

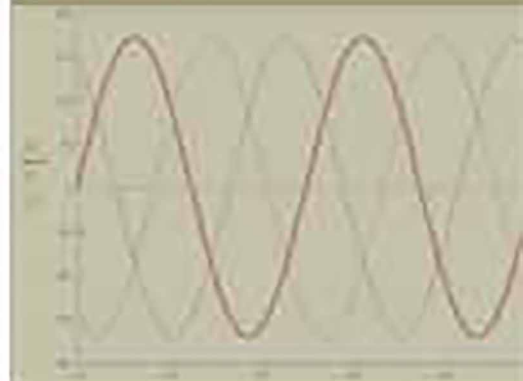
Revised Edition

Basic Electrical Engineering

(For B.E./B.Tech. and other Engineering Examinations)



**V.K. MEHTA
ROHIT MEHTA**



S. CHAND

BASIC ELECTRICAL ENGINEERING

For B.E./B.Tech. and Other Engineering Examinations

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Preface to Sixth Edition

The general response to the Fifth Edition of the book was very encouraging. Authors feel that their work has been amply rewarded and wish to express their deep sense of gratitude to the large number of readers who have used it and in particular to those of them who have sent helpful suggestions from time to time for the improvement of the book.

The popularity of the book is judged from the fact that authors frequently receive feedback from many quarters including teachers, students and serving engineers. This feedback helps the authors to make the book up-to-date. In the present edition, many new topics/numericals/illustrations have been added to make the book more useful.

Authors lay no claim to the original research in preparing the book. Liberal use of materials available in the works of eminent authors has been made. What they may claim, in all modesty, is that they have tried to fashion the vast amount of material available from primary and secondary sources into coherent body of description and analysis.

The authors wish to thank their colleagues and friends who have contributed many valuable suggestions regarding the scope and content sequence of the book. Authors are also indebted to S. Chand & Company Ltd., New Delhi for bringing out this revised edition in a short time and pricing the book moderately inspite of heavy cost of paper and printing.

Errors might have crept in despite utmost care to avoid them. Authors shall be grateful if these are pointed out along with other suggestions for the improvement of the book.

V.K. MEHTA

ROHIT MEHTA

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Contents

<i>Chapter</i>	<i>Pages</i>
1. Basic Concepts	1—35
Nature of Electricity—Unit of Charge—The Electron—Energy of an Electron—Valence Electrons—Free Electrons—Electric Current—Electric Current is a Scalar Quantity—Types of Electric Current—Mechanism of Current Conduction in Metals—Relation Between Current and Drift Velocity—Electric Potential—Potential Difference—Maintaining Potential Difference—Concept of E.M.F. and Potential Difference—Potential Rise and Potential Drop—Resistance—Factors Upon Which Resistance Depends—Specific Resistance or Resistivity—Conductance—Types of Resistors—Effect of Temperature on Resistance—Temperature Co-efficient of Resistance—Graphical Determination of α —Temperature Co-efficient at Various Temperatures—Summary of Temperature Co-efficient Relations—Variation of Resistivity With Temperature—Ohm's Law—Non-ohmic Conductors—Electric Power—Electrical Energy—Use of Power and Energy Formulas—Power Rating of a Resistor—Non-linear Resistors—Objective Questions.	
2. D.C. Circuits	36—105
D.C. Circuit—D.C. Series Circuit—D.C. Parallel Circuit—Main Features of Parallel Circuits—Two Resistances in Parallel—Advantages of Parallel Circuits—Applications of Parallel Circuits—D.C. Series-Parallel Circuits—Applications of Series-Parallel Circuits—Internal Resistance of a Supply—Equivalent Resistance—Open Circuits—Short Circuits—Duality Between Series and Parallel Circuits—Wheatstone Bridge—Complex Circuits—Kirchhoff's Laws—Sign Convention—Illustration of Kirchhoff's Laws—Method to Solve Circuits by Kirchhoff's Laws—Matrix Algebra—Voltage and Current Sources—Ideal Voltage Source or Constant-Voltage Source—Real Voltage Source—Ideal Current Source—Real Current Source—Source Conversion—Independent Voltage and Current Sources—Dependent Voltage and Current Sources—Circuits With Dependent-Sources—Ground—Voltage Divider Circuit—Objective Questions.	
3. D.C. Network Theorems	106—238
Network Terminology—Network Theorems and Techniques—Important Points About Network Analysis—Maxwell's Mesh Current Method—Shortcut Procedure for Network Analysis by Mesh Currents—Nodal Analysis—Nodal Analysis with Two Independent Nodes—Shortcut Method for Nodal Analysis—Superposition Theorem—Thevenin's Theorem—Procedure for Finding Thevenin Equivalent Circuit—Thevenin Equivalent Circuit—Advantages of Thevenin's Theorem—Norton's Theorem—Procedure for Finding Norton Equivalent Circuit—Norton Equivalent Circuit—Maximum Power Transfer Theorem—Proof of Maximum Power Transfer Theorem—Applications of Maximum Power Transfer Theorem—Reciprocity Theorem—Millman's Theorem—Compensation Theorem—Delta/Star and Star/Delta Transformation—Delta/Star Transformation—Star/Delta Transformation—Tellegen's Theorem—Objective Questions.	
4. Units—Work, Power and Energy	239—259
International System of Units—Important Physical Quantities—Units of Work or Energy—Some Cases of Mechanical Work or Energy—Electrical Energy—Thermal Energy—Units of Power—Efficiency of Electric Device—Harmful Effects of Poor Efficiency—Heating Effect of Electric Current—Heat Produced in a Conductor by Electric Current—Mechanical Equivalent of Heat (J)—Objective Questions.	
5. Electrostatics	260—294
Electrostatics—Importance of Electrostatics—Methods of Charging a Capacitor—Coulomb's Laws of Electrostatics—Absolute and Relative Permittivity—Coulomb's Law in Vector Form—The	

Superposition Principle—Electric Field—Properties of Electric Lines of Force—Electric Intensity or Field Strength (E)—Electric Flux (ψ)—Electric Flux Density (D)—Gauss's Theorem—Proof of Gauss's Law—Electric Potential Energy—Electric Potential—Electric Potential Difference—Potential at a Point Due to a Point Charge—Potential at a Point Due to Group of Point Charges—Behaviour of Metallic Conductors in Electric Field—Potential of a Charged Conducting Sphere—Potential Gradient—Breakdown Voltage or Dielectric Strength—Uses of Dielectrics—Refraction of Electric Flux—Equipotential Surface—Motion of a Charged Particle in Uniform Electric Field—Objective Questions.

6. Capacitance and Capacitors **295—349**

Capacitor—How does a Capacitor Store Charge?—Capacitance—Factors Affecting Capacitance—Dielectric Constant or Relative Permittivity—Capacitance of an Isolated Conducting Sphere—Capacitance of Spherical Capacitor—Capacitance of Parallel-Plate Capacitor with Uniform Medium—Parallel-Plate Capacitor with Composite Medium—Special Cases of Parallel-Plate Capacitor—Multiplate Capacitor—Cylindrical Capacitor—Potential Gradient in a Cylindrical Capacitor—Most Economical Conductor Size in a Cable—Capacitance Between Parallel Wires—Insulation Resistance of a Cable Capacitor—Leakage Resistance of a Capacitor—Voltage Rating of a Capacitor—Capacitors in Series—Capacitors in Parallel—Joining Two Charged Capacitors—Energy Stored in a Capacitor—Energy Density of Electric Field—Force on Charged Plates—Behaviour of Capacitor in a D.C. Circuit—Charging of a Capacitor—Time Constant—Discharging of a Capacitor—Transients in D.C. Circuits—Transient Relations During Charging Discharging of Capacitor—Objective Questions.

7. Magnetism and Electromagnetism **350—385**

Poles of a Magnet—Laws of Magnetic Force—Magnetic Field—Magnetic Flux—Magnetic Flux Density—Magnetic Intensity or Magnetising Force (H)—Magnetic Potential—Absolute and Relative Permeability—Relation Between B and H —Important Terms—Relation Between μ_r and χ_m —Refraction of Magnetic Flux—Molecular Theory of Magnetism—Modern View about Magnetism—Magnetic Materials—Electromagnetism—Magnetic Effect of Electric Current—Typical Electromagnetic Fields—Magnetising Force (H) Produced by Electric Current—Force on Current-Carrying Conductor Placed in a Magnetic Field—Ampere's Work Law or Ampere's Circuital Law—Applications of Ampere's Work Law—Biot-Savart Law—Applications of Biot-Savart Law—Magnetic Field at the Centre of Current-Carrying Circular Coil—Magnetic Field Due to Straight Conductor Carrying Current—Magnetic Field on the Axis of Circular Coil Carrying Current—Force Between Current-Carrying Parallel Conductors—Magnitude of Mutual Force—Definition of Ampere—Objective Questions.

8. Magnetic Circuits **386—429**

Magnetic Circuit—Analysis of Magnetic Circuit—Important Terms—Comparison Between Magnetic and Electric Circuits—Calculation of Ampere-Turns—Series Magnetic Circuits—Air Gaps in Magnetic Circuits—Parallel Magnetic Circuits—Magnetic Leakage and Fringing—Solenoid—B-H Curve—Magnetic Calculations From B-H Curves—Determination of B/H or Magnetisation Curve—B-H Curve by Ballistic Galvanometer—B-H Curve by Fluxmeter—Magnetic Hysteresis—Hysteresis Loss—Calculation of Hysteresis Loss—Factors Affecting the Shape and Size of Hysteresis Loop—Importance of Hysteresis Loop—Applications of Ferromagnetic Materials—Steinmetz Hysteresis Law—Comparison of Electrostatics and Electromagnetic Terms—Objective Questions.

9. Electromagnetic Induction **430—480**

Electromagnetic Induction—Flux Linkages—Faraday's Laws of Electromagnetic Induction—Direction of Induced E.M.F. and Current—Induced E.M.F.—Dynamically Induced E.M.F.—Statically Induced E.M.F.—Self-inductance (L)—Magnitude of Self-induced E.M.F.—Expressions for Self-inductance—Magnitude of Mutually Induced E.M.F.—Expressions for Mutual Inductance—Co-efficient of Coupling—Inductors in Series—Inductors in Parallel with no Mutual Inductance—Inductors in Parallel with Mutual Inductance—Energy Stored in a Magnetic Field—

(vii)

Magnetic Energy Stored Per Unit Volume—Lifting Power of a Magnet—Closing and Breaking an Inductive Circuit—Rise of Current in an Inductive Circuit—Time Constant—Decay of Current in an Inductive Circuit—Eddy Current Loss—Formula for Eddy Current Power Loss—Objective Questions.

10. Chemical Effects of Electric Current 481—520

Electric Behaviour of Liquids—Electrolytes—Mechanism of Ionisation—Electrolysis—Back e.m.f. or Polarisation Potential—Faraday's Laws of Electrolysis—Relation Between E and Z—Deduction of Faraday's Laws of Electrolysis—Practical Applications of Electrolysis—Cell—Types of Cells—Lead-Acid Cell—Chemical Changes During Discharging—Chemical Changes During Recharging—Formation of Plates of Lead-acid Cells—Construction of a Lead-acid Battery—Characteristics of a Lead-acid Cell—Curves of a Lead-acid Cell—Indications of a Fully Charged Lead-acid Cell—Load Characteristics of a Lead-acid Cell—Sulphation of Plates—Methods of Charging Batteries—Important Points About Charging of Lead-Acid Batteries—Effects of Overcharging—Care of Lead-acid Batteries—Applications of Lead-acid Batteries—Voltage Control Methods—Alkaline Batteries—Nickel-Iron Cell or Edison Cell—Electrical Characteristics of Nickel-Iron Cell—Nickel-Cadmium Cell—Comparison of Lead-acid Cell and Edison Cell—Silver-Zinc Batteries—Solar Cells—Fuel Cells—Objective Questions.

11. A.C. Fundamentals 521—577

Alternating Voltage and Current—Sinusoidal Alternating Voltage and Current—Why Sine Waveform?—Generation of Alternating Voltages and Currents—Equation of Alternating Voltage and Current—Important A.C. Terminology—Important Relations—Different Forms of Alternating Voltage—Values of Alternating Voltage and Current—Peak Value—Average Value—Average Value of Sinusoidal Current—R.M.S. or Effective Value—R.M.S. Value of Sinusoidal Current—Importance of R.M.S. Values—Form Factor and Peak Factor—Complex Waveforms—R.M.S. Value of a Complex Wave—Phase—Phase Difference—Representation of Alternating Voltages and Currents—Phasor Representation of Sinusoidal Quantities—Phasor Diagram of Sine Waves of Same Frequency—Addition of Alternating Quantities—Subtraction of Alternating Quantities—Phasor Diagrams Using R.M.S. Values—Instantaneous Power—A.C. Circuit Containing Resistance Only—A.C. Circuit Containing Pure Inductance Only—A.C. Circuit Containing Capacitance Only—Complex Waves and A.C. Circuit—Fundamental Power and Harmonic Power—Objective Questions.

12. Series A.C. Circuits 578—633

R-L Series A.C. Circuit—Impedance Triangle—Apparent, True and Reactive Powers—Power Factor—Significance of Power Factor—Q-factor of a Coil—Power in an Iron-Cored Choking Coil—R-C Series A.C. Circuit—Equivalent Circuit for a Capacitor—R-L-C Series A.C. Circuit—Resonance in A.C. Circuits—Resonance in Series A.C. Circuit (Series Resonance)—Resonance Curve—Q-Factor of Series Resonant Circuit—Bandwidth of a Series Resonant Circuit—Expressions for Half-power Frequencies—To Prove : $f_r = \sqrt{f_1 f_2}$ —Expressions for Bandwidth—Important Relations in R-L-C Series Circuit—Applications of Series Resonant Circuits—Decibels—Objective Questions.

13. Phasor Algebra 634—665

Notation of Phasors on Rectangular Co-ordinate Axes—Significance of Operator j —Mathematical Representation of Phasors—Conversion from One Form to the Other—Addition and Subtraction of Phasors—Conjugate of a Complex Number—Multiplication and Division of Phasors—Powers and Roots of Phasors—Applications of Phasor Algebra to A.C. Circuits—R-L Series A.C. Circuit—R-C Series A.C. Circuit—R-L-C Series A.C. Circuit—Power Determination Using Complex Notation—Power Determination by Conjugate Method—A.C. Voltage Divider—Objective Questions.

14. Parallel A.C. Circuits**666—721**

Methods of Solving Parallel A.C. Circuits—By Phasor Diagram—By Phasor Algebra—Equivalent Impedance Method—Admittance (Y)—Importance of Admittance in Parallel A.C. Circuit Analysis—Admittance Triangle—Admittance Method for Parallel Circuit Solution—Application of Admittance Method—Some Cases of Parallel Connected Elements—Series-Parallel A.C. Circuits—Series-to-Parallel Conversion and Vice-Versa—Resonance in Parallel A.C. Circuits (Parallel Resonance)—Graphical Representation of Parallel Resonance—Q-factor of a Parallel Resonant Circuit—Bandwidth of Parallel Resonant Circuit—Key Points About Parallel Resonance—General Case for Parallel Resonance—Comparison of Series and Parallel Resonant Circuits—Objective Questions.

15. Polyphase Circuits**722—829**

Polyphase System—Reasons for the Use of 3-phase System—Elementary 3-Phase Alternator—Some Concepts in 3-Phase System—Interconnection of Three Phases—Star or Wye Connected System—Important 3-Phase Terminology—Voltages and Currents in Balanced Y-Connected Supply System—Checking Correct Connections for Y-connected Alternator—Delta (Δ) or Mesh Connected System—Correct and Incorrect Δ Connections of Alternator—Voltages and Currents in Balanced Δ Connected Supply System—Advantages of Star and Delta Connected Systems—Constancy of Total Power in Balanced 3-phase System—Effects of Phase Sequence—Phase Sequence Indicator—Y/ Δ or Δ /Y Conversions for Balanced Loads—3-phase Balanced Loads in Parallel—Use of Single-Phase Wattmeter—Power Measurement in 3-phase Circuits—Three-Wattmeter Method—Two-Wattmeter Method—Proof for Two-Wattmeter Method—Determination of P.F. of Load by Two-wattmeter Method (For balanced Y or Δ load only)—Effect of Load p.f. on Wattmeter Readings—Leading Power Factor—How to Apply p.f. Formula?—One-Wattmeter Method—Balanced Load—Reactive Power with Two-Wattmeter Method—Reactive Power with One Wattmeter—Unbalanced 3-Phase Loads—Four-Wire Star-Connected Unbalanced Load—Unbalanced Δ -Connected Load—Unbalanced 3-Wire Star-Connected Load—Methods of Solving Unbalanced 3-wire Y load—Solving Unbalanced 3-Wire Y Load by Kirchhoff's Laws—Solving Unbalanced 3-wire Y Load By Loop Current Method—Solving Unbalanced 3-Wire Y Load by Y/ Δ Conversion—Solving Unbalanced 3-Wire Y Load by Millman's Theorem—Significance of Power Factor—Disadvantages of Low Power Factor—Causes of Low Power Factor—Power Factor Improvement—Power Factor Improvement Equipment—Calculations of Power Factor Correction—Objective Questions.

16. Electrical Instruments and Electrical Measurements**830—935**

Classification of Electrical Measuring Instruments—Types of Secondary Instruments—Principles of Operation of Electrical Instruments—Essentials of Indicating Instruments—Deflecting Torque—Controlling Torque—Damping Torque—Ammeters and Voltmeters—Permanent-Magnet Moving Coil (PMMC) Instruments (Ammeters and Voltmeters)—Extension of Range of PMMC Instruments—Extension of Range of PMMC Ammeter—Extension of Range of PMMC Voltmeter—Voltmeter Sensitivity—Dynamometer Type Instruments (Ammeters and Voltmeters)—Deflecting Torque (T_d) of Dynamometer Type Instruments in Terms of Mutual Inductance—Range Extension of Dynamometer Type Instruments—Moving-Iron (M.I.) Ammeters and Voltmeters—Attraction Type M.I. Instruments—Repulsion Type M.I. Instruments— T_d of M.I. Instruments in Terms of Self-Inductance—Sources of Errors in Moving Iron Instruments—Characteristics of Moving-Iron Instruments—Extending Range of Moving-Iron Instruments—Comparison of Moving Coil, Dynamometer type and Moving Iron Voltmeters and Ammeters—Hot-Wire Ammeters and Voltmeters—Thermocouple Instruments—Electrostatic Voltmeters—Attracted Disc Type Voltmeter—Quadrant Type Voltmeter—Multicellular Electrostatic Voltmeter—Characteristics of Electrostatic Voltmeters—Range Extension of Electrostatic Voltmeters—Induction Type Instruments—Induction Ammeters and Voltmeters—Characteristics of Induction Ammeters and Voltmeters—Wattmeters—Dynamometer Wattmeter—Characteristics of Dynamometer Wattmeters—Wattmeter Errors—Induction Wattmeters—Three-phase Wattmeter—Watt-hour

Meters or Energy Meters—Commutator Motor Meter—Mercury Motor Watthour Meter—Induction Watthour Meters or Energy Meters—Single-Phase Induction Watthour Meters or Energy Meters—Errors in Induction Watthour Meters—Three-Phase Watthour Meter—D.C. Potentiometer—Direct Reading Potentiometers—Modern D.C. Potentiometers—Crompton D.C. Potentiometers—Volt Ratio Box—Applications of D.C. Potentiometers—A.C. Potentiometer—Drysdale A.C. Potentiometer—Ballistic Galvanometer—Vibration Galvanometer—Frequency Meters—Vibrating-Reed Frequency meter—Electrodynamic Frequency Meter—Moving-Iron Frequency Meter—Power Factor Meters—Single-Phase Electrodynamic Power Factor Meter—3-Phase Electrodynamic Power Factor Meter—Moving-Iron Power Factor Meter—3-Voltmeter Method of Determining Phase Angle—Ohmmeter—Megger—Instrument Transformers—Current Transformer (C.T.)—Potential Transformer (P.T.)—Advantages of Instrument Transformers—Objective Questions.

17. A.C. Network Analysis 936—983

A.C. Network Analysis—Kirchhoff's Laws for A.C. Circuits—A.C. Mesh Current Analysis—A.C. Nodal Analysis—Superposition Theorem for A.C. Circuits—Thevenin's Theorem for A.C. Circuits—Norton's Theorem for A.C. Circuits—Thevenin and Norton Equivalent Circuits—Millman's Theorem for A.C. Circuits—Reciprocity Theorem—Maximum Power Transfer Theorem for A.C. Circuits—A.C. Network Transformations—Objective Questions.

■ Index 985—989

(x)

Basic Concepts

Introduction

Everybody is familiar with the functions that electricity can perform. It can be used for lighting, heating, traction and countless other purposes. The question always arises, “What is electricity”? Several theories about electricity were developed through experiments and by observation of its behaviour. The only theory that has survived over the years to explain the nature of electricity is the *Modern Electron theory of matter*. This theory has been the result of research work conducted by scientists like Sir William Crooks, J.J. Thomson, Robert A. Millikan, Sir Earnest Rutherford and Neils Bohr. In this chapter, we shall deal with some basic concepts concerning electricity.

1.1. Nature of Electricity

We know that matter is electrical in nature *i.e.* it contains particles of electricity *viz.* protons and electrons. The positive charge on a proton is equal to the negative charge on an electron. Whether a given body exhibits electricity (*i.e.* charge) or not depends upon the relative number of these particles of electricity.

(i) If the number of protons is equal to the number of electrons in a body, the resultant charge is zero and the body will be electrically neutral. Thus, the paper of this book is electrically neutral (*i.e.* paper exhibits no charge) because it has the same number of protons and electrons.

(ii) If from a neutral body, some *electrons are removed, there occurs a deficit of electrons in the body. Consequently, the body attains a *positive charge*.

(iii) If a neutral body is supplied with electrons, there occurs an excess of electrons. Consequently, the body attains a *negative charge*.

1.2. Unit of Charge

The charge on an electron is so small that it is not convenient to select it as the unit of charge. In practice, *coulomb* is used as the unit of charge *i.e.* SI unit of charge is coulomb abbreviated as C. *One coulomb of charge is equal to the charge on 625×10^{16} electrons, i.e.*

$$1 \text{ coulomb} = \text{Charge on } 625 \times 10^{16} \text{ electrons}$$

Thus when we say that a body has a positive charge of one coulomb (*i.e.* +1 C), it means that the body has a deficit of 625×10^{16} electrons from normal due share. The charge on one electron is given by ;

$$\text{Charge on electron} = -\frac{1}{625 \times 10^{16}} = -1.6 \times 10^{-19} \text{ C}$$

1.3. The Electron

Since electrical engineering generally deals with tiny particles called electrons, these small particles require detailed study. We know that an electron is a negatively charged particle having negligible mass. Some of the important properties of an electron are :

(i) Charge on an electron, $e = 1.602 \times 10^{-19}$ coulomb

(ii) Mass of an electron, $m = 9.0 \times 10^{-31}$ kg

(iii) Radius of an electron, $r = 1.9 \times 10^{-15}$ metre

* Electrons have very small mass and, therefore, are much more mobile than protons. On the other hand, protons are powerfully held in the nucleus and cannot be removed or detached.

The ratio e/m of an electron is 1.77×10^{11} coulombs/kg. This means that mass of an electron is very small as compared to its charge. It is due to this property of an electron that it is very mobile and is greatly influenced by electric or magnetic fields.

1.4. Energy of an Electron

An electron moving around the nucleus possesses two types of energies *viz.* kinetic energy due to its motion and potential energy due to the charge on the nucleus. The total energy of the electron is the sum of these two energies. The energy of an electron increases as its distance from the nucleus increases. Thus, an electron in the second orbit possesses more energy than the electron in the first orbit ; electron in the third orbit has higher energy than in the second orbit. It is clear that electrons in the last orbit possess very high energy as compared to the electrons in the inner orbits. These last orbit electrons play an important role in determining the physical, chemical and electrical properties of a material.

1.5. Valence Electrons

The electrons in the outermost orbit of an atom are known as valence electrons.

The outermost orbit can have a maximum of 8 electrons *i.e.* the maximum number of valence electrons can be 8. The valence electrons determine the physical and chemical properties of a material. These electrons determine whether or not the material is chemically active; metal or non-metal or, a gas or solid. These electrons also determine the electrical properties of a material.

On the basis of electrical conductivity, materials are generally classified into *conductors*, *insulators* and *semi-conductors*. As a rough rule, one can determine the electrical behaviour of a material from the number of valence electrons as under :

(i) *When the number of valence electrons of an atom is less than 4 (i.e. half of the maximum eight electrons), the material is usually a metal and a conductor.* Examples are sodium, magnesium and aluminium which have 1, 2 and 3 valence electrons respectively.

(ii) *When the number of valence electrons of an atom is more than 4, the material is usually a non-metal and an insulator.* Examples are nitrogen, sulphur and neon which have 5, 6 and 8 valence electrons respectively.

(iii) *When the number of valence electrons of an atom is 4 (i.e. exactly one-half of the maximum 8 electrons), the material has both metal and non-metal properties and is usually a semi-conductor.* Examples are carbon, silicon and germanium.

1.6. Free Electrons

We know that electrons move around the nucleus of an atom in different orbits. The electrons in the inner orbits (*i.e.*, orbits close to the nucleus) are tightly bound to the nucleus. As we move away from the nucleus, this binding goes on decreasing so that electrons in the last orbit (called valence electrons) are quite loosely bound to the nucleus. In certain substances, especially metals (*e.g.* copper, aluminium etc.), the valence electrons are so weakly attached to their nuclei that they can be easily removed or detached. Such electrons are called free electrons.

Those valence electrons which are very loosely attached to the nucleus of an atom are called free electrons.

The free electrons move at random from one atom to another in the material. Infact, they are so loosely attached that they do not know the atom to which they belong. It may be noted here that all valence electrons in a metal are not free electrons. It has been found that one atom of a metal can

provide at the most one free electron. Since a small piece of metal has billions of atoms, one can expect a very large number of free electrons in metals. For instance, one cubic centimetre of copper has about 8.5×10^{22} free electrons at room temperature.

(i) A substance which has a large number of free electrons at room temperature is called a **conductor** of electricity *e.g.* all metals. If a voltage source (*e.g.* a cell) is applied across the wire of a conductor material, free electrons readily flow through the wire, thus constituting electric current. The best conductors are silver, copper and gold in that order. Since copper is the least expensive out of these materials, it is widely used in electrical and electronic industries.

(ii) A substance which has very few free electrons is called an **insulator** of electricity. If a voltage source is applied across the wire of insulator material, practically no current flows through the wire. Most substances including plastics, ceramics, rubber, paper and most liquids and gases fall in this category. Of course, there are many practical uses for insulators in the electrical and electronic industries including wire coatings, safety enclosures and power-line insulators.

(iii) There is a third class of substances, called **semi-conductors**. As their name implies, they are neither conductors nor insulators. These substances have crystalline structure and contain very few free electrons at room temperature. Therefore, at room temperature, a semiconductor practically behaves as an insulator. However, if suitable controlled impurity is imparted to a semi-conductor, it is possible to provide controlled conductivity. Most common semi-conductors are silicon, germanium, carbon etc. However, *silicon* is the principal material and is widely used in the manufacture of electronic devices (*e.g.* crystal diodes, transistors etc.) and integrated circuits.

1.7. Electric Current

The directed flow of free electrons (or charge) is called **electric current**. The flow of electric current can be beautifully explained by referring to Fig. 1.1. The copper strip has a large number of free electrons. When electric pressure or voltage is applied, then free electrons, being negatively charged, will start moving towards the positive terminal around the circuit as shown in Fig. 1.1. This directed flow of electrons is called electric current.

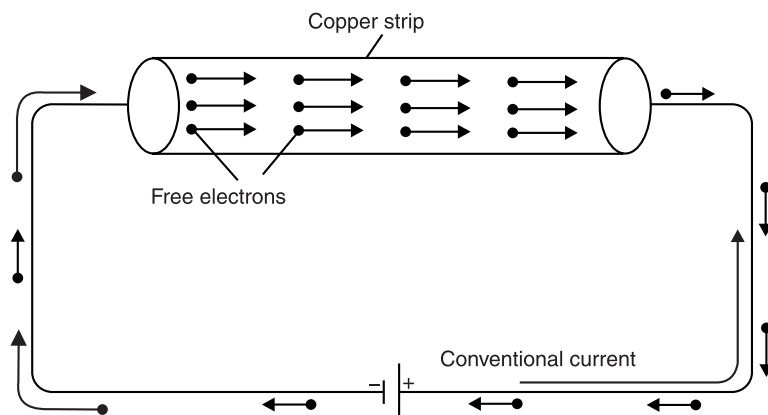


Fig. 1.1

The reader may note the following points :

(i) Current is flow of electrons and electrons are the constituents of matter. Therefore, electric current is matter (*i.e.* free electrons) in motion.

(ii) The actual direction of current (*i.e.* flow of electrons) is from negative terminal to the positive terminal through that part of the circuit external to the cell. However, prior to Electron theory, it was assumed that current flowed from positive terminal to the negative terminal of the cell

via the circuit. This convention is so firmly established that it is still in use. This assumed direction of current is now called *conventional current*.

Unit of Current. The strength of electric current I is the rate of flow of electrons *i.e.* charge flowing per second.

$$\therefore \text{Current, } I = \frac{Q}{t}$$

The charge Q is measured in coulombs and time t in seconds. Therefore, the unit of electric current will be *coulombs/sec or ampere*. If $Q = 1$ coulomb, $t = 1$ sec, then $I = 1/1 = 1$ ampere.

One ampere of current is said to flow through a wire if at any cross-section one coulomb of charge flows in one second.

Thus, if 5 amperes current is flowing through a wire, it means that 5 coulombs per second flow past any cross-section of the wire.

Note. $1 \text{ C} = \text{charge on } 625 \times 10^{16} \text{ electrons}$. Thus when we say that current through a wire is 1 A, it means that 625×10^{16} electrons per second flow past any cross-section of the wire.

$$\therefore I = \frac{Q}{t} = \frac{ne}{t} \quad \text{where } e = -1.6 \times 10^{-19} \text{ C ; } n = \text{number of electrons}$$

1.8. Electric Current is a Scalar Quantity

(i) Electric current, $I = \frac{Q}{t}$

As both charge and time are scalars, electric current is a scalar quantity.

(ii) We show electric current in a wire by an arrow to indicate the direction of flow of positive charge. But such arrows are not vectors because they do not obey the laws of vector algebra. This point can be explained by referring to Fig. 1.2. The wires OA and OB carry currents of 3 A and 4 A respectively. The total current in the wire CO is $3 + 4 = 7$ A irrespective of the angle between the wires OA and OB . This is not surprising because the charge is conserved so that the magnitudes of currents in wires OA and OB must add to give the magnitude of current in the wire CO .

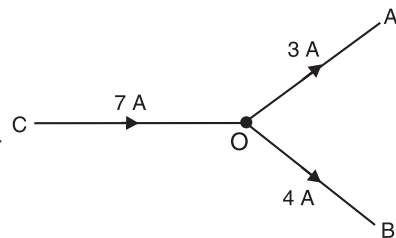


Fig. 1.2

1.9. Types of Electric Current

The electric current may be classified into three main classes: (i) steady current (ii) varying current and (iii) alternating current.

(i) Steady current. When the magnitude of current does not change with time, it is called a steady current. Fig. 1.3 (i) shows the graph between steady current and time. Note that value of current remains the same as the time changes. The current provided by a battery is almost a steady current (*d.c.*).

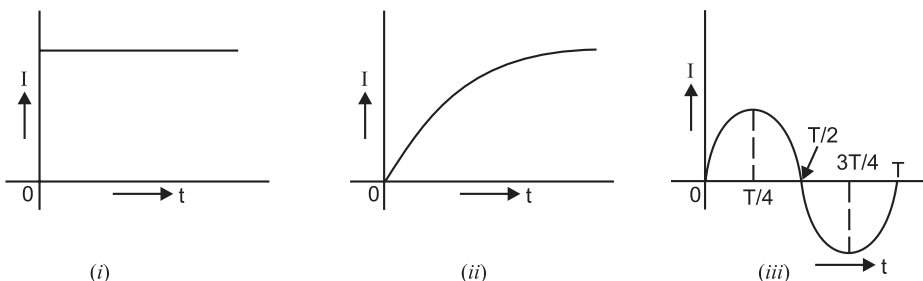


Fig. 1.3

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