, when the loads are balanced but it is pulsating in a single-phase system.

d. The voltage regulation of a three-phase transmission line is better than that of a single-phase line. Similarly, a single phase can be obtained from three phases but three phases cannot be obtained from a single phase.

e. Higher power can be obtained from a three-phase system, and hence can be used for running big and heavy motors.

Exercises

Choose the correct answer from the given alternatives.

1. What is electric current?

   a. The flow of voltage in a circuit

   b. The flow of charge through a conductor

   c. The resistance to flow in a circuit

   d. The potential energy stored in a circuit

2. In a balanced three-phase system, how does phase current relate to line current?

   a. Phase current is always greater than line current.

   b. Phase current is always less than line current.

   c. Phase current equals line current.

   d. Phase current varies independently from line current.

3. How is current typically measured in a circuit?

   a. Voltmeter   b. Ammeter   c. Ohmmeter   d. Multimeter

4. What is the unit of electric current?

   a. Watt   b. Ohm   c. Ampere   d. Volt

5. Alternating current (AC) and direct current (DC) differ primarily in:

   a) Voltage level   b) Current direction

   c) Frequency   d) Power consumption

Write short answer to the following questions.

1. Define the concept of phase current.
2. What are the units of current?
3. How is current measured in a circuit?
4. Describe the direction of current flow in a circuit.
5. What is meant by alternating current (AC) and direct current (DC)?

Write long answers to the following questions.

1. Discuss the advantages of a three-phase system over a single-phase system.
2. Explain the significance of phase current in three-phase electrical systems.\

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