SHA-SHIB GROUP OF INSTITUTIONS

Training Notes

Module 03- Electrical Fundamental

SHA-SHIB GROUP

EMPOWERING KNOWLEDGE THROUGH VISION

FOREWORD

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- The information in this book is for study/ training purposes only and no revision service will be provided to the holder.
- While carrying out a procedure/ work on aircraft/ aircraft equipment you must always refer to the relevant Aircraft Maintenance Manual or Equipment Manufacturer's Handbook.
- For health and safety in the workplace you should follow the regulations/ Guidelines as specified by the Equipment Manufacturer, your company, National Safety Authorities and National Governments.

Knowledge Levels – Category A, B1, B2, B3 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1, B2 and B3 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each application subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

- A familiarization with the principal elements of the subject.

Objectives: The applicant should be familiar with the basic elements of the subject.

- The applicant should be able to give a simple description of the whole subject, using common words and examples.
- The applicant should be able to use typical terms.

LEVEL 2

- A general knowledge of the theoretical and practical aspects of the subject.
- An ability to apply that knowledge.

Objectives: The applicant should be able to understand the theoretical fundamentals of the subject.

- The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.
- The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

- A detailed knowledge of the theoretical and practical aspects of the subject.
- A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives: The applicant should know the theory of the subject and interrelationships with other subjects.

- The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
- The applicant should understand and be able to use mathematical formulae related to the subject.
- The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
- The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

: DGCA MODULARISATION :-

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CAR – 66 ISSUE II R 2
(LICENSING OF AIRCRAFT MAINTENANCE ENGINEERS)
DIRECTORATE GENERAL OF CIVIL AVIATION
TECHNICAL CENTRE, OPP SAFDURJUNG AIRPORT, NEW DELHI

Modules	Subject	A or B1 Aero plane with		A or B1 Helicopter with		B2
		Turbine Engine (s)	Piston Engine (s)	Turbine Engine (s)	Piston Engine (s)	Avionics
1	Not Applicable					
2	Not Applicable					
3	ELECTRICAL FUNDAMENTALS	X	X	X	X	X
4	ELECTRONIC FUNDAMENTALS	X	X	X	X	X
5	DIGITAL TECHNIQUES ELECTRONIC INSTRUMENT SYSTEMS	X	X	X	X	X
6	MATERIALS AND HARDWARE	X	X	X	X	X
7A	MAINTENANCE PRACTICES	X	X	X	X	X
7B	MAINTENANCE PRACTICES					
8	BASIC AERODYNAMICS	X	X	X	X	X
9A	HUMAN FACTORS	X	X	X	X	X
9B	HUMAN FACTORS					
10	AVIATION LEGISLATION	X	X	X	X	X
11A	TURBINE AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS	X				
11B	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS		X			
11C	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS					
12	HELICOPTER AERODYNAMICS, STRUCTURES AND SYSTEMS			X	X	
13	AIRCRAFT AERODYNAMICS, STRUCTURES AND SYSTEMS					X
14	PROPULSION					X
15	GAS TURBINE ENGINE	X		X		
16	PISTON ENGINE		X		X	
17A	PROPELLER	X	X			
17B	PROPELLER					

MODULE 3. Electrical Fundamental		LEVEL	
		B1.1	B2
3.1	**3.1 Electron Theory** Structure and distribution of electrical charges within: atoms, molecules, ions, compounds; Molecular structure of conductors, semiconductors and insulators.	1	1
3.2	**3.2 Static Electricity and Conduction** Static electricity and distribution of electrostatic charges; Electrostatic laws of attraction and repulsion; Units of charge, Coulomb's Law; Conduction of electricity in solids, liquids, gases and a vacuum.	2	2
3.3	**3.3 Electrical Terminology** The following terms, their units and factors affecting them: potential difference, electromotive force, voltage, current, resistance, conductance, charge, conventional current flow, electron flow.	2	2
3.4	**3.4 Generation of Electricity** Production of electricity by the following methods: light, heat, friction, pressure, chemical action, magnetism and motion.	1	1
3.5	**3.5 DC Sources of Electricity** Construction and basic chemical action of: primary cells, secondary cells, lead acid cells, nickel cadmium cells, other alkaline cells; Cells connected in series and parallel; Internal resistance and its effect on a battery; Construction, materials and operation of thermocouples; Operation of photo-cells.	2	2
3.6	**3.6 DC Circuits** Ohms Law, Kirchoff's Voltage and Current Laws; Calculations using the above laws to find resistance, voltage and current; Significance of the internal resistance of a supply.	2	2
3.7	**3.7 Resistance/Resistor** (a) Resistance and affecting factors; Specific resistance; Resistor colour code, values and tolerances, preferred values, wattage ratings; Resistors in series and parallel; Calculation of total resistance using series, parallel and series parallel combinations; Operation and use of potentiometers and rheostats; Operation of Wheatstone Bridge. (b) Positive and negative temperature coefficient conductance; Fixed resistors, stability, tolerance and limitations, methods of construction; Variable resistors, thermistors, voltage dependent resistors; Construction of potentiometers and rheostats; Construction of Wheatstone Bridge;	2	2
3.8	**3.8 Power** Power, work and energy (kinetic and potential); Dissipation of power by a resistor; Power formula; Calculations involving power, work and energy.	2	2
3.9	**3.9 Capacitance/Capacitor** Operation and function of a capacitor; Factors affecting capacitance area of plates, distance between plates, number of plates, dielectric and dielectric constant, working voltage, voltage rating; Capacitor types, construction and function;	2	2

	Capacitor colour coding; Calculations of capacitance and voltage in series and parallel circuits; Exponential charge and discharge of a capacitor, time constants; Testing of capacitors.		
3.10	**3.10 Magnetism** (a) Theory of magnetism; Properties of a magnet Action of a magnet suspended in the Earth's magnetic field; Magnetisation and demagnetisation; Magnetic shielding; Various types of magnetic material; Electromagnets construction and principles of operation; Hand clasp rules to determine: magnetic field around current carrying conductor. (b) Magnetomotive force, field strength, magnetic flux density, permeability, hysteresis loop, retentivity, coercive force reluctance, saturation point, eddy currents; Precautions for care and storage of magnets.	2	2
3.11	**3.11 Inductance/Inductor** Faraday's Law; Action of inducing a voltage in a conductor moving in a magnetic field; Induction principles; Effects of the following on the magnitude of an induced voltage: magnetic field strength, rate of change of flux, number of conductor turns; Mutual induction; The effect the rate of change of primary current and mutual inductance has on induced voltage; Factors affecting mutual inductance: number of turns in coil, physical size of coil, permeability of coil, position of coils with respect to each other; Lenz's Law and polarity determining rules; Back emf, self induction; Saturation point; Principle uses of inductors;	2	2
3.12	**3.12 DC Motor/Generator Theory** Basic motor and generator theory; Construction and purpose of components in DC generator; Operation of, and factors affecting output and direction of current flow in DC generators; Operation of, and factors affecting output power, torque, speed and direction of rotation of DC motors; Series wound, shunt wound and compound motors; Starter Generator construction.	2	2
3.13	**3.13 AC Theory** Sinusoidal waveform: phase, period, frequency, cycle; Instantaneous, average, root mean square, peak, peak to peak current values and calculations of these values, in relation to voltage, current and power Triangular/Square waves; Single/3 phase principles.	2	2
3.14	**3.14 Resistive (R), Capacitive (C) and Inductive (L) Circuits** Phase relationship of voltage and current in L, C and R circuits, parallel, series and series parallel; Power dissipation in L, C and R circuits; Impedance, phase angle, power factor and current calculations; True power, apparent power and reactive power calculations.	2	2
3.15	**3.15 Transformers** Transformer construction principles and operation; Transformer losses and methods for overcoming them; Transformer action under load and no-load conditions;	2	2

	Power transfer, efficiency, polarity markings; Calculation of line and phase voltages and currents; Calculation of power in a three phase system; Primary and Secondary current, voltage, turns ratio, power, efficiency; Auto transformers.		
3.16	**3.16 Filters** Operation, application and uses of the following filters: low pass, high pass, band pass, band stop.	1	1
3.17	**3.17 AC Generators** Rotation of loop in a magnetic field and waveform produced; Operation and construction of revolving armature and revolving field type AC generators; Single phase, two phase and three phase alternators; Three phase star and delta connections advantages and uses; Permanent Magnet Generators.	2	2
3.18	**3.18 AC Motors** Construction, principles of operation and characteristics of: AC synchronous and induction motors both single and polyphase; Methods of speed control and direction of rotation; Methods of producing a rotating field: capacitor, inductor, shaded or split pole.	2	2

Module 3: Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of DGCA, CAR – 66 (Appendix I) and the associated Knowledge Levels as specified.

REVISION LOG

TABLE OF CONTENTS

CHAPTER PAGE

3.1 ELECTRON THEORY

1. ELECTRICAL FUNDAMENTAL Electron Theory
Atomic Structure (INTRODUCTION)

According to the modern theory, matter is electrical in nature. All materials are composed of very small particles called atoms. It is the smallest component of an element having the chemical properties of the element, consisting of a nucleus containing combinations of neutrons and protons and one or more electrons bound to the nucleus by electrical attraction; the number of protons determines the identity of the element.

These atoms are building bricks of all matter.

An atom consist of central nucleus of positive charge around which small negatively charged particles called electrons revolve in different paths or orbits.

Structure of Atom

Atom consist of two parts mainly:

NUCLEUS: It is central part of an atom and contains protons and neutrons. A proton is a positively charged particle whereas neutron has no charge but same mass as that of proton.

Therefore the nucleus of an atom is positively charged and the sum of proton and neutron constitute entire weight of an atom and is called as Atomic Weight as the particles in the extra nucleus (electrons) have negligible weight as compared to protons and neutrons.
Atomic weight=No. of protons + No. of neutrons

EXTRANUCLEUS: It is outer part of an atom and contains electron only which is negatively charged particle having negligible mass. The charge on electron is equal and opposite to that of proton. An atom is considered to be neutral as no. of electrons is equal to no. of proton
Atomic Number = No. of protons or electrons

The electron in an atom revolve around the nucleus in different paths or orbit and the arrangement of electron in any orbit is given by 2n2 where nis the no. of orbit.
Eg: 1st orbit has 2 x 12= 2 e-
2nd orbit has 2 x 2 2= 8 e-
3rd orbit has 3 x 2 2 = 18 e- and so on
Note: the last orbit cannot have more than 8 electrons and the last but one orbit cannot have more than 18 electrons.

1.Structure of elements

We have seen that all atoms are made up of protons, neutrons and electrons. The difference between various types of elements is to due to the different number and arrangement of these particles within their atoms. For example, the structure of copper atom is different from that of carbon atom and hence the two elements have different properties.
The atomic structure can be easily built up if we know the atomic weight and atomic number of the element. Thus taking the case of copper atom.

Atomic weight = 64 Atomic number = 29
No. of protons = No. of electrons = 29

And No. of neutrons =64-29=35

Fig. 1.1 shows the structure of copper atom. It has 29 electrons which are arranged in different orbits as follows. The first orbit will have 2 electrons, the second 8 electrons, the third 18 electrons and the fourth orbit will have 1 electron. The atomic structure of all known elements can be shown in this way and the reader is advised to try for a few commonly used elements.

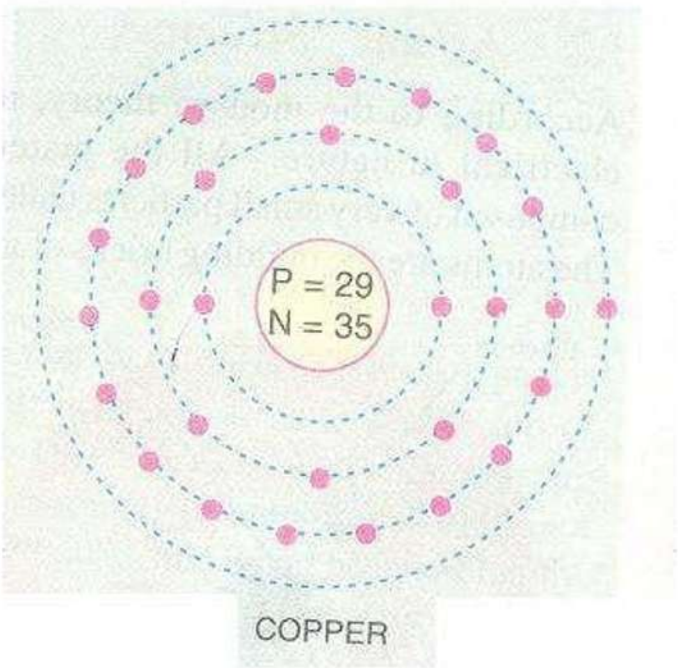


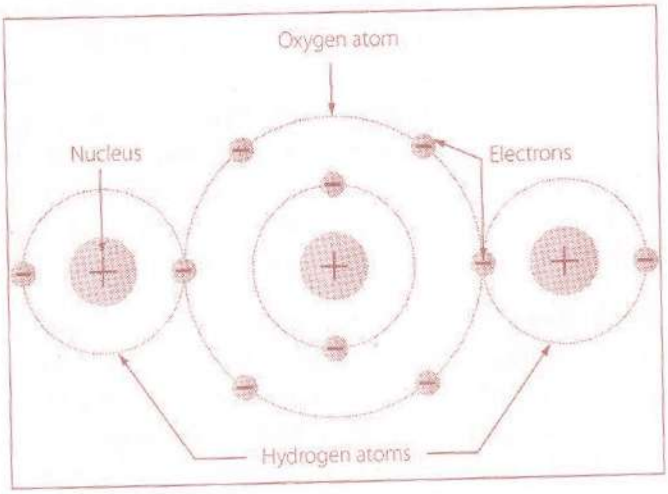
FIGURE 1.1

Compound

A compound is a chemical combination of two or more elements. Water is one of the most common compounds and is made up of two hydrogen atoms and oxygen atom.

The Molecule

A molecule is the smallest particle in chemical element or compound that has the chemical properties of that element or compound. water (H2O) is called a molecule. A molecule of water is illustrated in Figure 1.2. Substances composed of only one type of atom are called elements. But most substances occur in nature as compounds, that is combination of two or more types of atoms. It would no longer retain the characteristics of water if it were compounded of one atom of hydrogen and two atoms of oxygen. If a drop of water is divided in two and then divided again and again until it cannot be divided any longer, it will still be water. Molecules are made up of atom s that are held together by chemical bonds. These bonds form as a result of the sharing or exchange of electron s among atoms.



A water molecule.

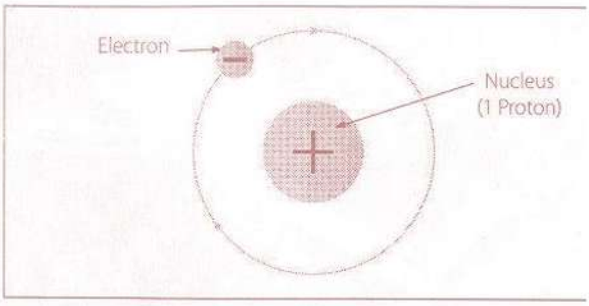
Figure1.2

Valence Electrons

Valence is the number of chemical bonds an atom can form. Valence electrons are electrons that can participate in chemical bonds with other atoms. The number of electrons in the outermost shell of the atom is the determining factor in its valence. Therefore, the electrons contained in this shell are called valence electrons.

Ions

Ionization is the process by which an atom loses or gains electrons. Dislodging an electron from an atom will cause the atom to become positively charged. This net positively charged cation atom is called a positive ion or action. An atom that has gained and extra number of electrons is negatively charged and is called a negative ion or an anion. When atoms are neutral, the positively charged proton and the negatively charged electron are equal.



Hydrogen atom.

Figure 1.3

Molecular Structure

1.Conductors

Elements such as gold, copper and silver possess many free electrons and make good conductors. The atoms in these materials have a few loosely bound electrons in their outer orbits. Energy in the form of heat can cause these electrons in their outer orbit to break loose and drift throughout the material. Copper and silver have one electron in their outer orbits. At room temperature, a piece of silver wire will have billions of free electrons. They conduct electric current as they have electrons less than 4 in outermost shell.

2.Insulators

These are materials that do not conduct electrical current very well or not at all. Good examples of these are: glass, ceramic, and plastic. Under normal conditions, atoms in these materials do not produce free electrons. The absence of the free electrons means that electrical current cannot be conducted through the material. Only when the material is in an extremely strong electrical field will the outer electrons be dislodged. This action is called breakdown and usually causes physical damage to the insulator. A good insulator has strongly bound electron in the atom of material. Insulators have more than 4 electrons in the outermost shell.

3.Semiconductors

This material falls in between the characteristics of conductors and insulators, in that they are not good at conducting or insulating. Silicon and germanium are the most widely used semiconductor materials. The no. of electrons in the outermost orbit is 4.

3.2 Static Electricity and Conduction

Static electricity

Electricity is often described as being either static or dynamic. The difference between the two is based simply on whether the electrons are at rest (static) or in motion (dynamic). Static electricity is a build up of an electrical charge on the surface of an object. It is considered "static" due to the fact that there is no current flowing as in AC or DC electricity. Static electricity is usually caused when non conductive material such as rubber, plastic or glass are rubbed together, causing a transfer of electrons, which then results in an imbalance of charges between the two materials. The face that there is an imbalance of charges between the two materials means that the objects will exhibit an attractive or repulsive force.(fig 2.1)

Laws of Electrostatics

First law: Like charges of electricity repel each other, whereas unlike charges attract each other.

Second Law: According this law, the force exerted between two point charges (i) is directly proportional to the product of their strengths (ii) is inversely proportional to the square of the distance between them.

1.Attractive and Repulsive forces

electrons possess a negative charge and as such will repel each other. Similarly, all protons possess a positive charge and as such will repel each other. Electrons (negative) and protons (positive) are opposite in their charge and will attract each other.

COULOMB OF CHARGE

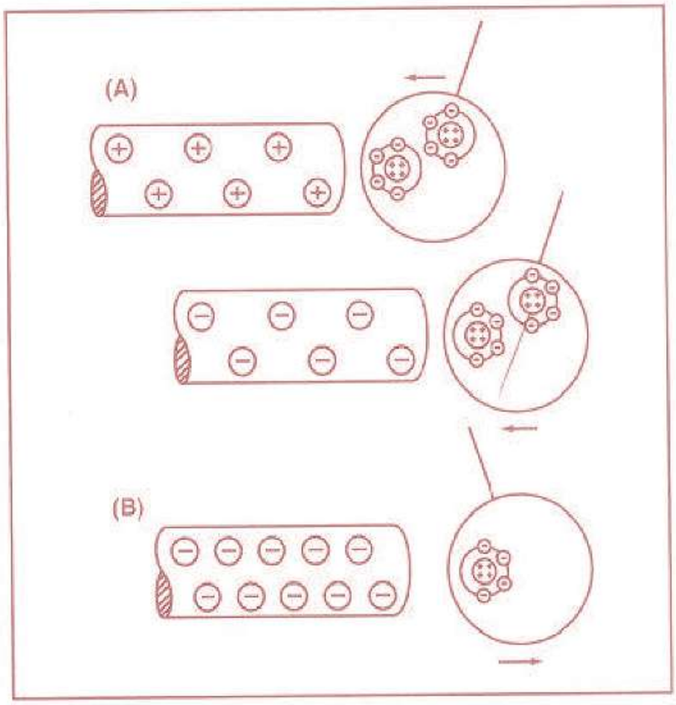
Hence ,one coulomb of charge may be defined as that charge which when placed in air (strictly vacuum) from an equal and of 9*109N

ELECTROSTATIC FIELD

Afieldofforceexistsaroundachargedbody.Thisfieldisan electrostatic field (sometime called a dielectric field) and is represented by lines extending in all directions from the charged body and terminating where there is an equal and opposite charge.

Lines are used to represent the direction and intensity of the electric field of force. As illustrated in figure 2.2 the intensity of the field is indicated by the number of lines per unit area and the direction is shown by arrowheads on the lines pointing in the direction in which a small test charge would move or tend to move if acted upon by the field of force.

Either a positive or negative test charge can be used, but it has been arbitrarily agreed that a small positive charge will always be used in determining the direction to the field. Thus, the direction of the field around a positive charge is always from the charge, as shown in figure 2.2 because a positive test charges would be repelled. On the other hand, the direction of the lines about a negative harge is to ward the charge ,since a positive test charge is attracted toward it.



An uncharged pith ball is attracted to a rod that has either a positive or a negative charge. (B) — Once the charged rod contacts the ball, the ball assumes the same charge as the rod and is repelled.

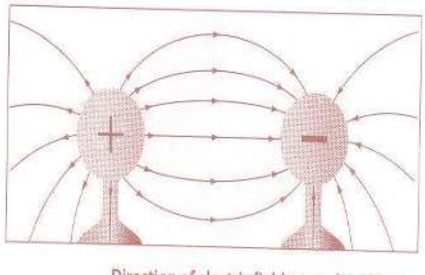
Fig. 2.1

Figure 2.3illustrates the field around bodies having likecharges. Positive charges are shown, but regardless of the type ofcharge,the lines o f forcewouldrepelonmaterial objects

and always extend from a positive charge to a negative charge.

In case of the charge on a hollow sphere, although the sphere is made of conducting material , the charge is evenly distributed over the outside surface. The inner surface is completely neutral.

The distribution of the charge on an irregularly shaped object differs from that on regularly shaped object. In this, the charge on such objects is not evenly distributed. The greatest charge is at the points, or areas of sharpest curvature, of the objects



Direction of electric field around positive and negative charges.

Fig. 2.2 Direction of electric field around positive and negativce charges

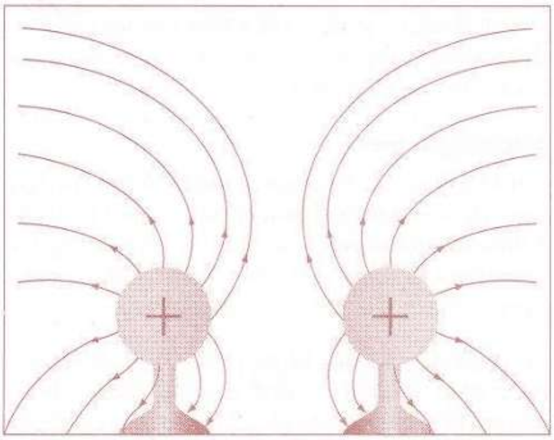


Fig. 2.3 Field around two positively charged bodies

CONDUCTION OF ELECTRICITY IN SOLIDS , LIQUIDS AND A VACUUM

SOLIDS

Electric current is the movement of valence electrons. Conduction is the name of this process. Only metals conduct electricity. Some conduct better than others. The exception to this is graphite, (one of the forms of the element carbon). Carbon is a non metal which exhibits some electrical conductivity.

LIQUIDS

Theonlyliquidelementswhichconductaretheliquidmetals. At room temperature liquid mercury isaconductor. Other metals continue to conduct electricity when they aremelted. Liquidssuchaswater,alcohol,ethnicacid,propane,hexane and so on, are all non conductors of electricity.

Howeveritispossibletomakesomenon-conductingliquids conduct electricity, by a process called ionization. Ionized substances are called ionic substances.

Ionic substance are made of charged particles- positive and negative ions. In the solid state they are held very firmly in place in a lattice structure. In the solid state the ions cannot move about at all. When the ionic solid is melted, the bonds holding the ions in place in the lattice are broken. The ions can then move around freely.

When an electric current is applied to an ionic melt the electricity is carried by the ions that are now able to move. In an ionic melt the electric current is a flow ofions.

Taking water as an example. Remember firstly , that water is considered to be a non – conductor of electricity. It can allow some electricity through it if a high voltage is applied to it. This is due to the presence of a minute concentration oh H+ and OH- ions in the water. However, electrons cannot flow through water.

Covalent substances do not conduct at all in solution. Ionic substance are able to conduct electricity when they are dissolved in water.

The reason lies again in the fact that ionic substances are made of charged particles. Ions. When the ionic solid is dissolved in water the ion breaks up and the ions become free to move the ionic substance in solution, the ions are able to carry the electric current because of their ability to move freely

. A solution conducts by means of freely moving ions. An electrolyte is a liquid which can carry anelectric current through it. Ionic solute ions and ionic melts are all electrolytes.

Electrolysis describes the process which takes place when an ionic solution or melt has electricity passed through it.

GASES

A gas in its normal state is one of the best insulators known, however, in similar way as liquid; it can be forced to conduct electricity by ionization of the gas molecules. Ionisation of the gas molecules can be effected by extremely high voltages. For examples lightning, is electric current flowing through an ionized path through air due to the huge electrical potential difference between the storm cloud and the ground.
In air and other ordinary gases, the dominant source of electrical conduction is via a relatively small number of mobile light, or cosmic rays. Since the electrical conductivity is extremely low, gases are dielectrics or insulators. However once the applied electric field approaches the breakdown value, free electrons become sufficiently accelerated by the electric field to create additional free atoms or molecules in a process called avalanche breakdown. The breakdown process forms a plasma that contains a significant number of mobile electrons and positive ions, causing it to behave as an electrical conductor. In the process it forms a light emitting conductive path, such as a spark arc or lighting.

Plasmaisthestateofmatterwheresomeoftheelectronsinagasarestrippedor“ionized”fromtheirmoleculesoratoms.A
plasma can be formed by high temperature, or by application of a high electric or alternating magnetic field as noted above.

ACUUM

It is a common belief that electricity cannot flow through a vacuum. This is however incorrect. Remember that a conductor is “something through which electricity can flow,” rather than“something which contains movable electricity.” A vacuum offers no blockage to moving charges. Should electronsbe injectedintoavacuum,theelectronswillflowuninhibitedand un-retarded. As such, a vacuum is an ideal conductor.

This fact is taken advantage of in many situations, from television to vacuum valves. A vacuum arc can arise when the surfaces of metal electrodes in contact with vacuum begin to emit electrons either through heating or via an electric field that is sufficient to cause fields emission. Once initiated a vacuum arc can persists since the freed particles gain kinetic energy from the electric field, heating the metal surfaces through high speed particle collisions. This process can create an incandescent cathode spot which frees more particle thereby sustaining the arc

Electrical discharge in vacuum is important for certain types of vacuum tubes and for high voltage vacuum switches.

Electrical Bonding

When you connect all the metal parts of an aircraft to complete an electrical unit, it is called bonding. Bonding connections are made of screws, nuts, washers, clamps, and bonding jumpers. (fig 2.4) An aircraft can become highly charged with static electricity while in flight. If the aircraft is improperly bonded, all metal parts do not have the same amount of static charge. A difference of potential exists between the various metal surfaces. If the resistance between insulated metal surfaces is great enough, charges can accumulate. The potential difference could become high enough to cause a spark. This constitutes a fire hazard and also causes radio interference. If lighting strikes an aircraft, a good conductingpathforheavycurrentisnecessarytominimizesevere arcing and sparks.

Bondingalsoprovidesthenecessarylow- resistancereturnpathforsingle-wireelectrical systems throughthe aircraft.Thislow-resistancepathprovidesameansofbringingthe entire aircraft to the earth's potential when it is grounded.

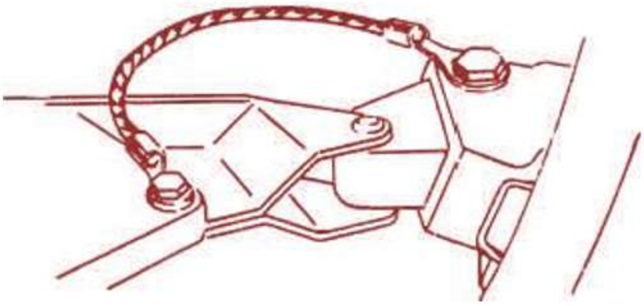


Fig 2.4

Inaircraft,electricalbondingpreventsstaticelectricitybuildupthatcaninterferewithradioandnavigationalequ ipment.Bonding lprotectionbyallowingthecurrenttopass through the airframe with minimum arcing. Bonding prevents dangerous static discharges in aircraft fuel tanks and hoses. BONDINGJUMPERRESISTANCE SHOULD NOT EXCEED 0.003 OHMS.

3.3 Electrical Terminology

1. Potential Difference:

Voltage, electrical potential difference, electric tension or electric pressure (denoted ΔV or ΔU and measured in units of electricpotential: volts, or joules per coulomb) is the electric potential difference between two points, or the difference in electricpotential energy of a unit charge transported between two
points. voltage is equal to the work done per unit charge against a static electric field to move the charge between two points. a voltage may represent either a source of energy (electromotiveforce), or lost, used, or stored energy (potential drop).
a voltmeter can be used to measure the voltage (or potential difference) between two points in a system; often a common reference potential such as the ground of the system is used as one of the points.

2. electromotive force(voltage)

voltage as a value across two points, the symbol for emf is the capital letter"e".
Across the terminals of the typical aircraft battery, voltage can be measured as the potential difference of 12 volts or 24 volts. That is to say that between the two terminal posts of the battery, there is an electromotive force of 12 or 24 volt available to push current through a circuit .relatively free electrons in the negative terminal will move toward the excessive number of positive charges in the positiveterminal.

The net result is a flow of current through a conductor. The potential difference,or the voltage across any two points in an electrical system, can be determined by : Where

E = e
sQ
E = potential difference in volts
e =energy expanded or absorbed in joules (j)
Q = charge measured in coulombs

Figure 3.1 illustrates the flow of electrons of electric current. Two interconnected water tanks demonstrate that when a difference of pressure exists between the two tanks, water will flow until the two tanks are equalized. The illustration shows the level of water in tank A to be at a higher level, reading 10 psi (higher potential energy) than the water level in tank B reading 2 psi (lower potential energy). Between the two tanks there is 8-psi potential difference. If the valve in the interconnecting line between the tanks is opened, water will flow from tank A into tank B until the level of water (potential energy) of both tanks isequalized.
It was the difference in pressure between tank A and tank B that caused the flow.
Electrons move, when a path is available, from a point of excess electrons(higher potential energy) to a point deficient in electrons(lower potential energy). The force that causes this movementisthepotentialdifferenceinelectricalenergybetween the two points. This force is called the electrical pressure or the potential difference or the electromotive force (electron moving force).

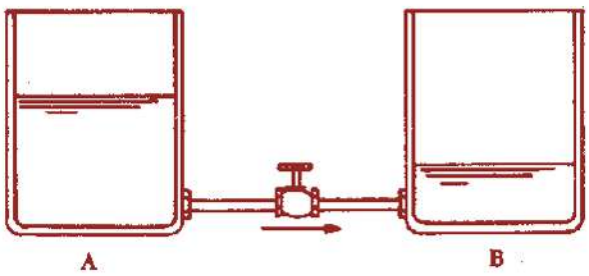


Fig. 3.1 Difference of Pressure

CURRENT

Electrons in motion make up an electric current. Current is measurement of a rate at which a charge flows .The moving charges are the free electrons found in conductors, such as copper, silver aluminum, and gold.

These loosely bound electrons can be easily motivated to move in agiven direction when an external source, which as a battery is applied to the circuit. These electrons are attracted to the positive terminal of the battery, while the negative terminal is the source of the electrons. The greater amount of charge moving through the conductor in a given amount of time it is translated into a current.

Greater amount of charge moving through the conductor in a given amount of time will be translated into acurrent.

Current=charg
TimOr

I = Q
T

Where :

I = system international unit for current is the Ampere (A), where

I A = 1 C
S

That is , I ampere (A) of current is equivalent to 1 coulomb (C) of charge passing through a conductor in 1 second(s). one coulomb of charge equal 6.28 billion electrons. The symbol used to indicatecur in formulas or on schematics in the capital letter'I".

Types of current

1. Conventional flow

It was initially advanced by Benjamin Franklin who reasoned that current flowed out of a positive source into a negative source or an area that lacked an abundance of charge. The notation assigned to the electric charges was positive (+) for the abundance of charge and negative(-) for a lack of charge. It then seemed natural to visualize the flow of current as being from the positive (+) to thenegative(-)

2. Electron flow

Later discoveries were made that proved that just the opposite is true. Electron flow is what actually happens where an abundance
of electrons flow out of the negative(-) source to an area that lacks
electrons or the positive (+)source.
Both conventional flow and electron flow are used in industry.

RESISTANCE

It may be defined as the property of a substance due to which it opposes (or restricts) the flow of electricity (i.e. electrons) through it.
Metals (as a class) acids and salts solutions are good conductors of electricity. Amongst pure metals, silver, copper and aluminum are very good conductors in the given order. Due to the presence of a large number of free or loosely attached electrons in their atoms.

Those substances which offer relatively greater difficulty or hindrance to the passage of these electrons are said to be relatively poor conductors of electricity like bake lite, mica , glass rubber
p.v.c (polyvinylchloride)and dry wood etc.

1.The unit ofresistance

The practical unit of resistance is ohm. A conductor is said to have a resistance of one ohm if it permits one ampere current to flow through it when one volt is impressed across its terminals.
For insulators whose resistances are very high, a much bigger unit is used i.e.
Mega kilo –
small micro

The resistance R offered by a conductor depends on the following factors:

- It varies directly as itslength
- It varies inversely as the cross-section A of theconductor.
- It depends on the nature of thematerial.
- It also depends on the temperature of theconductor.

R = L/A

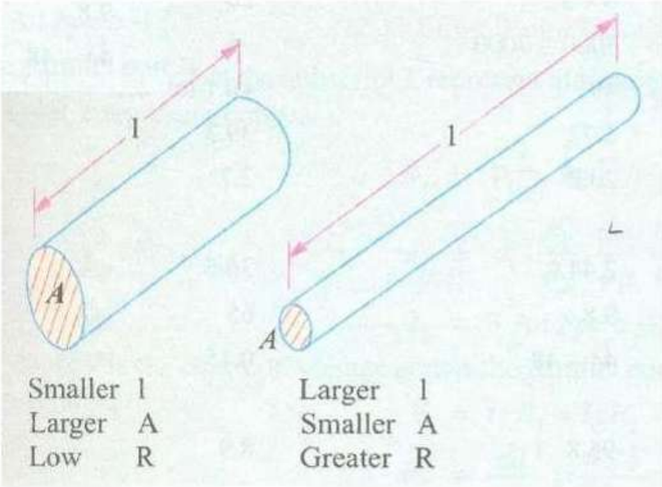


Fig. 3.2

Neglecting the last factor for the time being, we can say that
R α l = p l

Where p is a constant depending on the nature of the material of conductor and is known as its specific resistance or resistivity.
If in Eqi), we put
l = 1 metre and A= 1 metre2, then R=p
Hence, specific resistance of a material may be defined as the resistance between the opposite face of a metre cube of that material.

5. Units of resistivity

then:

G = I/E

We know,

R = p L A

In the S.I system of unit

Ametre2 * R ohm =AR
Lmetre
ohm-metre

In general, when the applied voltage is held constant, the current in a direct-current (DC) circuit is directly proportional to the conductance. If the conductance is doubled, the current is also doubled; if the conductance is cut to 1/10 its initial value, the current also becomes 1/10 as great.

Conductance is inversely related to resistance.If R is the resistance of a component or device (in ohms), then the conductance G (in Siemens) is given by:

Hence, the unit of resistivity is ohm – metre (Ω-m)

CONDUCTANCE

Conductance is an expression of the ease with which electric current flows through a substance. In equations, conductance is symbolized by the letter G. The standard unit of conductance is the siemens(abbreviated S), formerly known as the mho.

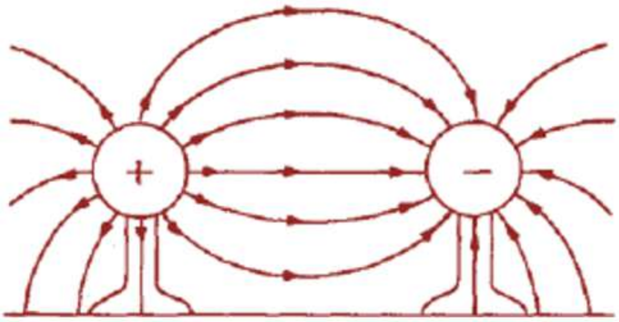
When a current of one ampere (1 A) passes through a component across which a voltage of one volt (1 V) exists, then the conductance of that component is 1 S. The siemens is, in fact, equivalent to one ampere per volt. If G is the conductance of a component (in siemens), I is the current through the component (in amperes), and E is the voltage across the component (in volts),

G =I'/R

CHARGE

Electric charge is the physical property of matter that causes it to experience a force when placed in an electromagnetic field. There are two types of electric charges: positive and negative.Positively charged substances are repelled from other positively charged s; negatively charged substances are repelled from negative and attracted to positive. An object is negatively charged if it has an excess of electrons, and is otherwise positively charged or uncharged. The SIderived unit of electric charge is the coulmb

Fig. 3.3



What is Electricity?

Any appliances that we use in our daily lives such as household appliances, office equipments and industrial equipments, almost all of those things take electricity. Therefore, we should understandelectricity.

3.4

The first question that we will find out the answer is "where does electricity come from?"

Fig. 4.1

All matters are made up of atoms. Then ask the next question, "What are atoms?"

Atoms are the smallest part of an element. They are composed of nucleus and electrons, electrons surround nucleus. Elements are identified by the number of electrons in orbit around nucleus of atoms and by the number of protons in nucleus.

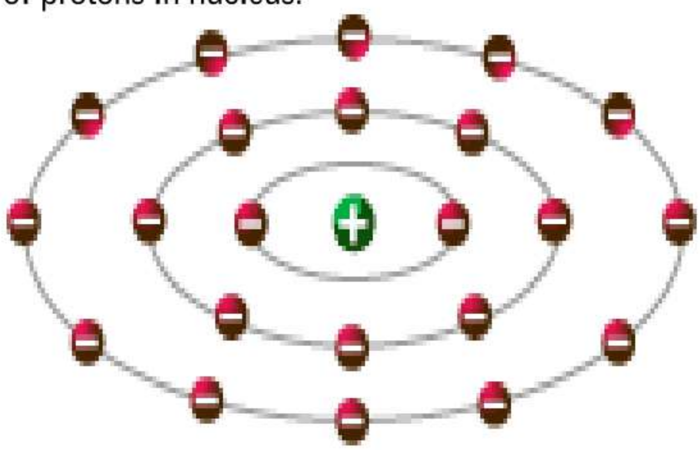


Fig. 4.2

Nucleus is made up of protons and neutrons, and the number of protons and neutrons are balanced. Neutrons have no electric charge, protons have positive charges (+) and electrons have negative charges (-). A positive charge of proton equals a negative charge of electron.

Electrons are bound in their orbit by attraction of protons, but electrons in the outer band can become free of their orbit by some external forces. These are referred to as free electrons, which move from one atom to the next, electron flows are produced. These are the basis of electricity. Materials that allow many electrons to move freely are called conductors and materials that allow few free electrons to move are called insulators.

All matters are made up of atoms that have electric charges. Therefore, they have electric charges. For the matter that has a balanced the number of protons and electrons, positive charge force and negative charge force are balanced. It is called neutral state of an atom. (The number of protons and electrons remains equal.)

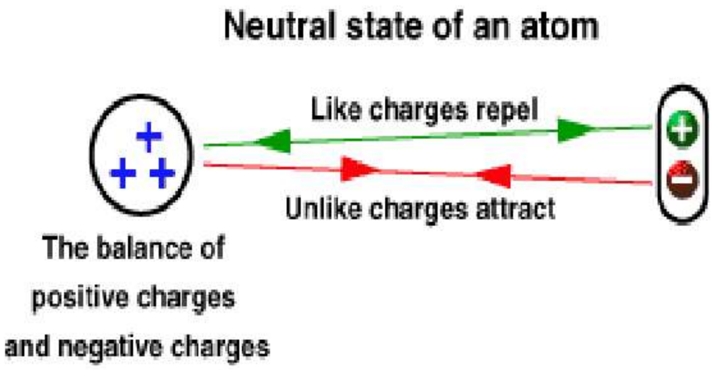


Fig. 4.3 Neutral State of an atom

"Static electricity" represents a situation that all things are made up of electric charges. For example, the rubbing of material against another can cause the static electricity. Free electrons of one material move forcefully till they are freed of their orbits around nucleus and move to another. Electrons of one material decrease, it presents positive charges. At the same time, electrons of another increase, it has negative charges.(Fig4.4)

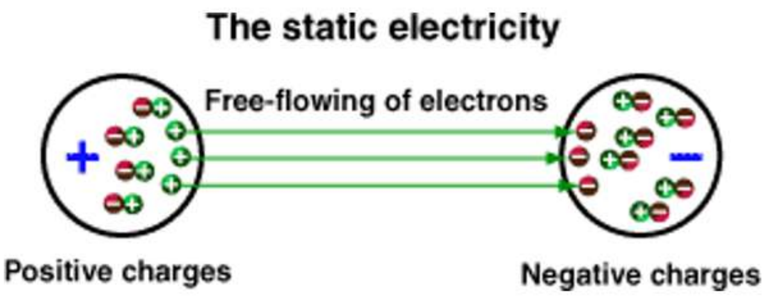


Fig. 4.4

In general, charge producing of the matter means the matter has electric charges. It has positive and negative charges, which is expressed in coulomb.

DIFFERENT METHODS OF PRODUCING ELECTRICITY

The following methods produce a voltage:

- Electrochemistry
- Static electricity
- Magneticinduction
- Piezoelectriceffect
- Thermoelectricity
- Photoelectriceffect
- Thermionicemission

Electrochemistry

Chemicals can be combined with certain metals to cause a chemical reaction that will transfer electrons to produce electrical energy. This process works onthe electrochemistry principle.One example of this principle is the voltaic chemical cell, shown inFigure 4.5. A chemical reaction produces and maintains opposite charges on two dissimilar metals that serve as thepositive and negative terminals. The metals are in contact with an electrolyte solution.Connecting together more than one of these cells will produce abattery.

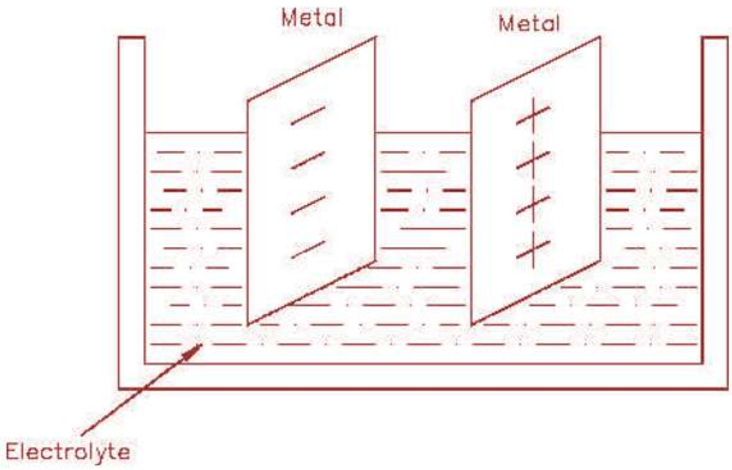


Fig. 4.5

Example:A battery can maintain a potential difference between its positive and negative terminals by chemical action.

Static Electricity

Atoms with the proper number of electrons inorbit around them are in a neutral state, or havea "zero charge." A body of matter consisting ofthese atoms will neither attract nor repel othermatter that is in its vicinity. If electrons are removedfrom the atoms in this body of matter,as happens due to friction when one rubs a glass rod with a silk cloth, it will become electrically positive as shown in Figure 4.6. If this body of matter (e.g., glass rod) comes near, but not in contact with, another body having a normal charge, an electric force is exerted between them because of their unequal charges. The existence of this force is referred to as static electricity or electrostatic force.

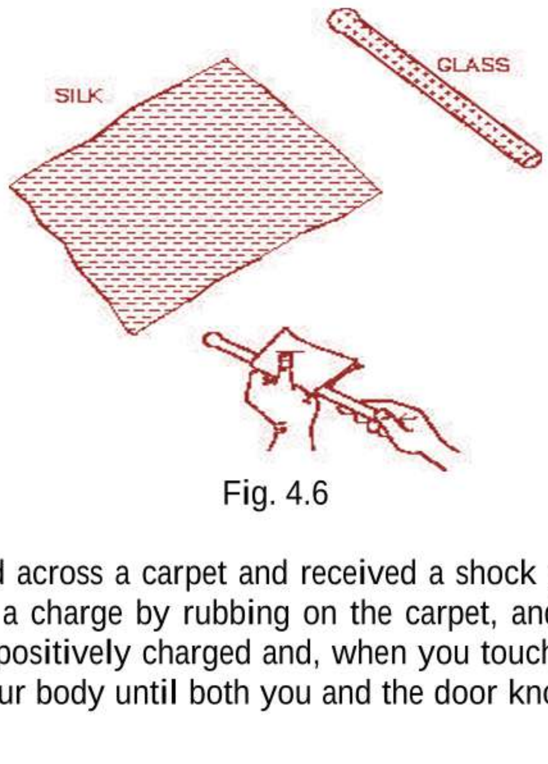


Fig. 4.6

Example:Have you ever walked across a carpet and received a shock when you touched a metal door knob? Your shoe solesbuilt up a charge by rubbing on the carpet, and this charge was transferred to your body. Your body became positively charged and, when you touched the zero-charged door knob, electrons were transferred to your body until both you and the door knob them are in a neutral state, or havea "zero charge." A body of matter consisting of these atoms will neither attract nor repel othermatter that is in its vicinity. If electrons are removed had equal charges.

Magnetic Induction

A generator is a machine that converts mechanical energy into electrical energy by using the principle of magnetic induction. Magnetic induction is used to produce avoltage by rotating coils of wire through a stationary magnetic field, as shown in Figure 4.7, or by rotating a magnetic field through stationary coils of wire. This is one of the most useful and widely-employed applications of producing vast quantities of electric power.

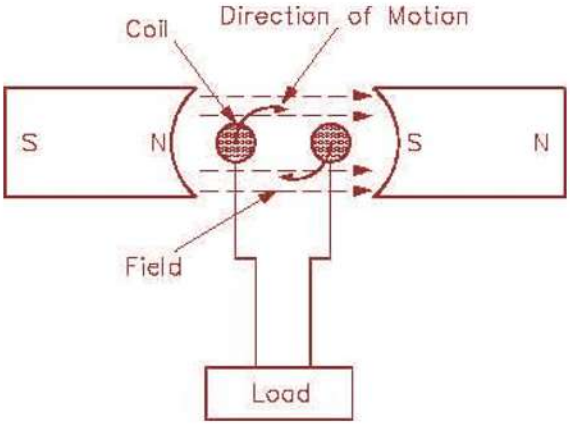


Fig. 4.7 Generator - Electromagnetic Induction

Piezoelectric Effect By applying pressure to certain crystals (such as quartz or Rochelle salts) or certain ceramics(like barium titan ate), electrons can be driven out of orbit in the direction of the force. Electrons leave one side of the material and accumulate on the other side, building up positive and negative charges on opposite sides, as shown in Figure 4.8. When the pressure is released, the electrons return to their orbits.

Some materials will react to bending pressure, while others will respond to twisting pressure. This generation of voltage is known as the piezoelectric effect. If external wires are connected while pressure and voltage are present, electrons will flow and current will be produced. If the pressure is held constant, the current will flow until the potential difference is equalized. When the force is removed, the material is decompressed and immediately causes an electric force in the opposite direction. The power capacity of these materials is extremely small.However, these materials are very useful because of their extreme sensitivity to changes of mechanical force.

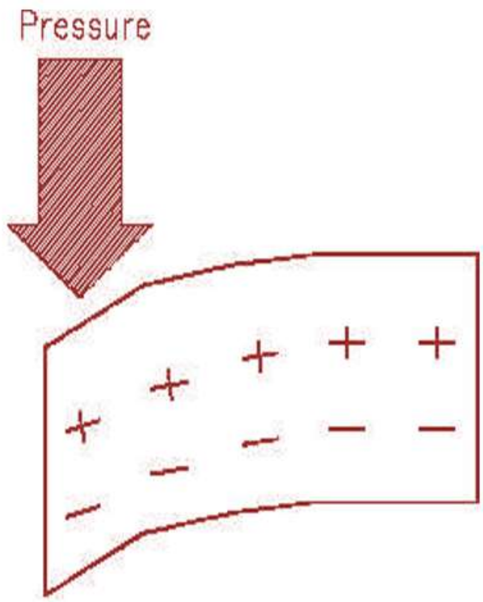


Fig. 4.8 Pressure Applied to Certain Crystals Produces an Electric Charge

Example:One example is the crystal phonograph cartridge that contains a Rochelle salt crystal. A phonograph needle is attached to the crystal. As the needle moves in the grooves of a record, it swings from side to side, applying compression and decompression to the crystal. This mechanical motion applied to the crystal generates a voltage signal that is used to reproduce sound.

Thermoelectricity

Some materials readily give up their electrons and others readily accept electrons. For example, when two dissimilar metals like copper and zinc are joined together, a transfer of electrons can take place. Electrons will leave the copper atoms and enter the zinc atoms. The zinc gets a surplus of electrons and becomes negatively charged. The copper loses electrons and takes on a positive charge. This creates a voltage potential across the junction of the two metals. The heat energy of normal room temperature is enough to make them release and gain electrons,causing a measurable voltagepotential.As moreheat energyisappliedtothejunction,moreelectronsarereleased,and the voltage potential becomes greater, as shown inFigure 4.9.When heat is removed and the junction cools, the charges will dissipate and the voltage potential willdecrease. This processis called thermoelectricity. A device like this is generally referredto as a "thermocouple."

The thermoelectric voltage in a thermocouple is dependent upon the heat energy applied to the junction of the two dissimilar metals. Thermocouples are widely used tomeasure temperature andasheat-sensingdevicesinautomatictemperaturecontrolled equipment.A thermocouple indicator is basically a type of millivolt meter.

Thermocouple power capacities are very small compared to some other sources, but are somewhat

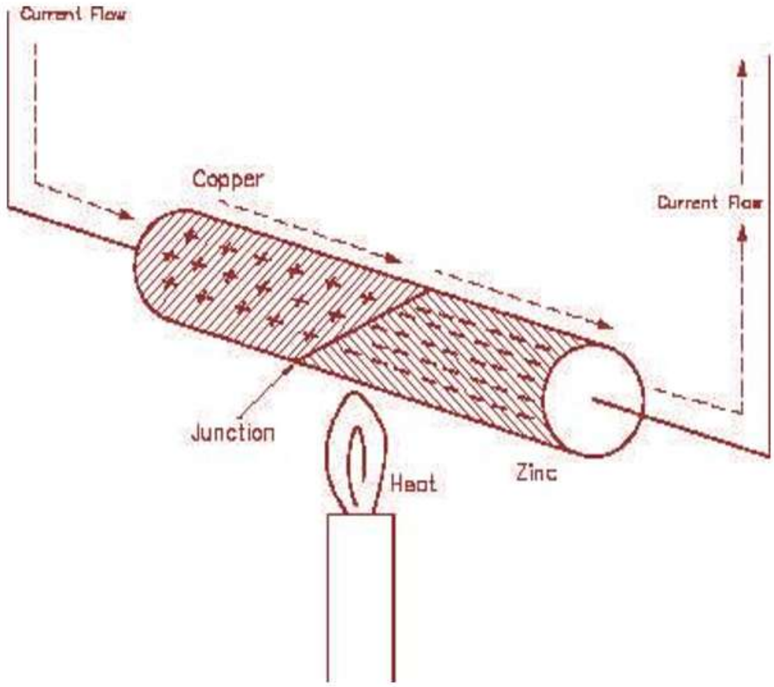


Fig 4.9

greater than those of crystals.Generallyspeaking,athermocouplecanbesubjected To higher temperatures than ordinarymercury or alcohol thermometers.

Photoelectric Effect

Light is a form of energy and is considered by many scientists to consist of small particles ofenergy called photons. When the photons in a light beam strike the surface of a material, they release their energy and transfer it to the atomic electrons of the material. This energy transfer may dislodge electrons from heir orbits around the surface ofthe substance. Upo losing electrons, the photosensitive (light sensitive)material becomes positively charged and an electric force is created, as shown in Figure 4.10

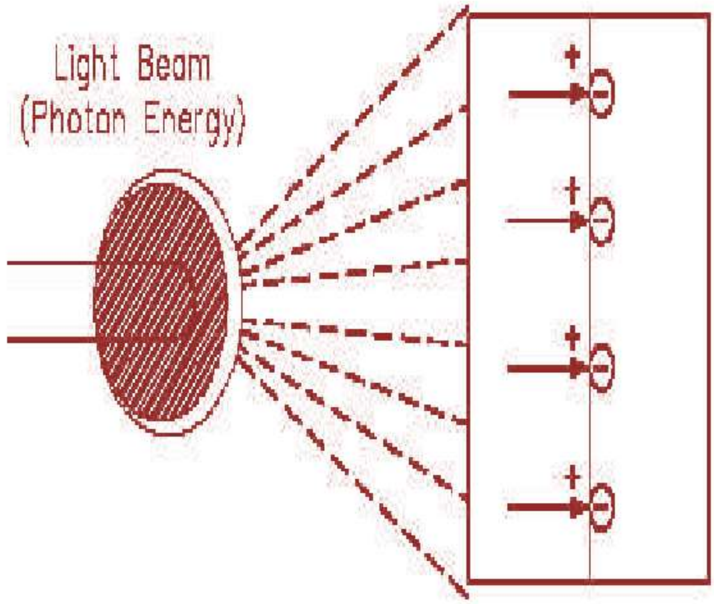


Fig. 4.10 Producing Electricity from Light Using a Photovoltaic Cell

This phenomenon is called the photoelectric effect and has wide applications in electronics, suchas photoelectric cells, photovoltaic cells, optical couplers, and television camera tubes. Three uses of the photoelectric effect are described below. Photovoltaic: The light energy in one of two plates that are joined together causes one plate to release electrons to the other. The plates build up opposite charges, like a battery (Figure 4.10).Photoemission: The photon energy from a beam of light could cause a surface to release electrons in a vacuum tube. A plate would then collect the electrons. Photoconduction: The light energy applied to some materials that are normallypoor conductor's causes free electrons to be produced in the materials so that they become betterconductors.

Thermionic Emission

A thermionic energy converter is a device consisting of two electrodes placed near one another in a vacuum. One electrode is normally called the cathode, or emitter, and the other is called the anode, or plate. Ordinarily, electrons in the cathode are prevented from escaping from the surface by a potential-energy barrier. When an electron starts to move away from the surface,it induces a corresponding positive charge in the material, which tends to pull it back into the surface. To escape, the electron must somehow acquire enough energy to overcome this energy barrier. At ordinary temperatures, almost none of the electrons can acquire enough energy to escape. However, when the cathode is very hot, the electron energies are greatly increased by thermal motion. At sufficiently high temperatures, a considerable number of electrons are ableto

escape. The liberation of electrons from a hot surface is called thermionicemission.

The electrons that have escaped from the hot cathode form a cloud of negative charges near itcalled a space charge. If the plate is maintained positive with respect to the cathode by a battery, the electrons in the cloud are attracted to it. As long as the potential difference between the electrodes is maintained, there will be a steady current flow from the cathode to the plate.The simplest example of a thermionic device is a vacuum tube diode in which the only electrodes are the cathode and plate, or anode, as shown in Figure 4.11. The diode can be used to convert alternating current (AC) flow to a pulsating direct current (DC) flow.

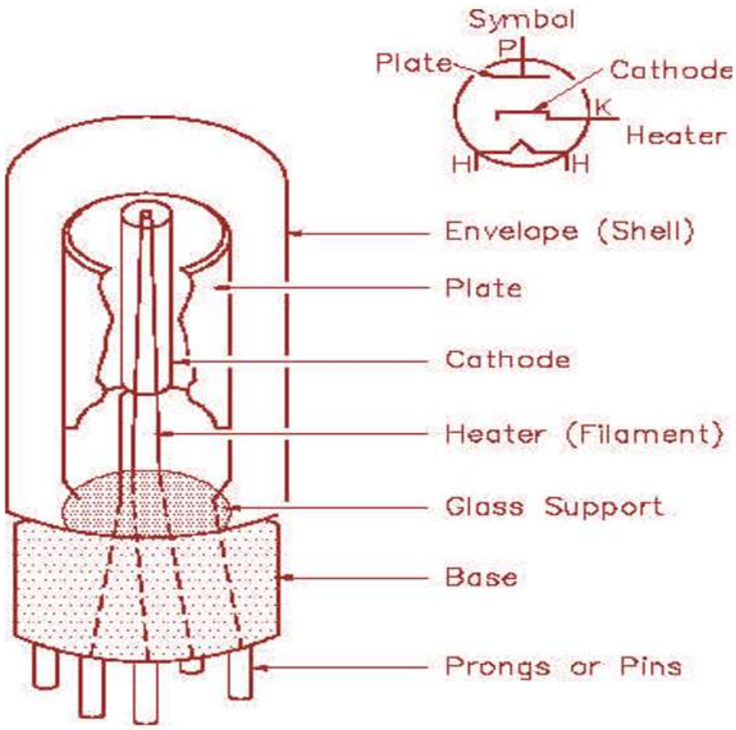

Symbol
P
Plate
Cathode
K
Heater
H
H
Envelope (Shell)
Plate
Cathode
Heater (Filament)
Glass Support
Base
Prongs or Pins

Fig. 4.11

3.5 DC sources of electricity

DCisthecurrentthatflowsinonedirectiononly.Themost commonly used method of generating DC is theelectrochemical cell. In this section we shall describe the basic principles of cells and batteries. We shall also be looking at two other important devices that generate electric current, thermocouples and photocells.

Cells and batteries

A cellis a device that produces a charge when a chemicalreaction takes place. When several cells are connected together they form Most aircraft have several batteries, the mostimportant of which are the main aircraft batteries. The two principal functions of the main aircraft batteries are:

- to supply emergency electrical power in case of electrical generation system failure in flight
- to provide an autonomous source of electrical power forstarting engines or APU on the ground or in flight.

Engine or APU starting requires high initial peak current (sometimes over 1000 A) to overcome mechanical inertia followed by high current discharge (hundreds of amperes) during a time interval of typically 30 s. Several successive attempts, which progressively deplete capacity, may be required, but because the duration is short, starting usually determines what power capacity the battery should have. Conversely, emergency loads usually determine what energy the battery should have. The precise configuration of aircraft batteries depends both on aircraft complexity and airworthiness requirements. For example, one or more batteries may be dedicated to supporting essential systems (such as avionics) for 30–60 min b without the voltage falling below a minimum level (typically 18 V). Furthermore, one battery may be dedicated to starting whilst the other supports essential equipment during engine start-up. When required, both batteries can then be connected in parallel tosupport

emergency loads. When alternative emergency power generation is available, such as a ramair turbine(RAT), the battery may only be needed for a few minutes during RAT deployment or during a final (low-speed) approach to a runway. Having briefly set the scene, we will now look briefly at the nature of cells and batteries but, before we do, we need to introduce you to the concept of primary and secondary cells. Primary cells produce electrical energy at the expense of the chemicals from which they aremade andoncethesechemicalsareusedup,nomoreelectricitycanbe obtainedfromthecell.Insecondarycells,thechemicalactionis reversible. This means that the chemical energy is converted into electrical energy when the cell is dischargedwhereaselectrical energyisconvertedintochemicalenergywhenthecellisbeing

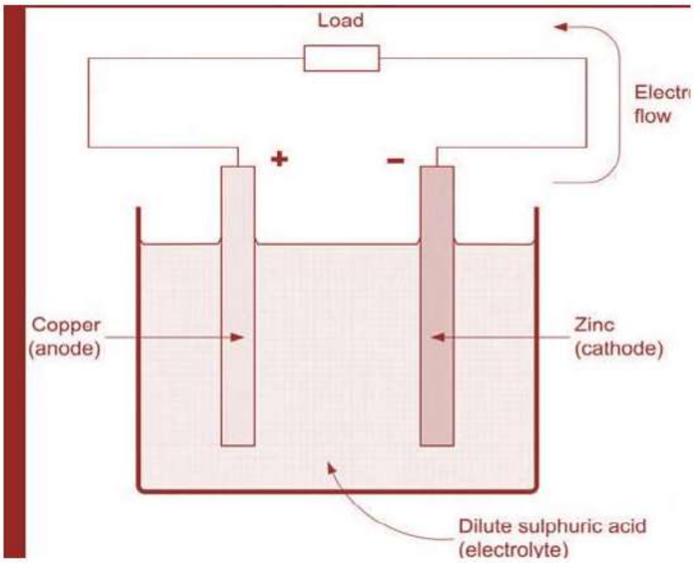
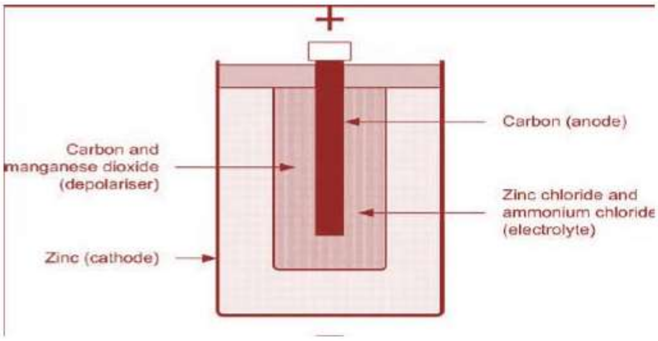


Fig. 5.1 A simple primary cell

Primary cells

All cells consist of two electrodes which are dissimilar metals, or carbonandametal,whichareplacedintoanelectrolyte.Oneof the simplest examples of a primary cell is the voltaic type. This cellconsistsofaplateofzincformingthenegativeelectrode,a Dilute sulphuric acid as the electrolyte. The negative electrodeis knownasthecathodeandthepositiveelectrodeisknownasthe anode. When the electrodes are connected outside the cell so that a circuit is completed, a current flows from the copper electrode, through the external circuit to the zinc and from the zinc to the copper, through the electrolyte in the cell. One of the problems with the voltaic cell is that it only works for a short time before a layer of hydrogen bubbles builds up on the positive copper electrode, drastically reducing the e.m.f. of the cell and increasing its internal resistance. This effect is called polarization. The removal of this hydrogen layer from the copper electrode may be achieved by mechanical brushing or adding a depolarizersuchaspotassiumdichromatetotheacidsolution. The removal of this hydrogen layer is known as depolarization. If the zinc electrode is not 100% pure, which for cost reasons is often the case, then the impurities react with the zinc and the sulphuric acid to produce miniature cells on the surface of the zinc electrode. This reaction takes place in the voltaic cell, irrespective of whether a current is being taken from the cell or not. This local action, as it is known, is wasteful and may be eliminated by coating the zinc plate with mercury, or by using the more expensive pure zinc. The e.m.f. of a cell of this type is approximately equal to 1.0 V. A second type of primary cell is the dry cell. In this type of cell instead of using a dilute acid electrolyte we use ammonium chloride in thick paste form. In one variant of this cell the positive electrode is a centrally positionedcarbonwhilethenegativeelectrodeisthezincouter casing the cell(fig 5.2). Carbon and manganese dioxide act as the depolarizing agent that surrounds the carbon electrode. This type of cell is often used to power torches and other portable

equipment and each cell has an e.m.f. of approximately 1.5 V.



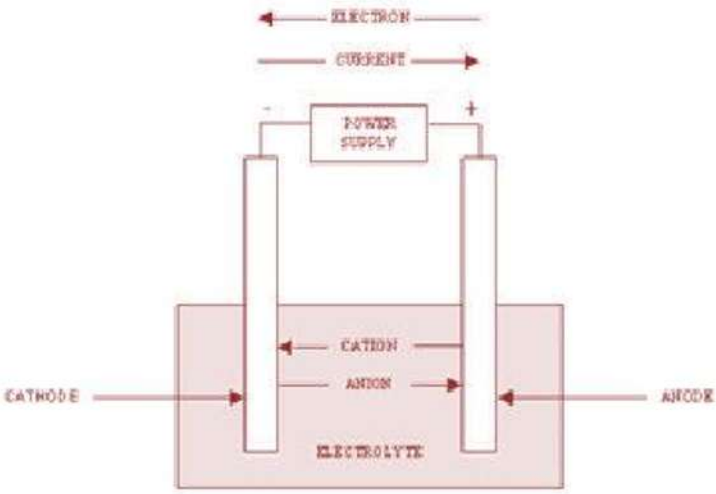


Fig. 5.2 A zinc carbon cell(leclanche cell)

Fig. 5.3

Internal resistance = Open circuit voltage - closed circuit voltage
Load (Resistance of resistor)

Secondary batteries fall into two sub-categories depending on their intended applications.
Lead–acid cells

The lead–acid cell is one of the most common secondary cells. In this type of cell, the electrical energy is initially supplied from an external source and converted and stored in the cell as chemical energy. This conversion of energy is reversible and when required this stored chemical energy can be released as a direct electric current. This process of storage leads to the alternative name for this type of cell, the lead–acid accumulator. The manufacture of this cell is quite complex. The positive plate consists of a grid of lead and antimony filled with leadperoxide.
The negative plate uses a similar grid, but its open spacesare filled with spongy lead. Thus the cells are made up of a group of positive plates, joined together and interlaced between a stack of negative plates. Positive plate is surrounded by negative plate on both side.Negative plates are more in number than positive plate as positive plate is more subject to warping and deterioration if chemical action takes place on one side. Porous separators keep the plates apart and hold a supply of electrolyte in contact with the active materials. The electrolyte consists of a mixture of sulphuricacidandwater(i.e.dilutesulphuricacid)whichcovers the plates nad take active part in charging and dischsrging or the cell.

A fully charged lead–acid cell has an e.m.f. of approximately 2.2 ` V,but when in use this value falls rapidly to about 2.0V. In the Fully charged condition the negative plate is spongy lead and the positive plate is lead peroxide. In the discharged condition, where the e.m.f. is about 1.8 V, the chemical action of the cell converts both positive and negative plates into a lead sulphate mix. When discharged, the cell may then be recharged from an external source and made ready for further use. The condition of this type of cell may be checked by measuring the relative density of the electrolyte. In the fully charged condition this will be around 1.26, while in the discharged condition it drops to around 1.15. This type of cell, when joined together as a battery, has many commercial uses, the most familiar of which is as a motor vehicle battery.

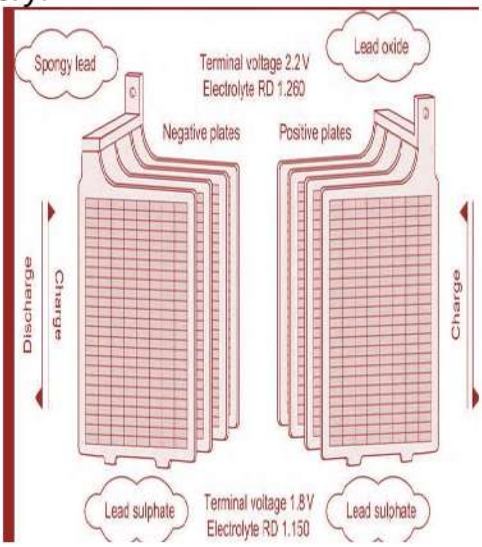


Fig. 5.4 A lead acid cell construction

Flooded cells are housed within an impact- and acid resistant casing made from polystyrene-based materials. The casing retains the two terminals and includes a vent cap to prevent gas pressure build-up whilst not allowing the electrolyte to escape. individual plates are separated by a porous material to prevent short circuit through physical contact; there is space below the plates to allow any material shedfrom
the plates to accumulate without shorting the plates. Flooded cells can be accessed on an individual basis for checking the content and condition of the electrolyte. Each positive plate is a cast lead/antimony frame formed as a grid; this is impregnated with a paste of lead dioxide (PbO2). The negative plate is a similar frame containing lead (Pb); this is sometimes referred to as „spongy lead‟ . In practice, a typical cell is constructed with several plates in order to get the required current output. Positive plates distort when chemical reactions take place on only one side; for this reason, there are always an even number of positive platessandwichedbetweenanoddnumbersofnegativeplates.

All positive plates are connected together as are all the negatives. The plates are interlaced and separated by a porous separator that allows free circulation of the electrolyte at the plate surfaces; the plates are all stacked within the cell container. The electrolyte is sulphuric acid diluted with distilled (pure) water (H_2SO_4).

Charging/discharging

When fully charged, each cell has a potential difference of 2.5 V (falling to 2.2 V after a period of approximately one hour) at its terminals; when discharged this potential difference is 1.8 V. A six-cell battery would produce 13.2 V fully charged, and 10.8 V DC when discharged. A twelve-cell battery would produce 26.4 V DC fully charged, and 21.6 V DC when discharged. During normal use of lead-acid cells, the terminal voltage stays at around 2 V for a long period of cell life, this is referred to as the cell‟s nominalvoltage. When fully charged, the positive plate is lead dioxide (PbO_2) and the negative plate is lead (Pb).Connecting an external load to the battery completes the electrical circuit, electrons are transferred from the negative plate and the battery starts to discharge. The chemical reaction that takes place during discharge changes each of the plates into lead sulphate ($PbSO_4$). Molecules of water are formed, there by diluting the electrolyte. For a given battery capacity, a steady discharge rating forms part of the battery specification, e.g. a 20 hour rate produces a constant current for 20 hours until the cell isdischarged.

The discharge current, in amps (A), is expressed as a fraction of the numerical value of C. For example, 0.1 C means C/10 A, and discharging will take approximately 10 hours. If the battery capacity was 35 Ah, a discharge current of 3.5 A can be expressed as 0.1 C (or C/10). This means that batteries of different sizes can be compared by a single set of graphs. Since a battery may be rated for different discharge times, its rated capacity will normally be an indication of current used. With a 20-hour discharge capacity, the chart shows that C/20 will discharge the battery at 1 A current in 20 hours. The condition of each cell can be determined by the specific gravity (SG) of its electrolyte. When the battery is charged, the above process is reversed. The lead sulphate on the positive plate is returned to lead peroxide. The negative plate is returned to lead, and the electrolyte is restored to its original specific gravity; SG ranges will be from 1.25–1.3 (charged) down to 1.15–1.2 when discharged.

Flooded lead-acid batteries are susceptible to damage at low temperatures due to freezing of the electrolyte causing plate damage. The point at which the electrolyte freezes depends on its specifi c gravity; at a specifi c gravity of 1.15 (discharged) the
freezing point is - 15ºC. To prevent freezing, the specific gravity should be maintained at higher levels; at a specific gravity of
1.275 (charged) the freezing point is - 62ºC. Although this guards against freezing, the consequence of maintaining a battery in this condition is that it will gradually self-discharge. Lead-acid batteries require a three-month capacity check, and have approximately 18–24 months "life. The condition of a fully charged lead-acid battery canbe confirmed by three factors: The terminal voltage remains at its maximum level. There is a free discharge of gas. The SG is in the range 1.25–1.3. The specific gravity of the electrolyte provides the definitive means of checking the charged condition of a lead-acid cell; this must be checked with a hydrometer on a periodic basis. (Specific gravity of a fluid is the relative density, or ratio of fluid"s weight compared to pure water.) The electrolyte must always cover the plates; it can be topped up with distilled water. Differences of specific gravity readings between cells indicates that the battery is reaching the end of its usefullife.
When checking the SG of the electrolyte in a lead acid battery, you should check all cells because they may be different

In the event of electrolyte spillage/leaks , (always refer to the aircraft maintenance manual for any specific requirements) the following generic actions should be taken:
Report theincident.
top-up the electrolyte with a damp rag orsponge.
Brush the affected area with a dilute solution of sodium bicarbonate.
Sponge the area with clean water; drythoroughly.
Press a moist piece of blue litmus paper on the affected area; a change of colour to red indicates the presence of acid (repeat steps 3–4 until the acid isremoved).
Leavefor24hours,andthencheckforanyevidenceof corrosion.
Restore any protective finish to the aircraftstructure.

Ni-Cd cells
Ni-Cd batteries are now increasingly used in aircraft because they offer a long service life coupledwith excellent performance and reliability Like their lead–acid counterparts, Ni-Cd batteries consist of a number of series connected cells each comprising a set of positive and negative plates, separators,

electrolyte, cell vent and a cell container. The positive plates of a Ni-Cd battery comprise a porous plate on which nickel hydroxide has been deposited. The negative plates are made from similar plates on which cadmium hydroxide has been deposited. A continuous strip of porous plastic separates these two sets of plates from each other. The electrolyte used in a Ni-Cd is a 30% solution (by weight) of potassium hydroxide (KOH) in distilled water. The specific gravity (relative density) of the electrolyte remains between 1.24 and 1.30 at room temperature and (unlike thelead– acid battery) no appreciable change occurs in the specific gravity of the electrolyte during charge and discharge
.
For this reason it is not possible to infer much about the state of a Ni-Cd battery from a measurement of the specific gravity check of the electrolyte. However, as with a lead–acid battery, the electrolyte level should be maintained just above the tops of the plates. When a charging current is applied to a Ni- Cd battery,the negative plates lose oxygen and begin to form metallic cadmium.
At the same time, the active material of the positive plates,nickel hydroxide, becomes more highly oxidized.

This process continues while the charging current is applied or until all the oxygen is removed from the negative plates and only cadmium remains. Toward the end of the charging cycle (and when the cells are overcharged) the water in the electrolyte the positive plate. This transfer takes place for as long as charging current exists, until all the oxygen is driven out of the negative plate (leaving metallic cadmium) and the positive plate becomes nickel oxide. The electrolyte acts as an ionized conductor and it does not react with the plates in any way. There is virtually no chemical change taking place in the electrolyte during charging or discharging, therefore its condition does not provide an indication of cell condition. Towards the end of charging, gassing occurs as a result of electrolysis and the water content of the electrolyte is reduced. Gas emitted by decomposition of water molecules is converted into hydrogen at the negative plate and oxygen at the positive plate. This gassing leads to the loss of some water; the amount of gas released is a function of electrolyte temperature and charging voltage. When fully charged, each cell has a potential difference of between 1.2 and 1.3 V across its terminals. This reduces to 1.1 V when discharged. An aircraftbattery containing 19 cells at 1.3 V therefore produces a battery of 24.7 V. Charging voltage depends on the design and construction, but will be in the order of 1.4/1.5 V percell.

Discharging

This is a reverse chemical activity of the charging process; the positive plate gradually loses oxygenand the negative plate gradually regains oxygen. No gassing takes place during a normal discharge; the electrolyte is absorbed into the plates and may not be visible over the plates. When fully charged, the volume of electrolyte is high; this is the only time that water should be added to a Ni-Cd battery. Ni-Cd battery electrolyte freezes at approximately –60ºC and is therefore less susceptible to freezing compared tolead-acid. The formation of white crystals of potassium carbonate indicates the possibility that Over charginghas occurred. the nickel-cadmium cell voltage
remains relatively constant at approximately 1.2 V through to the end of discharge, at which point there is a steep voltage drop. The discharge characteristics of a cell are affected by the:

- dischargerate
- dischargetime
- depth ofdischarge
- celltemperature
- charge rate and overchargerate
- charge time, and rest period aftercharge
- previous cyclinghistory.Every nickel-cadmium cell (and hence a battery) has a specifi c:
- ratedcapacity

- dischargevoltage
- effectiveresistance.

Individual cells are rated at a nominal 1.2 V, and voltage for battery voltages are multiples of the individual cell nominal voltage. Five cells connected in series would therefore result in a 6 V battery. It can be seen from Fig. 5.6 that the discharge voltage will exceed 1.2 V for some portion of the discharge period. Cell capacity is normally rated by stating a conservative estimate of the amount of capacity that can be discharged from a relatively new, fully charged cell. The cell rating in ampere-hours (or mill ampere hours)is therefore quoted by most manufacturers to a voltage of 0.9 V at 5 hour discharge rate. When rates of discharge rates increase, the available capacity decreases. Charging of nickel-cadmium batteries needs specific methods since they can suffer from an effect called thermal runaway. This occurs at high temperatures and if the battery is connected to a constant charging voltage that can deliver high currents. Thermal runaway causes an increase in temperature and lower internal resistance, causing more current to flow into the battery. In extreme cases sufficient heat may be generated to destroy the battery. Dedicated battery charges (either on the aircraft or in the decomposes into hydrogen (at the negative plates) and oxygen (at the positive plates). The time taken to charge a battery will depend partly on the charging voltage and partly on the temperature. It is important to note that to completely charge a Ni-Cd battery, some gassing, however slight, must take place. Furthermore, when the battery is fully charged the volume of the electrolyte will be at its greatest thus water should only be added in order to bring the electrolyte to its correct level when the battery is fully charged and allowed to rest for a period of several hours. During subsequent discharge, the plates will absorb a quantity of the electrolyte and the level of the electrolyte will fall as a result. The useful life of a Ni-Cd battery depends largely on how well it is maintained and whether or not it is charged and discharged regularly.

Construction

Plates are formed from a nickel mesh on which a nickel powder is sintered. The sintering process (where powdered materialis formed into a solid) is used to form the porous base-plates(called plaques). This process maximizes the available quantity of active material. The plaques are vacuum impregnatedwithNickel or cadmium salts, electrochemically deposited with the pores of the plaques. Nickel tabs are spot welded onto the plates and formed into the terminals; these plates are then stacked and separated by a porous plastic in a similar fashion to the lead-acid battery. The electrolyte is potassium hydroxide (KOH) diluted in distilled water giving a specific gravity of between 1.24 and 1.3. Both the plates and electrolyte are sealed in a plastic container.

Charging

During charging, there is an exchange of ions between plates. Oxygen is removed from the negative plate, and transferred to the positive plate. This transfer takes place for as long as charging current exists, until all the oxygen is driven out of the negative plate (leaving metallic cadmium) and the positive plate becomes nickel oxide. The electrolyte acts as an ionized conductor and it does not react with the plates in any way. There is virtually no chemical change taking place in the electrolyte during charging or discharging, therefore its condition does not provide an indication of cell condition. Towards the end of charging, gassing occurs as a result of electrolysis and the water content of the electrolyte is reduced. Gas emitted by decomposition of water molecules is converted into hydrogen at the negative plate and oxygen at the positive plate. This gassing leads to the loss of some water; the amount of gas released is a function of electrolyte temperature and charging voltage. When fully charged, each cell has a potentialdifference

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- charge rate and overchargerate
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Maintenance

Since there is virtually no chemical change taking place during nickel-cadmium cell charging or discharging, the condition of the electrolyte does not provide an indication of the battery‟s condition. Cell terminal voltage does not provide an indication of charge since it remains relatively constant. The only accurateand practicalwaytodeterminetheconditionofthenickelcadmium battery is with a measured discharge in the workshop. The fully charged battery is tested after a two hour „resting ‟ period, after which the electrolyte is topped up using distilled or demineralised water. Note that since the electrolyte level depends on the state of charge, water should never be added to the battery on the aircraft. This could lead to the electrolyte overflowing when the battery discharges, leading to corrosion and self- discharging (both of which could lead to premature failure of the battery).

Ni-Cd batteries emit gas near the end of the charging process and during overcharging. This is an explosive mixture and must be prevented from accumulating; maintenance of the venting system is essential. In the event of electrolyte spillage/leaks (always refer to the aircraft maintenance manual for specific details):

- reportincident
- mop electrolyte with damp rag orsponge
- cover the area with a dilute solution of acetic acid, 5%solution of chromic acid, or 10% solution of boric acid
- pressmoistpieceofredlitmuspaperonaffectedarea;change of colour to blue indicates presence of alkaline
- leave for a minimum of 24 hours, check forcorrosion
- restore protectivefinish.

Lithium batteries

Lithium batteries include a family of over 20 different products with many types of anodes, cathodes and electrolytes. The type of materials selected depends on many factors, e.g. cost,capacity, temperature,
life etc.; these are all driven by what the application requirements are. Applications range from consumer products (accounting for the largest market requirement) through to specialist applications including communications and medical equipment. Aircraft are often equipped with systems requiring an autonomous source of energy, e.g. emergency locator beacons, life rafts and lifejackets.
Lithium (Li) is one of the alkali group of reactive metals ; it is one of the lightest elements, giving it an immediate advantage for aircraft applications. It has a single valence electron with low combining power, therefore readily becoming a positive ion.The
materials used in these cells are:

- electrolyte:lithium-ion
- cathode:cobalt
- anode:graphite.

Lithium-ion is a fast-growing and promising battery technology. This type of battery is often found in consumer products (mobile phones and laptop computers) because they have very high energy-to-weight ratios, no memory effect, and a slow discharge charge rate when not in use. They are being introduced for aircraft applications (e.g. in smoke detectors) on a cautious basis because they are significantly more susceptible to thermal runaway. Applications on aircraft now include engine start and emergency back-up power, the first such application of the devices in the business aviation sector. In the longer term, they are being developed for main battery applications. They offer several advantages compared to lead-acid and nickel-cadmium products, including:

- longerlife
- lessweight
- lowmaintenance
- reduced chargingtime.

In order to produce a battery, individual cells are usually connected in series with one another, Cells can also be connected in parallel. In the series case, the voltage produced by a battery with n cells will be n times the voltage of one individual cell (assuming that all of the cells are identical). Furthermore, each cell in the battery will supply the same current. In the parallel case, the current produced by a battery of n cells will be n times the current produced by an individual cell (assuming that all of the cells are identical). Furthermore, the voltage produced by the battery will be the sameas the voltage produced by an individual cell.(refer fig 5.5)

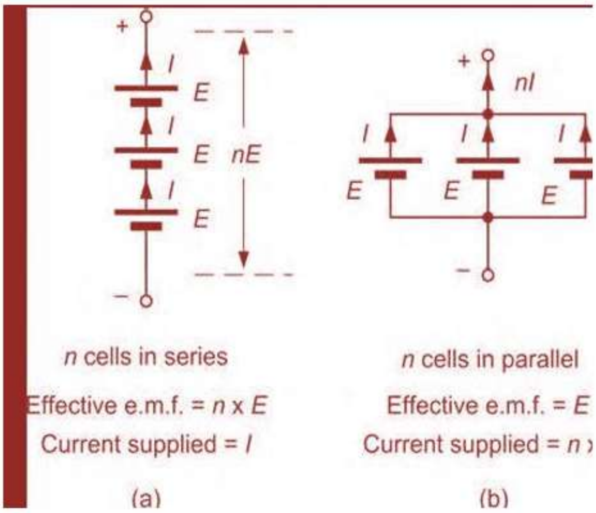


Fig.5.5

Internal resistance of a cell

Internal resistance of a cell

Every practical source of e.m.f. (e.g. a cell, battery or power supply) has some internal resistance. This value of resistance is usually extremely small but, even so, it has the effect of limiting the amount of current that the source can supply and also reducing the e.m.f. produced by the source when it is connected to a load (i.e. whenever we extract a current from it). The idea of an "invisible" internal resistance can be a bit confusing so, when we need to take it into account we show it as a fixed resistor connected in series with a "perfect" voltage source. To clarify this point, It is important to note that the internal resistance, r, is actually inside the cell (or battery) and is not actually something that we can measure with anohmmeter!

I.R. = OCV-CCV/LOAD(amperes)

OCV = open circuit voltage when battery is not connected to load CCV = closed circuit voltage when battery is connected to load Battery locations

An aircraft is fitted with one or two main batteries depending on its size and role. The battery is locatedas close as possible to its point of distribution; this is to reduce IR losses through heavy- duty cables. In smaller general aviation (GA) aircraft, the battery can be located in the engine compartment, alternatively behind the luggage compartment in the rear fuselage. On some larger GA aircraft the battery is located in the leading edge of the wing. Other locations include the nose equipment bay on medium size helicopters or attached to the external airframe. For larger aircraft, e.g. the Boeing 747, one battery is located in the flight compartment; the other is located in the auxiliary power unit (APU) bay at the rear of the aircraft. Batteries are installed in a dedicated box or compartment designed to retain it in position and provide ventilation. The battery compartment is usually fi tted with a tray to collect any spilt electrolyte and protect the airframe. Tray material will be resistant to corrosion and non- absorbent. The structure around the battery compartment will be treated to reduce any damage from corrosion resulting from any spilt electrolyte or fumes given off during charging. Batteries must be secured to prevent them from becoming detached during aircraft man oeuvres; they are a fire risk if they become detached from their tray.(refer fig5.6)

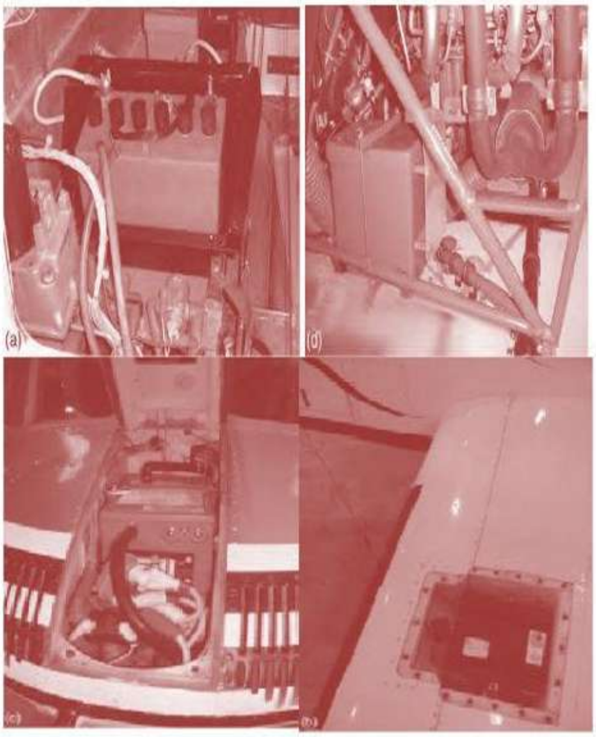


Fig. 5.6

Battery venting

Main battery installations must be vented to allow gases to escape, and accommodate electrolyte spillage.Rubber or other non-corroding pipes are used as ventilation lines which direct the gases overboard, usually terminating at the fuselage skin. On pressurized aircraft the differential pressures between cabin and atmosphere are used to draw air through the venting system. Some installations contain traps to retain harmful gases and vapours. Battery venting, acid traps and how pressurized cabin air is used to ventilate the battery.

Battery connections

These depend on the type of battery and aircraft installation. On smaller aircraft the cable connections a nut, bolt and washers. On larger aircraft, the main batteries have quick-release connectors. These provide protection for the terminals and cable connections, the aircraft connector is a plastic housing with two shrouded spring-loaded terminals (for connecting the battery cables) and a hand-wheel with lead-screw. The battery connection is a plastic housing integrated into the casing; it contains two shrouded pins and a female lead screw. When the two halves are engaged, the lead screws are pulled together and eventually form a lock. This mechanism provides good contact pressure and a low resistance connection.(refer fig 5.7)

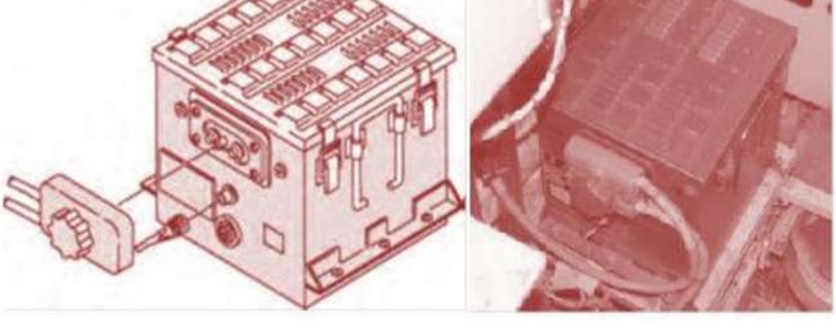


fig.5.7 Battery Connections

Thermocouples

The output of a thermocouple depends on two factors:

•the difference in temperature between the hot junction and the cold junction (note that any change in either junction temperature will affect the e.m.f. produced by the thermocouple);

•themetalschosenforthetwowiresthatmakeupthe thermocouple. It is also worth noting that a thermocouple is often pictured as two wires joined at one end, with the other ends not connected; it is important to remember that it is not a true thermocouple unless the other end is also connected! In many practical applications the cold junction is formed by the load to which a hot junction is connected. In measuring applications this load can be a measuring instrument, such as a sensitive voltmeter.Thepolarityofthee.m.f.generatedisdeterminedby

(a) the particular metal or alloy pair that is used (such as iron and constantan) and (b) the relationship of the temperatures at the two junctions. If the temperature of the cold junction is maintained constant, or variations in that temperature are compensated for, then the net e.m.f. is a function of the hot junction temperature.

In most installations, it is not practical to maintain the cold junction at a constant temperature.

junction) is 32◦F(0◦C). This is the basis for published tables of e.m.f. versus temperature for the various types of thermocouples. Note that, where additional metals are present in the thermocouple circuit, they will have no effect on the e.m.f. produced provided they are all maintained at the same temperature.

PHOTOCELL

The output of a photocell depends on the amount of light that falls on the surface of the cell. As more light hits the photocell,More electrons will be released and thus more voltage will be.

Charging method:

Methods of Charging the Valve Regulated (Sealed) Lead- Acid Battery

Classification by application:

1.by power source (tricklecharging)

Charging Schemes

The charger has three key functions produced. In order to generate a useful voltage and current, photocells are usually connected in large series and parallel arrays. However, they are still rather inefficient in terms of energy conversion (typically only 10–15% of the incident light energy is converted to useful electrical energy). Cells constructed from indium phosphide and gallium arsenide are, in principle, more efficient but conventional silicon-based cells are Solar photovoltaic cells have long been used to provide electric power for spacecraft and other devices that have no access to a power source. However, recent developments have driven costs down to the point where the silicon photocells are being used more and more as a replacement for conventional energy sources (such as dry cells and lead–acid batteries). Photocells also make it possible for us to “top-up” the charge in a secondary cell battery that can later be used to maintain an electrical supply during the hours of darkness. generally less costly.

- Getting the charge into the battery(Charging)
- Optimising the charging rate(Stabilising)
- Knowing when to stop (Terminating)

The charging scheme is a combination of the charging and termination methods.

Basic Charging Methods

•Constant Voltage A constant voltage charger is basically a DC power supply which in its simplest form may consist of a step down transformer from the mains with a rectifier to provide the DC voltage to charge the battery. Such simple designs are often found in cheap car battery chargers. The lead-acid cells used for cars and backup power systems typically use constant voltage chargers. In addition, lithium- ion cells often use constant voltage systems, although these usually are more complex with added circuitry to protect both the batteries and the user safety.
charged preferably with constant voltage charging system.

• Constant Current Constant current chargers vary the voltage they apply to the battery to maintain a constant current flow, switching off when the voltage reaches the level of a full charge.Thisdesignisusuallyusedfornickel-cadmiumand
nickel-metal hydride cells or batteries.

The optimum current profile depends on the cell chemistry and construction.

• Trickle charge Trickle charging is designed to compensate for the self discharge of the battery. Continuous charge. Long term constant current charging for standby use. The charge rate varies according to the frequency of discharge. Not suitable for some battery chemistries, e.g. NiMH and Lithium, which are susceptible to damage from overcharging. In some applications the charger is designed to switch to trickle charging when the battery is fullycharged.

• Float charge. The battery and the load are permanently connected in parallel across the DC charging source and held at a constant voltage below the battery's upper voltage limit. Used for emergency power back up systems. Mainly used with lead acidbatteries.

BATTERY CAPACITY

The capacity of a storage battery is the product of the current drawn from a battery, multiplied by the number of hours this current flows. The unit in which capacity is measured is the ampere-hour. Theoretically, a battery has a capacity of 40 ampere hours if it furnishes ten amperes for four hours, and if it is unable, at the end of that time, to furnish any more current. If we drew only five amperes from this battery, it should be able to furnish this current for eight hours. Thus, theoretically, the capacity of a battery should be the same, no matter what current is taken from it. That is, the current in amperes, multiplied by the number of hours the battery, furnished this current should be constant.

2.Conditions of Operation.

Design and Construction.

Each classification may be subdivided. Under the Design and Construction we have:

- Quantity, arrangement, and porosity of active materials.
- Quantity and strength ofelectrolyte.
- Circulation ofelectrolyte.

These sub -classifications require further explanation. Taking them in order:

(a) Area of Plate Surface.It is evident that the chemical and electrical activity of a battery are greatest at the surface of the plates since the acid and active material are in intimate contact here, and a

supply of fresh acid is more readily available to replace that which is depleted as the battery is discharged. This is especially true with high rates of discharge, such as are caused in starting automobile engines. Therefore, the capacity of a battery will be greater if the surface area of its plates is increased.With
large plate areas a greater amount of acid and active materials is
available, and an increase in capacity results.

(b) Quantity, Arrangement, and Porosity ofActive,
Materials.Since the lead and lead peroxide are changed to lead sulphate on discharge, it is evident that the greater the amount of these materials, the longer can the discharge continue, and hence the greater the capacity and voltage of secondary cell.

The arrangement of the active materials is also important, since the acid and active materials must be in contact in order to produce electricity. Consequently the capacity will be greater in a battery, all of whose active materials are in contact with the acid, than in one in which the acid reaches only a portion of the active materials. It is also important that all parts of the plates carry the same amount of current, in order that the active materials may be used evenly. As a result of these considerations, we find that the active materials are supported on grids of lead, that the plates are made thin, and that they have large surface areas. For heavy discharge currents, such as starting motor currents, it is essential that there be large surface areas. Thick plates with smaller surface areas are more suitable for low discharge rates.

Since the inner portions of the active materials must have a plentiful and an easily renewable supply of acid, the active materials must be porous in order that diffusion may be easy and rapid. The voltage of secondary cell depends on the active materials on the plates.

(c) Quantity and Strength of Electrolyte.It is important that there be enough electrolytes in order that the acid may notbecome exhausted while there is still considerable active material left. An insufficient supply of electrolyte makes it impossible to obtain the full capacity from a battery. On the other hand, too much electrolyte, due either to filling the battery too full, or to having the plates in a jar that holds too much electrolyte, results in an increase in capacity up to the limit of the plate capacity. There is a danger present, however, because with an excess of electrolyte the plates will be discharged before the specific gravity of the electrolyte falls to 1.150. This results in over discharge of the battery.

d) Circulation of Electrolyte. This refers to the passing of electrolyte from one plate to another, and depends upon the ease with which the acid can pass through the pores of the separators. A porous separator allows more energy to be drawn from the battery than a nonporous one.

Operating Conditions.

Considering now the operating conditions, we find several items to be taken into account. The most important are
(e) Rate of discharge.

(f) Temperature.

(e) Rate of Discharge. As mentioned above, the ampere hour rating of a battery is based upon a continuous discharge, starting with a specific gravity of 1.280-1.300, and finishing with 1.150. The end of the discharge is also considered to be reached when the voltage per cell has dropped to 1.7. With moderate rates of discharge the acid is abstracted slowly enough to permit the acid from outside the plates to diffuse into the pores of the plates and keep up the supply needed for the chemical actions. With increased rates of discharge the supply of acid is used up so rapidly. that the diffusion is not fast enough to hold up the voltage. This fact is shown clearly by tests made to determine thetime required to discharge a 100 Amp. Hr., 6 volt battery to 4.5 volts. With a discharge rate of 25 amperes, it required 160 minutes. With a discharge rate of 75 amperes, it required 34 minutes. From this we see that making the discharge rate three times as great caused the battery to be discharged in one fifth the time. These discharges were continuous, however, and if the battery were allowed to rest, the voltage would soon rise sufficiently, to burn the lamps for a number ofhours.

f) Temperature. Chemical reactions take place much more readily at high temperatures than at low. Furthermore, the active materials are more porous, the electrolyte lighter, and the internal resistance less at higher temperatures. Opposed to this is the fact that at high temperatures, the acid attacks the grids and active materials, and lead sulphate is formed, even though no current is taken from the battery. Other injurious effects are the destructive actions of hot acid on the wooden separators used in most starting and lighting batteries. Greater expansion of active material will also occur, and this expansion is not, in general, uniform over the surface of the plates. This results in unequal strains and the plates are bent out of shape, or "buckled." The expansion of the active material will also cause much of it to fall from the plates, and we then have "shedding."

When sulphuric acid is poured into water, a marked temperature rise takes place. When a battery is charged, acid is formed, and when this mixes with the diluted electrolyte, a temperature rise occurs. In discharging, acid is taken from the electrolyte, and the temperature has a tendency to drop. On charging, therefore, there is danger of overheating, while on discharge, excessive temperatures are not likely.

3.6 SIMPLE ELECTRICAL CIRCUIT

Here is a simple electric circuit. It has a cell, a lamp and a switch. To make a circuit, these components are connected together with metal connecting wires.(Fig 6.1)

When the switch is closed, the lamp lights up. This is because there is a continuous path of metal for the electric current to flow around. If there were any breaks in the circuit, the current could notflow.

The current flows all the way around the circuit. The cell pushes the current around the circuit. As the current passes through the lamp, it makes it light up.

Series circuit

This circuit is called a series circuit. The components are connected end-to-end, one after the other. They make a simple loop for the current to flow round.

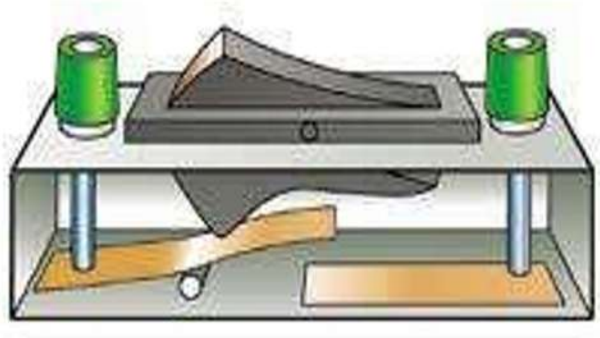
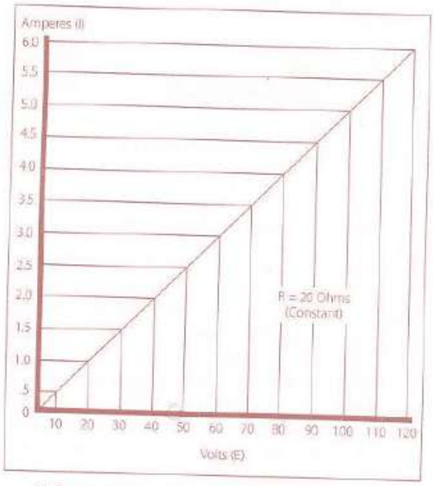


Fig. 6.1 A simple switch. Closing it joins the contacts together and lets the current flow through.

A simple switch is made of a metal lever that can join up with a metal contact. When you press the switch, the two pieces of metal touch and the current can flow through it. When you open it, this breaks the circuit.

OHM'S LAW

We have already studied the three fundamental of element of electricity voltage, amperage and resistance. Ohm's law describes the relationship between theseelements.
Ohm's law is necessary to determine the correct size and length of wire to be used in a circuit, the proper sizes of fuses and circuit breakers etc.
This law states that "current in an electric circuit is directly proportionaltotheemf(voltage)andinverselyproportionalto
the resistance. $I = E/R$
Current in a given circuit is equal to voltage divided by resistance.
Or
The ratio of potential difference (V) between any two point on a conductor to the current (I) flowing between them is constant
Therefore, if cross sectional area of the conductor is doubled keeping the voltage is constant the current will also be doubled.



Voltage vs. current in a constant-resistance circuit.

.fig.6.2

A graph of this relationship is shown in Figure 6.2 which uses a constant resistance of 20 ohms. The relationship between voltage and current in this example shows voltage plotted horizontally along the X axis in values from 0 to 120 volts and the corresponding values of current are plotted vertically in values from 0 to 6.0 amp along the Y axis. A straight line drawn through all the points where the voltage and current lines meet represents theequation

I = E/20 And is called linear relationship.

If E = 10V Then 10V/20Ω = 0.5 A If E = 60V Then 60V/20Ω = 3 A If E= 120V Then 120V/20Ω = 6A

Eg: If a battery of 2V is connected to a lamp of resistance 1

Ω,then current in the circuit can be determined as follows:

I=V/R=2/1 = 2 Amp

If in the above example battery voltage is increased to 4V then current will be

I=V/R =4/1=4 Amp

NOTE: In the above example, you see as the voltage is doubled, current doubles. This shows that current is directly proportional to voltage.

I∞V

In the same example if resistance is double current will be half

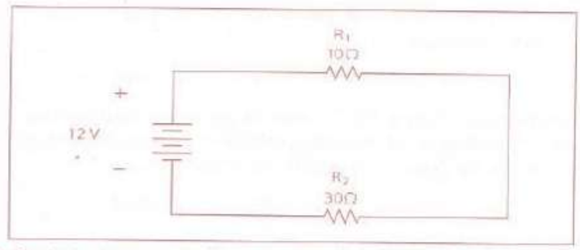
say R= 2Ω and V= 4V Then

I = 4/2=2 Amp

Insert fig of simple resistance finding

SERIES DC CIRCUIT

The series circuit is the most basic electrical circuit. It is the first building block of all the circuit to be studied and analyzed. A series circuit is a circuit in which all components are connected end to end to ensure same current flow in all. Batteries and resistor are in series with each other and there is only one path for current toflow.



Inducing minimum voltage in an elementary generator.

Fig. 6.3

In the above example (fig 6.3) there is 12 V DC Source in series with two resistors R1= 10Ω and R2 = 30Ω. To calculate total resistance in a series circuit take the sum of individual resistors. RT = R1 + R2 +R3+……RN

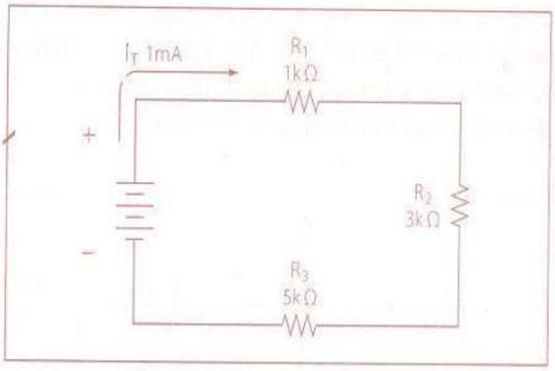
Therefore, RT = 10Ω + 30Ω = 40Ω

Current remains same at all points in a series circuit …so

I= V/R I=12/40 =0.3A

The amount of charge moving through the conductor in a given amount of time translated into a current.(I = Q/T)

TO CALCULATE VOLTAGE DROP IN A SERIES CIRCUIT



Example of three resistors in series

Fig. 6.4

Voltage drop is caused by a loss of electrical pressure or emf
caused by forcing electrons through a resistor.

In the fig 6.4, there are three resistors in series with the circuit so three voltage drop will be there as per the resistor value.

Current given as I = 1mA

R1 = 1 KΩ R2 = 3 KΩ R3 = 5 KΩ

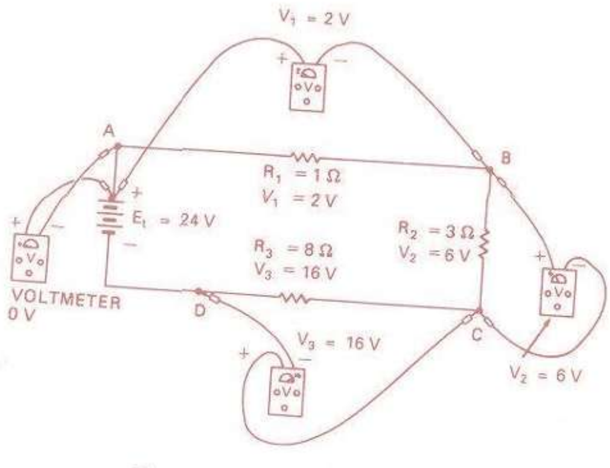
Voltage drop across each resistor is calculated by product of each resistance and total current in thecircuit

(same current flows in series network)

Voltage drop at R1 = I X R1 = 1 mA x 1 kΩ = 1 volt Voltage drop at R2 = I X R2 = 1 mA x 3 kΩ = 3 volt Voltage drop at R3 = I X R3 = 1 mA x 5 kΩ = 5 volt

Source voltage = I X RT RT=1 kΩ + 3 kΩ + 5 kΩ = 9 kΩ

Source voltage = 1 mA



The summation of voltage drops.

Fig. 6.5

In the figure 6.5 three resistance are connected in series with 24 V battery.

Total voltage = 24V

R1= 1Ω R2= 3Ω R3= 8Ω

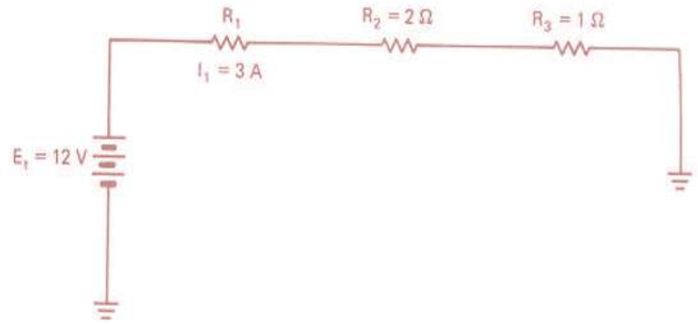
RT = 1Ω + 3Ω + 8Ω =12 Ω

Total current in the circuit ; IT = VT/RT= 24 V/12Ω =2 Amp

Voltage drop across R1 = I X R1 = 2 X 1 = 2V

Voltage drop across R2 = I X R2 = 2 X 3 = 6V

Voltage drop across R3 = I X R3 = 2 X 8 = 16 V When we add all voltage drop we find that it is equalto source voltage: 2V + 6V + 16V =24 V This determines Kirchhoff's VoltageLaw



Series circuit for Example A.

Fig. 6.6

In the figure 6.6 VT = 12 V

I1 = 3 A R2 = 2 Ω R3 = 1Ω

We know, current remains same across each resistor in a series ircuit.

Total resistance RT = VT/IT

RT =12/3 = 4 Ω

Unknown resistance R1 can be determined as RT = R1 + R2 +R3

4Ω = R1 + 2Ω + 1Ω R1 = 4Ω - 3Ω =1Ω

Voltage drop across each resistoris

Characteristics of a Series Circuit

Same current flows through all the part of thecircuit
Different resistors have their individual voltagedrop
Voltage drops areadditive
Applied voltage is equal to the sum of different voltage drop 5.Resistance isadditive
Power isadditive

KIRCHOFF'S VOLTAGE LAW

In 1847,G.R. Kirchoff ,a german physicist develop these laws that are more comprehensive than Ohms law and are used for solving electrical network which are not solved by latter.Kirchoff's Law two in number are used for
determining equivalent resistance of a complicated network of conductors
calculating the currents flowing in the variousconductors
We will be studying about Kirchoff's Voltage Law first
KIRCHOFF'S VOLTAGE LAW or MESH LAW(KVL)

In a series circuit, the algebraic sum of the voltage drops in that circuit must be equal to the source voltage. Or the algebraic sum of all voltages and electromotive force around a close pathor loop is zero. Electromotive force is the supply or source voltage.
Determination of Voltage Polarity
Some definitions that will help in understanding electronic circuits:
Voltage Rise - Just like it sounds a voltage rise is created by an electrical device in a circuit that creates a Voltage increase or "Rise". Examples of these devices are batteries, solar cells,
generators, alternators, and thermocouples. Simply put aVoltageRise is an increase in electrical pressure. A Voltage Rise maybe a positive or a negative.

Voltage Drop - A Voltage Drop occurs when a Current flows through a Resistive electrical component in an electrical circuit. This Voltage drop will be the opposite polarity from the Voltage rise that caused the Current flow, thus named a Voltage Drop. Using Ohm's Law it can be shown that a Voltage is present when Current flows through a Resistor (V= I • R). Simply put a Voltage
Drop is a decrease in electrical pressure. "
In an electrical circuit, the Voltage across a resistor is always the opposite polarity from the
Voltage source. This means if the Voltage source is a positive polarity (+), the Voltage drop across the resistors in that electrical circuit will be a negative polarity (-). If the Voltage source is a negative polarity (-), the Voltage drop across the resistors in the electrical circuit will be a positive polarity (+).

Application of Kirchoff's Voltage Law

Kirchhoff's voltage law can be written as an equation, as shown below:

$$E_a + E_b + E_c + \ldots E_n = 0$$

where Ea, Eb, etc., are the voltage drops or emf's around any closed circuit loop. To set up the equation for an actual circuit, the following procedure is used.

Assume a direction of current through the circuit. (The correct direction is desirable but not necessary.)
Using the assumed direction of current, assign polarities to all resistors through which the current flows. Place the correct polarities on any sources included in the circuit. Starting at any

point in the circuit, trace around the circuit, writing down the amount and polarity of the voltage across each component in succession. The polarity used is the sign AFTER the assumed current has passed through the component.Stop when the point at which the trace was started is reached. Place these voltages, with their polarities, into the equation and solve for the desired quantity.

Example: Three resistors are connected across a 50-volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15volts?

Solution: First, a diagram, such as the one shown in figure 3-23, is drawn. Next, a direction of current is assumed (as shown). Using this current, the polarity markings are placed at each end of each resistor and also on the terminals of the source. Starting at point A, trace around the circuit in the direction of current flow, recording the voltage and polarity of each component. Starting at point A and using the components from the circuit: Example: Three resistors are connected across a 50-volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15volts?

Solution: First, a diagram, such as the one shown in figure 6.8, is drawn. Next, a direction of current is assumed (as shown). Using this current, the polarity markings are placed at each end of each resistor and also on the terminals of the source. Starting at point A, trace around the circuit in the direction of current flow, recording the voltage and polarity of each component. Starting at point A and using the components from the circuit:

$$(+E_x) + (+E_2) + (+E_1) + (-E_A) = 0$$

Fig. 6.8Determining unknown voltage in a series circuit.

Using the same idea as above, you can solve a problem in whichthe current is the unknown quantity.

Example: A circuit having a source voltage of 60 volts contains three resistors of 5 ohms, 10 ohms, and 15 ohms. Find the circuit current.

Solution: Draw and label the circuit (fig.6.9). Establish a direction of current flow and assign polarities. Next, starting at any point - point A will be used in this example - write out the loopequation.

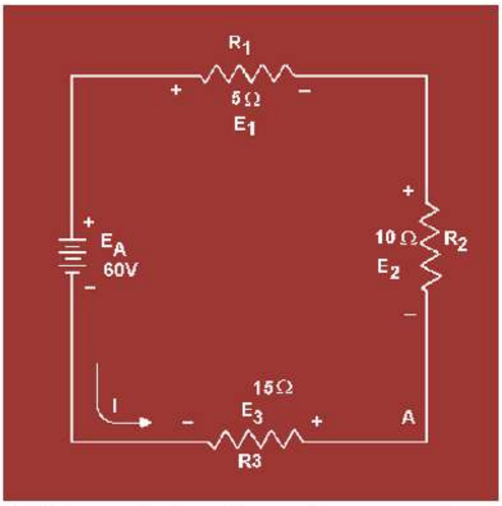


Fig. 6.9Correct direction of assumed current.

Basic equation:

$$E_2 + E_1 + E_A + E_3 = 0$$

Since E=IR, by substitution:

$$(I \times R_2) + (I \times R_1) + E_A + (I \times R_3) = 0$$

Since the current obtained in the above calculations is a positive 2 amps, the assumed direction of current was correct. To show what happens if the incorrect direction of current is assumed, the problem will be solved as before, but with the opposite direction of current. The circuit is redrawn showing the new direction of current and new polarities in figure 6.10. Starting at point A the loop equation is:

$$E_3 + E_A + E_1 + E_2 = 0$$

$$(I \times R_3) + E_A + (I \times R_1) + (I \times R_2) = 0$$

Substituting Values:

$$(I \times 10 \text{ ohms}) + (I \times 5 \text{ ohms}) + (-60 \text{ volts}) + (I \times 15 \text{ ohms}) = 0$$

Combining like terms:

$$(I \times 30 \text{ ohms}) + (-60 \text{ volts}) = 0$$

$$(I \times 30 \text{ ohms}) = 60 \text{ volts}$$

$$I = \frac{60 \text{ volts}}{30 \text{ ohms}}$$

$$I = 2 \text{ amps}$$

Substituting Values:

$(I \times 15 \text{ ohms}) + 60 \text{ volts} + (I \times 5 \text{ ohms}) + (I \times 10 \text{ ohms}) = 0$

Combining like terms:

$(I \times 30 \text{ ohms}) + 60 \text{ volts} = 0$

$I \times 30 \text{ ohms} = -60 \text{ volts}$

$$I = \frac{-60 \text{ volts}}{30 \text{ ohms}}$$

$I = -2 \text{ amps}$

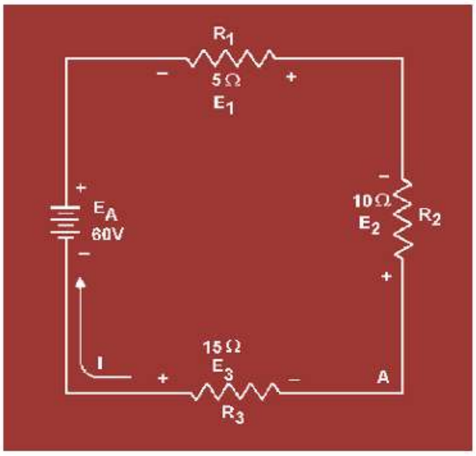


Fig. 6.10Incorrect direction of assumed current.

Notice that the AMOUNT of current is the same as before. The polarity, however, is NEGATIVE. The negative polarity simply indicates the wrong direction of current was assumed. Should it be necessary to use this current in further calculations on the circuit using Kirchhoff's law, the negative polarity should be retained in the calculations.

Series Aiding and Opposing voltage source

In many circuit applications, more than one source of emf may be present. A rise in voltage should be given as positive sign and fall in voltage a negative sign. As we go from negative terminal of the battery to its positive terminal, there is a rise in potential hence this voltage should be given a positive sign.If we go from positive to negative terminal ,there is a fall in potential hence this voltage should be preceded by negative sign .Former voltage can be considered as series aiding and latter as series opposing and the effective source voltage is the difference between the opposing voltages.

When two opposing sources are inserted into a circuit current direction is determined by the larger source.

For a simple series circuit, Kirchhoff's voltage law corresponds to Ohm's Law. To find the current in a circuit (Figure 6.11) by using Kirchhoff's voltage law, use equation.

$$\Sigma E_{source} = \Sigma IR \qquad (2\text{-}15)$$

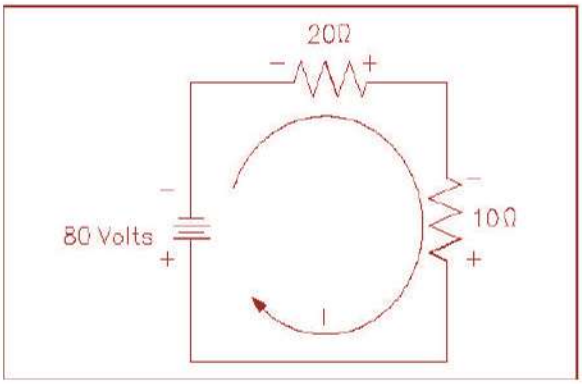


Fig. 6.11Using Kirchhoff's Voltage Law to find Current with one source.

Source

$$80 = 20(I) + 10(I)$$

$$80 = 30(I)$$

$$I = 80/30 = 2.66 \text{ amperes}$$

For example, what is the current flow in Figure 6.12? Assume that the current is flowing in the direction shown.

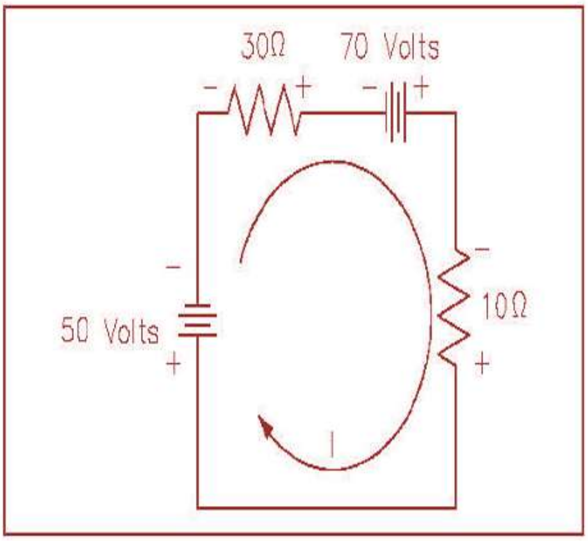


Fig. 6.12Using Kirchhoff's Voltage Law to find Current with Multiple Battery Sources

Using Kirchhoff's Voltage Law:
Example

$$\Sigma E_{source} = \Sigma IR$$

$$50 - 70 = 30I + 10I$$

$$-20 = 40I$$

$$I = \frac{-20}{40}$$

$$I = -0.5$$

The result is negative. The current is actually 0.5 ampere in the opposite direction to that of the assumed direction.

KIRCHOFF'S CURRENT LAW

Kirchoff's Current Law states that in a parallel circuit, the algebraic sum of the current entering a point is equal to the algebraic sum of the current leaving that point. This law is also known as junction law or node law or point law.

Inotherwords,totalcurrentleavingajunctionisequaltothetotalcurrententeringthatjunctionasthereisnoaccumulationof charge at the junction of the network. Junction may be defined as a point in the circuit where two or more circuit path come together. In case of parallel circuit , it is the point in the circuit where the individual branches join. Consider some conductors having current leading to point A

Incoming current = outgoing current
I1 + (-I2) + (-I3) +(+I4) +(-I5) = 0
I1+I4-I2-I3-I5=0
I1+I4=I2+I3+I5
Example using Kirchoff's both law

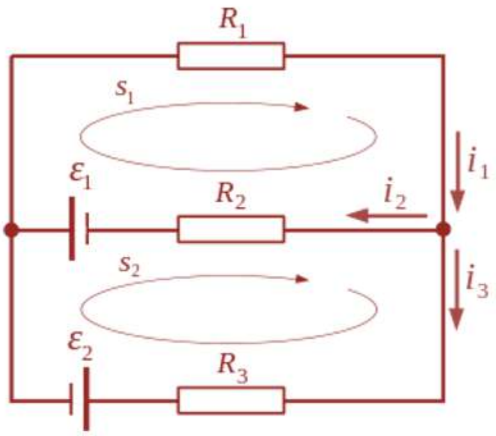


Fig. 6.13

Assume an electric network consisting of two voltage sources and three resistors.(fig 6.13)

According to the first law we have

$$i_1 - i_2 - i_3 = 0$$

The second law applied to the closed circuit s1 gives

$$-R_2 i_2 + \epsilon_1 - R_1 i_1 = 0$$

The second law applied to the closed circuit s2 gives

$$-R_3 i_3 - \epsilon_2 - \epsilon_1 + R_2 i_2 = 0$$

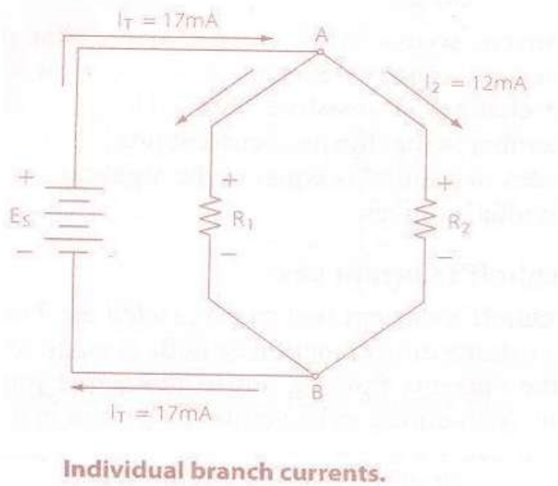
Thus we get a linear system of equations in i_1, i_2, i_3:

$$\begin{cases} i_1 - i_2 - i_3 & = 0 \\ -R_2 i_2 + \epsilon_1 - R_1 i_1 & = 0 \\ -R_3 i_3 - \epsilon_2 - \epsilon_1 + R_2 i_2 & = 0 \end{cases}$$

the solution is

$$\begin{cases} i_1 = \frac{1}{1100} \\ i_2 = \frac{4}{275} \\ i_3 = -\frac{3}{220} \end{cases}$$

$R_1 = 100,\ R_2 = 200,\ R_3 = 300$ (ohms); $\epsilon_1 = 3,\ \epsilon_2 = 4$ (volts)



Individual branch currents.

Fig.6.14

In the fig 6.14
IT= 17 mA
I1=?
I2=12mA

By using Kirchoff's current law
At junction A
Incoming current = Outgoing current
IT = I1 + I2
17 mA = I1 + 12 mA I1 = 5 mA
PARALLEL DC CIRCUIT

A circuit in which two or more electrical resistance or load are connected across the same voltage source is called a parallel circuit. As compare to series circuit,parallel circuit provides more than one path for current flow. Each parallel path is called as a branch.

The figure 6.15 is a basic parallel circuit. Current from the battery divides at point A and goes through R1 and R2.

VOLTAGE DROP IN A PARALLEL CIRCUIT

Unlike series circuit, voltage in a parallel circuit across any branch is equal to the voltage across all of the other branches. Again as per Ohm's law , voltage drop across any resistive component is equal to the product of its electrical resistance and current through it. As the voltage drop across every component connected in parallel is the same, the current through them is inversely proportional to its resistance value

Let's start with a parallel circuit consisting of three resistors and a single battery(fig 6.16)

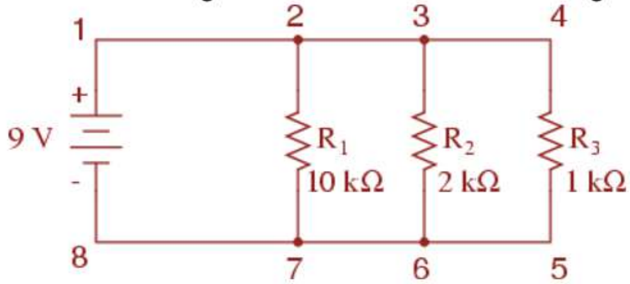


Fig. 6.16

The first principle to understand about parallel circuits is that the voltage is equal across all components in the circuit. This is because there are only two sets of electrically common points in a parallel circuit, and voltage measured between sets of common points must always be the same at any given time. Therefore, in the above circuit, the voltage across R1 is equal to the voltage across R2 which is equal to the voltage across R3 which is equal to the voltage across the battery. This equality of voltages can be represented in another table for our starting values.

	R_1	R_2	R_3	Total	
E	9	9	9	9	Volts
I					Amps
R	10k	2k	1k		Ohms

Fig. 6.17

Just as in the case of series circuits, the same law for Ohm's Law applies: values for voltage, current, and resistance must be in the same context in order for the calculations to work correctly.

However, in the above example circuit, we can immediately apply Ohm's Law to each resistor to find its current because we know the voltage across each resistor (9 volts) and the resistance of each resistor:

RESISTANCE OF A PARALLEL CIRCUIT

Resistors are said to be connected together in "Parallel" when both of their terminals are respectively connected to each terminal of the other resistor or resistors. Unlike the previous series resistor circuit, in a parallel resistor network the circuit current can take more than one path as their are multiple nodes. Then parallel circuits are currentdividers.

Since there are multiple paths for the supply current to flow through, the current is not the same at all points in a parallel circuit. However, the voltage drop across all of the resistors in a parallelresistivenetworkisthesame.Then,ResistorsinParallel have a Common Voltage across them and this is true for all parallel connected elements.

Parallel Resistor Circuit

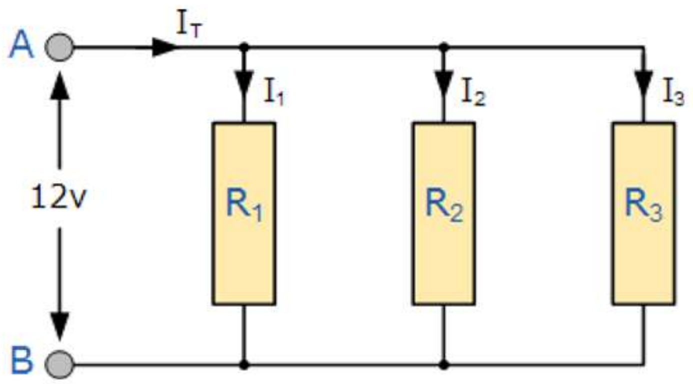


Fig. 6.18

In the previous series resistor network we saw that the total resistance, RTof the circuit was equal to the sum of all the individual resistors added together. For resistors in parallel the equivalent circuit resistance RTis calculated differently (fig 6.18)

Here, the reciprocal (1/R) value of the individual resistances are all added together instead of the resistances themselves with the inverse of the algebraic sum giving the equivalent resistance as shown.

Parallel Resistor Equation

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \;\ldots\ldots + \frac{1}{R_n} \text{ etc}$$

Then the inverse of the equivalent resistance of two or more resistors connected in parallel is the algebraic sum of the inverses of the individual resistances.

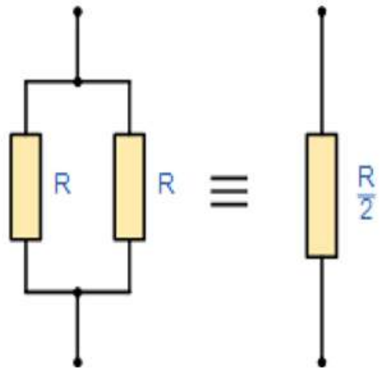


Fig. 6.19

If the two resistances or impedances in parallel are equal and of the same value, then the total or equivalent resistance, RTis equal to half the value of one resistor(fig 6.19). That is equal to R/2 and for three equal resistors in parallel, R/3, etc.
Note that the equivalent resistance is always less than the smallest resistor in the parallel network so the total resistance, RTwill always decrease as additional parallel resistors are added.

Parallel resistance gives us a value known as Conductance, symbol G with the units of conductance being the Siemens, symbol S. Conductance is the reciprocal or the inverse of resistance, (G = 1/R).If conductance increases, current value

three resistors are of equal value and one resistor gets open, then
current in remaining two will remain same however taking the above case in series, current in other two resistor will increase.

We now know that resistors that are connected between the same two points are said to be in parallel. But a parallel resistive circuit can take many forms other than the obvious one given above and here are a few examples of how resistors can be connected together in parallel(fig 6.20)

Various Parallel Resistor Net

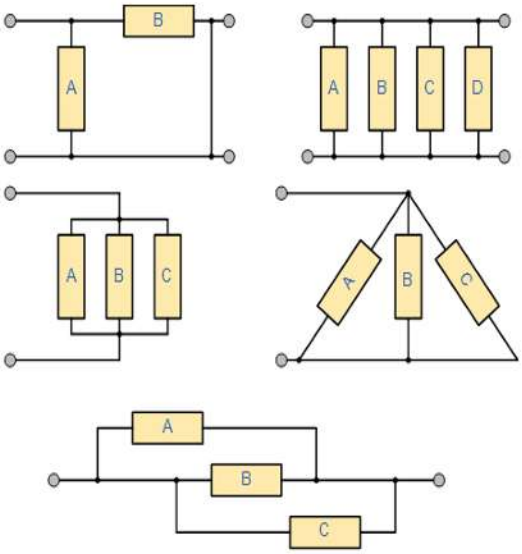


Fig. 6.20

Resistors in Parallel (fig 6.21)
Find the total resistance, RTof the following resistors connected in a parallel network.

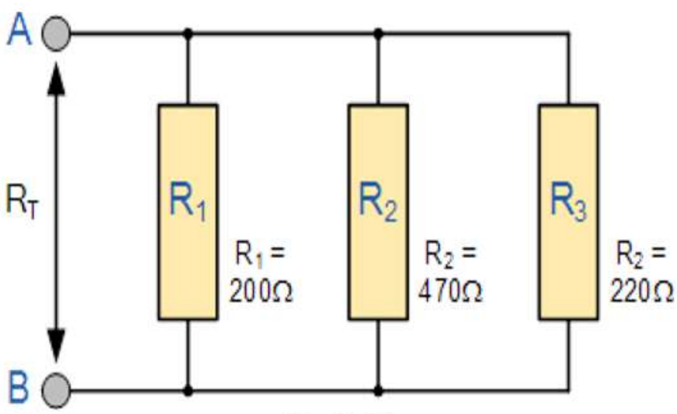


Fig.6.21

The total resistance RT across the two terminals A and B is calculated as:

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

$$= \frac{1}{200} + \frac{1}{470} + \frac{1}{220} = 0.0117$$

$$\text{therefore: } R_T = \frac{1}{0.0117} = 85.67\Omega$$

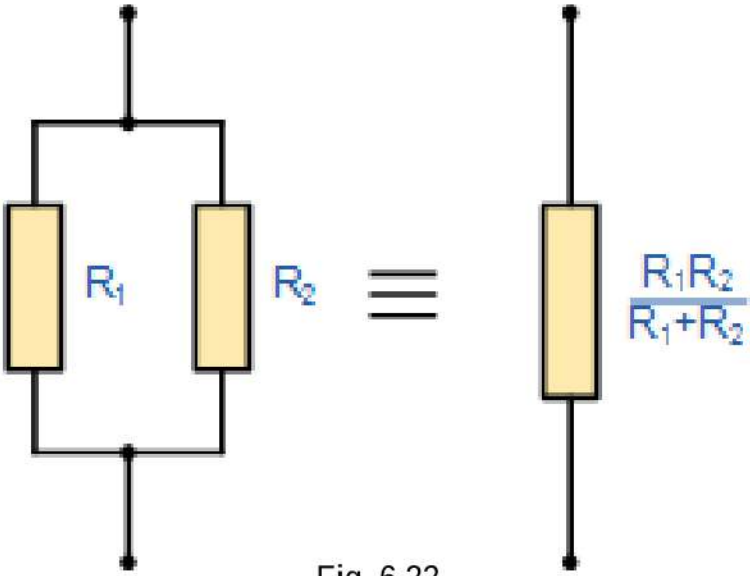


Fig. 6.22

This method of reciprocal calculation can be used for calculating any number of individual resistances connected together with in a single parallel network. (fig6.22)
If however, there are only two individual resistors in parallel then we can use a much simpler and quicker formula to find the total or equivalent resistance value, RT and help reduce the reciprocal math's a little. This quicker method of calculating two resistors either equal or unequal connected together in parallel is given as:

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

Resistors in Parallel (fig 6.23)

Consider the following circuit which has only two resistors in a parallel combination.

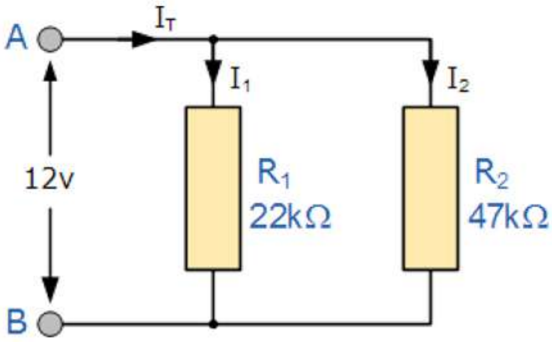


Fig. 6.23

Using our formula above for two resistors connected together in parallel we can calculate the total circuit resistance, RT as:

$$R_T = \frac{22k\Omega \times 47k\Omega}{22k\Omega + 47k\Omega} = 14{,}985\Omega \text{ or } 15k\Omega$$

One important point to remember about resistors in parallel, is that the total circuit resistance (RT) of any two resistors connected together in parallel will always be LESS than the value of the smallest resistor in that combination.

In our example above, the value of the combination was calculated as: RT = 15kΩ, where as the value of the smallest resistor is 22kΩ, much higher. In other words, the equivalent resistance of a parallel network will always be less than the smallest individual resistor in the combination.

Also, in the case of R1being equal to the value of R2, that isR1 = R2, the total resistance of the network will be exactly half the value of one of the resistors, R/2.

Likewise, if three or more resistors each with the same value are connected in parallel, then the equivalent resistance will be equal to R/n where R is the value of the resistor and n is the number of individual resistances in the combination.

For example, six 100Ω resistors are connected together in a parallel combination. The equivalent resistance will therefore be: RT = R/n = 100/6 = 16.7Ω. But note that this ONLY works for equivalent resistors.

Currents in a Parallel Resistor Circuit

The total current, IT in a parallel resistor circuit is the sum of the individual currents flowing in all the parallel branches. The amount of current flowing in each parallel branch is not necessarily the same as the value of the resistance in each branch determines the current within that branch.

For example, although the parallel combination has the same voltage across it, the resistances could be different therefore the current flowing through each resistor would definitely be
different as determined by Ohms Law.

parallel is not necessarily the same value as it depends upon the resistive value of the resistor. However, we do know that the current that enters the circuit at point A must also exit the circuit at point B.
Some examples related to parallel dc circuits
EXAMPLE In the following schematic diagram(fig 6.24), find the total current, I.

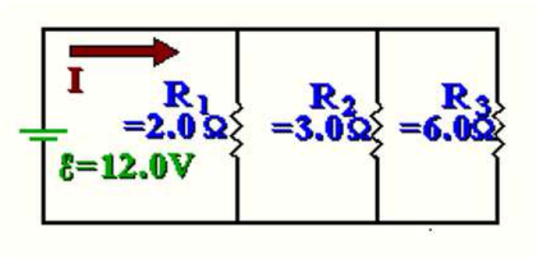


Fig. 6.24Example Problem: Resistors in Parallel

Hints

1. You will need Ohm'sLaw.
2. How are resistors related when connected inparallel?
3. What is the potential drop across eachresistor?
4. How does current behave in parallelbranches?

e know the total potential of this circuit,

= 12.0 V ε

So, between points A and B, the potential must drop 12.0V. Also, the potential drop across branches of a circuit are equal. That is

$$V_1 = V_2 = V_3 = \mathcal{E} = 12.0V$$

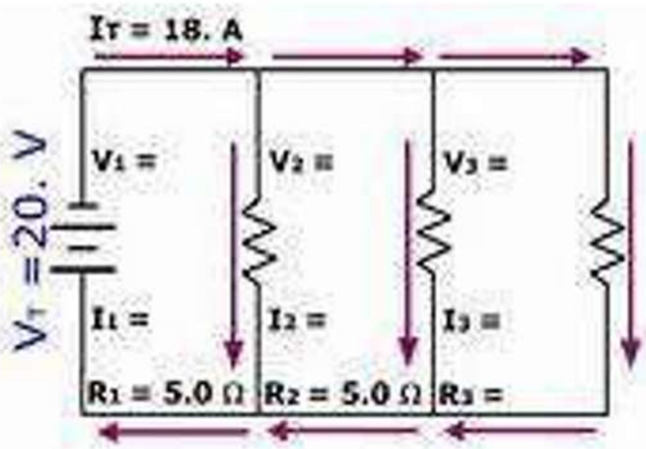
,

We can use Ohm's Law
V = IR
or
I = V/R
to find the current across each resistor.

$$I_1 = \frac{V_1}{R_1} = \frac{12.0V}{2.0\ \Omega} = 6.0A$$
$$I_2 = \frac{V_2}{R_2} = \frac{12.0V}{3.0\ \Omega} = 4.0A$$
$$I_3 = \frac{V_3}{R_3} = \frac{12.0V}{6.0\Omega} = 2.0A$$

Recall that the currents through branches of a parallel circuit add to give the total current. That is, the total current 'splits up' so that part of the total current travels down each branch. Because of conservation of charge, the sum of the currents in each branch must equal the amount going into the branch. (This is Kirchhoff's Current Law.)
So, adding up the three currents, we get:

$$I = I_1 + I_2 + I_3$$
$$= 6.0 + 4.0 + 2.0 = 12.0A$$



EXAMPLE (fig 6.25)

Calculate
R3=? I1=? I2=? I3=?
Solution: we know VT = 20 V , IT = 18 A, R1 = 5 Ω, R2 = 5 Ω By Ohm's Law
RT = VT/IT
RT = 20/18 = 10/9 Ω

We know, Resistance in parallel is 1/RT=1/R1 + 1/R2 + 1/R3
1/10/9 =1/5 + 1/5 + 1/R3
9/10 = 2/5 + 1/R3

1/R3 = 9/10 -2/5
1/R3 = 9-4/10
1/R3 = 5/10 = 1/2
R3 = 2Ω
Referring above figure
I1 = V1/R1 = 20 /5 = 4 A I2 = V2/R2 = 20/5 = 4 A I3 = V3 / R3 = 20/2 = 10A
Hence Kirchoffs current law is proved as
I1 + I2 + I3 = IT
4A + 4A + 10A = 18 A EXAMPLE(fig 6.26)

In this circuit, three resistors receive the same amount of voltage (24 volts) from a single source. Calculate the amount of current "drawn" by each resistor, as well as the total resistance:

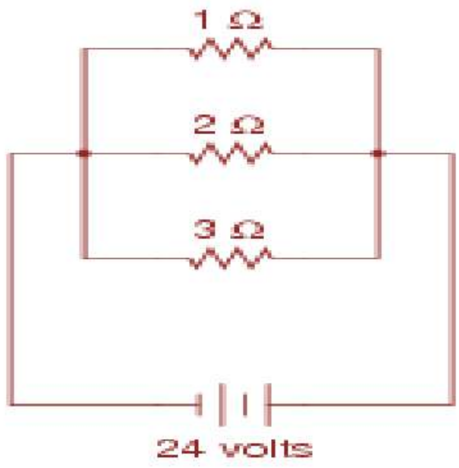


Fig. 6.26

Given R1= 1Ω ; R2 = 2Ω ; R3 = 3Ω

In a parallel circuit
1/RT = 1/R1 + 1/R2 + 1/R3
1/RT = 1/1 + 1/2 + 1/3
1/RT = 6 + 3 + 2 = 11/6
6

1/RT = 11/6
RT =6/11Ω
I1 = V/R1 = 24 /1=24A
I2 = V /R2 = 24/2 =12A
I3 = V/R3 = 24/3 = 8A

EXAMPLE(fig 6.27)

What will happen to the brightness of the light bulb if the switch in this circuit is suddenly closed?

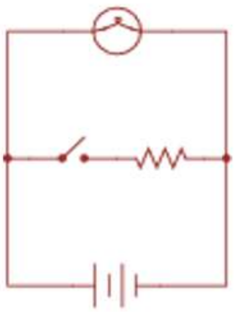


Fig. 6.27

Ideally, there will be no change whatsoever in the light bulb's brightness when the switch is closed, because voltage sources are supposed to maintain constant voltage output regardless of

loading. As you might have supposed, though, the additional current "drawn" by the resistor when the switch is closed might actually cause the lamp to dim slightly

EXAMPLE(fig 6.28)

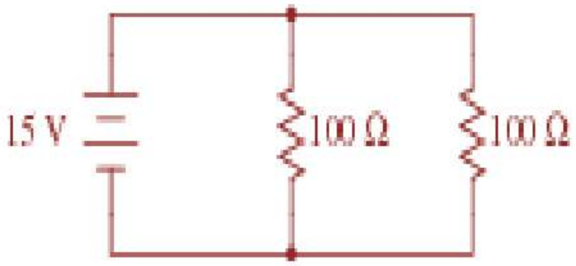


Fig. 6.28

Given: VT = 15 V
R1 = 100 Ω R2 = 100 Ω
I/RT = 1/R1 + 1/R2 = 1/100+1/100 1/RT = 2/100
1/RT = 1/50
RT = 50 Ω

Characteristics of a parallel circuit

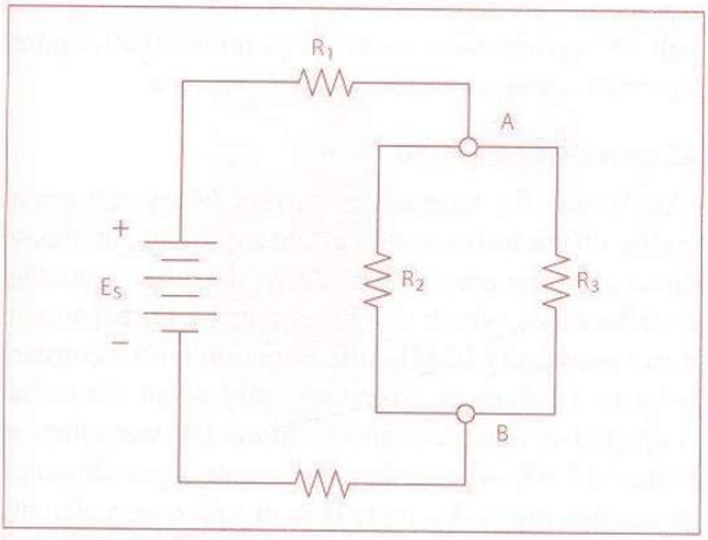
Same voltage act across all the parts of thecircuit
Different resistors have their individualcurrent
Branch currents areadditive
Conductances areadditiv
Powers areadditive

SERIES PARALLEL DC CIRCUIT

Most of the circuits in electrical are series- parallel circuits that is it is a combination of series and parallel circuit. A series parallel circuit consists of group of parallel resistors connected in series with other resistors. To solve series-parallel circuit the same rule can be applied as for the individual series and parallel circuits.

UNDERSTANDING A SERIES PARALLEL CIRCUIT(COMBINATION CIRCUIT)

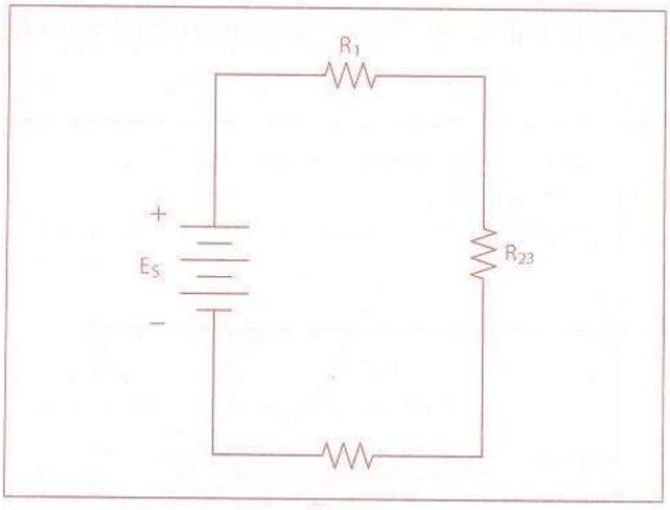
EXAMPLE(fig 6.29)



Series-parallel circuits.

Fig. 6.29

In the fig 6.29, voltage source will provide a current out to resistor R1, then to parallel resistors R2 and R3 and then to
unknown resistor after junction B say R4 before returning to source voltage.
First step is to recognize parallel group of resistors R2 and R3 and find out their equivalent resistance.
R23=R2R3



Equivalent circuit with three series connected resistors.

R2 + R3

R2 and R3 can be reduced to R23. Now the above diagram can be simplified as below (fig 6.30)
fig.6.30
VOLTAGE DIVIDER

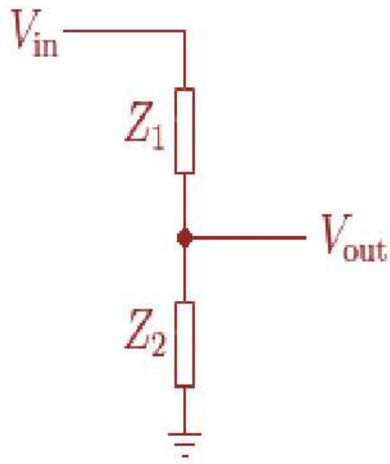


Fig. 6.44 A simple voltage divider

A voltage divider are devices that make it possible to obtainmore thanonevoltagefromasinglepowersource(fig6.44).Itconsistofresistororresistorsconnectedinserieswithfixedormovable contact and two fixed terminal contacts. As current flowthrough the resistor, different voltages can be obtained between the contacts.

Series circuit are used as Voltage Divider. As same current flow in the series circuit, voltage drop is proportional to the ohmic value of resistors.

To understand how a voltage divider works, examine fig 6.45.Each load draws a given amount of current: I1,I2,I3.In addition to load current ,some bleed current IB flows. The current IT is drawn from the power source and is equal to the sum of all currents.

The voltage at each point is measured with respect to common point or reference point.

NOTE: Common point is the point at which the total current IT divides into separate current (I1,I2,I3)

The current which does not flow through any of the load devices is called a bleed current.

Each part of voltage divider has different current flowing in it. The current distribution is as follows:

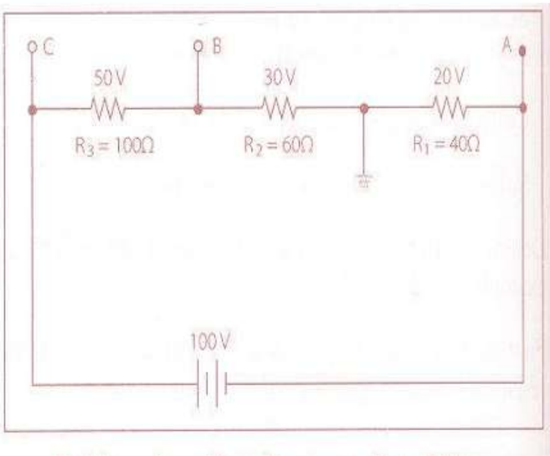
ThroughR1 bleeder current(IB)

ThroughR2 B plusI1

ThroughI3 B plus I1, plusI2

The voltage across each resistor of voltage divider is 90 V acrossR1

60 V across R2 50 V acrossR3



Positive and negative voltage on a voltage divider.

Fig. 6.46

In the figure 6.46,the common reference point that is ground symbol has been moved to a different point on the voltage divider. The voltage drop across R1 is 20 V, however since tap A is connected to point in the circuit that is at the same potential as the negative side of the battery, the voltage between tap A and reference point is a negative (-)20V .Since resistors R2 and R3 are connected to the positive

side of the battery, the voltages between the reference point and tap B or C arepositive.
The following points should be kept in mind while determining negative and positive voltages:
If current enters a resistance flowing away from the reference point, the voltage drop across that resistance is positive in respect to the referencepoint.
If current flows out of a resistance towards the reference point, the voltage drop across that resistance is negative in respect to the referencepoint.
It is the location of the reference point that determines whether a voltage is positive or negative.

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{45V}{1.5k\Omega}$$

$$I_{R1} = 30mA$$

Using this value for IR1, calculate the resistance needed for the next divider resistor. The current (IR2) is equal to the bleeder current plus the current used by load 1.

$$I_{R1} = 30mA$$
$$I_{load1} = 210mA$$

Solution:

$$I_{R2} = I_{R1} + I_{load1}$$
$$I_{R2} = 30mA + 210mA$$
$$I_{R4} = 240mA$$

The voltage across R2 (ER2) is equal to the difference between the voltage requirements of loads 2 and1, or 120 volts.

Calculate the value of R2. Given:

$$E_{R2} = 120V$$
$$I_{R2} = 240mA$$

Solution:

$$R_2 = \frac{E_{R2}}{I_{R2}}$$

$$R_2 = \frac{120V}{240mA}$$

$$R_2 = 500\Omega$$

The value of the final divider resistor is calculated with IR3 (IR2 + I load 2) equal to 340 mA and E R3 (Es - E load 2) equal to25.5V.

Given:

$$E_{R3} = 25.5V$$
$$I_{R3} = 340mA$$

Solution

$$R_3 = \frac{E_{R3}}{I_{R3}}$$

$$R_3 = \frac{25.5V}{340mA}$$

$$R_3 = 75\Omega$$

A 75-ohm resistor may not be easily obtainable, so a network of resistors equal to 75 ohms can be used in place of R3.

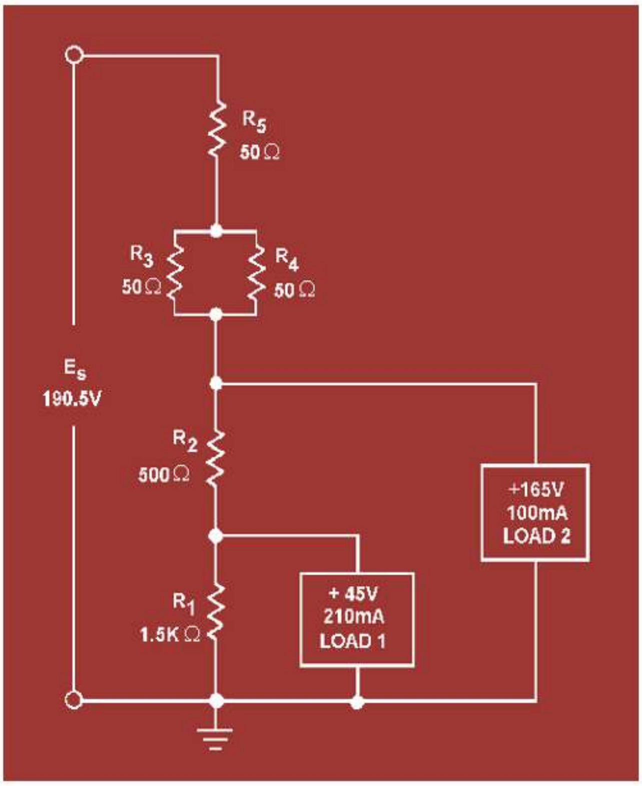


Fig.6.47

SIGNIFICANCE OF INTERNAL RESISTANCE OF A SUPPLY

The resistance present of a battery while connected to a load is called internal resistance(IR).IR restricts the movement of current inside of any power source, including batteries. In case of a battery , the IR is determined by the load applied and the battery's state of charge.

A battery's IR is equal to the difference between the OCV and CCV, divided by the applied load. IR = OCV-CCV/I(Load Amperage)

This equation is derived by Ohm's Law R = E/I

If OCV of a battery is 14 V and the CCV is 12V with 100 A load applied,

IR = OCV –CCV/I(LOAD) = 14V-12V/100A = 2V/100A =

0.02Ω

OCV is the terminal voltage of a battery when battery is not connected to load CCV is the terminal voltage of a battery when battery is connected to load

As the battery becomes discharged its internal resistance becomes greater. This is due to lowering of battery's CCV as the battery becomes weaker. The OCV remains nearly constant while the CCV drops, therefore the difference between these two voltages increases. Hence IR increases.

The IR of a battery becomes very significant when a power source is chosen or a delicatecircuit is designed. However, for general purpose application, a battery's internal resistance will not adversely affect an aircraft electrical system until that battery becomes over 75% discharged. When the battery reaches this low state of charge, its internal resistance becomes too high and the CCV lowers. This low CCV obviously affects circuit performance.

CURRENT

Electrons in motion make up an electric current. Current is measurement of a rate at which a charge flows .The moving charges are the free electrons found in conductors, such as copper, silver aluminum, and gold

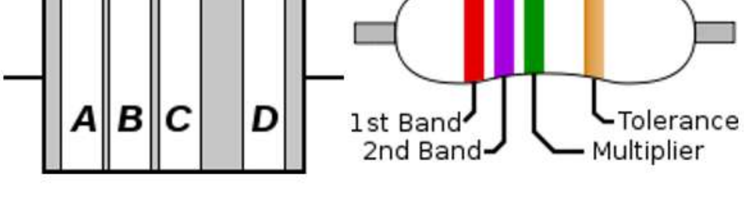
.

These loosely bound electrons can be easily motivated to move in a given direction when an external source, which as a battery is applied to the circuit. These electrons are attracted to the positive terminal of the battery, while the negative terminal is the sourceof the electrons. The greater amount of charge moving through the conductor in a given amount of time it is translated into acurrent.
Greater amount of charge moving through the conductor in a given amount of time will be translated into a current.

Current=charge
Time
Or
I = Q
T

COLOUR CODE SYSTEMS (resistor)

With end to center band system, four bands are commonly used on resistor.



To distinguish left from right there is a gap between the C and D bands.
Band A is the first significant figure of component value (left side)
Band B is the second significant figure (Some precision resistors have a third significant figre, and thus five bands.) Band C is the decimal multiplier
Band D if present, indicates tolerance of value in percent (no band means 20%)

For example, a resistor with bands of yellow, violet, red, andgoldwill have first digit 4 (yellow in table below), second digit 7 (violet), followed by 2 (red) zeros: 4,700 ohms. Gold signifies that the tolerance is ±5%, so the real resistance could lie anywhere between 4,465 and 4,935ohms.
Resistors manufactured for military use may also include a fifth band which indicates component failure rate (reliability)

The first and second band represent the numerical valueof theresistor,andthecolorofthethirdbandspecifythepower-of-tenmultiplier.Thecolorbandsarealwaysreadfromleft to right starting with the side that has a band closer to the edge.
For carbon-composition and carbon film resistors, the common tolerances are 5%, 10%, and 20%, indicating that the actual value of the resistor can vary from the nominal value by ±5%, ±10% and ±20%. If the band is gold,it specifies a 5% tolerance; silver specifies a 10% tolerance; if no band is present, the tolerance is20%.

The table below shows the color code and their associated value:

Color	First-band Digit	Second-band Digit	Third-band Multiplier	Fourth-band
Black	0	0	100 = 1	
Brown	1	1	101 = 10	1%
Red	2	2	102 = 100	2%
Orange	3	3	103 = 1000	3%
Yellow	4	4	104 = 10000	4%
Green	5	5	105 = 100000	
Blue	6	6	106 = 1000000	
Violet	7	7	107 = 10000000	
Gray	8	8	108 = 100000000	
White	9	9	109 = 1000000000	
Gold				5%
silver				10%
None	20%			

The first and second bands represent the numerical value of the resistor, and the color of the third band specifiesthe power-of-ten multiplier. The color bands are always read from left to right starting with the side that has a band closer to theedge.
For carbon-composition and carbon film resistors, the common tolerances are 5%, 10%, and 20%, indicating that the actual value of the resistor can vary from the nominal value by ±5%, ±10% and ±20%. If the band is gold, it specifies a 5% tolerance; silver specifies a 10% tolerance; if no band is present, the tolerance is 20%.

3.7 RESISTANCE

It may be defined as the property of a substance due to which it opposes (or restricts) the flow of electricity (i.e. electrons) through it.

Metals (as a class) acids and salts solutions are good conductors of electricity. Amongst pure metals, silver, copper and aluminum are very good conductors in the given order. Due to the presence of a large number of free or loosely attached electrons in theiratoms.

Those substances which offer relatively greater difficulty or hindrance to the passage of these electrons are said to be relatively poor conductors of electricity like bake lite, mica m glass rubber p.v.c (polyviny1chloride) and dry woodetc.

For insulators whose resistances are very high, a much
bigger unit is used i.e. mega-ohm = 106 (the prefix _mega' or mego meaning a million) or kilo – ohm = 103 ohm (kilo means thousand). In the case of very small resistances, smaller units like milli- ohm = 10-3 ohm or micro-ohm =10-6ohm are used. The symbol for ohm is Ω.

Prefix	Its meaning	Abbreviation	Equal to
Mega-	One million	mMΩ	106Ω
Kilo-	One thousand	kΩ	103Ω
Centi-	One hundredth	cΩ	10-2Ω
Milli-	One thousandth	mΩ	10-3Ω
Micro-	One millionth	μΩ	10-6Ω

Table 1.1. Multiple and sub-multiples of Ohm

Law ofresistance
The resistance R offered by a conductor depends on the following factors:
i It varies directly as itslength
It varies inversely as the cross-section A of theconductor.
It depends on the nature of thematerial.
It also depends on the temperature of theconductor.

1. length of conductor: The resistance of a metallic conductor is directly proportional to the length of a given wire. The longer the length of given size of wire greater is its resistance. If length of a given wire increases, some energy will be given off as heat as free electrons move from atom to atom. This energy loss is subtracted from the energy given to the conductor (given voltage).Finally this leads to decrease of current flow and increase of resistance. If length of conductor increases, resistanceincreases.

R is directly proportional to the Length of Conductor

We can use the K M etc signs in between 2 no's the place of decimal for eg :- 1.2KΩ can be written as 1K2 Ω

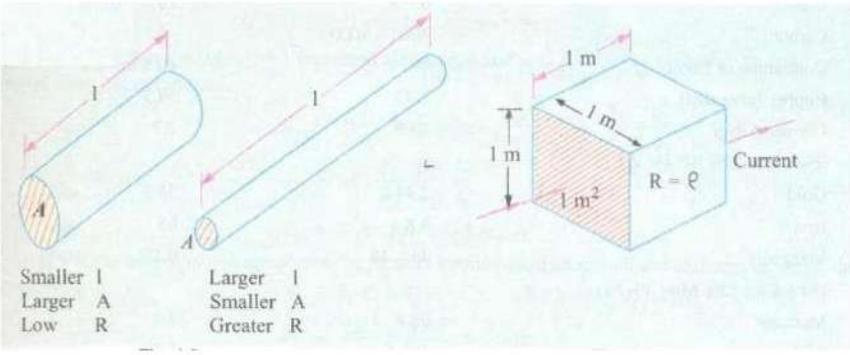


Fig.7.1

Type of conductor material (Resistivity): The resistance ofa metallic conductor is dependent on the type of conductor material .Certain metals are used as conductors due to free electrons in the outermost orbit. Copper is one of the best conductor as compare to aluminum for a given diameter. However, aluminum is often used when the weight factor is important.

Unit of resistivity is ohm-meter(Ω-m)

Conductor MATERIA	L RESISTIVITY (OHM MATERS @200 C
Silver	1.64x10-8
Copper	1.72x10-8
Aluminum	2.83x10-8
Tungsten	5.50x10-8
Nickel	7.80x10-8
Iron	12.0x10-8
Constantan	49.0x10-8
Nichrome ii	110x10-8

3.Cross sectional Area of conductor:The resistance ofa conductor is inversely proportional to the cross sectionalarea of the conductor.If cross sectional area is increased, more no. of electrons moves through a conductor. Resulting in large amount of current flow for a given voltage. More thecurrent flow, less will be the resistance and vice versa. Resistance of a conductor is inversely proportional to the cross sectional area.

4. Effect of Temperature: The fourth significant factor influencingtheresistanceofaconductoristhetemperature. The amount of change in resistance per unit change of temperature is called as the temperature coefficient. Some material shows positive temperature coefficient (their resistance increases with increase of temperature). Some material shows negative temperature coefficient (their resistance decreases with increase of temperature. An increase in operating temperature in most electrical devices result in increase in resistance and decrease in current.

ρ meter

Unit of resistivity is ohm-meter(Ω-m)

Conductor MATERIA L RESISTIVITY

(OHM MATERS @200 C

Silver 1.64x10-8
Copper 1.72x10-8
Aluminum 2.83x10-8
Tungsten 5.50x10-8
Nickel 7.80x10-8
Iron 12.0x10-8
Constantan 49.0x10-8
Nichrome ii 110x10-8

Metals have positive temperature coefficient(PTC) insulators(such as paper, rubber, glass, mica

Some alloys such as Constantan and Manganin have zero temperature coefficient as their resistance remains relatively constant with change in temperature.

The resistance R_t at a temperature of t(°C) can be calculated from the approximation$R_t = R_0 (1 +t)$ Where,R_0 is the resistance at 0°C, t is the temperature coefficient per degree, taking 0°C as standard.

Optional band

A few resistors have an additional band - often giving beginners a bit of trouble - indicating either the reliability or the temperature coefficient.

The reliability band specifies the failure rate per 1000 hours (assuming that a full wattage being applied to the resistor). This stripe is found primarily on 4-band resistors made for military applications and seldom used in commercial electronics.

The temperature coefficient is more commonly marked, especially on quality 5-band resistors, as it starts to become an important factor for precision components. For a resistor with temperature coefficient of 200 ppm, for example, a change in temperature of 50°C causes a value change of 1%. The most common values for this band are presented in the color chart above.

Examples:
Four band code:

Green, blue, red, with silver tolerance band: 56 x 100 = 5.6 kohms, with a tolerance of 10%

Red, red, brown, silver tolerance band: 22 x 10 = 220 ohms (220 ohms), with a tolerance of 10%

More 4 band resistor color code examples: E12 and E24series

Five band code:

 Blue, brown, white, brown, red tolerance band:

619x10=6190ohms(6.19Kohms),withatoleranceof2%

Red, red, brown, black, with a brown tolerance band:221x1=221ohms,withatoleranceof1%

Brown, black, black, red, with a brown tolerance band: 100 x 100 = 10000 ohms (10.0K), with a tolerance of 1%

Examples of multiples and sub-multiples commonly used
A resistance of 15M would be written as 15 x 10 The omega(Ω)sign is not used when a prefix is used and the accepted way of writing resistance values is asfollow:
10 Ω written as 10 ohms
1.5 kΩ written as 1K5
43.7 meg ohms as 43M7

RESISTOR IN SERIES AND PARALLEL SERIES RESISTANCE:

Resistors can be connected in series; that is, the current flows through them one after another. The circuit inFigure7.2 shows three resistors connected in series, and the direction of current is indicated by the arrow.

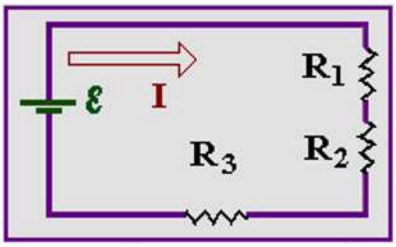


Figure 7.2 Resistors connected in series

Note that since there is only one path for the current to travel, the current through each of the resistors is the same.

OPERATION AND USE OF POTENTIOMETER AND RHEOSTAT


fig 7.16)

A potentiometer, a pot, is a three-terminal resistor with as liding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat.(fig 7.16)

A potentiometer measuring instrument is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle ,hence its name.
Potentiometers are commonly used to control electrical devices such as volume controls audio

equipment. Potentiometers operated by a mechanism can be used as position transducers, for example, in a joystick. Potentiometers are rarely used to directly control significant power (more than a watt), since the power dissipated in the potentiometer would be comparable to the power in the controlled load.

Potentiometer construction

Fig 7.17

A potentiometer is a manually adjustable electrical resistor that uses three terminal electrical devices,

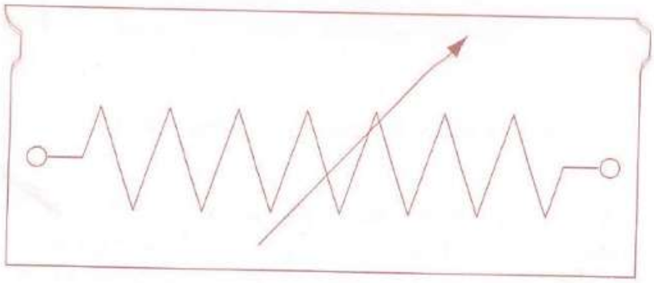
potentiometers are what establish the levels of output. For example, in a loudspeaker,a potentiometer is used to adjust the volume. In a television set, computer monitor or light dimmer, it can be used to control the brightness of the screen or light bulb.

How it works

Potentiometers, sometimes called pots, are relatively simple devices. One terminal of the potentiometer is connected to a power source,and another is hooked up to a ground— apoint withnovoltageorresistanceandwhichservesasaneutral reference point. The third terminal slides across a strip of resistive material. This resistive strip generally has a low resistance at one end, and its resistance gradually increases to The third terminal serves as the connection between the power source and ground, and it usually is operated by the user through the use of a knob or lever.

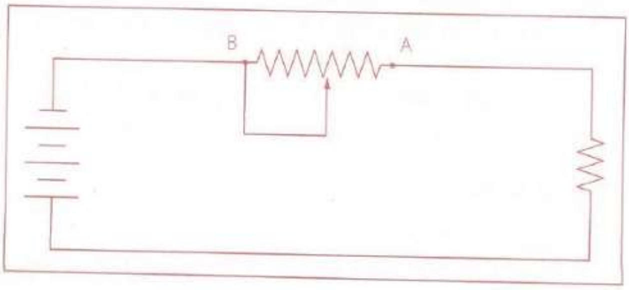
The user can adjust the position of the third terminal along the resistive strip to manually increase or decrease resistance. The amount of resistance determines how many current flows through a circuit. When used to regulate current,thepotentiometer is limited by themaximum resistivity of the difference, or voltage, acThe setup involved inutilizing a potentiometer for this purpose is a little more complicated. It involves two circuits, with the first circuit consisting of a cell and a resistor. At one end, the cell is connected in series to the second circuit, and at the other end,it is connected to a potentiometer in parallel with the second circuit.

The potentiometer in this arrangement drops the voltage by an amount equal to the ratio between the resistance allowed by the position of the third terminal and the highest possible resistivity of the strip. In other words, if the knob controlling the resistance is positioned at the exact halfway point on the resistive strip, then the output voltage will drop by exactly50 percent, no matter what the input voltage is. Unlike with electrical current regulation, voltage regulation is not limited by the maximum resistivity of the strip.



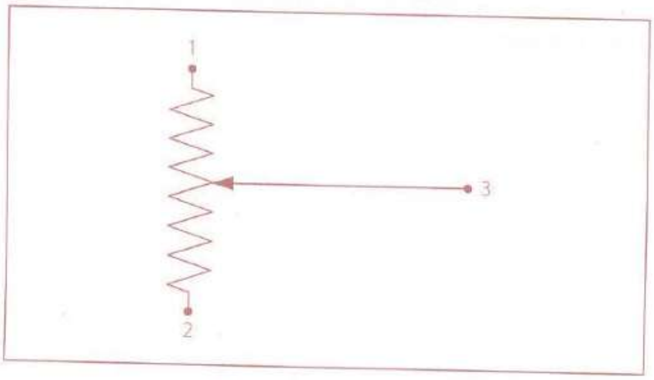
. Rheostat schematic symbol.

Fig 7.18



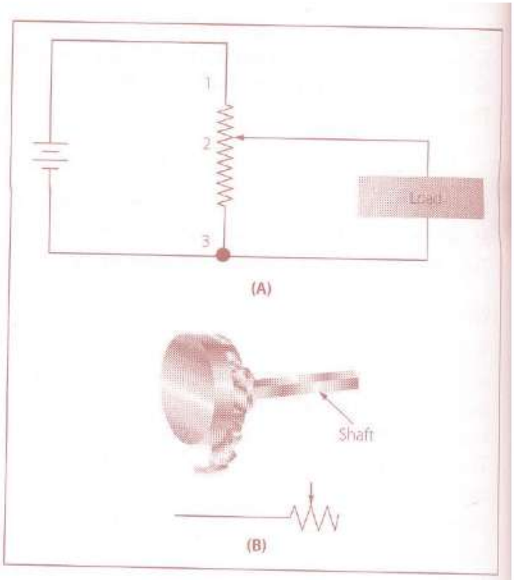
. Rheostat connected in series.

Fig. 7.19



. Potentiometer schematic symbol.

Fig. 7.20

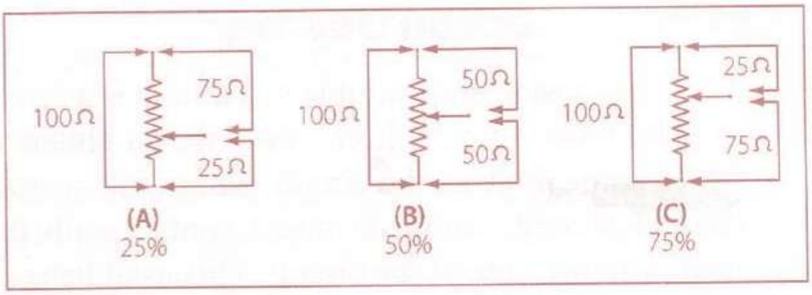


Potentiometer and schematic symbol.

Fig. 7.21

In the figure 7.21, potentiometer is used to obtain variable voltage from affixed voltage source to an electrical load. The voltage applied to the load is between point 2 and 3.When the slider arm is moved to point 1,entire voltage is applied to electrical load and when the arm is moved to point 3,the voltage applied to the load is zero. Thus, potentiometer varies the voltage between full to zero to the load

Linear Potentiometer



Linear potentiometer schematic.

Fig 7.22

In linear type, the resistance between both theterminal and the wiper varieslinearly with the position of the wiper.(fig 7.22)
machinery

A rheostat is a variable resistor which is used to control current. They are able to vary the resistance in a circuit without interruption. The construction is very similar to the construction of a potentiometers. It uses only two connections, even when 3 terminals (as in a potentiometer) are present. The first connection is made to one endofthe resistive element and the other connection to the wiper (sliding contact). In contrast to potentiometers, rheostats have to carry a significant current. Therefore they are mostly constructed as wire wound resistors. Resistive wire is wound around an insulating ceramic core and the wiper slides over thewindings.

Rheostats were often used as power control devices, for example to control light intensity (dimmer), speed of motors, heaters and ovens. Nowadays they are not used for this function anymore. This is because of their relatively low efficiency. In power control applications they are replaced by switching electronics. As a variable resistance they are often used for tuning and calibration incircuits.

OPERATION OF THE WHEATSTONE BRIDGE

Wheatstone Bridge
The Wheatstone Bridge was originally designed by Charles Wheatstone to measure unknown resistance values and as a means of calibrating measuring instruments, voltmeters, ammeters, etc, by the use of a long resistive slide wire. Although today digital multi-meters provide the simplest way to measure a resistance, The Wheatstone Bridge can still be used to measure very low values of resistances down in the milli-Ohmsrange.

The Wheatstone Bridge circuit is nothing more than two simple series-parallel arrangements of resistors connected between a voltage supply terminal and ground producing zero voltage difference when the two parallel resistor legs are balanced. A Wheatstone bridge circuit has two input terminals and two output terminals consisting of four resistors configured in a diamond-like arrangement as shown. This is typical of how the Wheatstone bridge isdrawn.

The Wheatstone Bridge

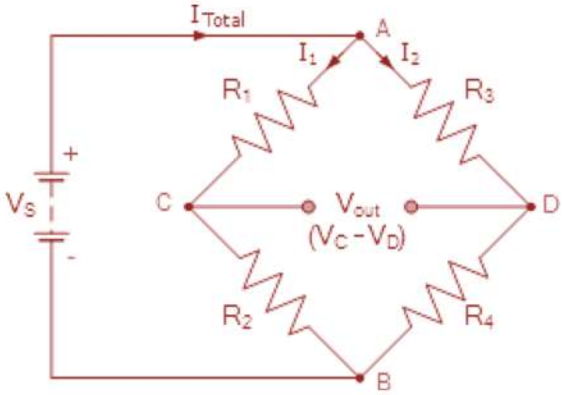


Fig 7.25

When balanced, the Wheatstone bridge can beanalysed simply as two series strings in parallel (fig 7.25). In resistorsin Series, we saw that each resistor within the series chain produces an IR drop, or voltage drop across itself as a consequence of the current flowing through it as defined by Ohms Law. Consider the series circuit below.(fig7.26)

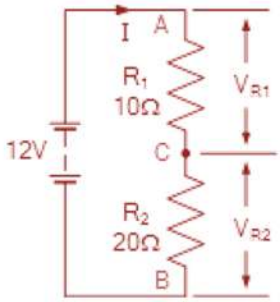


Fig 7.26

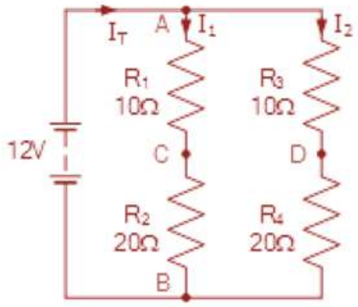
As the two resistors are in series, the same current (i) flows through both of them. Therefore the current flowing through these two resistors in series is given as: V/RT.

$I = V \div R = 12V \div (10\Omega + 20\Omega) = 0.4A$

The voltage at point C, which is also the voltage drop acrossthe lower resistor, R2is calculatedas:

$VR2 = I \times R2 = 0.4A \times 20\Omega = 8$ volts

Then we can see that the source voltage VS is divided among the two series resistors in direct proportion to their resistances as VR1= 4V and VR2= 8V. This is the principle of voltage division, producing what is commonly called a potential divider circuit or voltage dividernetwork.



APPLICATION OF WHEATSTONE BRIDGE

Resist

A typical axial-lead

Tvp Passiv

The Wheatstone Bridge has many uses in electronic circuits other than comparing an unknown resistance with a known resistance. When used with Operational Amplifiers, the Wheatstone bridge circuit can be used to measure and amplify small changes in resistance, RX due, for example, to changes in light intensity as we have seen above.

ELECTRICAL RESISTOR

Working Electric

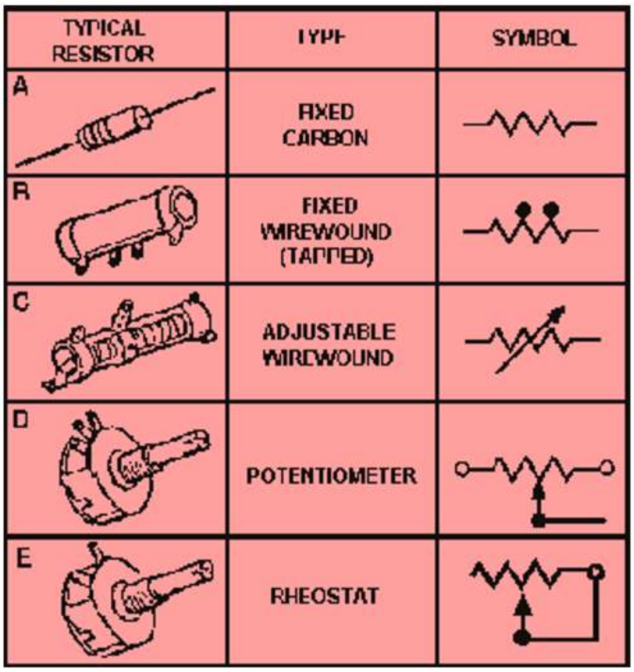
Electronic

Two common schematic

Fig 7.31

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. Resistors act to reduce current flow, and, at the same time act to lower voltage levels within circuits. Resistors are manufactured in different types and sizes ans possess different resistance value.

TYPES OF RESISTORS WITH ELECTRICAL SYMBOLS



TYPES OF RESISTORS

1. Fixed resistor

Fixed resistors have built into the design a resistorof opposingcurrent.Thegeneraluseofaresistorinacircuitisto limit the amount of current flow. There are a number of methods used in construction and sizing of a resistor or that control properties such a resistance value, the precision of the resistance value, and the ability to dissipate heat. While in some applications the purpose of the resistive elementis used

to generate heat, such as in propeller anti-ice boots, heat typically is the unwanted loss of energy.

a. Carboncomposition

Thecarboncomposedresistorisconstructedfromamixtureof finely grouped carbon / graphite an insulation material for filler, and a substance for binding the material together.The amount of graphite in relation to the insulation material will r. This mixture is compressed into a rod, which is then fitted withaxial leads or ―pigtails.‖The finished product is then sealed inaninsulatingcoatingforisolationandphysicalprotection. This resistive material can be graphite for the carbon film resistor, nickel chromium for the metal film resistor, metal and glass for the metal glaze resistor and last and an insulating oxide for the metal oxide resistor. They are available in power ratings of 1/8,1/4,1/2,1and 2 W, in voltage ratings of 250,350 and500V. they have low failure rates when properlyused.

b. DepositedCarbon

Deposited carbon resistors consist of ceramic rods which have a carbon film deposited on them. As compared to carbon composition resistors, these resistors offer a major improvement in lower current noise and in closer tolerance. These resistor are being replaced by metal film and metal glaze resistors.

c. High – Voltage InkFilm

These resistor consist of ceramic base on which a special resistiveinkislaiddowninhelicalband.Theseresistorsare apableofwithsandinghighvoltagesandfindextensiveuse in cathode-ray circuits in radar and in medicalelectronics.

Their resistance range from 1 k Ω to 100,000MΩ withvoltage
range up to 1000 kV.

d. Metal film

Metal film resistors are made by depositing vaporized metal in vacuum on an ceramic – core rod. Metal film resistor have excellent tolerance and temperature coefficient and are extremely reliable. Hence, they are very suitable for numerous high grade applications in low- level of certain instruments although they are much more costlier.

e. Metal glaze

Ametalglazeresistorconsistsofametalglassmixturewhich is applied as a thick film to a ceramic substrate and then fired to form a film. The resistance can be made to vary from 1 Ω to many mega ohms.

g.Cermet (Ceramic Metal)

The cermet resistors are made by firing certain metals blended resistance depends on the type of mixand its thickness. These resistor have very accurate resistance values and show high stability even under extreme temperatures. Usually, they are produced as small rectangles having leads forbeing attached to printed circuit boards(PCB).

a. Rheostat:It is a variable resistor use to vary the amount of It can handle high current.eg. dimmer control of lights Potentiometer:It isa variable resistor having three connection One movable and two fixed.

Special Resistor:

a. Thermistor

The thermistor is a type of a variable resistor, whichis temperature sensitive. This component has what is known as a Negative temperature coefficient which means that as the sensedtemperatureincreases,theresistanceofthethermistor decrease.

b. Varistor

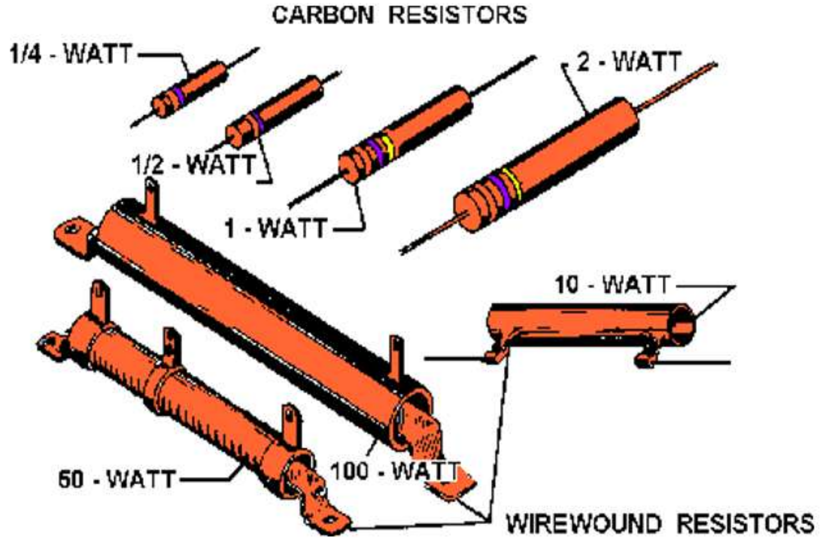
It is a voltage dependent metal oxide material whose resistance. Decreases sharply with increase of voltage. The zinc oxide based varistor are used for protecting solidstate power supply from low and medium surge voltage. It has nonlinear current–voltage characteristic, and is therefore also known as a voltage-dependent resistor (VDR).

Wattage Rating of Resistors

When a current is passed through a resistor, heat is developed within the resistor The resistor must be capable of dissipating this heat into the surrounding air; otherwise, the temperature of the resistor rises causing a change in resistance, or possibly causing the resistor to burnout.

The ability of the resistor to dissipate heat depends upon the design of the resistor itself. This ability to dissipate heatdepends on the amount of surface area which is exposed to the air. A resistor designed to dissipate a large amount of heat must therefore have a large physical size.The heatdissipating capability of a resistor is measured in WATTS. Someof the more common wattage ratings of carbon resistors are:one- eighth watt, one-fourth watt, one-half watt, one watt, andtwo watts. In some of the newer state-of-the-art circuitsof today, much smaller wattage resistors are used.

Generally, the types that you will be able to physically work with are of the values given. The higher the wattage rating of the resistor the larger is the physical size. Resistors that dissipate very large amounts of power (watts) are usually wire woundresistors. Wire wound resistors with wattage ratings up to 50 wattsare not uncommon. Figure 7.33 shows some resistors which have different wattage ratings. Notice the relative sizes of the resistors.



Resistors of different wattage ratings Fig 7.33

Module 3.8: Power

The unit of electric power, the watt, is named for Scottish inventor and engineer James Watt (1736–1819). One watt equals one joule of energy transferred in one second. In physics, power is the rate of doing work. It is equivalent toan amount of energy consumed per unit. In the MKS system, theunit of power is the joule per second (J/s), known as the watt.

One watt of power equals the work done in one second by one volt of potential difference in moving one coulomb of charge.
Remember that one coulomb per second is an ampere. Therefore power in watts equals the product of volts times amperes.
Power in watts = Volts X Amperes P = V X I
When a 6-V battery produces 2 A in a circuit, for example, the battery is generating 12 W of power.
The power formula can be used in three ways:

I = P/V V = P/I
Which formula to use depends on whether you want to calculate P, I, or V. Note the followingexamples.
A toaster takes 10 A from the 120-V power line. Howmuch power isused?
P = V X I = 120V X 10A
P = 1200 W or 1.2KW

Work and Power

Work and energy are essentially the same with identical units. Power is different, however, because it is the time rate of doing work.
As an example of work, if you move 100 lb a distance of 10 ft, the work is 100 lb X 10 ft or 1000 ft•lb, regardless of how fast or how slowly the work is done.
Note that the unit of work is foot-pounds, without any reference to time.
However, power equals the work divided by the time it takes to do the work. If it takes 1 s, the power in this example is 1000 ft•lb/s; if the work takes 2 s, the power is 1000 ft•lb in 2 s, or 500 ft•lb/s.

Watts and Horsepower Units

A further example of how electric power corresponds to mechanical power is the fact that
746 W = 1 hp = 550 ft. lb/s

Practical Units of Power and Work

Starting with the watt, we can develop several other important units. The fundamental principle to remember is that power is the time rate of doing work, whereas work is power used during a period of time. The formulas are

and Work = Power XTime

Withthewattunitforpower,onewattusedduringonesecond equalstheworkofonejoule.Oronewattisonejoulepersecond. Therefore,1W=1J/s.Thejouleisabasicpracticalunitofwork or energy.

1 joule = 1 watt · second
1 watt = 1 joule/second
In terms of charge and current,
1 joule = 1 volt · coulomb
1 watt = 1 volt · ampere
Electron Volt (eV)

Thisunitofworkcanbeusedforanindividualelectron,rather thanthelargequantityofelectronsinacoulomb.Anelectronis charge,andthevoltispotentialdifference.Therefore,1eVisthe amountofworkrequiredtomoveanelectronbetweentwopoints that have a potential difference of one volt.

The number of electrons in one coulomb for the joule unit equals 6.25X1018 .

As a formula,
018e
Either the electron volt or the joule unit of work is the product of charge times voltage, but the watt unit of power is the product of voltage times current. The division by time to convert work to power corresponds to the division by time that converts charge to current.
Kilowatt-Hours

This is a unit commonly used for large amounts of electricalwork orenergy.Theamountiscalculatedsimplyastheproductofthe powerinkilowattsmultipliedbythetimeinhoursduringwhich thepowerisused.Asanexample,ifalightbulbuses300Wor

We pay for electricity in kilowatt-hours of energy. The power-line voltage is constant at 120 V. However, more appliances and light bulbs require more current because they all add in the main line to increase the power.
Suppose that the total load current in the main line equals 20 A. Then the power in watts from the 120-V line is
P = 120 V X 20 A

P = 2400 W or 2.4 kW

If this power is used for 5 h, then the energy or work supplied equals 2.4 X 5 = 12 kWh. If the cost of electricity is 6¢/kWh, then 12 kWh of electricity will cost 0.06 X 12 = 0.72 or 72¢. This charge is for a 20-A load current from the 120-V line during the time of 5 h.
Power Dissipation in Resistance

When current flows in a resistance, heat is produced because friction between the moving free electrons and the atomsobstructs thepathofelectronflow.Theheatisevidencethatpowerisused inproducingcurrent.Thisishowafuseopens,asheatresulting from excessive current melts the metal link in the fuse.

The power is generated by the source of applied voltage and consumed in the resistance as heat. As much power as the resistance dissipates in heat must be supplied by the voltage source; otherwise, it cannot maintain the potential difference required to produce the current.
Thecorrespondencebetweenelectricpowerandheatisindicated
by the fact that 1W used during 1 s is equivalent to 0.24 calorieof
heat energy. The electric energy converted to heat is considered dissipated or used up because the calories of heat cannot be returned to the circuit as electric energy.
Since power is dissipated in the resistance of a circuit, it is convenient to express the power in terms of the resistance R. The formula P = V X I can be rearranged as follows:
Substituting IR for V,
P = V X I = IR X I

$$P = I^2R$$

This is a common form of the power formula because of the heat produced by current in a resistance. For another form, substitute V/R for I. Then

P = V X I = –

In all the formulas, V is the voltage across R in ohms, producing the current I in amperes, for power in watts.

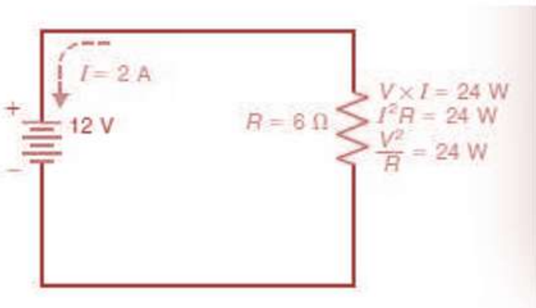


Figure 8-1 Calculating the electric power in a circuit as P = V X I, P = I2 R, or P = V2 / R.

In Fig. 8–1, for example, the power dissipated with 2 A through the resistance and 12 V across it is 2 X 12 = 24 W.

Or, calculating in terms of just the current and resistance, the power is the product of 2 squared, or 4, times 6, which equals 24W.
Using the voltage and resistance, the power can be calculated as 12 squared, or 144, divided by 6, which also equals 24W.
Nomatterwhichformulaisused,24Wofpowerisdissipatedas
heat. This amount of power must be generated continuously bythe
battery to maintain the potential difference of 12 V thatproduces
the 2-A current against the opposition of 6Ω.

In some applications, electric power dissipation is desirable because the component must produce heat to do its job. For instance, a 600-W toaster must dissipate this amount of power to produce the necessary amount of heat. Similarly, a 300-W light bulb must dissipate this power to make the filament white-hot so that it will have the incandescent glow that furnishes the light. In other applications, however, the heat may be just an undesirable by-product of the need to provide current through the resistance in a circuit. In any case, though, whenever there is current I in a resistance R, it dissipates the amount of power P equal to I2R.

Components that use the power dissipated in their resistance, such as light bulbs and toasters, are generally rated in terms of power. The power rating is given at normal applied voltage, which is usually the 120 V of the power line. For instance, a 600-W, 120-V toaster has this rating because it dissipates 600 W in the resistance of the heating element when connected across 120 V.

Power Formulas

To calculate I or R for components rated in terms of power at a specified voltage, it may be convenient to use the power formulas in different forms. There are three basic power formulas, but each can be in three forms for nine combinations.

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

$$\text{or} \quad I = \frac{P}{V} \qquad \text{or} \quad R = \frac{P}{I^2} \qquad \text{or} \quad R = \frac{V^2}{P}$$

$$\text{or} \quad V = \frac{P}{I} \qquad \text{or} \quad I = \sqrt{\frac{P}{R}} \qquad \text{or} \quad V = \sqrt{PR}$$

Summary

Power is the time rate of doing work or using energy. The unit is the watt. One watt equals 1 V X 1 A. Also, watts = joules persecond.

The unit of work or energy is the joule. One joule equals 1W X1s.

3.9 Introduction

A capacitor (originally known as a condenser) is a passive electrical component used to store energy electrostatically inan electric field. The forms of practical capacitors vary widely, but all contain at least two electrical conductors (separated by a dielectric (i.e. insulator).Theconductor can be thin , foilsor sinteredbeadsofmetalorconductiveelectrolyte,etc.The"no conducting" dielectric acts to increase the capacitor's charge capacity. A dielectric can be glass, ceramic, plastic film, air, vacuum, paper, mica, oxide layer etc. Capacitors are widely used as parts of electrical circuits in many common electrical devices. Unlikearesistor,anidealcapacitordoesnotdissipate.Instead,a capacitor stores energy in the form of an electrostatic field between its plates.A good capacitor blocks pure direct currentand passes the effect of alternating current and pulsating direct current.

ELECTROSTATICFIELD

A field of force that exist around a charged body is calledan electrostatic field(dielectric field).It is represented by thelineextending in all directions from the charged body and terminating where there is equal and opposite charge. Lines are used to represent direction and intensity of the electric would move or tend to move if acted upon by the field of force.

CHARACTERISTICS OF ELECTRIC LINES OFFORCE
Lines of force originate from a positive charge and to a negative charge

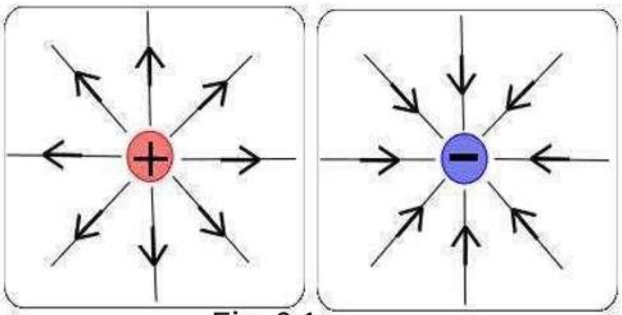
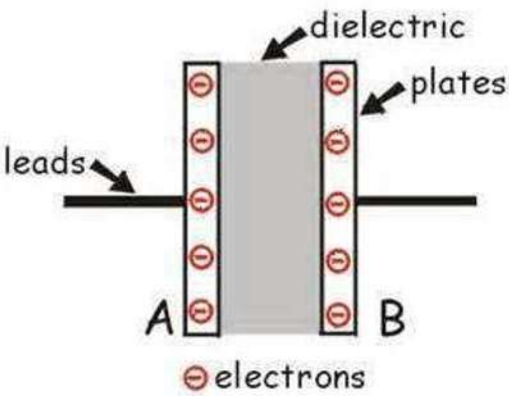


Fig. 9.1

They have the ability to distort the orbits of tightly bound electrons
They radiate in straight lines from positive to negative charge and don’t form close loop

A BASIC CAPACITOR



Rig 9.5 principle

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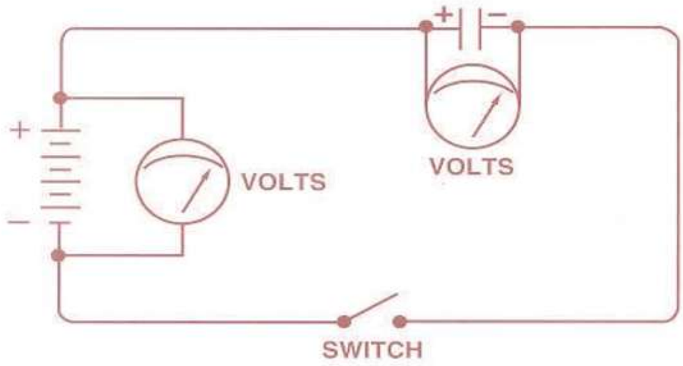
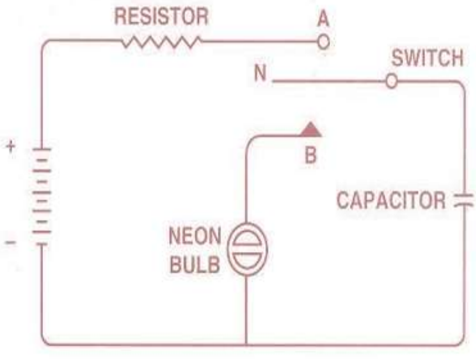


When two plates of a capacitor are initially attached to a battery, electrons are drawn from the plate attached to the positive terminal and flow to the plate attached to the negative terminal. This process continues until the plates become fully charged. Once charged, the voltage across the capacitor will match the voltage across the source.

Fig. 9.6

Principle of a capacitor is simple.Two flat metal plates face each other and are separated by an insulator(fig 9.5).One of the plate is attached to the positive terminal of the power source and the other to the negative terminal. In this configuration(fig 9.6)electrons are drawn from the plate attached to the positive terminal and flow to the plate attached to the negative terminal.Although, there is no flow across insulator, the plates become charged. If you connect a voltmeter across the plates ,it would read same as the battery voltage. Current flows while the plates are being charged but stops when they become fully charged.



. The resistor limits the rate at which the capacitor charges when the switch is in position A. When the switch is in position B, the capacitor discharges through the neon bulb, causing it to flash.

Fig. 9.7

In the figure 9.7,

UNIT OF CAPACITANCE

Conversely, it is the which, when charged to a potential difference of one volt, carries a charge of one coulomb. A coulomb is equal to the amount of charge (electrons)

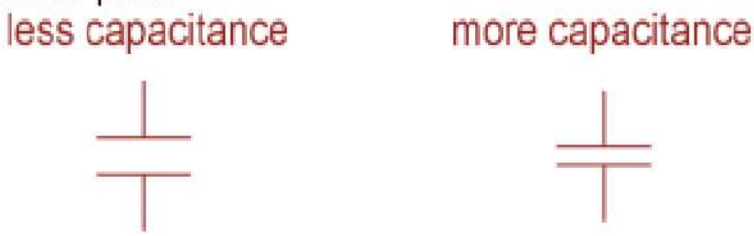
a.Explanation: If we double the area of the plates,there is room for twice as much charge. Since the charge at a given potential difference is doubled, so capacitance will get double($C = Q/V$)

Fig. 9.9

coulomb of charge is defined as a charge having 6.28 x 101 electrons.
C (farads) = Q (Coulomb)/V (Volts)
In practical terms,farad is a too large unit for capacitance.So, much smaller units are used such as microfarad(μF) ,which is 10-6 farad and picofarad (pF) which is 10-12farad.

FACTORS AFFECTING THE VALUE OF CAPACITANCE
The three basic factors affecting the value of capacitance are:

Explanation: Closer spacing results in a greater field force (voltage across the capacitor divided by the distance between the plates), which results in a greater field flux (charge collected on the plates) for any given voltage applied across the plates



(fig 9.10)

Permittivity
permittivity of the dielectric gives greater capacitance; less permittivity of the dielectric gives less capacitance
Explanation: Although it's complicated to explain, some materials offer less opposition to field flux for a given amount of field force. Materials with a greater permittivity allow for more field flux (offer less opposition), and thus a greater collected charge, for any given amount of field force (applied voltage). Dielectric constant is electrostatic storing ability of a capacitor.

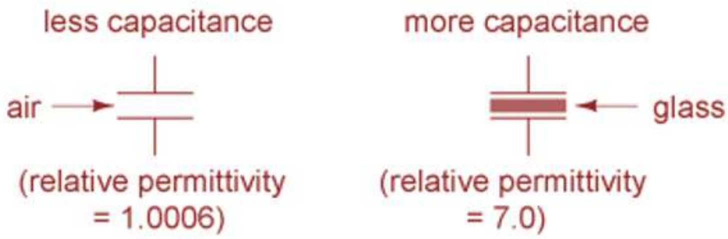


Fig. 9.11

Relative" permittivity means the permittivity of amaterial,
relative to that of a pure vacuum. The greater the number, the greater the permittivity of the material(fig 9.11). Glass, for instance, with a relative permittivity of 7, has seven timesthe

permittivity of a pure vacuum, and consequently will allow for the establishment of an electric field flux seven times stronger than that of a vacuum, all other factors being equal. The following is a table listing the relative permittivities (also known as the "dielectric constant") of various common substances:

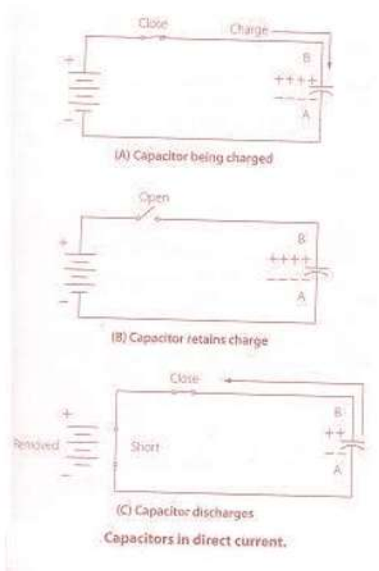
The voltage rating of the capacitor is a factor in determining the actual capacitance because capacitance decreases as the thickness of dielectricincreases. High voltage capacitor that has a thick dielectricmusthavealargeplateareainordertohavethesame
capacitance as similar as low voltage capacitor having a thin dielectric.

NOTE: The voltage rating also depends on frequency, because the losses and the resultant heating effect incre
as the frequency

LOSSES IN A CAPACITOR

Power loss in a capacitor may be attributed to dielectric Hysteresis and dielectric leakage. Dielectric Hysteresis may be defined as an effect in a dielectric material similar to the Hysteresis found in a magnetic material. It is the result of changes in orientation of electron orbits in the dielectric because of the rapid reversals of the polarity of the line voltage. The amount of power loss due to dielectric Hysteresis depends upon the type of dielectric use vacuum dielectric has the smallest power

Dielectric leakage occurs in a capacitor as the result of LEAKAGE CURRENT through the dielectric. Normally it is assumed that the dielectric will effectively prevent the flow of current through the capacitor. Although the resistance of the dielectric is extremely high, a minute amount of current does flow. Ordinarily this current is so small that for all practical purposes it is ignored.However, if the leakage through the dielectric is abnormally high, there will be a rapid loss of charge and an overheating of the capacitor
The power loss of a capacitor is determined by loss in the
dielectric. If the loss is negligible and the capacitor returns the total charge to the circuit, it is considered to be a perfectcapacitor with a power loss ofzero



CAPACITORS IN DIRECT CURRENT

Fig. 9.12

When a capacitor is connected across a source of direct current(storage battery) as shown above in fig 9.12A and the switch is then closed,the plate marked B becomes positively charged and the palte A becomes negatively charged.Current flow in the external circuit during the time the electron are moving from B to A.The current flow in the circuit is at maximum the instant the switch is closed but continuosly decreases until it reaches to zero.The current becomes zero as soon as the difference in the voltage of A and B becomes same as that of battery voltage. If the switch is opened as shown in the fig 9.12B,the plates remain charged.Oncethecapacitorisshorteditwilldischargequicklyas
shown in fig 9.12C.
It should be clear during the time the capacitor is being charged or discharged,there is a current in the circuit,even though the circuit is broken by the gap between the capacitor plates.Current is present only during the time of charge and discharge and this timeperiod is usuallyshort.

A ceramic capacitor is a fixed value capacitor in whichceramic
material acts as the dielectric(fig 9.19). It is constructed of two or more alternating layers of ceramic and a metal layer acting as the electrodes.(titanium acid barium).Internally these capacitors are not constructed as a coil so they are suited for high frequency applications.They are shaped like a disk,available in very small value and very small sizes.This type is fairly small,inexpensive and reliable.They are most widely used capacitor.They range from 1picofaradto0.01microfaradandusedwithhighvoltages as high as 30,000 Volts

4.Electrolytic Capacitor

Fig.9.20

An electrolytic is a type of capacitor that uses an electrolyte to Electrolytic capacitors can be either wet-electrolyte or solid
polymer. They are commonly made of tantalum or aluminum, although other materials may be used. Supercapacitors are a special subtype of electrolytic capacitors, also called double-layer electrolytic capacitors, with capacitances of hundreds and thousands of farads. . Aluminum electrolytic capacitors are found.

WET ELECTROLYTIC

2.DRY ELECTROLYTIC

The wet electrolytic capacitor is designed of two metalplates
separated by an electrolyte with an electrolyte dielectric which is a conductive salt in solvent.Thesecapacitors provide large
capacitance in small size and ranges from about 1 to 1500 microfarads.They are generally polarized,positive lead marked with a + and negative lead marked with a It can be subjected to
direct voltage or pulsating direct voltage only
The close spacing between positive and negative electrode give rise to the high capacitance value but

allows greater of voltage breakdown and leakage of electrons from one electrode
to other.

The electrolyte of the dry electrolytic unit is a paste contained ina
separator made up of an absorbent material such as gauze or paper.This separator not only holda the electrolyte in place but also prevents it from shorting circuiting the plates.Dry electrolytic is in both cylindrical and rectangular block form and may be contained either within a cardboard or metal covers.Dry electrolytic can be mounted in any convenient position as the electrolytic doesn'tspill.

5. TANTALUM CAPACITOR

Fig.9.21

These capacitors are constructed with a material calledas
tantalum, used for the electrodes(fig 9.21). They are superior to electrolytic capacitors and have better temperature frequency and temperature characteristics. When tantalum powder is baked in order to solidify it, a crack forms inside. This crack is used to store an electric charge. Like electrolytic capacitors, these arealso polarized and are indicated with+an d - symbols.

6.OIL CAPACITORS

Fig. 9.22

In radio and radar transmitters,voltages high enough tocause arcing or breakdown,of paper dielectric are often used.But in these applications capacitors that use oil or oil impregnated paper for the dielectric are preferred.These capacitors are generally more expensive than ordinary paper capacitors and are mostly restricted to radio and radar transmitting equipment.(fig9.22)

VARIABLE CAPACITORS

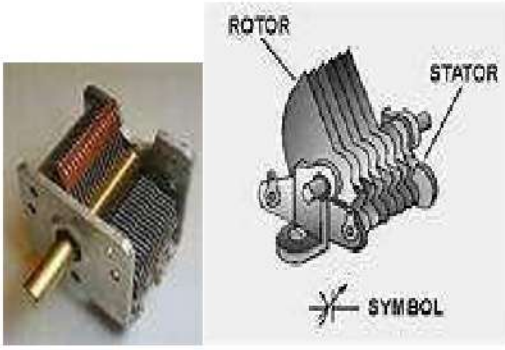


Fig. 9.23

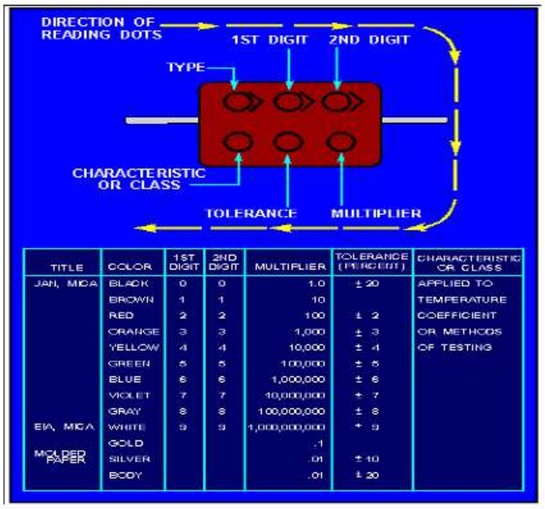
Variable capacitors ,capacitance value can be changed and they are used for radio tuning circuits and sometimes called as the tuning capacitor.A typical variable capacitor(adjustable capacitor) is a rotor-stator type.It consist of two sets of metal plates which can be arranged so that rotor plates move between stator plates.Air is a dielectric.As the position of rotor is changed,capacitance value change

COLOUR CODING OF CAPACITOR

Although the capacitance value may be printed on the body of a capacitor, it may also be indicated by a color code. The color code used to represent capacitance values is similar to that used to represent resistance values. The color codes currently in use are the Joint Army-Navy (JAN) code and the Radio Manufacturers' Association (RMA)code.

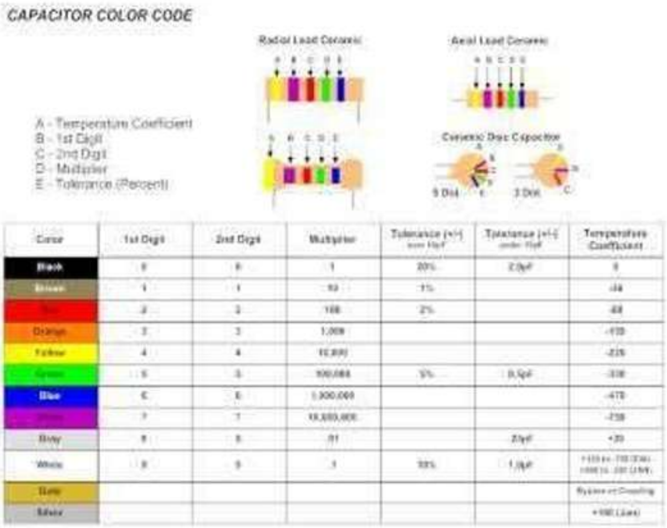
For each of these codes, colored dots or bands are used to indicate the value of the capacitor. A mica capacitor, it should be noted,

may be marked with either three dots or six dots. Both the three- and the six-dot codes are similar, but the six-dot code contains more information about electrical ratings of the capacitor, such as working voltage and temperature coefficient.



TITLE	COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	CHARACTERISTIC OR CLASS
JAN, MICA	BLACK	0	0	1.0	± 20	APPLIED TO
	BROWN	1	1	10		TEMPERATURE
	RED	2	2	100	± 2	COEFFICIENT
	ORANGE	3	3	1,000	± 3	OR METHODS
	YELLOW	4	4	10,000	± 4	OF TESTING
	GREEN	5	5	100,000	± 5	
	BLUE	6	6	1,000,000	± 6	
	VIOLET	7	7	10,000,000	± 7	
	GRAY	8	8	100,000,000	± 8	
EIA, MICA	WHITE	9	9	1,000,000,000	± 9	
	GOLD			.1		
MOLDED PAPER	SILVER			.01	± 10	
	BODY			.01	± 20	

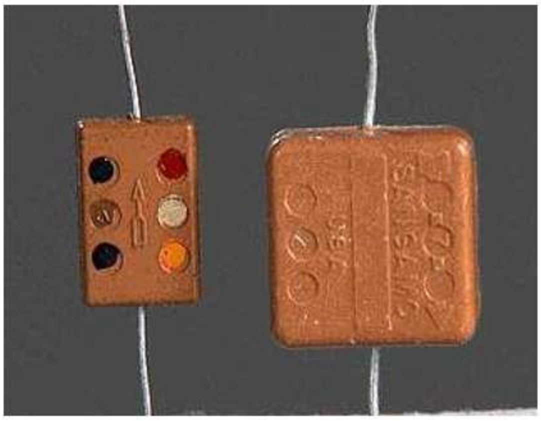
Fig.9.24



Color	1st Digit	2nd Digit	Multiplier	Tolerance (+/-) over 10pF	Tolerance (+/-) under 10pF	Temperature Coefficient
Black	0	0	1	20%	2.0pF	0
Brown	1	1	10	1%		[illegible]
Red	2	2	100	2%		[illegible]
Orange	3	3	1,000			[illegible]
Yellow	4	4	10,000			[illegible]
Green	5	5	100,000	5%	0.5pF	[illegible]
Blue	6	6	1,000,000			-470
Violet	7	7	10,000,000			-750
Gray	8	8	.01		[illegible]	+30
White	9	9	.1	10%	1.0pF	[illegible]
Gold						[illegible]
Silver						[illegible]

Fig. 9.25

Example of mica capacitors.



Example of mica capacitors.

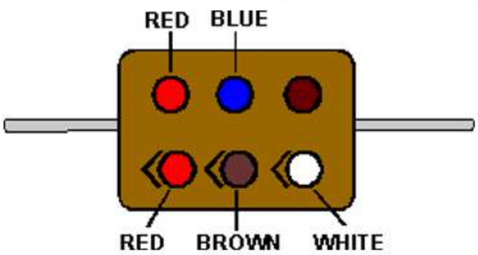


Fig. 9.27

To read the capacitor color code on the above capacitor: (fig 9.27) Hold the capacitor so the arrows point left to right.

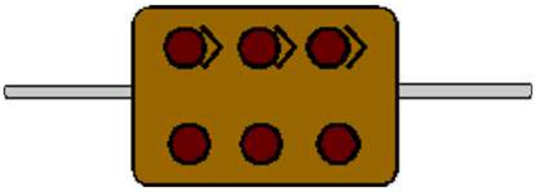


Fig. 9.28

Read the first dot.

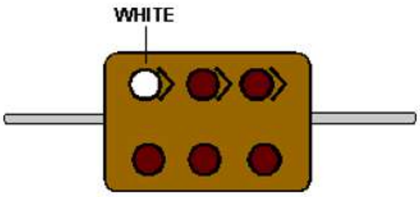


Fig. 9.29

Read the first digit dot.

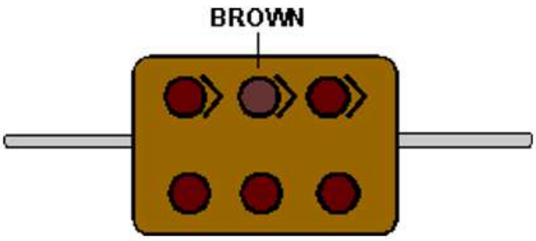
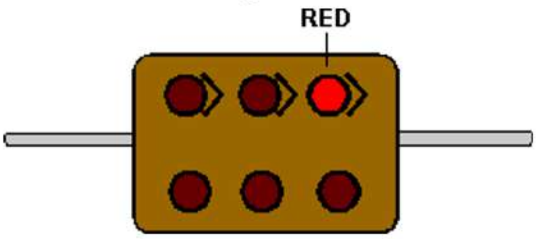


Fig. 9.30



Read the second digit dot and apply it to the first digit.

Fig. 9.31

multiplier dot and multiply the first two digits by multiplier (Remember that the multiplier is in picofarads).

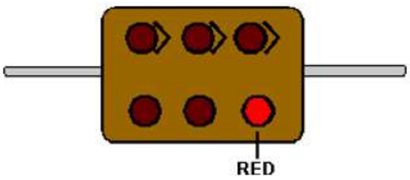


Fig. 9.32

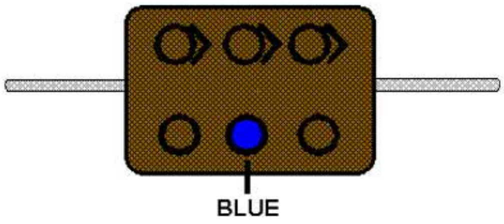


Fig.9.33

The above coding, the capacitor is a mica capacitor whose indicates a capacitance of 2200 Pf with a +/- 40% tolerance and a working voltage of 44 V

ALPHANUMERIC CODING OF CAPACITOR

The Capacitor Colour Code system was used for many years on unpolarised polyester and mica moulded capacitors. This system of colour coding is now obsolete but there are still many "old" capacitors around. Nowadays, Small Capacitors such as film or disk types are represented by a letter or number coded system.

Generally the code consists of 2 or 3 numbers and an optional tolerance letter code to identify the tolerance. Where a two number code is used the value of the capacitor only is given in picofarads, for example, 47 = 47 pF and 100 = 100pF etc. A three letter code consists of the two value digits and a multiplier much like the resistor colour codes in the resistors section.

For example, the digits 471 = 47*10 = 470pF. Three digit codes are often accompanied by an additional tolerance letter code as given below.

	Letter	B	C	D	F	G	J	K	M	Z
Tolerance	C <10pF ±pF	0.1	0.25	0.5	1	2				
	C >10pF ±%			0.5	1	2	5	10	20	+80-20

Consider the capacitor below:

letter J is the tolerance and this translates to: 47pF * 1,000 (3 zero's) = 47,000 pF , 47nF or 0.047 uF The J indicates a tolerance of +/- 5%

Then by just using numbers and letters as codes on the body of the capacitor we can easily determine the value of its capacitance either in Pico-farad's, Nano-farads or Micro-farads and a list of these "international" codes is given in the following table along with their equivalent capacitances.

CAPACITOR TESTING

Testing Capacitors with a Multimeter

WARNING: make sure the capacitor is discharged! This is both for your safety and the continued health of your multimeter.

Some DMMs have modes for capacitor testing. These work fairly well to determine approximate uF rating. However, for most applications, they do not test at anywhere near the normal working voltage or test for leakage. Normally, this type of testing requires disconnecting at least one lead of the suspect capacitor from the to get a reasonably accurate reading - or any reading at all. However, newer models may also do a decent job of testing capacitors in-circuit. Of course, all power must be removed and the capacitors should be discharged. This will generally work as long as the components attached to the capacitor are either semiconductors (which won't conduct with the low test voltage) or passive components with a high enough impedance to not load the tester too much. The reading may not be as accurate in-circuit, but probably won't result in a false negative - calling a capacitor good that isbad.

CAUTION: For this and any other testing of large capacitors and/or capacitors in power supply, power amplifier, or similar circuits, make sure the capacitor is fully discharged or else your multimeter may be damaged or destroyed!

However, a VOM or DMM without capacitance ranges can make certain types of tests.

For small caps (like 0.01 uf or less), about all you can really test is for shorts or leakage. (However, on an analog multimeter on the high ohms scale you may see a momentary deflection when you touch the probes to the capacitor or reverse them. A DMM may

notprovideanyindicationatall.)Anycapacitorthatmeasuresa few ohms or less is bad. Most should test infinite even on the highest resistance range.

For electrolytics in the uF range or above, you should be able to see the cap charge when you use a high ohms scale with the proper polarity - the resistance will increase until it goes to (nearly) infinity. If the capacitor is shorted, then it will never charge. If it is open, the resistance will be infinite immediately and won't change. If the polarity of the probes is reversed, it will not charge properly either - determine the polarity of your meter and mark it - they are not all the same. Red isusually **negative** with (analog) VOMs but **positive** with most DMMs, for example. Confirm with a marked diode - a low reading across a good diode (VOM on ohms or DMM on diode test) indicates that the positive lead is on the anode (triangle) and negative lead is on the cathode(bar).

If the resistance never goes very high, the capacitor is leaky.

The best way to really test a capacitor is to substitute a known good one. A VOM or DMM will not test the cap under normal operating conditions or at its full rated voltage. However, it is a quick way of finding major faults.

A simple way of determining the capacitance fairly accurately is to build an oscillator using a 555 timer. Substitute the cap in the circuit and then calculate the C value from the frequency. With a few resistor values, this will work over quite a widerange.

Alternatively, using a DC power supply and series resistor, capacitance can be calculated by measuring the rise time to 63% of the power supply voltage from T=RC orC=T/R.

3.10MAGNETISM

The phenomenon known as magnetism was first discovered bythe
ancient Greeks in about 100 BC. Then it was observed that a peculiar stonehadthepropertyofattractingsmallfragmentsofirontoitself.
magnetic poles repel each other and “unlike” poles attract. The discovery of natural magnets led to the invention of the compass, which is a direction-finding device. Since the earth itself is a huge natural magnet, a freely suspended magnet will align itself with the magnetic North and South Poles of the earth
Magnetism is the result of electron spinning on their own axis aroundAs shown in Figs. 10–2 and 10–3,

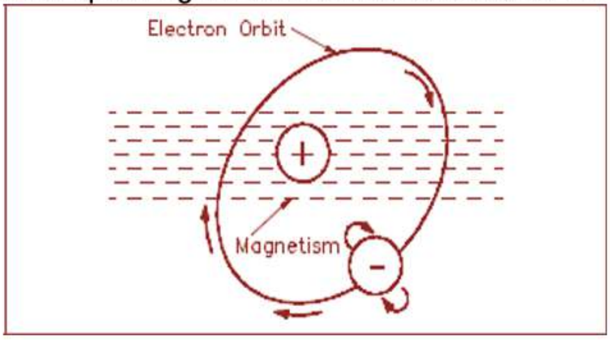


Figure 10.1 Electron spinning around nucleus produce magneticfield

The Magnetic Field
shown in Figs. 10–2 and 10–3, the north and south poles of a the nucleus

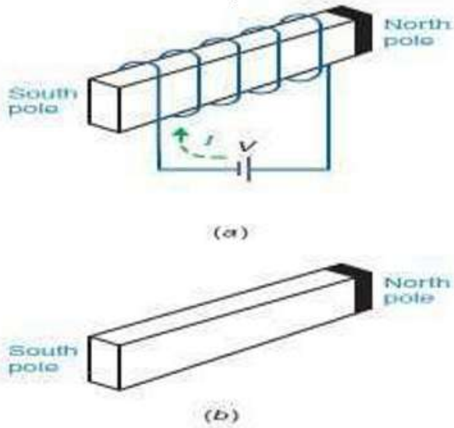


Figure 10.2 Poles of a magnet. (a) Electromagnet (EM) produced by current from a battery. (b) Permanent magnet (PM) without any external source of current.

The practical effects of this ferromagnetism result from the magnetic field of force between the two poles at opposite ends of the magnet. Although the magnetic field is invisible, evidence of its force can be seen when small iron filings are sprinkled on a glass or paper sheet placed over a bar magnet (Fig. 10–3a). Each iron filing becomes a small bar magnet. If the sheet is tapped gently to overcome friction so that the filings can move, they become aligned by the magnetic field.Manyfilingsclingtotheendsofthemagnet,showingthatthe
magnetic field is strongest at the poles. The field exists in all directions but decreases in strength with increasing distance fromthe
poles of the magnet.

Field Lines

To visualize the magnetic field without iron filings, we show the field as lines of force, as in Fig. 10–3b. The direction of the lines outside the magnet shows the path a north pole would follow in the field, repelled away from the north pole of the magnet and attracted to its south pole. Although we cannot actually have a unit north pole by itself, the field can be explored by noting how the north pole on a small compass needlemoves.

The magnet can be considered the generator of an external magnetic field, provided by the two opposite magnetic poles at the ends. This idea corresponds to the two opposite terminals on a battery as the source of an external electric field provided by opposite charges.Magnetic field lines are unaffected by nonmagnetic materials suchas
air, vacuum, paper, glass, wood, or plastics. When these materialsare
placedinthemagneticfieldofamagnet,thefieldlinesarethesame
as though the material were not there.

However, the magnetic field lines become concentrated when a magnetic substance such as iron is placed in the field. Inside the iron, the field lines are denser, compared with the field in air.

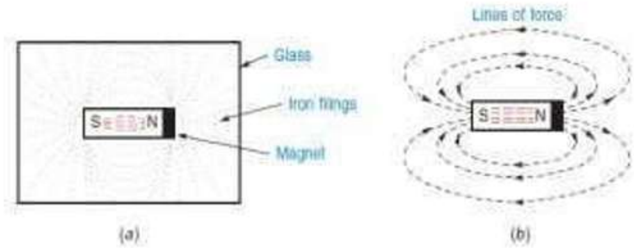
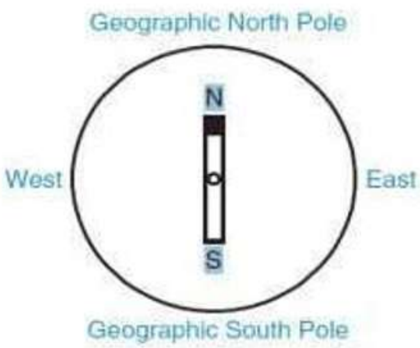


Figure 10.3 Magnetic field of force around a bar magnet.
Field outlined by ironfilings.

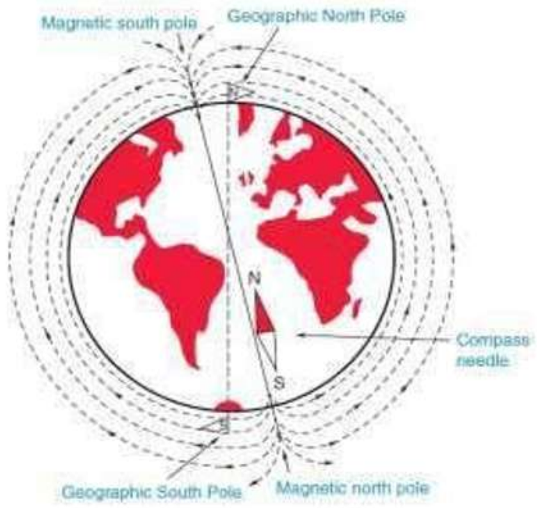
Field indicated by lines offorce.

North and South Magnetic Poles

The earth itself is a huge natural magnet, with its greatest strength at the North and South Poles. Because of the earth's magnetic poles, if a small bar magnet is suspended so that it can turn easily, one end will always point north. This end of the bar magnet is defined as the north-seeking pole, as shown in Fig. 10–4a. The opposite end is the south-seeking pole. When polarity is indicated on a magnet, the north-seeking end is the north pole (N) and the opposite end is the south pole (S). It is important to note that the earth's geographic North Pole has south magnetic polarity and the geographic South Pole has north magnetic polarity. This is shown in Fig. 10–4b.



(a)



(b)

Figure 10.4 Definition of north and south poles of a bar magnet.
North pole on bar magnet points to geographic North Pole of the earth.
Earth's magneticfield.

Similar to the force between electric charges is the force between magnetic poles causing attraction of opposite poles and repulsion between similar poles:

A north pole (N) and a south pole (S) tend to attract each other.

A north pole (N) tends to repel another north pole (N), and a south pole (S) tends to repel another south pole(S).

These forces are illustrated by the fields of iron filings between opposite poles in Fig. 10–5a and between similar poles in Fig. 10–5b.

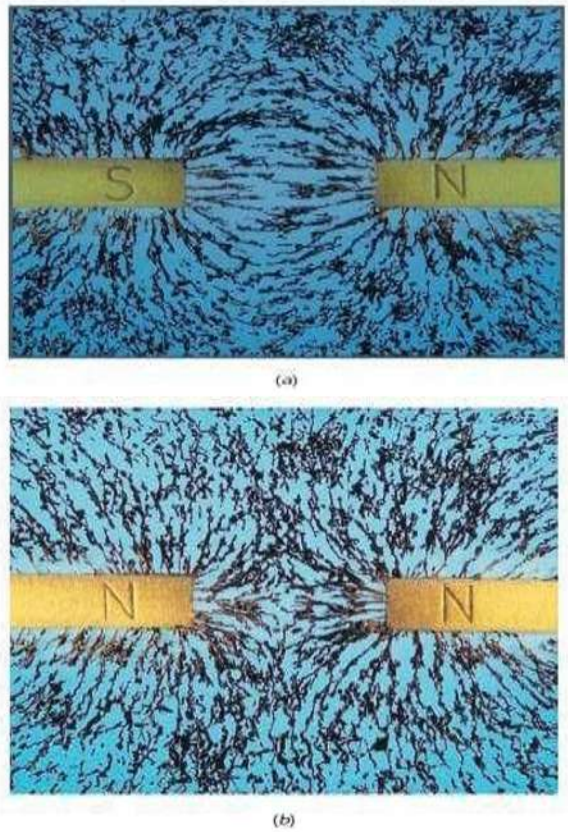


Figure 10.5 Magnetic field patterns produced by iron filings. (a) Field between opposite poles. The north and south poles could be reversed.

Field between similar poles. The two north poles could be south poles.

Types of Magnets

The two broad classes are permanent magnets and electromagnets. An electromagnet needs current from an external source to maintain zitsmagneticfield.Withapermanentmagnet,notonlyisitsmagnetic extreme heat, however, can cause demagnetization Electromagnets

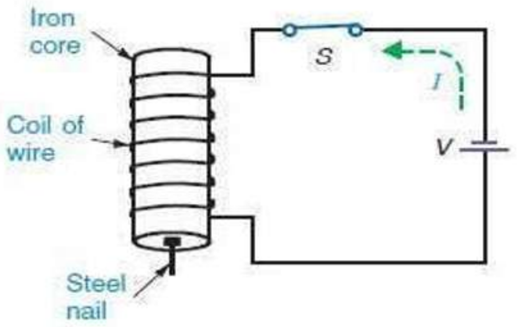


Figure 10.6 Electromagnet holding a nail when switch S is closed for current in the coil.

Current in a wire conductor has an associated magnetic field. If the wire is wrapped in the form of a coil, as in Fig. 10–6, the current and If the switch is opened, the magnetic field is reduced to zero, and the nail willdropoff.Thisabilityofanelectromagnettoprovideastrong Magneticforceofattractionthatcanbeturnedonoroffeasilyhas Electromagnets

Permanent Magnets

A Permanent magnet is one which maintains almost constant magnetic field without the application of any magnetizing force Certainsubstancessuchashardsteelaremoredifficulttomagnetize than soft iron because of the internal friction among the molecules.If suchasubstanceisplacedinastrongmagneticfieldandisstruck several blows with a hammer, the molecules become aligned withthe field. When such a substance is removed from the magnetic field, it willretainitsmagnetismhenceitiscalledaspermanentmagnet.
Hard steel and Alnico (an alloy of nickel, aluminum and cobalt)are examples of permanent magnet.
The ability of a material to become magnetized is called as permeability and the opposition which a material offers to magnetic lines of force is called reluctance.

Classification of Magnetic Materials

When we consider materials simply as either magnetic or nonmagnetic, this division is based on the strong magnetic properties of iron. However, weak magnetic materials can be important in some applications. For this reason, a more exact classification includes the following threegroups:
Ferromagnetic materials- These include iron, steel, nickel, cobalt, and commercial alloys such as alnico and Permalloy. They become strongly magnetized in the same direction as the magnetizing field, with high values of permeability from 50 to 5000.
Permalloy has a relative permeability of 100,000 but iseasily saturated at relatively low values of flux density.

Paramagnetic materials-These include aluminum,platinum, manganese,andchromium.Theirpermeabilityisslightlymorethan 1.Theybecomeweaklymagnetizedinthesamedirectionasthe magnetizing field.

Diamagnetic materials- These include bismuth,antimony,

copper, zinc, mercury, gold, and silver. Their permeability is less external field is removed.
than 1. They become weakly magnetized but in the direction
Oppositefrom the magnetizingfi eld.

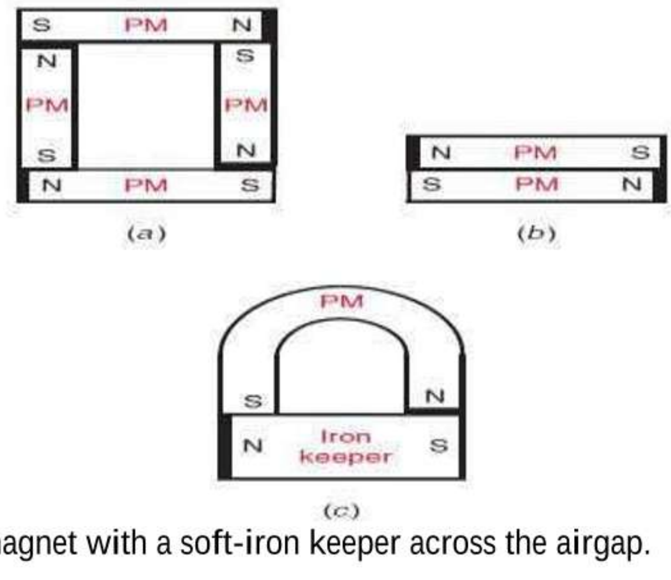
The basis of all magnetic effects is the magnetic field associated with electric charges in motion. Within the atom, the motion of its orbital electrons generates a magnetic field. There are two kinds of electron motion in the atom. First is the electron revolving in its orbit. This motion provides a diamagnetic effect. However, this magnetic effect is weak because thermal agitation at normal room temperature results in random directions of motion that neutralize each other.

More effective is the magnetic effect from the motion of each electron spinning on its own axis. The spinning electron serves as a tiny permanent magnet. Opposite spins provide opposite polarities. Two electrons spinning in opposite directions form a pair, neutralizing the magnetic fields. In the atoms of ferromagnetic
materials,however,therearemanyunpairedelectronswithspinsin
the same direction, resulting in a strong magnetic effect.

In terms of molecular structure, iron atoms are grouped in microscopically small arrangements called domains. Each domain is an elementary dipole magnet, with two opposite poles. In crystal form, the iron atoms have domains parallel to the axes of the crystal. Still, the domains can point in different directions because of the different axes. When the material becomes magnetizedby an external magnetic field, though, the domains become aligned in the same direction. With PM materials, the alignment remains after the external field is removed.

Keeper for a Magnet

The principle of the closed magnetic ring is used to protect permanent magnets in storage. In Fig. 10–7 a, four permanent- magnet bars are in a closed loop, while Fig. 10–7 b shows a stacked pair. Additional even pairs can be stacked this way, with opposite poles touching. The closed loop in Fig. 10–7 c shows



one permanent horseshoe magnet with a soft-iron keeper across the airgap.

Figure 10.7 Storing permanent magnets in a closed loop, with oppositepolestouching.(a)Fourbarmagnets.(b)Twobarmagnets.

Horseshoe magnet with iron keeper across air gap.

The keeper maintainsthestrengthof thepermanentmagnetasit becomimg magnetize by induction close loop.
external magnetic field is concentrated in the closed loopwithout inducing opposite poles in the permanent magnet. If permanent magnetsarenotstoredthisway,thepolaritycanbereversedwith induced poles produced by a strong external field from a dcsource; an alternating field can demagnetize the magnet.

Magnetic Shielding

The idea of preventing one component from affecting another through their common electric or magnetic field is called shielding. Magnetic fields are of affecting sensitive electronic. If the electronic equipment is sensitive enough and the magnetic field great enough, then the device can even be damaged or destroyed by the magnetic field. Technology was developed to address this problem. Today many sensitive electronic devices are protected by magnetic shields.
If a nonmagnetic material is placed in a magnetic field, the flux easily penetrates through the nonmagnetic material. For eg. If a glass plate is placed between a horseshoe magnet, it will have no appreciable effect on the field despite it is a good insulator. However, if we place a magnetic material such a soft iron in place of glass plate, the flux may be redirected due to strong permeability of soft iron.
Some sensitive instruments/meters are provided with magnetic shield/screen as they can easily be influenced by stray magnetic field that can make them erratic. Magnetic shielding is done by placing soft iron case about the instrument. The flux is established more

readily through iron than through the air inside the case, thus effectively shielding the instrument against stray magnetic field.
Electromagnetism

The relationship between magnetism and electrical current was discovered by Danish scientist named Oersted in 1819. He foundthat if an electric current was caused to flow through a conductor, the conductor produced a magnetic field around the conductor (figure 10-8).

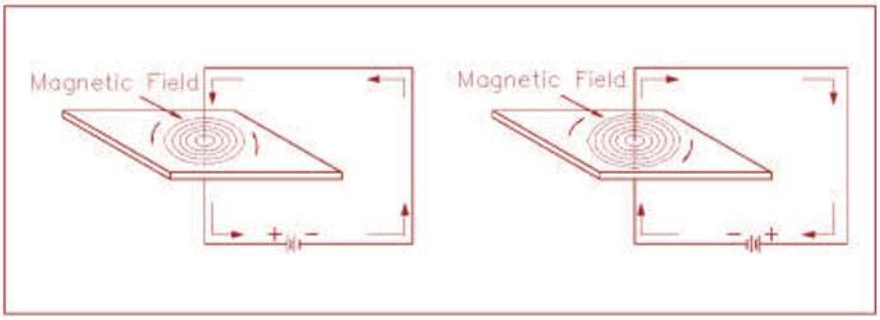


Figure 10.8 The magnetic field produced by current in a conductor
Polarity of a single conductor
A convenient way to determine the relationship between the current flow through a conductor and the direction of the magnetic lines of

force around the conductor is the left-hand rule for current carrying conductors as shown in figure

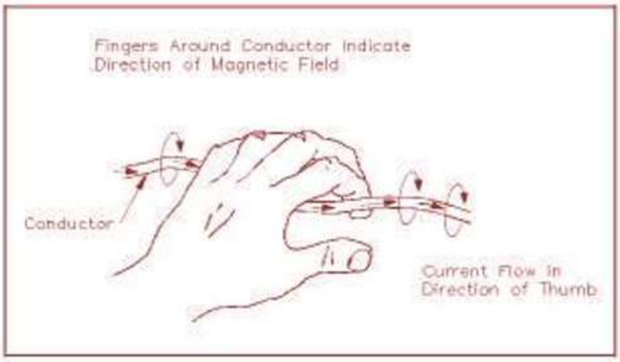
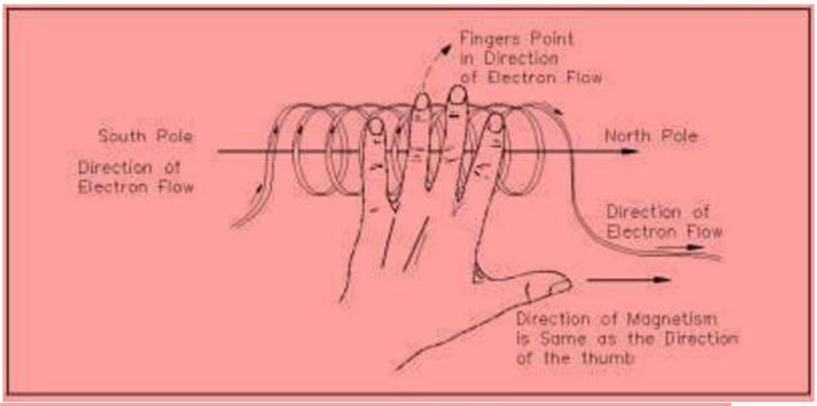
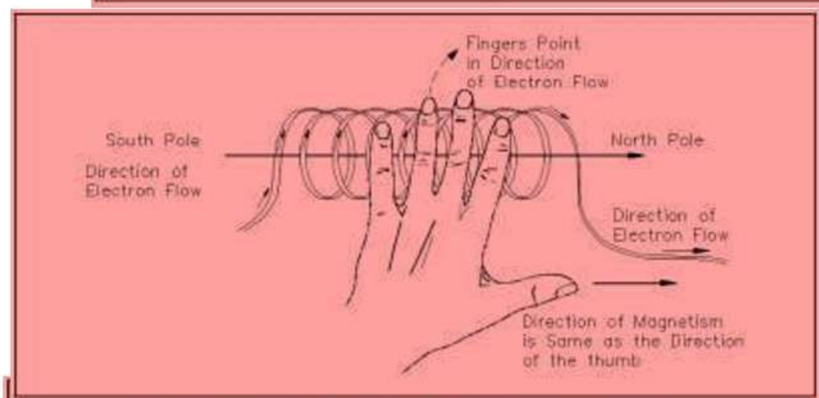


Figure 10.9 Left-hand rule for current carrying conductors

Magnetic Field and Polarity of a coil

Bending a straight into a loop has two results: (1) magnetic field lines become more dense inside the loop, and (2) all lines inside the loop are aiding in the samedirection.When a conductor is shaped into several loops, it is considered to be a coil. To determine the polarity of a coil, use the left-hand rule for coils (figure10.10)Adding an iron core inside of a coil will increase the flux density. The polarity of the iron core will be the same as that of the coil.





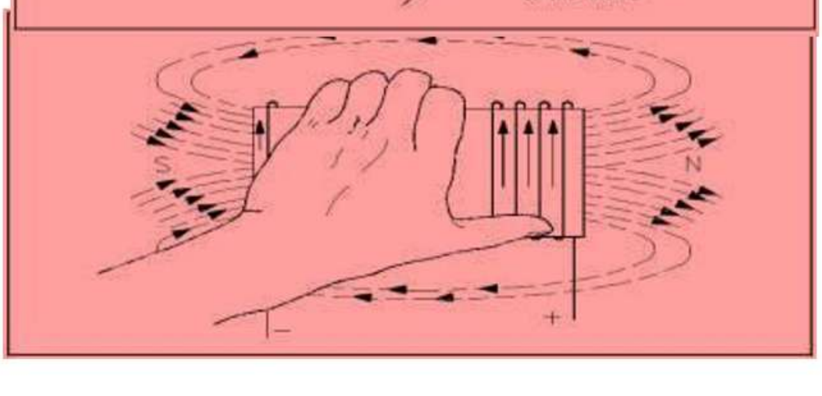


Figure 10.11 Left-hand rule to find North pole of an Electromagnet

As shown in Fig. 14–1, a solenoid with 5 turns and 2 amperes has the same magnetizing force as one with 10 turns and 1 ampere, as the product of the amperes

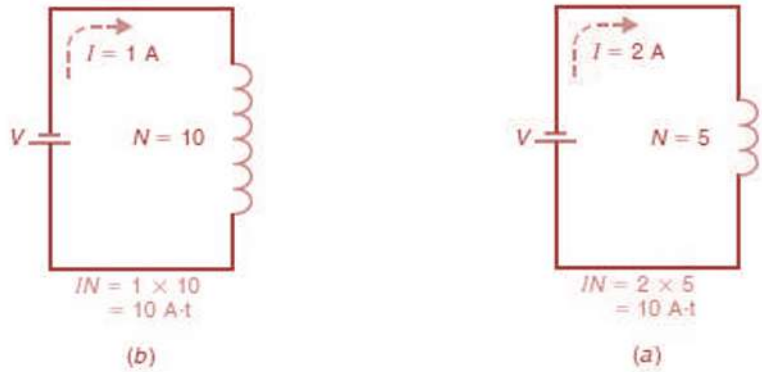


Figure 10.12 Two examples of equal ampere- turns for the same mmf.

Hysteresis Loss

When the magnetizing force reverses thousands or millions of times per second, as with rapidly reversing alternating current, hysteresis can cause a considerable loss of energy. A large part of the magnetizing force is then used to overcome the internal friction the molecular dipoles. The work done by the magnetizing force against this internal friction produces heat. This energy wasted in heat as the molecular dipoles lag the magnetizing force is called the hysteresis loss. For steel and the hard magnetic materials hysteresis losses are much higher than in soft magnetic materials like ions.

When the magnetizing force varies at a slow rate, hysteresis losses can be considered negligible. An example is an electromagnet with direct current that is simply turned on and off or the magnetizing force of an alternating current that reverses 60 times per second or less. The faster the magnetizing force changes, however,the greater the hysteresis effect.

Hysteresis Loop

To show the hysteresis characteristics of a magnetic material, its values of flux density B are plotted for a periodically reversing magnetizing force. See figure 10–13. This curve is the hysteresis loop of the material. The larger the area enclosed by the curve, the greater the hysteresis loss. The hysteresis loop is actually a B-H curve with an ac magnetizing force. Values of flux density B are indicated on the vertical axis. The units can be gauss or tesla.

The horizontal axis indicates values of field intensity H. On thisaxis, the units can be oersted, ampere-turns per meter, ampere-turns,or magnetizing current because all factors are constant except I.

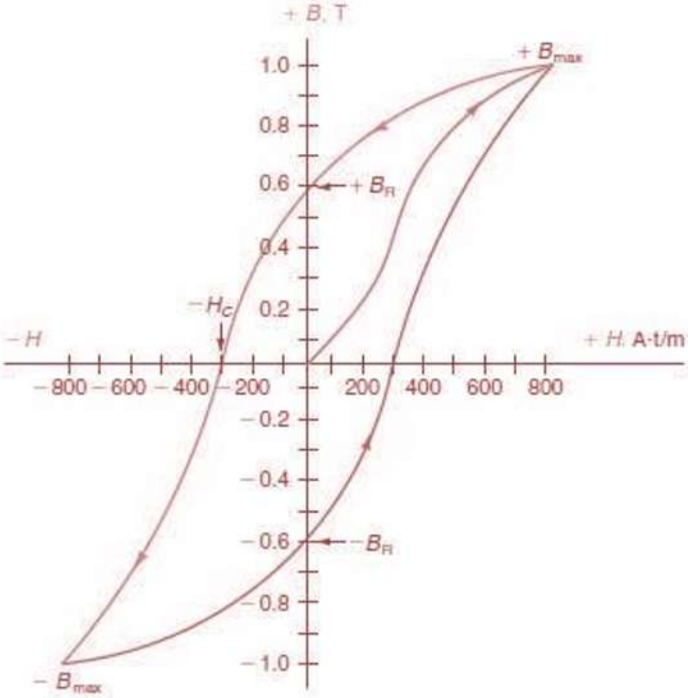


Figure 10.13 Hysteresis loop for magnetic materials.

Then, as the H values decrease, the flux density is reduced to BR. Finally, the loop is completed; positive values of H produce saturation at Bmax again. The curve does not return to the zero origin at the center because of hysteresis. As the magnetizing force periodically reverses, the values of flux density are repeated to trace out the hysteresisloop.

The value of either +BR or -BR , which is the flux density remaining after the magnetizing force has been reduced to zero, is the residual

induction of a magnetic material, also called its retentivity. In Fig. 10–13, the residual induction is 0.6 T, in either the positive or the negative direction.

The value of –HC, which equals the magnetizing force that must be applied in the reverse direction to reduce the flux density to zero, is the coercive force of the material.

3.11.INDUCTANCE

Inductance is the property of aconductor by which a change incurrentflowing through it "induces"(creates) a voltage inductance) and in any nearby conductors (mutual inductance).

These effects are derived from two fundamental observations of physics: First, that a steady current creates a steady magnetic field (Oersted's law), and second, that a time-varying magnetic field induces voltage in nearby conductors (Faraday's law ofinduction).

According to Lenz's law,a changing electric current througha circuit that contains inductance, induces a proportionalvoltage, which opposes the change in current (self-inductance).The varying field in this circuit may also induce an e.m.f.in neighboring circuits (mutual inductance).

e honour of the physicist Heinrich Lenz. In the SI system the measurement unit for inductance is the henry, H, named in honor of the scientist who discovered inductance, Joseph Henry.

CHARACTERISTICS OF INDUCTANCE

Michael Faraday discovered thatby moving a magnet through a coil of wire,a voltage was induced across the coil.If a complete circuit was provided,then a current was also induced.The amount of induced voltage is directly proportional to the rate of change of magnetic field with respect to the coil.Similarly, when a bar

magnet is move through a coil of wire,a voltage is induced and can be measured by GALVANOMETER.(refer fig11.1)

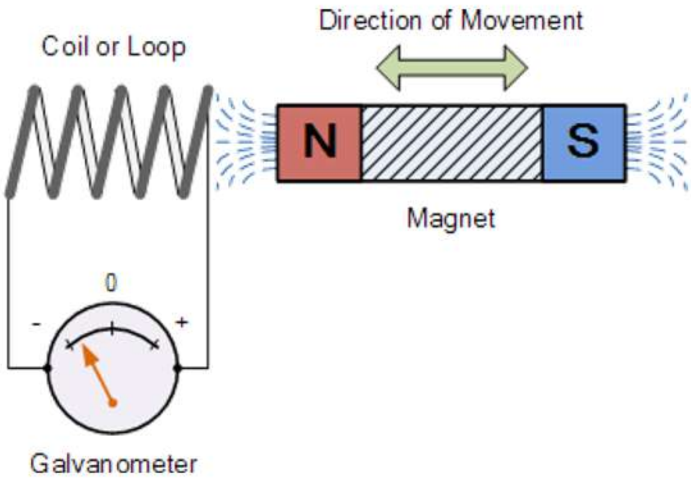


Fig. 11.1 Electromagnetic Induction by a MovingMagnet

Likewise, if the magnet is now held stationary and ONLY the coil is moved towards or away from the magnet the needle of the galvanometer will also deflect in either direction. Then the action of moving a coil or loop of wire through a magnetic field induces a voltage in the coil with the magnitude of this induced voltage being proportional to the speed or velocity of themovement.

Then we can see that the faster the movement of the magnetic field the greater will be the induced e.m.f or voltage in the coil, so for Faraday's law to hold true there must be "relative motion" or movement between the coil and the magnetic field and either the magnetic field, the coil or both can move.

This is commonly knownas Faraday's law or law of electromagnetic induction,which states that

The induced e.m.f or electromagnetic force in a closed loop of wire is proportional to the rate of changeof the magnetic flux through a coil of wire.

So how much voltage (emf) can be induced into the coil using just magnetism. Well this is determined by the following 3 different factors.

Increasing the number of turns of wire in the coil. – By increasing the amount of individual conductors cutting through the magnetic field, the amount of induced emf produced will be the sum of all the individual loops of the coil, so if there are 20 turns in the coil there will be 20 times more induced emf than in one piece ofwire.

Increasing the speed of the relative motion between the coil and the magnet. – If the same coil of wire passed through the same magnetic field but its speed or velocity is increased, the wire will cut the lines of flux at a faster rate so more induced emf would beproduced.

Increasing the strength of the magnetic field. – If the same coil of wire is moved at the same speed through a stronger magnetic field, there will be more emf produced because there are more lines of force tocut.

Lenz’s Law of Electromagnetic Induction

Lenz's Law

Soon after Faraday proposed his law of induction, Heinrich Lenz developed a rule for determining the direction of the induced current in a loop. Basically, Lenz's law states that an induced currenthasadirectionsuchthatitsmagneticfieldopposesthe change in magnetic field that induced the current. This means that the current induced in a conductor will oppose the emf producing it. Lenz's law is important in understanding the property of inductive reactance, which is one of the properties measured in eddy current testing.

Conversely,current flowing through a coil of wire produces a magnetic field.When this wire is formed into a coil,it then becomes a basic inductor.The magnetic lines of force around each loop or turn in the coil effectively add to the lines of force around the adjoining loops.This forms a strong magnetic field within and around the coil.The figure11.2 below shows idea of a coil of wirestrengthening the magneticfield.

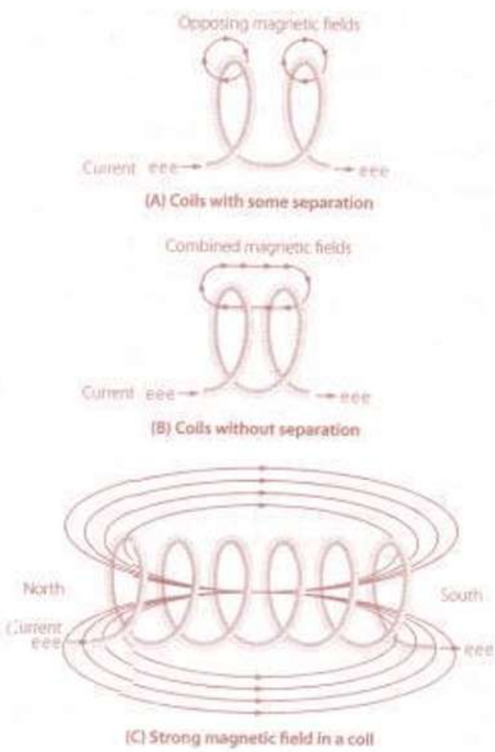


Fig. 11.2 Many loops of a coil

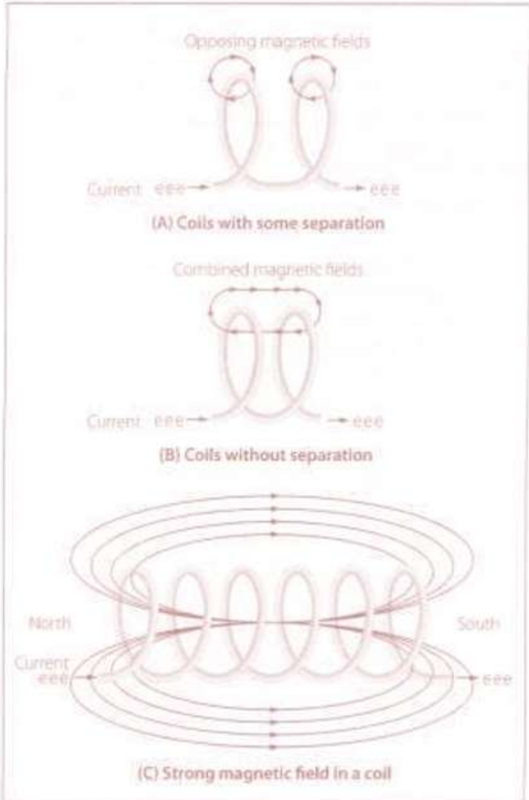


Fig. 11.3 Many loops of a coil

The magnetic lines of force around adjacent loops are deflected into outer paths when the loops are brought close together.This happens because the magnetic lines of force between adjacent loops are in opposition with each other.The total magnetic field for the two loops is shown in the figure11.3.

As more loops are added close together,the strength of magnetic field will increase(electromagnet).

When current flows through any conductor,a magnetic field start to expand from the center of the wire,as the lines of magnetic force grow outward through the conductor they induce an emf in the conductor itself.The induce voltage is always in the direction opposite to the direction of current flow.The effect of this counteremf is to oppose the immediate establishment of the maximum current.This effect is only a temporary condition.Once a current reaches a steady value in a conductor,the lines of magnetic force will no longer be expanding and the counteremf will no longer bepresent.

At the starting instant,the counter emf nearly equals the applied voltage,resulting in a small current flow.However, as the lines of force move outward,the number of lines cutting the conductor per second becomes very small,resulting in a diminished counter emf.Eventually, counteremf dropsto zero and the only voltage in the circuit is the applied voltage and the current at its maximum value.

SELF INDUCTANCE AND INDUCTIVE REACTANCE

The property ofself-inductanceis a particular form of electromagnetic induction. Self inductance is defined as the inductionofavoltageinacurrent-carryingwirewhenthecurrent inthewireitselfischanging.Inthecaseofself-inductance,the magnetic field created by a changing current in the circuit itself inducesavoltageinthesamecircuit.Therefore,thevoltageis self-induced.

The term inductor is used to describe a circuit element possessing the property of inductance and a coil of wire is a very common inductor. In circuit diagrams, a coil or wire is usually used to indicate an inductive component. Taking a closer look at a coil will help understand the reason that a voltage is induced in a wire carrying a changing current. The alternating current running through the coil creates a magnetic field in and around the coil that is increasing and decreasing as the current changes. The magnetic field forms concentric loops that surround the wire and join to form larger loops that surround the coil as shown in the image below.When the current increases in one loop the expanding magnetic field will cut across some or all of the neighboring loops of wire, inducing a voltage in these loops. This causes a voltage to be induced in the coil when the current is changing.

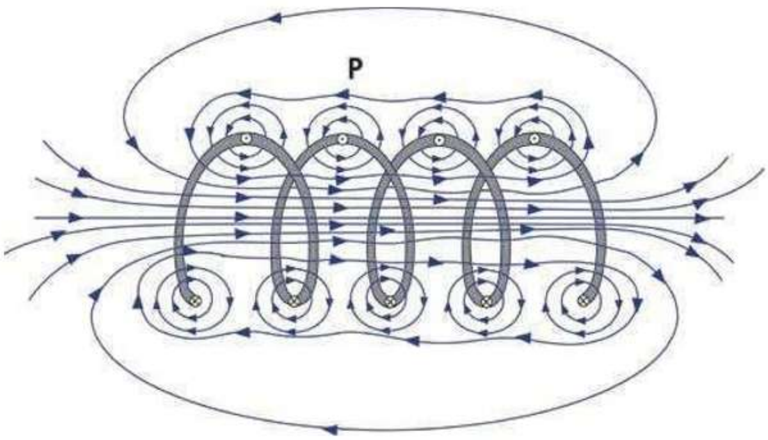


Fig. 11..4

Where:

VL= induced voltage in volts

N= Number of turns in the coil

dø/dt = rate of change of magnetic flux in webers/ second

The equation simply states that the amount of induced voltage VL) is proportional to the number of turns in the coil and the rate coil is increased, the amount of induced voltage will also increase

In a circuit, it is much easier to measure current than it is to measure magnetic flux, so the following equation can be used to determine the induced voltage if the inductance and frequency of the current are known. This equation can also be reorganized toallow the inductance to be calculated when the amount of inducted voltage can be determined and the current frequency is known.

$$V_L = L\frac{di}{dt}$$

Where:
VL= the induced voltage in volts
L= the value of inductance in henries
di/dt = rate of change of current in amperes second

Inductive Reactance
The reduction of current flow in a circuit due to inductionis called inductive reactance.By taking a closer look at a coil of wire and applying Lenz's law, it can be seen how inductance reduces the flow of current in the circuit. In the image below, the direction of the primary current is shown in red, and the magnetic field generated by the current isshown in blue. The direction of the pointing your thumb in the direction of the current. Your fingers will then point in the direction of the magnetic field. It can be seen that the magnetic field from one loop of the wire will cut across the other loops in the coil and this will induce current flow (shown

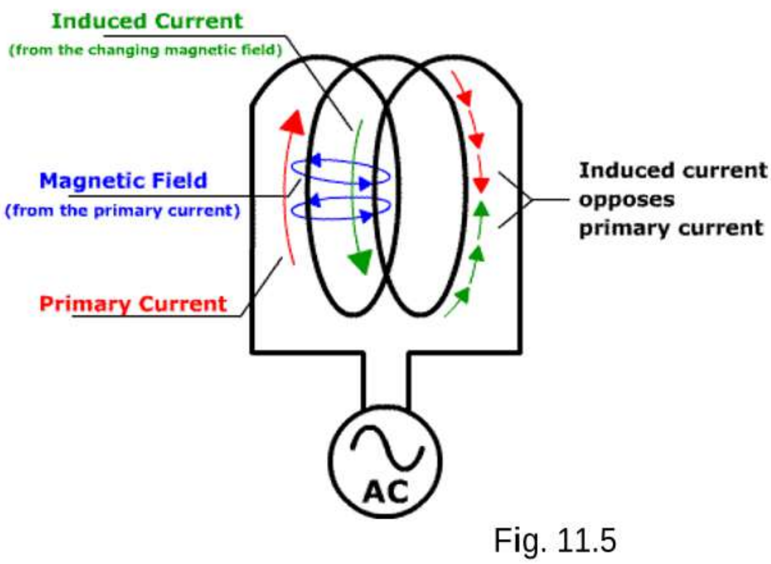


Fig. 11.5

Similarly to resistance, inductive reactance reduces the flow of current in a circuit. However, it is possible to distinguish between resistance and inductive reactance in a circuit by looking at the timing between the sine waves of the voltage and current of the alternating current. In an AC circuit that contains only resistive
components, the voltage and the current will be in-phase, meaning that the peaks and valleys of their

sine waves will occur at the same time. When there is inductive reactance present in the circuit, the phase of the current will be shifted so that its peaks and valleys do not occur at the same time as those of thevoltage.

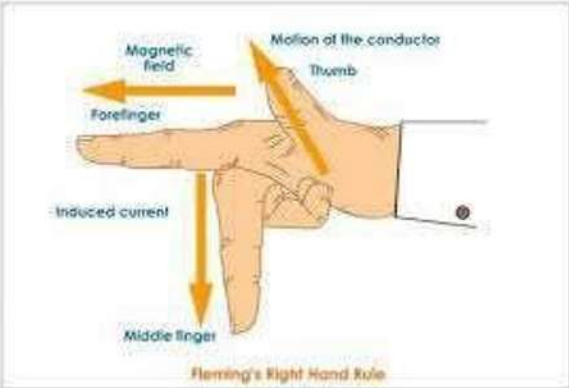


Fig. 11.6

The direction of induced voltage is determined by applying right hand rule for generators as shown above.(FIG 11.6)

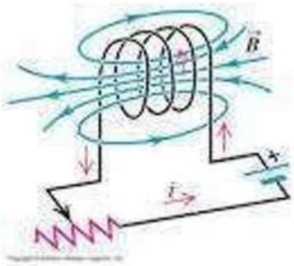


Fig11.7

The rule is applied to one of the loop of the inductor.It states that if you point the thumb of your right hand in the direction of relative motion of the conductor and your first finger in the direction of magnetic field,your second finger extended as shown above will now indicate the direction of induced conventional current .

TYPES OF INDUCTOR

Inductor used in radio can range from a straight wire at UHF to largechokesandtransformersusedforfilteringtheripplefrom the output of power supply and in audio amplifiers. Valueof inductor range from nanohenries to tens of henries. Inductorsareclassifiedbythetypeofcoreandthemethodof winding them. The number of turns in the inductor winding and the core material determine the capacity of the inductor.Cores made of dielectric material like ceramic, wood, paper provide small amount of stored energy while cores made of ferrite substance have a much higher degree of stored energy.

The core material is usually the most important aspect of the inductor construction. The conductor typically used in the construction of an inductor offer little resistance to the flow of current. However, with the introduction of the core, resistance is introduced in the circuit and the current now builds up in the windings until the resistance of the core is overcome. This build up is stored as magnetic energy in the core.Depending on thecore resistance, the buildup soon reaches a point of magneticsaturation anditcanbereleasedwhennecessary.Themostcommoncore materials are air,solidferrite,powderedferrite,steel,toroidand ferrite core.(refer fig 11.8 and 11.9)

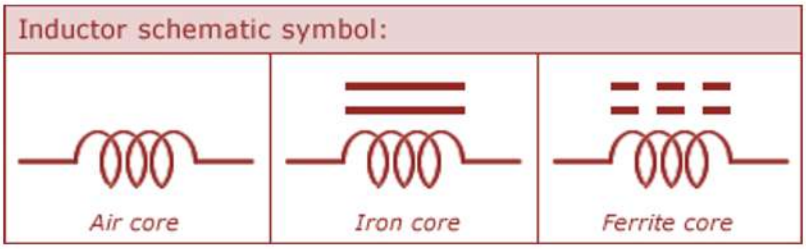


Fig.11.8

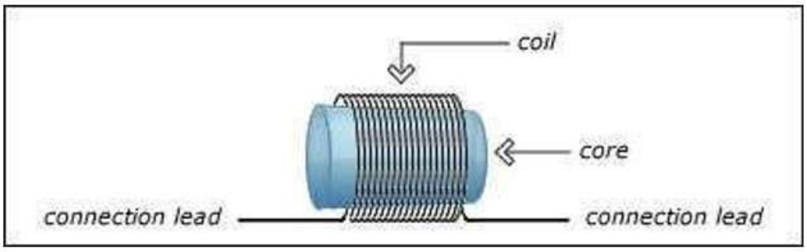


Fig.11.9

Higher current expands the magnetic field while a decrease in current will reduce the magneticfield.

NUMBER OF WIRE WRAPS, OR "TURNS" INTHE COIL: All other factors being equal, a greater number of turns of

wire in the coil results in greater inductance; fewer turns of wire in the coil results in less inductance.(refer fig 11.10).Inductanceis directly proportional to square of number of turns.

Explanation:More turns of wire means that the coil willgenerate a greater amount of magnetic field force (measured in amp-turns!), for a given amount of coil current.

Fig. 11.10

COILAREA:Allotherfactorsbeingequal,greatercoilarea(as measured looking lengthwise through the coil, at thecross-section ofthecore)resultsingreaterinductance;lesscoilarearesultsin less inductance.

Explanation: Greater coil area presents less opposition to the formation of magnetic field flux, for a given amount of field force (amp-turns). (refer fig 11.11)

Fig.11.11

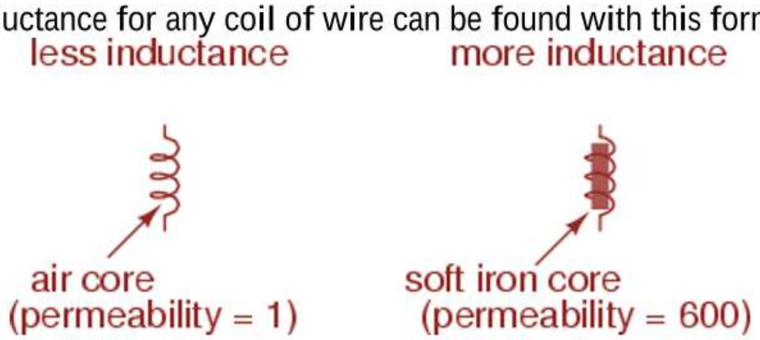
COILLENGTH:
Allotherfactorsbeingequal,thelongerthe coil'slength,thelessinductance;theshorterthecoil'slength,the greater the inductance. (refer fig 11.12)
Explanation: A longer path for the magnetic field flux totake resultsinmoreoppositiontotheformationofthatfluxforany given amount of field force (amp-turns).

Fig.11.12

COREMATERIAL: Allotherfactorsbeingequal,thegreater the magnetic permeability of the core which the coil iswrapped around, the greater the inductance; the less the permeability ofthe core, the less the inductance. (refer fig 11.13)

Explanation: A core material with greater magnetic permeability results in greater magnetic field flux for any given amount of field force (amp-turns).

An approximation of inductance for any coil of wire can be found with this formula



The above factors are all physical factors and are variable. Many differently constructed coils can have the same inductance. The important information to remember, however, is that inductance is dependent upon the degree of linkage between the wire conductor(s) and the electromagnetic field. In a straight length of conductor, there is very little flux linkage between one part of the conductor and another. Therefore, its inductance is extremely small. It was shown that conductors become much more inductive when they are wound into coils. This is true because there is maximum flux linkage between the conductor turns, which lie side by side in thecoil.

SELF INDUCTANCE AND MUTUAL INDUCTANCE

Self Inductance of a Coil

Inductance is the name given to the property of a componentthat opposes the change of current flowing through it and even a straight piece of wire will have some inductance. Inductors do this by generating a self-induced emf within itself as a result of their changing magnetic field.
In an Electrical Circuit ,
but it is sometimes commonly called back-emf as its polarity is in the opposite direction to the applied voltage.

When the emf is induced into an adjacent componentsituated withinthesamemagneticfield,theemfissaidtobeinduced byMutual-induction, (M) and mutual induction is the basic operating principal of transformers, motors, relays etc.Self inductanceisaspecialcaseofmutualinductance,andbecauseit isproducedwithinasingleisolatedcircuitwegenerallycallself- inductance simply, Inductance.
The basic unit of measurement for inductance is called the Henry, (H)afterJosephHenry,butitalsohastheunitsofWebersper

Lenz's Law tells us that an induced emf generates a current in a direction which opposes the change in flux which caused the emf in the first place, the principal of action and reaction. Then we can accurately define Inductance as being: “a circuit will have an inductance value of one Henry when an emf of one volt is induced in the circuit was the current flowing through the circuit changes at a rate of one ampere/second”. In other words, a coil has an inductance of one Henry when the current flowing through it changes at a rate of one ampere/second inducing a voltage of one volt in it and this definition can be presentedas:

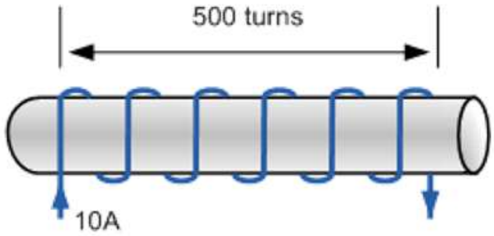
$$L = 1H = 1V\frac{dI}{dt} = 1\frac{\text{volt}}{\text{ampere/second}}$$

Inductance, L is actually a measure of an inductors “resistance”to the change of the current flowing through the circuit and thelarger is its value in Henries, the lower will be the rate of currentchange.

We know from the previous tutorial about theInductor, that inductorsaredevicesthatcanstoretheirenergyintheformofa magnetic field. Inductors are made from individual loops ofwire
This expression can also be defined as the flux linkage divided by thecurrentflowingthrougheachturn.Thisequationonlyapplies to linear magnetic materials.

Inductance Example No.1

A hollow air cored inductor coil consists of 500 turns of copper wire which produces a magnetic flux of 10mWb when passing a DC current of 10 amps. Calculate the self-inductance of the coil in milli-Henries.



$$L = N\frac{\Phi}{I} = 500\frac{0.01}{10} = 500mH$$

ENERGY IN AN INDUCTOR

Where L is inductance and I is the current through the inductor.

L/R TIME CONSTANT

The L/R TIME CONSTANT is a valuable tool for use in determining the time required for current in an inductor to reach a specific value. As shown in figure below, one L/R time constant is the time required for the current in an inductor to increase to 63 percent (actually 63.2 percent) of the maximum current. Each time constant is equal to the time required for the current to increase by
percent of the difference in value between the current flowing in the inductor and the maximum current. Maximum current flows in the inductor after five L/R time constants are completed. The following example should clear up any confusion about time constants. Assume that maximum current in an LR circuit is 10 amperes. As you know, when the circuit is energized, it takes time for the current to go

from zero to 10 amperes. When the first time constant is completed, the current in the circuit is equal to 63.2% of 10 amperes. Thus the amplitude of current at the end of 1 time constant is 6.32amperes.

Fig.11.14

During the second time constant, current again increases by 63.2% (.632) of the difference in value between the current flowing in the inductor and the maximum current. This difference is 10 amperesminus6.32amperesandequals3.68amperes;63.2%of
amperes is 2.32 amperes. This increase in current during the second time constant is added to that of the first time constant. Thus, upon completion of the second time constant, the amount of current in the LR circuit is 6.32 amperes + 2.32 amperes = 8.64 amperes.

During the third constant, current again increases:

$$10 \text{ amperes} - 8.64 \text{ amperes} = 1.36 \text{ amperes}$$
$$1.36 \text{ amperes} \times .632 = 0.860 \text{ ampere}$$
$$8.64 \text{ amperes} + 0.860 \text{ ampere} = 9.50 \text{ amperes}$$

During the fourth time constant, current again increases:

$$10 \text{ amperes} - 9.50 \text{ amperes} = 0.5 \text{ ampere}$$
$$0.5 \text{ ampere} \times .632 = 0.316 \text{ ampere}$$
$$9.50 \text{ amperes} + 0.316 \text{ ampere} = 9.82 \text{ amperes}$$

During the fifth time constant, current increases as before:

$$10 \text{ amperes} - 9.82 \text{ amperes} = 0.18 \text{ ampere}$$
$$0.18 \text{ ampere} \times .632 = 0.114 \text{ ampere}$$
$$9.82 \text{ amperes} + .114 \text{ ampere} = 9.93 \text{ amperes}$$

Thus, the current at the end of the fifth time constant is almost equal to 10.0 amperes, the maximum current. For all practical purposes the slight difference in value can be ignored.
When an LR circuit is deenergized, the circuit current decreases (decays) to zero in five time constants at the same rate that it previously increased. If the growth and decay of current in an LR circuit are plotted on a graph, the curve appears as shown in figure above. Notice that current increases and decays at the same rate in five time constants.
The value of the time constant in seconds is equal to the inductance in henrys divided by the circuit resistance in ohms.
The formula used to calculate one L/R time constant is:

$$\text{Time Constant (TC) in seconds} = \frac{\text{L (in henrys)}}{\text{R (in ohms)}}$$

When an LR circuit is deenergized, the circuit current decreases (decays) to zero in five time constants at the same rate that it previously increased. If the growth and decay of current in an LR circuit are plotted on a graph, the curve appears as shown in figure above. Notice that current increases and decays at the same rate in five time constants.

The value of the time constant in seconds is equal to the inductance in henrys divided by the circuit resistance in ohms.

The formula used to calculate one L/R time constant is:

$$\text{Time Constant (TC) in seconds} = \frac{\text{L (in henrys)}}{\text{R (in ohms)}}$$

Consider two coils placed near each other as shown in figure. When current is passed through the primary coil, magnetic flux is produced. This magnetic flux is also linked with the secondary coil. If the current is changed by varying the resistance in the primary circuit, the magnetic flux also change. As this changing flux is linked with the secondary coil, it induces an emf in it. This phenomenon of inducing emf in a coil by changing current in another coil is known as mutual inductance (fig 11.15)

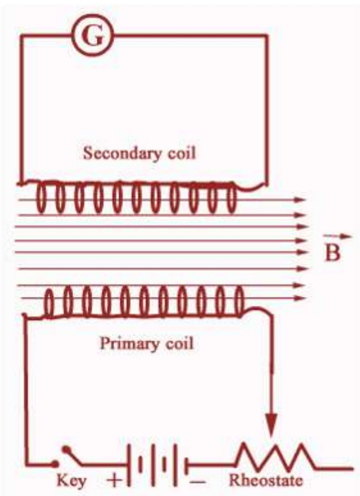


Fig. 11.15

Factors Affecting Mutual Inductance

The amount of Mutual Inductance that links one coil to another depends very much on the relative positioning of the two coils. If one coil is positioned next to the other coil so that their physi

Mutual Inductance between Coils

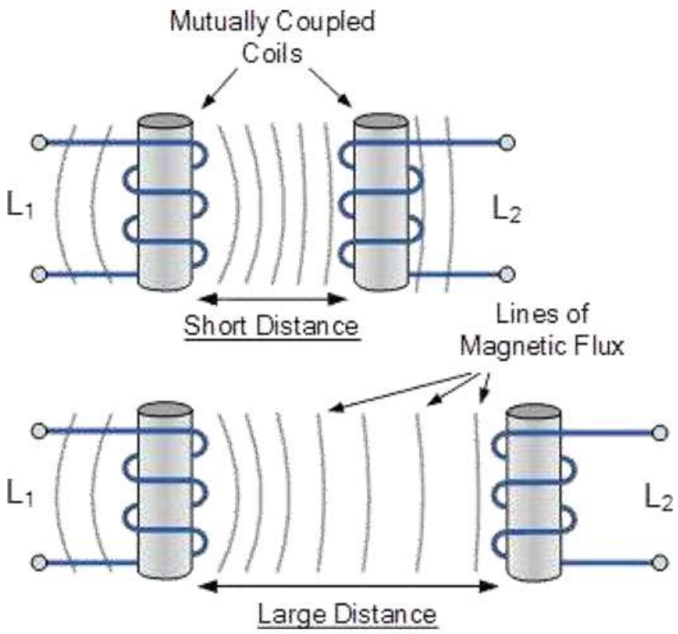


Fig. 11.16

Mutual Induction

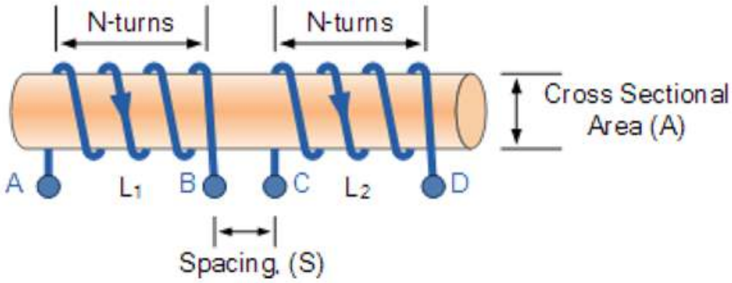


Fig 11.7

Here the current flowing in coil one, L1 sets up a magnetic field around itself with some of these magnetic field lines passing through coil two, L2 giving us mutual inductance. Coil one has a current of I1 and N1 turns while, coil two has N2 turns. Therefore, the mutual inductance, M12 of coil two that exists with respect to coil one depends on their position with respect to each other and is given as:

$$M_{12} = \frac{N_2 \Phi_{12}}{I_1}$$

Where:

Likewise, the flux linking coil one, L1 when a current flows around coil two, L2 is exactly the same as the flux linking coil two when the same current flows around coil one above, then the mutual inductance of coil one with respect of coil two is defined as M21. This mutual inductance is true irrespective of the size, number of turns, relative position or orientation of the two coils. Because of this, we can write the mutual inductance between the two coils as: M12 = M21 =M.

$$L_1 = \frac{\mu_o \mu_r N_1^2 A}{\ell} \quad \text{And} \quad L_2 = \frac{\mu_o \mu_r N_2^2 A}{\ell}$$

Then by cross-multiplying the two equations above, the mutual inductance that exists between the two coils can be expressed in terms of the self inductance of each coil.

$$M^2 = L_1 L_2$$

Giving us a final and more common expression for the mutual inductance between two coils as:
Mutual Inductance between Coils
However, the above equation assumes zero flux leakage and 100% magnetic coupling between the two coils, L 1 and L 2. In reality there will always be some loss due to leakage and position, so the magnetic coupling between the two coils can never reach or exceed 100%, but can become very close to this value in some special inductivecoils.

Generally, the amount of inductive coupling that exists between the two coils is expressed as a fractional number between 0 and 1 instead of a percentage (%) value, where 0 indicates zero or no inductive coupling, and 1 indicating full or maximum inductivecoupling.

In other words, if $k = 1$ the two coils are perfectly coupled, if $k > 0.5$ the two coils are said to be tightly coupled and if $k < 0.5$ the two coils are said to be loosely coupled. Then the equation above which assumes a perfect coupling can be modified to take into account this coefficient of coupling, k and is givenas:
Coupling Factor between Coils

$$k = \frac{M}{\sqrt{L_1 L_2}} \quad \text{or} \quad M = k \text{ x } \sqrt{L_1 L_2} \text{ H}$$

`

or
When the coefficient of coupling, k is equal to 1, (unity) such that all the lines of flux of one coil cuts all of the turns of the other, the mutual inductance is equal to the geometric mean of the two individual inductances of the coils. So when the two inductances are equal and L 1 is equal to L 2, the mutual inductance that exists between the two coils can be defined as:

$$M = \sqrt{L_1 L_2} = L$$

Mutual Inductance Example No1
Two inductors, whose self-inductances are given as 75mH and 55mH respectively, are positioned next to each other on a common magnetic core so that 75% of the lines of flux from the first coil are cutting the second coil. Calculate the total mutual inductance that exists betweenthem.

$$M = k\sqrt{L_1 L_2}$$

$$M = 0.75\sqrt{75\text{mH x } 55\text{mH}} = 48.2\text{mH}$$

INDUCTORS IN SERIES

Inductor in Series Circuit

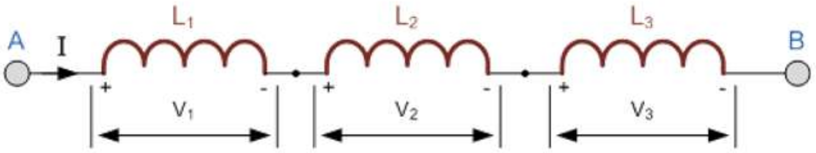


Fig 11.8

The current, (I) that flows through the first inductor, L1 has no other way to go but pass through the second inductor and the third and so on. Then, inductors in series have a Common Current flowing through them, for example:

$$I_{L1} = I_{L2} = I_{L3} = I_{AB}$$

Thus, the total inductance for series inductors is more than any one of the individual inductors' inductances. In the example above, the inductors L1, L2 and L3 are all connected together in series between points A and B. The sum of the individual voltage drops across each inductor can be found using Kirchhoff's Voltage Law (KVL) where, VT = V1 + V2 + V3 and we know from the previous tutorials on inductance that the self-induced emf across an inductor is given as: V = Ldi/dt.

So by taking the values of the individual voltage drops across each inductor in our example above, the total inductance for the series combination is given as:

$$L_T \frac{di}{dt} = L_1 \frac{di}{dt} + L_2 \frac{di}{dt} + L_3 \frac{di}{dt}$$

By dividing through the above equation by di/dt we can reduce it to give a final expression for calculating the total inductance of a circuit when connecting inductors in series and this is given as:

The formula for calculating the series total inductance is the same form as for calculating series resistances:

Series Inductances

$$L_{total} = L_1 + L_2 + \ldots L_n$$

EXAMPLE

Three inductors of 10mH, 40mH and 50mH are connected together in a series combination with no mutual inductance between them. Calculate the total inductance of the series combination.

$$L_T = L_1 + L_2 + L_3 = 10mH + 40mH + 50mH = 100mH$$

INDUCTORS IN PARALLEL

Inductors are said to be connected together in "Parallel" when both of their terminals are respectively connected to each terminal of the other inductor orinductors.

VL1 = VL2 = VL3 = VAB …etc

In the following circuit the inductors L1, L2 and L3 are all connected together in parallel between the two points A and B. Inductors in Parallel Circuit.

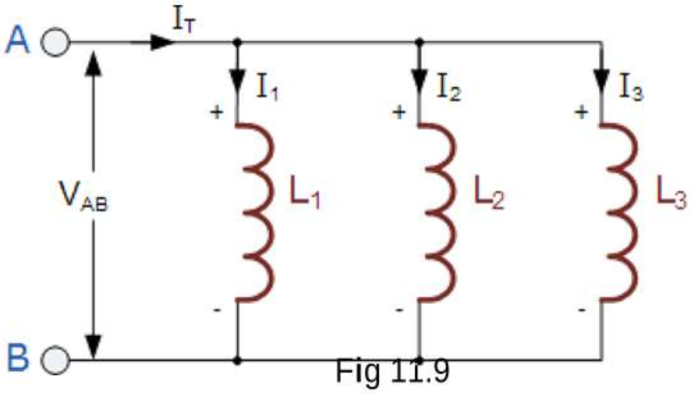


Fig 11.9

In the series inductors, we saw that the total inductance, LT of the circuit was equal to the sum of all the individual inductors added together. For inductors in parallel the equivalent circuit inductance LT is calculateddifferently

Then by taking the values of the individual currents flowing through each inductor in our circuit above, and substituting the current i for i1 + i2 + i3 the voltage across the parallel combination is givenas:

$$V_{AB} = L_T \frac{d}{dt}\left(i_1 + i_2 + i_3\right) = L_T\left(\frac{di_1}{dt} + \frac{di_2}{dt} + \frac{di_3}{dt}\right)$$

By substituting di/dt in the above equation with v/L gives:

$$V_{AB} = L_T\left(\frac{V}{L_1} + \frac{V}{L_2} + \frac{V}{L_3}\right)$$

We can reduce it to give a final expression for calculating the total inductance of a circuit when connecting inductors in parallel and this is given as:

Parallel InductorEquation

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

Inductors in Parallel Example

Three inductors of 60mH, 120mH and 75mH are connected together in a parallel combination with no mutual inductance between them. Calculate the total inductance of the parallel combination.

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} = \frac{1}{60\,mH} + \frac{1}{120\,mH} + \frac{1}{75\,mH} = 26\,mH$$

PRINCIPLE USE OF INDUCTORS

They are also used in electronic filters to separate signals of different frequencies, and in combination with capacitors to make tuned circuits, used to tune radio and TV receivers.

Inductors in AC Circuits

Inductors are extensively used in alternating current (AC) applications such as radio, TV and communications equipment, and in these systems, how inductors react to AC signals of different frequencies is very useful.

Chokes

Another name used for an inductor is a "Choke". Inductors, being just coils of copper wire, will allow DC to pass easily, but when AC is applied, inductors create an opposition to current flow that increases, as the frequency of the alternating current increases. Therefore AC is prevented from flowing or is "Choked off" while DC is allowed to pass. This effect is used in power supplycircuits where the public AC mains (line) supply has to be converted to a DC supply suitable for powering electronic circuits.

Energy Storage

This can produce a pulse of high voltage across the coil. The pulse of energy can be a problem in some electronic circuits and can easily destroy other components if not properly controlled, but it can
Inductors of many types

The physical size of inductors varies greatly, depending on the power being handled, and on the frequency of the AC being used; from huge power transformers in power stations and the electricity supply grid, to tiny inductors in radio equipment consisting of a few turns of wire and only a few millimetres across.

INDUCTIVE REACTANCE

$$XL = 2\pi FL$$

When a DC voltage is applied across an inductor, the growth of the current through it is not instant but is determined by the inductors self-induced or back emf value. Also that the inductors current continues to rise until it reaches its maximum steady state condition after five time constants.

We also saw that the maximum current flowing through an inductive coil is limited only by the resistive part of the coils windings in Ohms, and as we know from Ohms law, this is determined by the ratio of voltage over current, V/R.

When an alternating or AC Voltage is applied across an inductor the flow of current through it behaves very differently to that of an applied DC voltage. The effect of a sinusoidal supply produces a phase difference between the voltage and the current waveforms. Now in an AC circuit, the opposition to current flow through the coils windings not only depends upon the inductance of the coil but also the frequency of the AC waveform.

Just like resistance, the value of reactance is also measured in Ohm's but is given the symbol X, (uppercase letter "X"), to distinguish it from a purely resistive value.

$X_L = 2 \pi f L$

XL is inductive reactance in ohms

F is frequency in cycles per sec

Π is 3.1416

GENERATOR THEORY

Energy for the operation of most electrical equipment on large aircraft and some small aircraft is supplied by generato Generators designed to produce direct current are called DC
generators whereas generators that produce alternating current are called AC generators.AC power drives ac motor.

On many older aircraft, the DC generator is the source of electrical energy. With this type of system, one or more DC generators are driven by the engine(s) to supply power for all electrical equipment as well as for charging the battery. In most cases only one generator is driven by each engine; however some large aircraft have two generators that are driven by a single engine.

PRINCIPLE OF OPERATION

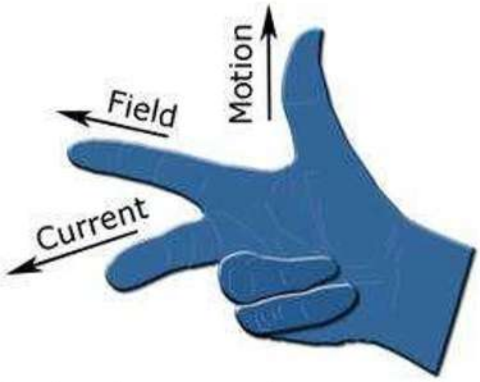
There are two types of generators, one is ac generator and other is dc generator. Whatever may be the types of generators, it always converts mechanical power to electrical power. An ac generator produces alternating power. A DC generator produces direct power. Both of these generators produce electrical power, based emf fundamentals .

The amount of voltage or emf depends upon

1. The strength of the magnetic field
2. The angle at which the conductor cuts the magnetic field

3 The speed at which the conductor is moved

4. The length of the conductor within the magnetic field



Fleming's right hand rule(for generators) shows the direction of induced current when a conductor moves in a magneticfield.

The right hand is held with the thumb, first finger and secondfinger mutually perpendicular to each other (at right angles), as shown in the diagram.

The Thumb represents the directionof otion of the conductor.

Hence the most basic two essential parts of a generator are a magnetic fieldand conductors which move inside that magneticfield

Theory of operation
Single Loop DC Generator

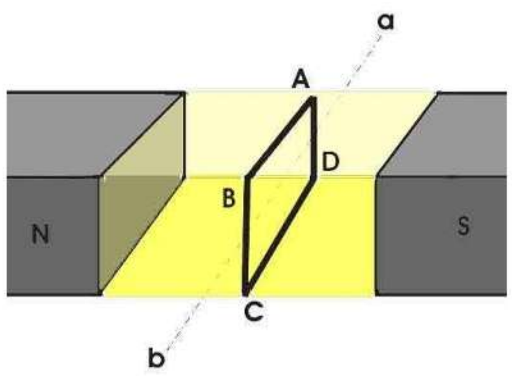
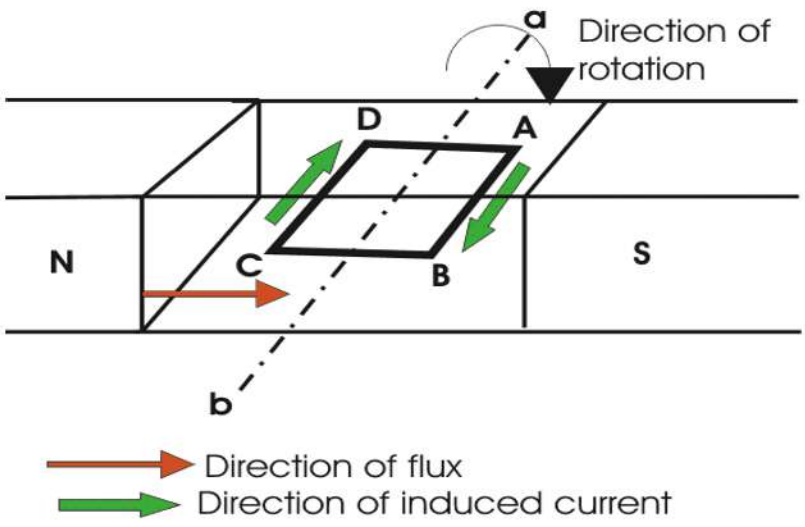


Fig. 12.1 Single Loop DC Generator

In the figure 12.1 above, a single loop of conductor of rectangular shape is placed between two opposite poles of magnet.

•Let's us consider, the rectangular loop of conductor is ABCD which rotates inside the magnetic field about its own axis ab.



. Fig. 12.2

As the loop is closed there will be a current circulating through the loop. The direction of the current can be determined by Flemming's right hand rule. This rule says that is you stretch thumb, index finger and middle finger of your right hand perpendicular to each other then thumbs indicates the direction of motion of the conductor index finger indicates the direction of magnetic field i.e. N-pole to A-pole, and middle finger indicates the direction of flow of current through theconductor.

Now if we apply this right hand rule. We will see at this horizontal position of the loop. Current will flow from point A to B and on the other side of the loop current will flow from point C to D.(refer fig12.2)

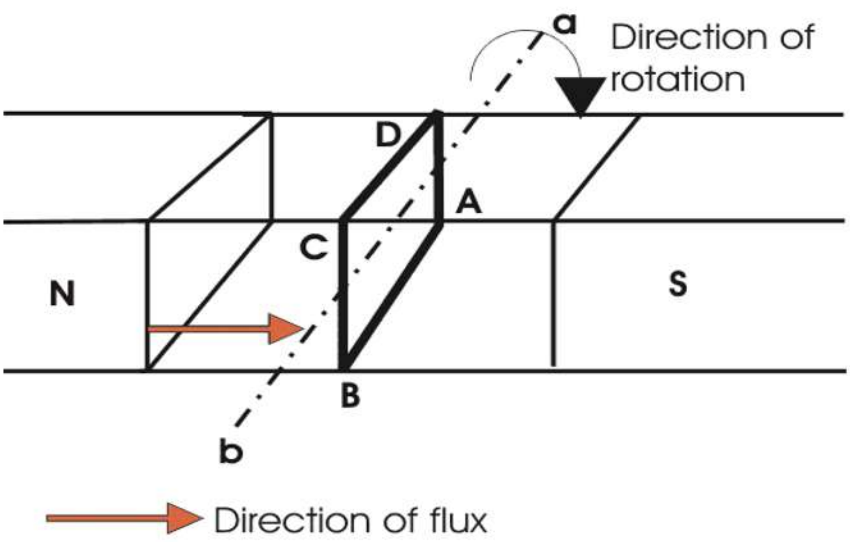


Fig. 12.3

Now if we allow the loop to move further. It will come again to its vertical position but now upper side of the loop will be CD and lower side will be AB (just opposite of the previous vertical position). At this position the tangential motion of the sides of the loop is parallel to the flux lines of the field. Hence there will be no question of flux cutting and consequently there will be no current in the loop.

If the loop rotates further it comes to again in horizontal position.
But now, said AB side of the loop comes in front of N pole and CD comes in front of S pole, i.e. just opposite to the previous horizontal.

Position as shown in the figure 12.

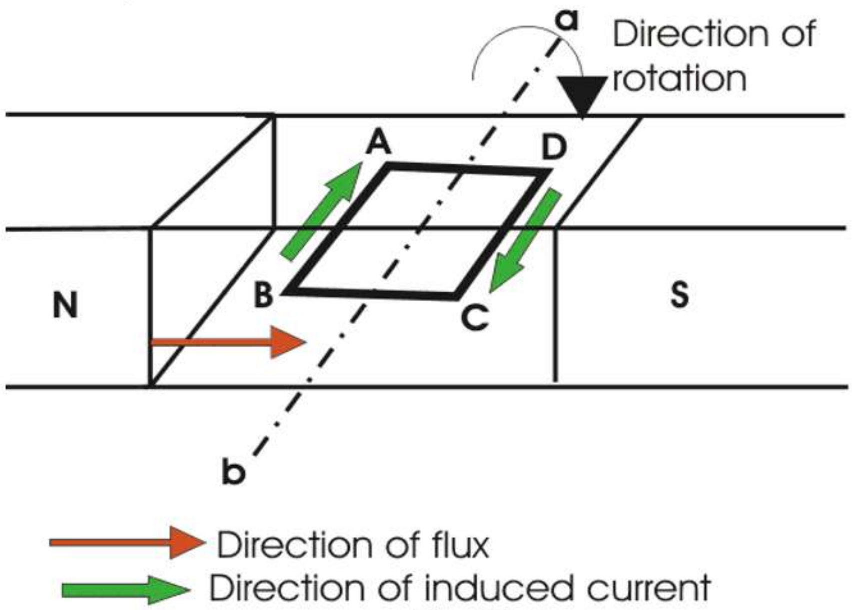


Fig. 12.4

Here the tangential motion of the side of the loop is perpendicular right hand rule, at this position current flows from B to A and on other side from D to C.

Now if the loop is continued to rotate about its axis, every time the side AB comes in front of S pole the current flows from A to B and when it comes in front of N pole the current flows from B toA.similarly,everytimethesideCDcomesinfrontofSpole

the current flows from C to D and when it comes in front of N pole the current flows from D toC.

If we observe this phenomena in different way, it can be conducted that each side of the loop comes in front of N pole the current will flow through that side in same direction i.e. downward to the reference plane and similarly each side of the loop comes in front of S pole current through it flows in same direction i.e. upwards from referenceplane.

Now the loop is opened and connects it with a split ring as shown in the figure below. Split ring is made out of a conductingcylinder which cuts into two halves or segments insulated from each other. The external load terminals are connected with two carbon brushes which are rest on these split slip ringsegments.

Working Principle of DC Generator

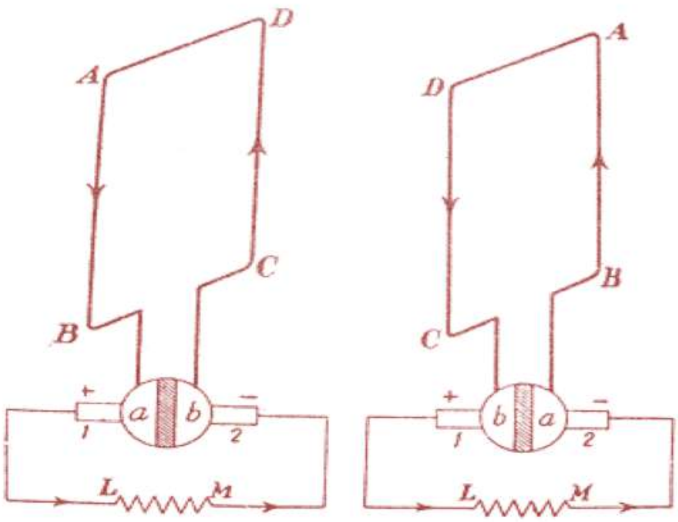


Fig. 12.5

It is seen that in the first half of the revolution current flows always along ABLMCD i.e. brush no 1 in contact with segment a in the next half revolution in the figure the direction of the induced current in the coil is reserved. But at the same time the position of the segments A and B are also reversed which results that brush no 1 comes in touch with that segment B. hence the current in the load resistance again flows from L to M. the wave form of the current

through the load circuit is as shown in the figure 12.6. This current is unidirectional.

V = sinØ

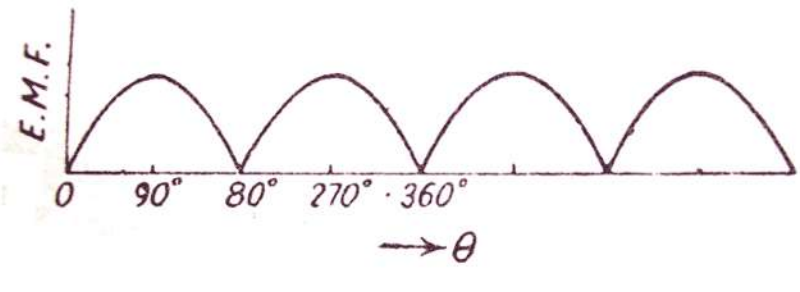


Fig. 12.6

This is basic working principle of DC generator explainedby single loop generatormodel.

The position of the brushes of DC generator is so arranged that the changeover of the segments A and B from one brush to other takes place when the plane of rotating coil is at right angle to the plane of the lines of force. It is so become in that position the induced emf in the coilzero.

COMMUTATOR AND ITS PURPOSE

Effects of commutation

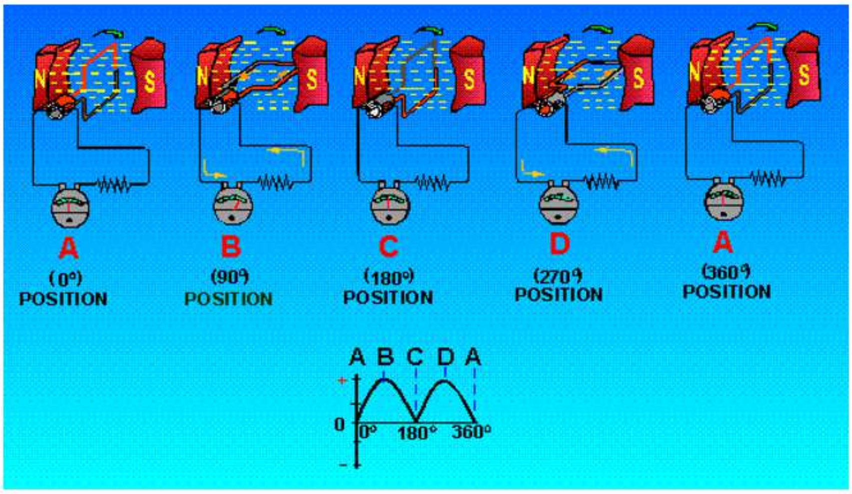


Fig. 12.7 Effects of Commutation

For the remainder of this discussion, refer to figure, parts A through D. This will explain step-by-step description of the operation of a dc generator. When the armature loop rotates clockwise from position A to position B, a voltage is induced in the armature loop which causes a current in a direction that deflects the meter to the right. Current flows through loop, out of the negative brush, through the meter and the load, and back through the positive brush to the loop. Voltage reaches its maximum value at point B on the graph for reasons explained earlier. The generated voltage and the current fall to zero at position C. At this instant each brush makes contact with both segments of the commutator. As the armature loop rotates to position D, a voltage is again induced in the loop. In this case, however, the voltage is of opposite polarity.

The voltages induced in the two sides of the coil at position D are in the reverse direction to that of the voltages shown at position B. Note that the current is flowing from the black side to thewhite side in position B and from the white side to the black side in positionD.

Construction Features of DC Generators

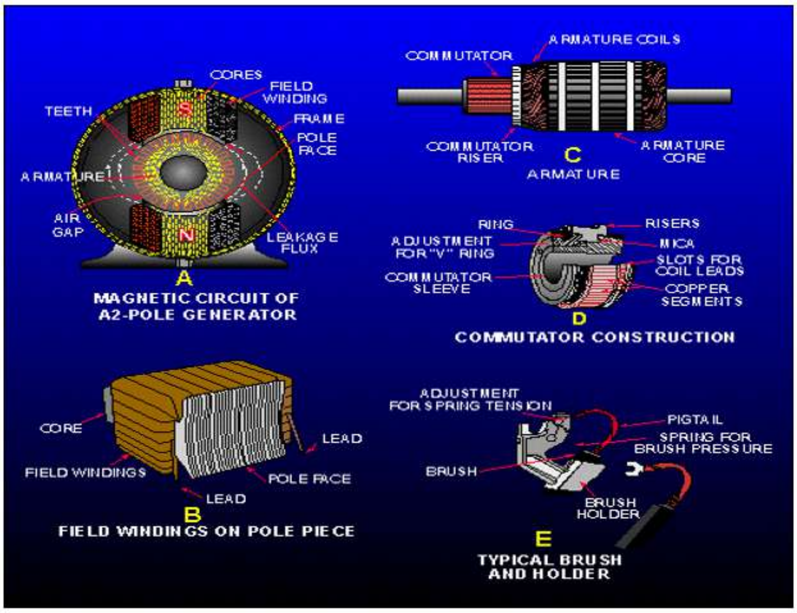


Fig. 12.8 Construction Features of DC Generators

Generators used on aircraft may differ somewhat in design, since they are made by various manufacturers. All, however, are of the same general construction and operate similarly. The major parts, or assemblies, of a dc generator are a field frame (or yoke), a rotating armature, and a brush assembly. The parts of a typical aircraft generator are shown in figure 12.8.

Field Frame

The field frame is also called the yoke, which is the foundation or frame for the generator. The frame has two functions:
n A of figure12.9, the frame for a two pole generator is shown in a cro ss-sectional view. A four pole generator frame is shown in B of figure12.9.

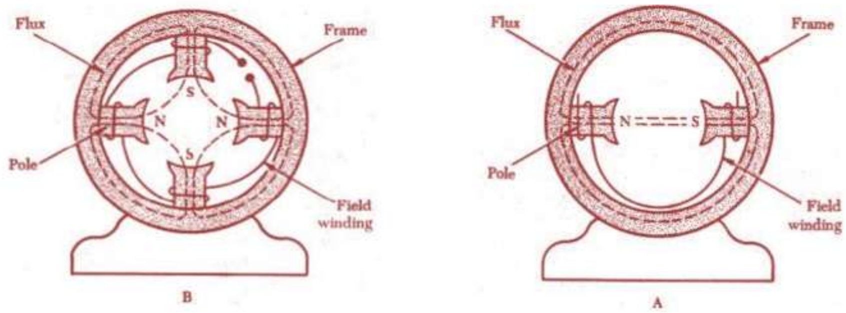


Fig. 12.9 A two pole and four pole frame assembly of the generator.\
The field coils are made up of many turns of insulated wire and are usually wound on a form which fits over the iron core of the pole to which it issecurely fastened.

The exciting current,which is used to produce the magnetic field and which flows throughthe field coils, is obtained from an external source or from the generated dc of the machine. No electrical connection exists between the windings of the field coils and the polepieces

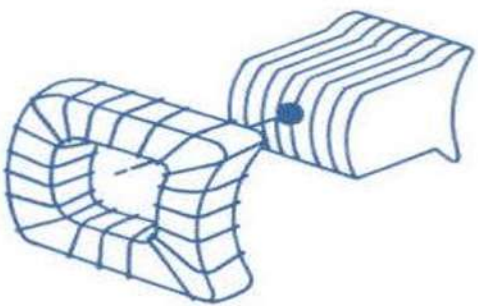


Fig. 12.10 A field coil removed from a field pole

Note that the pole pieces in figure 12.9 project from the frame Becauseairoffersagreatamountofreluctancetothemagnetic field, this design reduces the length of the air gap between the poles and the rotating armature and increases the efficiency of the generator.Whenthepolepiecesaremadetoprojectasshown.

The armature assembly consists of armature coils wound on an iron core, a commutator, and associated mechanical parts. Mounted on a shaft, it rotates through the magnetic field produced by the field coils. The core of the armature acts as an iron
There are two general kinds of armatures: drum. a ring

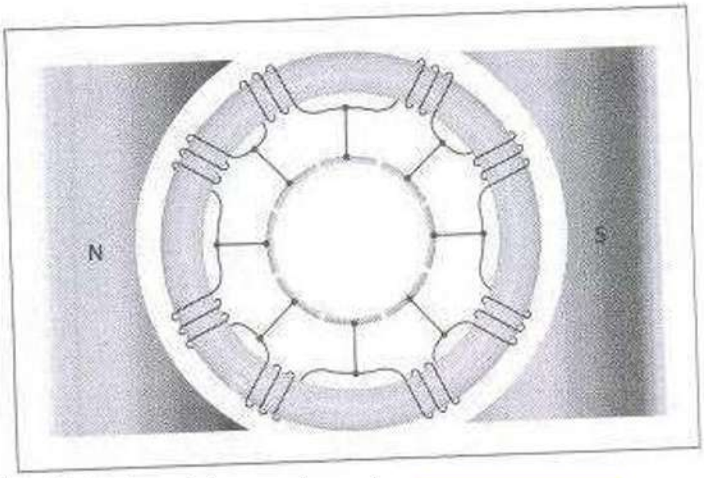


Fig. 12.11 An eight-section, ring-type armature

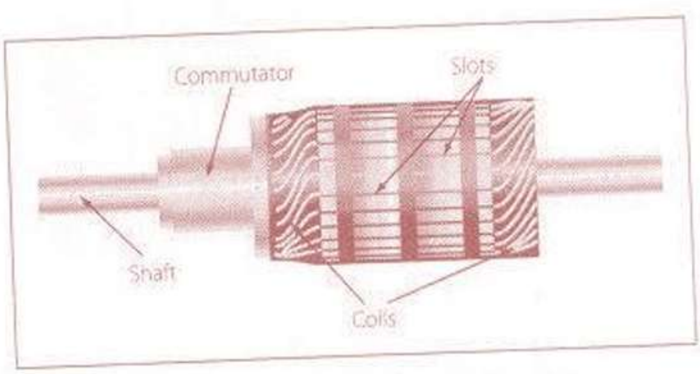


Fig. 12.12 A drum-type armature

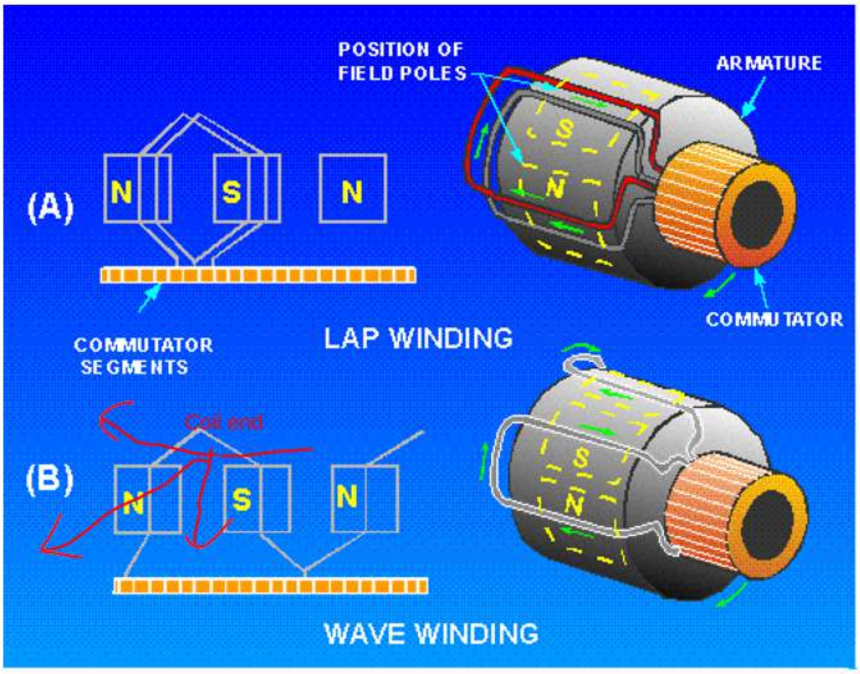


Fig. 12.13

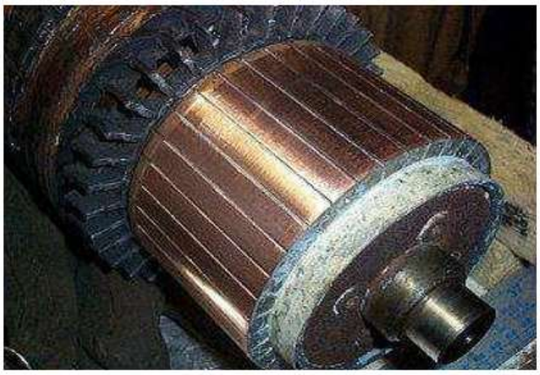


Figure12.14 Commutators

A flexible, braided copper conductor, commonly calleda
Thebrushes,
usually made of high grade carbon and held in place bybrush holdersinsulatedfromtheframe,arefreetoslideupanddownin

their holders in order to follow any irregularities in the surface of the commutator. The brushes are usually adjustable so that the pressureofthebrushesonthecommutatorcanbevariedandthe position of the brushes with respect to the segments can be adjusted.

Graphite is also used for brushes
The constant making and breaking of connections to the coils in which a voltage is being induced necessitates the use of material for brushes which has a definite contact resistance. Also, this material must be such that the friction between the commutator and the brush is low, to prevent excessive wear.For thesereasons, the material commonly used for brushes is high grade carbon.The carbon must be soft enough to prevent undue wear of the commutator and yet hard enough to provide reasonable brush life.

The voltage generated in the armature, placed in a rotating magneticfield,ofaDCgeneratorisalternatinginnature. The commutation in DC machine or more specifically commutation in DC generator is the process in which generated armature winding of a dc machineis current and the stationary brushes.

This transformation of current from the rotating armature of a dc machine to the stationary brushes needs to maintain continuously moving contact between the commutator segments and the brushes. When the armature starts to rotate, then the coils situated

under one pole (let it be N pole) rotates between a positive brush and its consecutive negative brush and the current flows through this coil is in a direction inward to the commutator segments. Then the coil is short circuited with the help of a brush for a very short fraction of time (1⁄500 sec). It is called commutation period.

After this short-circuit time the armature coils rotates under S pole and rotates between a negative brush and its succeeding positive brush. Then the direction of become is reversed which is in the away from the commutator segments. This phenomenon of the reversal of current is termed as commutation process. We get direct current from the brush terminal.

The commutation is called ideal if the commutation process orthe reversal of current is completed by the end of the shortcircuit time or the commutation period. If the reversal of current is completed during the short circuittim commutated.

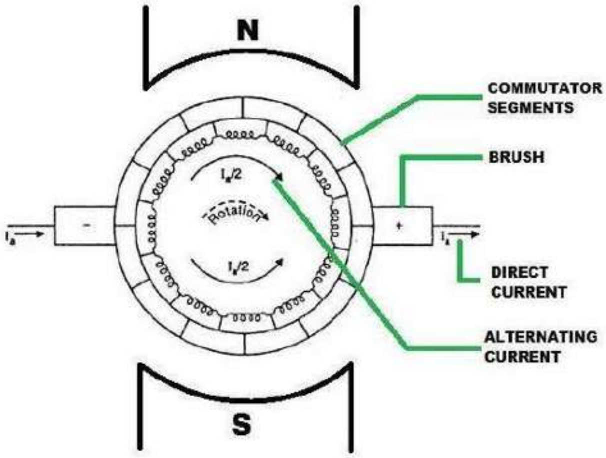


Fig. 12.15

Motor Reaction In a Generator

When a generator delivers current to a load, the armature current creates a magnetic force that opposes the rotation of the armature. This is called MOTOR REACTION. A single armature conductor is represented in figure 12.16, view A. When the conductor is stationary, no voltage is generated and no current flows. Therefore, no force acts on the conductor. When the conductor is moved downward (fig12.16., view B) and the circuit is completed through an external load, current flows through the conductor in the direction indicated. This sets up lines of flux around the conductor in a clockwise direction.

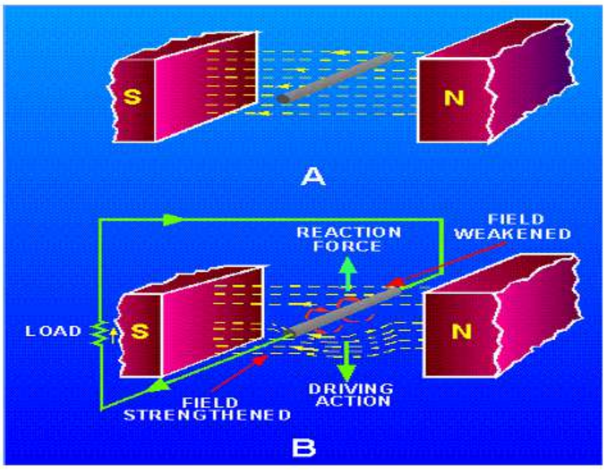


Fig. 12.16 Motor reaction in a generator

Theinteractionbetweentheconductorfieldandthemainfield of the generator weakens the field above the conductor and strengthens the field below the conductor. The main field consists of lines that now act like stretched rubber bands. Thus, an upward reaction force is produced that acts in opposition to the downward driving force applied to the armature conductor. If the current in the conductor increases, the reaction force increases.

Therefore, more force must be applied to the conductor to keep it moving. With no armature current, there is no magnetic (motor) reaction. Therefore, increases, the reaction of each armature conductor againstrotation increases. The actual force in a generator is multiplied by the numberofconductorsinthearmature.Thedrivingforcerequired to maintain the generator armature speed must be increased to Copper loss is minimized in armature windings by using large diameter wire.

LOSSES IN A DC GENERATOR

In dc generators, as in most electrical devices, certain forces act to decrease the efficiency. These forces, as they affect the armature, are considered as losses and may be defined as follows:

CopperlossThepowerlostintheformofheatinthearmature winding of a generator is known as Copper loss. Heat isgenerated any time current flows in a conductor.

Lossis the Copper loss, which increases as current increases. The amount of heat generated is also proportional to the resistance of the conductor. The resistance of the conductor varies directly with its length and inversely with its cross- sectional area.

It is the loss in series or shunt field of generator. is the field copper loss in case of series generators, where Rse is the resistance of the series field widing.
This loss is about 20 to 30% of F.L losses.
iii) The loss due to brsh contact resistance. It is usually included in the armture copperloss.

Magnetic Losses (also known as iron or core losses)
i) Hysteresisloss(Wh)Hysteresislossisaheatlosscausedby
the magnetic properties of the armature. When an armature core is in a magnetic field, the magnetic particles of the core tend to line up with the magnetic field. When the armature core is rotating, its magnetic field keeps changing direction. The continuous movement of the magnetic particles, as they try to align themselves with the magnetic field, produces molecular friction. This, in turn, produces heat. This heat is transmitted to the armature windings.

ii) Eddy Current Loss(We)the core of a generator armature is made from soft iron, which is a conducting material with desirable magnetic characteristics. Any conductor will have currents induced in it when it is rotated in a magnetic field. These currents that are induced in the generator armature core are called EDDY CURRENTS. The power dissipated in the form of heat, as a result of the eddy currents, is considered a
loss.

Eddy currents, just like any other electrical currents, are affected bytheresistanceofthematerialinwhichthecurrentsflow.The resistance of any material is inversely proportional to itscross- sectional area. Figure12.17, view A, shows the eddy currents induced in an armature core that is a solid piece of soft iron. Figure12.17, view B, shows a soft iron core of the same size, but made up of several small pieces insulated from each other. This process is called lamination. The currents in each piece of the laminated core are considerably less than in the solid core because the resistance of the pieces is much higher. (Resistance is inversely proportional to cross-sectional area.) The currents in the individual pieces of the laminated core are so small that the sum of the individual currents is much less than the total of eddy

currents in the solid iron core.

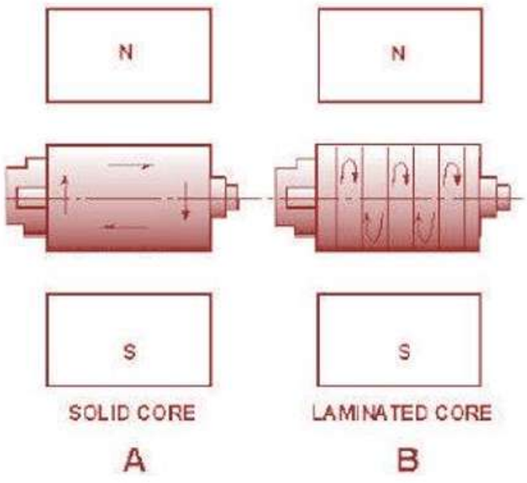


Fig. 12.17

As you can see, eddy current losses are kept low when the core material is made up of many thin sheets of metal.Laminations ina small generator armature may be as thin as 1/64 inch. The laminations are insulated from each other by a thin coat oflacquer or, in some instances, simply by the oxidation of the surfaces. Oxidation is caused by contact with the air while the laminations are being annealed. The insulation value need not be high because the voltages induced are very small.

These magnetic losses are practically constant for shunt and compound-wound generators, because in their case, field current is constant.
Mechanical or Rotational LossesThese consist of
(i) friction loss at bearings and comutator.
(ii) air-friction or windage loss of rotatingarmature
These are about 10 to 20% of F.L losses.

Careful maintenance can be instrumental in keeping bearing friction to a minimum. Clean bearings and proper lubrication are essential to the reduction of bearing friction. Brush frictionis reduced by assuring proper brush seating, using properbrushes, and maintaining proper brush tension. A smooth and clean commutator also aids in the reduction of brush friction.

Usually, magnetic and mechanical losses are collectively known as Stray Losses. These are also known as rotational losses for obvious reasons.

Hence, for shunt and compound generators, Total loss = armature copper loss + W_c
Armature Cu loss is known as variable loss because it varies with the load current.
Total loss = Variable loss + constant losses W_c

TYPES OF DC GENERATOR

Separately Excited DC Generator

These are the generators whose field magnets are energized by some external dc source such as battery. A circuit diagram of separately excited DC generator is shown in figure12.18.
I_a =Armature current I_L =Load current V=Terminalvoltage E_g = Generated emf

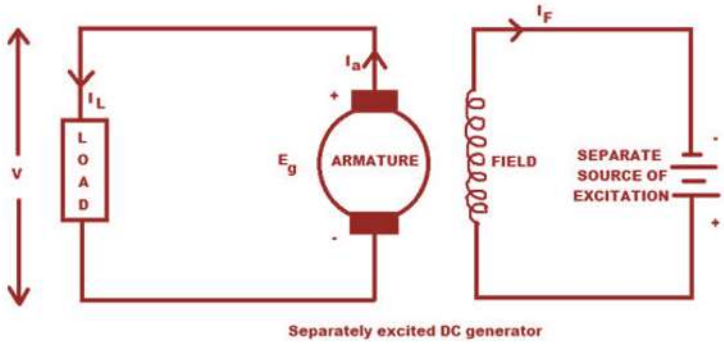


Fig. 12.18Separately Excited DC Generator

Self-excited DC Generators

These are the generators whose field magnets are energized by the currentsuppliedbythemselvesinthesetypesofmachinesfield coils are internally connected with the armature. Due to residual magnetismsomefluxisalwayspresentinthepoles.Whenthe armature is rotated some emf is induced. Hence some induced current is produced. This small current flows through the field coil as well as the load and thereby strengthening the pole flux. As the pole flux strengthened it will produce more armature emf. Which cause further increase of current through the field. This increased field current further raises armature emf and this cumulative phenomenon continues until the excitation to the rated value.

According to the position of the field coils the Self-excited DC generators may be classified as…

A. Series woundgenerators
B. Shunt woundgenerators
C. Compound wound generators Series Wound Generator

In these types of generators, the field windings are connected in series with armature conductors as shown figure 12.19. So whole current flows through the field coils as well as the load, as series field winding carries full load current. It is designed with relatively few turns of thick wire.

The electrical resistance of series field winding is therefore very low (nearly 0.5Ω

Let,
Rsc= Series winding resistance
Isc= Current flowing through these series field Ra= Armature resistance
Ia= Armature current IL Load Current

V= Terminal voltage Eg= Generated emf.

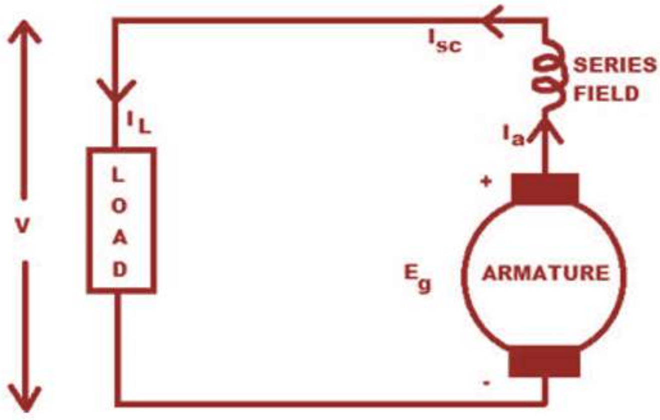


Fig. 12.19 Series Wound Generator

Then Ia= Isc= IL=I (Say)
voltage across the load, V= Eg-I (Ia x Ra) Power generated, Pg= Eg x I
Power delivered to the load, PL = V x I
As load on series generator increases, the output voltage increases.

Shunt Wound DC Generators

In these type of DC generators the field windings are connected in parallel with armature conductors as shown in figure 12.20. In shunt wound generators the voltage in the field winding is same as the voltage across the terminal.

Let,
Rsh = Shunt winding resistance
Ish = Current flowing through the shunt field

Rs = armature resistance Ia = armature current
IL = Load current
V = Terminal voltage Eg = Generated emf.

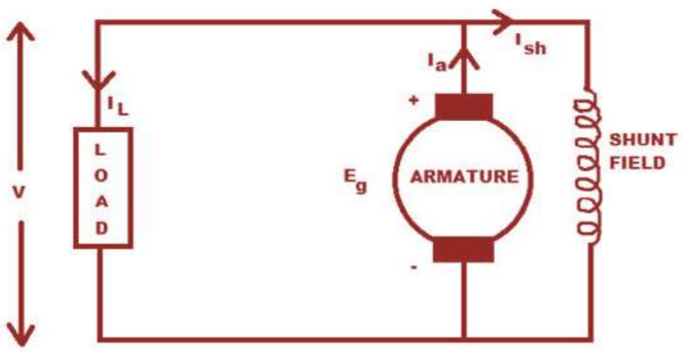


Fig. 12.20 Shunt WoundGenerator

Here armature current Ia is dividing in two parts, one is shunt field current Ishand another is load current.
IL
So,
Ia = Ish + IL

The effective power across the load will be maximum when ILwill be maximum. So, it is required to keep shunt field current as small as possible. For this purpose the resistance of the shunt field winding generally kept high (100 Ω) and large no of turns are used for the desired emf shunt field current. This type is commonly used onaircraft.

Ish = V/Rsh
Voltage across the load, V = Eg - Ia Ra

Power generated Pg = Eg x Ia
Power delivered to the load, PL = V x IL
As load on series generator increases, the output voltage decreases.
Compound Wound DC Generator

In series wound generators, the output voltage is directly proportional with load current. In shunt wound generators, output voltage is inversely proportional with load current. A combination of these two types of generators can overcome the disadvantages of both. This combination of windings is called compound wound DC generator. Compound wound generators have both series field winding and shunt field winding. One winding is placed in series with the armature and the other is placed in parallel with the armature.ThistypeofDCgeneratorsmaybeoftwotypes-short shunt compound wound generator and long shunt compound wound generator.

Short Shunt Compound Wound DC Generator

The generators in which only shunt field winding is in parallel with the armature winding as shown in figure 12.21

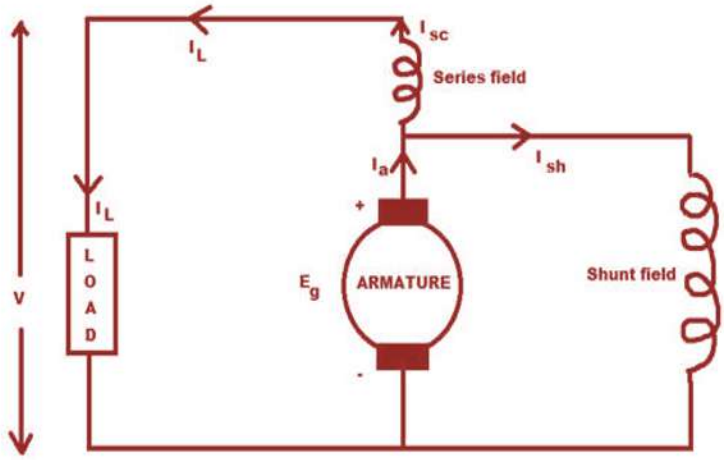


Fig. 12.21 Short Shunt Compound Wound Generator

Series field current, Isc= IL
Shunt field current, Ish = (V+Isc RSC) / Rsh Armature current Ia= Ish +IL
Voltageacrosstheload,V=Eg– IaRa–IscRsc Power Generated Pg = Eg xIa
Power delivered to the load, PL = V x IL

Long Shunt Compound Wound DC Generator

The generators in which shunt field winding is in parallel with both series field and armature winding as shown in the figure12.22.

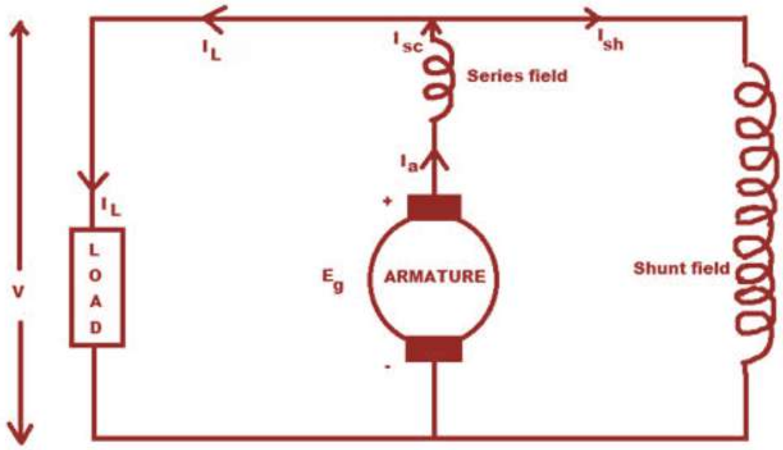


Fig. 12.22 Long Shunt Compound Wound Generator

Shunt Field Current, Ish = V/Rsh
Armature current, Ia = series field current, Isc = IL + Ish
Voltage across the load, V= Eg-Ia Ra-Rsc = Eg-Ia (Ra + Rsc) [.: Ia = Ics]
Power generated Pg = Eg x Ia
Power delivered to the load, PL = V x IL

Inacompoundwoundgenerator,theshuntfieldisstrongerthan the series field. When the series fieldassists the shunt field, generator is said to be cumulative compound wound (refer fig12.23).Ontheotherhandifseriesfieldopposestheshuntfield the generator is said to be differentially compoundwound.(fig 12.23)

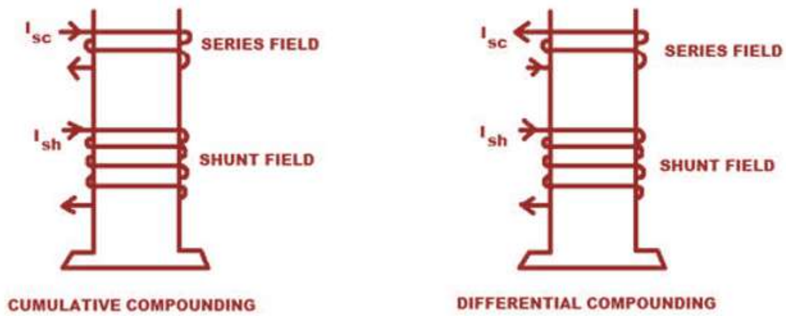


Fig. 12.23

Compound generators are usually designed to be over compounded. This feature permits varied degree of compounding by connecting a variable shunt across the series field. Such a shunt is sometimes called as diverter. Compound generators are mostly used where voltage regulation is needed.

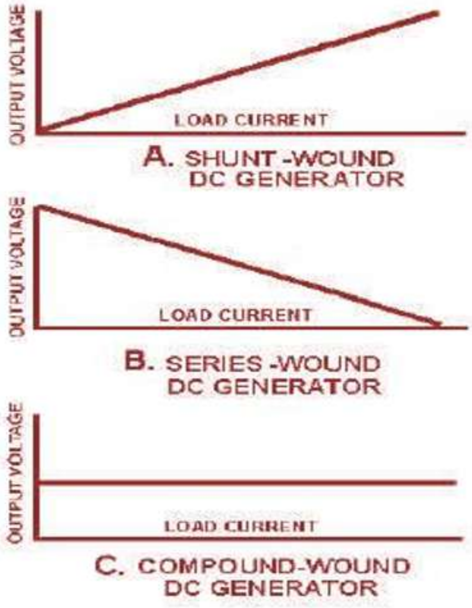


Fig. 12.24

THREE WIRE GENERATOR

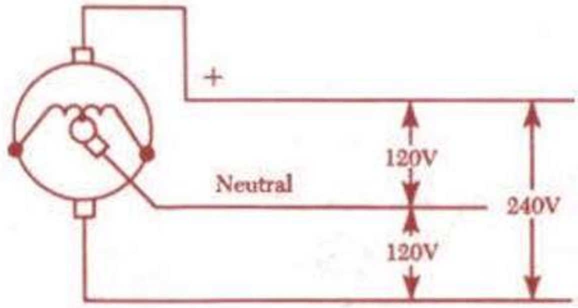


Fig. 12.25 Three-wire Generators

These generators deliver 210 volts or 110 volts from either side of the neutral wire.

Reactance coil is connected to the opposite side of the commutator and the neutral is connected to the midpoint of the reactance coil, which acts as a low loss voltage divider.

If we use the resistors, the IR loss will be prohibitive unless the two loads are perfectly matched. The coil is built into the generator as an armature part, with the midpoint connected to single slip ring where the neutral contacts by brush.

In other generators, the two connections to the commutator are connected in turn to two slip rings and the reactor is located outside the generator. In either cases, the load unbalance on either side of the neutral must not be more than 25% than the rated current output of the generator. The three wire generator permits simultaneous operation of 120 volts lighting circuit and 240 volts motor from the same generator.(Fig 12.25)

ARMATURE REACTION

As the name suggests, the field winding produces the field current & the armature winding carries the armature current. But as the armaturewindingisnothingbutaclosedcoilsothereshouldbea magnetic flux as armature current is passing through the armature conductor.

Thus, there are two magnetic field acting inside the machine. One is due to the field winding, called as main flux & another produced by the armature, namely armature flux. Obviously, there is an interaction in between those fluxes.(refer fig12.26)

The main flux, which is produced by field winding, is very much useful because this flux creates the magnetic field. But the interaction of the armature flux with main flux distorts and weakens the main flux & creates problems for the proper operation of the DC machine.

Thus, the effect of armature flux on the main field flux is called armature reaction. Armature reaction has the effect of reducing the output by distorting the main field .

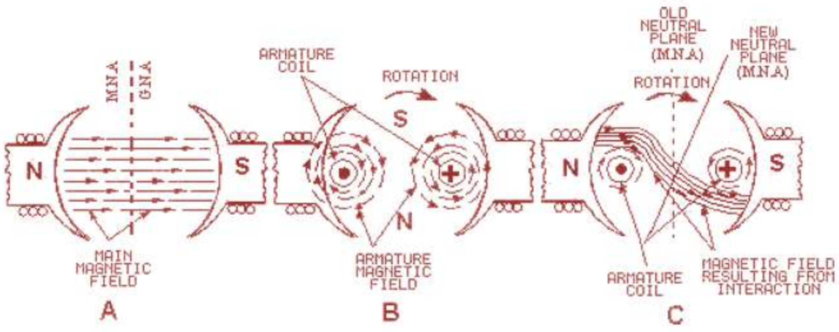


Fig. 12.26

The adverse effects of armature reaction are: The main flux is distorted due to the interaction.
An unequal flux density occurs at pole tips.
So, we can say that armature reaction can reduce the efficiency of a dc machine.

EFFECT OF ARMATURE REACTION ON MAIN FLUX

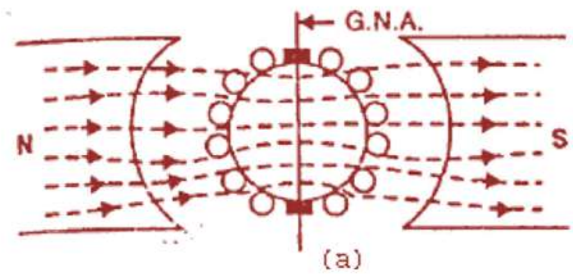
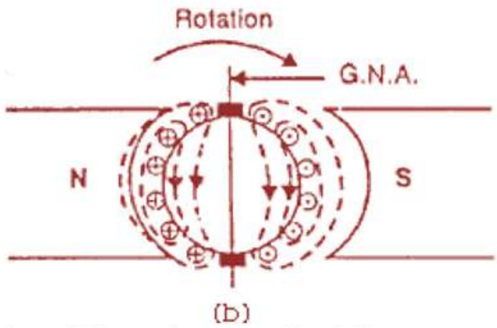
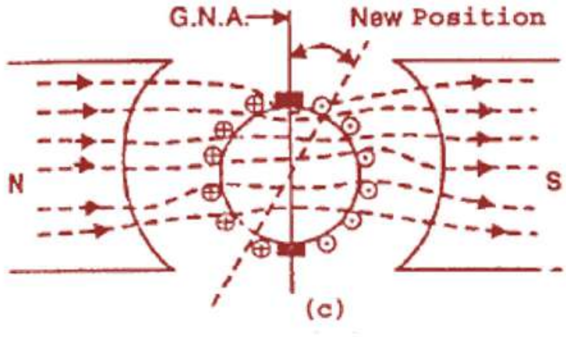


Fig. 12.27

When current runs through the rotor conductors, there is a flux generation which is inevitable. Now this rotor flux superimpose with the main flux and thereby disturbing the natural flow of the main field flux, which is shown in figure (b)of Fig 12.27.



Now, when these two fluxes interact there is a resultant flux generated which tilts the geometric neutral axis (GNA) and there is a new axis for the flow of resultant flux, which is shown in figure(c) of fig12.27.



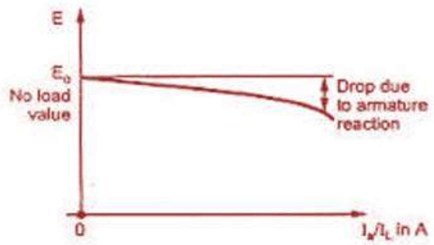
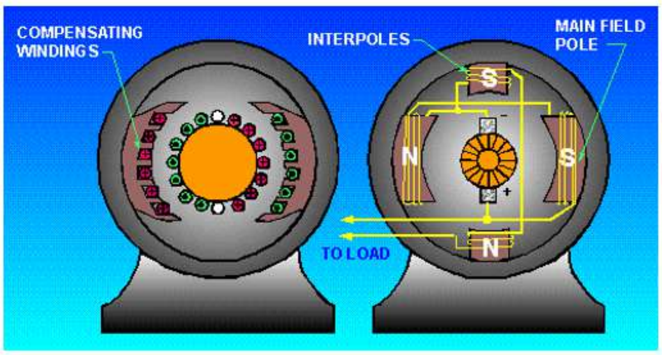


Fig. 12.28

HOW TO OVERCOME ARMATURE REACTION

Armature field distorts the main field and how the neutral plane is shifted in the direction of rotation. If the brushes remain in the old neutral plane, they will be short-circuiting coils that have voltage induced in them. Consequently, there will be arcing between the brushes and commutator.

To prevent arcing, the brushes must be shifted to the new neutral
plane Shifting the brushes to the advanced position (the new neutral plane) doesnot completely solve the problems of armature reaction. The effect of armature reaction varies with the load



current and power factor. Therefore, each time the load current varies, the neutral plane shifts. This means the brush position must be changed each time the load currentvaries.

Fig. 12.29

In small generators, the effects of armature reaction are reduced by actually mechanically shifting the position of the brushes. The practice of shifting the brush position for each current variation is not practiced except in small generators. In larger generators, other means are taken to eliminate armaturereaction.

RATING OF GENERATOR

A generator is rated in power output. Since a generator is designed to operate at a specified voltage, the rating usually is given as the number of amperes the generator can safely supply at its rated voltage.

Generator rating and performance data are stamped on the name plate attached to the generator. When replacing a generator, it is important to choose one of the proper ratings.
The rotation of the generators is termed either clockwise or Condition of Generator Brushes
Sparking of brushes quickly reduces the effect of brush area in anticlockwise as viewed from the driven end. Usually the direction of rotation is stamped on the data plate. If no direction is stamped on the plate, the rotation may be marked by an arrow on the cover plate of the brush housing. It is important that a generator with correct direction of rotation must be used; otherwise the voltage will bereversed.

DC GENERATOR MAINTENANCE

The information about dc generator maintenance and inspection is general in nature because of the large number of differing aircraft generator system. Always follow the applicable manufacturer's instructions for a given generator system.
In general, the inspection of the generator installed in the aircraft
should include the following items:

contact with the commutator bars. The degree of such sparking should be determined. Excessive wear warrants a detailed inspection.

The following information pertains to brush seating, brush pressure, high mica condition, and brush wear.
Manufacturer's usually recommending the following procedures to seat brushes that do not make good contact with slip rings or commutators.

The brush should be lifted sufficiently to permit the insertion of the strip of No.000, or finer sandpaper under the brush, rough side out as shown in the figure below. Pull sandpaper in the direction of armature rotation, being careful to keep the ends of the sandpaper as close to the slip ring or commutator surface as possible in order to a sold rounding the edges of the brush. When pulling the sandpaper back to the starting point, the brush should be raised so it does not ride on the sandpaper. The brush should be sanded only in the direction ofrotation.

After the generator has run for a short period, brushes should be inspected to make sure that pieces of sand have not become embedded in the brush and are collecting copper.
Under no circumstances should emery cloth or similar abrasives be used for seating brushes (or smoothing commutators) since they contain conductive materials which will cause arcing between brushes and commutatorbars.

A carbon graphite or light metalized brush should exert apressure of 11/2to 22/2 psi on the commutator.The pressurerecommended by the manufacturer should be checked with the use offspring scale graduated in ounces. Brush spring tension is usuallyadjusted between32to36ounces;howeverthetensionmaydifferslightly for each specific generator.

When a spring scale is used, the measurement of the pressure which a brush exerts on the commutator is read directly on the scale. The scale is applied at the point of contact between the spring arm and the top of the brush, with the brush installed in the guide. The scale is drawn up until the arm just lifts off

the brush surface. At this instant, the force on the scale should be read.
Flexible low resistance pigtails are provided on mostheavy current carrying brushes, and their connections should besecurely made and checked at frequent intervals.

The pigtails should never be permitted to alter or restrict the free movement of brush.
The purpose of the pigtail is to conduct current, rather than subjecting the brush spring to current which would alter its spring action by overheating. The pigtails also eliminate any possible sparking to the brush guides caused by the movement of the brushes within the holder, thus minimizing side wear of the brush. Carbon dust resulting from brush sanding should be thoroughly cleanedfromallpartsofthegeneratorsafterasandingoperation.

Whenever, this condition exist, or if the armature has been turned
on a lathe carefully undercut the mica insulation to a depth equal to the width of mica or approximately 0.020 inch.
Each brush should be a specified length to work properly. If a brush is too short, the contact it makes with the commutator will be faulty, which can also reduce the spring force holding the brush in place. Most manufacturers specify the amount of wear permissible from a new brush length. When a brush has worn to a minimum length permissible, it must be replaced. Some special generator brushes should not be replaced because of the slight grooving of the brush. These grooves are normal and will appear in DC and AC generator brushes which are installed in some model of aircraft generators. These brushes have two cores made of a harder material with a higher expansion rate than the material used in the main body of the brush. Usually, the main body of the brush faces rides on the commutator. However, atcerta in temperatures, the core extends and wears through any film on the commutator.

FIELD EXCITATION

When a dc voltage is applied to the field windings of a dc
generator, current flows through the windings and sets up a steady magnetic field. This is called FIELD EXCITATION.

This excitation voltage can be produced by the generator itself or it can be supplied by an outside source, such as a battery.A generatorthatsuppliesitsownfieldexcitationiscalledaSELF-EXCITEDGENERATOR.Self-excitationispossibleonlyifthe field pole pieces have retained a slight amount of permanent magnetism, calledRESIDUAL MAGNETISM.
When the generator starts rotating, the weak residual magnetism causes a small voltage to be generated in the armature. This small voltage applied to the field coils causes a small field current. Although small, this field current strengthens the magnetic field and allows the armature to generate a higher voltage. The higher voltage increases the field strength, and so on. This process continues until the output voltage reaches the rated output of thegenerator.

FORCE BETWEEN PARALLELCONDUCTORS

Two wires carrying current in the vicinity of one another exert a force on each other because of their magnetic fields. An end view of two conductors is shown in fig below.

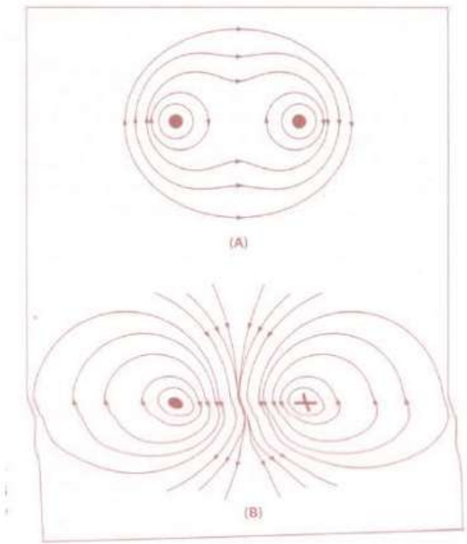


Fig. 12.30 Fields surrounding parallel conductors

In A, the electron flow in both conductors is toward the reader, and the magnetic field is clockwise around the conductors. Between the wires, the field cancels because the direction of the two fields opposes each other. The wires are forced in the direction of weaker field, towards each other. This force is one of attraction. In B, the electron flow in the two wires is in opposite directions.

The magnetic field, are therefore, clockwise in one and counterclockwise in the other as shown in fig.12.30.

The field reinforces each other between the wires, and the wires are forced in the direction of the weaker field, away from each other. This force is one of repulsion.

Therefore, conductors carrying current in the same direction tend to be drawn together; conductors carrying current in opposite direction tend to be repelled from each other.

DEVELOPING TORQUE IN A DC MOTOR

If a coil in which a current is flowing is placed in a magnetic field, a force is produced which will cause a coil to rotate. As shown in the fig 12.31, current flows inward in the side A and outward on the side B. The magnetic field about B is anticlockwise and that about A is clockwise.

As explained earlier, a force will develop which pushes B upward and at the same time, the field of the magnets and the field about A in which current is inward will add at the top and subtract at the bottom. Therefore, A will move downward. The coil thus rotate until its plane is perpendicular to the magnetic lines between the north and south poles of the magnet as in fig above by the white coils at right angles to the blackcoil.

Torque is developed also by reacting magnetic field about thecurrent carrying coil just described. This is the torque which turns the coil.

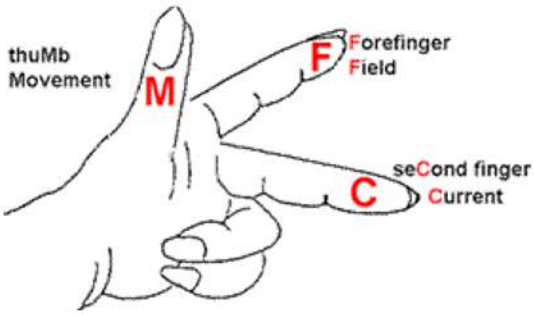


Fig. 12.31 Fleming's right hand rule(for generators)

To determine the direction of a current carrying wire moving in a magnetic field, left hand motor rule is used. The first finger of the left hand is pointed in the direction of magnetic field and the second finger in the direction of conventional current flow, the thumb will indicate the direction current carrying wire will move.

The amount of a torque developed in a coil depends upon several factors:

1. The strength of the magneticfield
2. The number of turns in thecoil
3. The position of coil in thefield

Magnets are made of special steel which produces a strong field. Since there is a torque acting on each turn, the greater the number of turns in a coil, the greater the torque. In a coil carrying a steady current located in a uniform magnetic field, the torque will vary at successive positions of rotation. When the plane of the coil is parallel to the lines of force, the torque is zero. When its plane cuts the lines of force at right angle, the torque is 100%. At intermediate positions, the torque ranges between zero and100%.

BASIC DC MOTOR

A coil of wire through which the current flows will rotate when place dinamagnetic field. This is the technical basis governing the construction of a DC motor. Figure below shows a coil mounted in a magnetic field in which it can rotate. However, if the connecting wires from the battery were permanently fastened to the terminal soft he coil and the rewash a flowofcur- rent, the coil would rotate only until it lined itself up with the magnetic field. Then, it would stop, because the torque at that point would be zero.

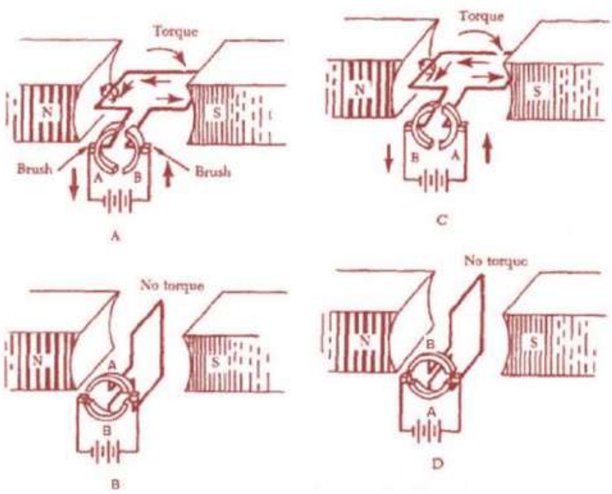


Fig. 12.32 Basic DC motor operation

A motor, of course, must continue rotating. It is there- fore necessary to design device that will reverse the current in the coil just at the time the coil becomes parallel to the lines of force. This will create torque again and cause the coil to rotate. If the current

reveres- in device is setup to reverse the current each time the coil is about to stop, the coil can be made to continue rotating as long as desired. One method of doing this is to connect the circuit so that, as the coil rotates, each contact slides off the terminal to which it connects and slides on to the terminal of opposite polarity.
In other words, the coil contacts switch terminals continuously as the coil rotates, preserving the torque and keeping the coil rotating. In Figure above, the coil terminal segments are labeled, the segments A and B. As the coil rotates, the segments slide onto and past the fixed terminals or brushes. With this arrangement the direction of conventional current in the side of the coil next to the north seeking pole flows towards the reader and the force acting on that side of the coil turns it downwards. The part of the motor which changes the current from one wire to the other is called the commutator.

POSITION A

When the coil is positioned as shown in Figure A, current will flow from positive terminal of the battery to positive brush, to segment B of the commutator, through the loop to segment A of the commutator, to the negative brush and back to the negative terminal of the battery. By using left hand motor rule, it is seen that the coil will rotateclockwise.

The torque at this position of the coil is maximum since the greatest number of lines of force is being cut by the coil.

When the coil has rotated 90° to the position shown in B of figure, segments A and B of the commutator no longer make contact with the battery circuit and no current can flow through the coil. At this position, the torque has reached a minimum value, since a

minimum number of lines of force are being cut. However, the momentum of the coil carries it beyond this position until the segments again make contact with the brushes, and current again enters the coil; this time, though, it enters through segment A and leaves through segment B. However, since the positions of segments A and B have also been reversed, the effect of the current is as before, the torque acts in the same direction, and the coil continues its clockwise rotation. On passing through the position shown in C of figure, the torque again reaches maximum.

Continued rotation carries the coil again to a position of minimum torque, as in D of figure 12.32. At this position the brushes no longer carry current, but once more the momentum rotates the coil to the point where current enters through segment B and back through A. Further rotation brings the coil to the starting point and, thus, one revolution is completed.

The switching of the coil terminals from the positive to the negative brushes occurs twice per revolution of the coil.

The torque in a motor containing only a single coil isneither
continuous nor very effective, for there are two positions where there is actually no torque at all. To overcome this, a practical DC motor contains a large number of coils wound on the armature.

These coils are so spaced that, for any position of the armature, there will be coils near the poles of the magnet. This makes the torque both continuous and strong. The commutator, likewise, contains a large number of segments instead of only two.

The armature in a practical motor is not placed between the poles of a permanent magnet but between those of an electromagnet, since a much stronger magnetic field can be furnished. The coreis usuallymadeofmildorannealedsteel,whichcanbemagnetized

strongly by induction. The current magnetizing the electromagnet is from the same source that supplies the current to the armature,

D.C. Motor Construction

The major parts in a practical motor are the armature assembly, the field assembly, the brush assembly, and the endframe.

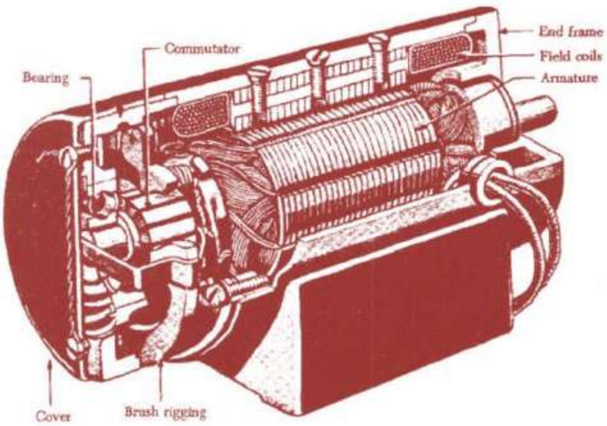


Fig. 12.33Cutaway view of a practical DC motor Armature Assembly

Thearmatureassemblycontainsalaminated,softironcore,coils, and a commutator, all mounted on a rotating steel shaft. Laminations made of stacks of soft iron, insulated from each other, form the armature core. Solid iron is not used, since a solid iron core revolving in the magnetic field would heat and use energy needlessly. The armature windings are insulated copper wire,whichareinsertedinslotsinsulatedwithfibrepaper(fish paper) to protect the windings. The ends of the windings are connected to the commutator segments. Wedges or steel bands hold the windings in place to prevent them from flying out of the slots when the armature is rotating at high speeds. The commutator consists of a large number of copper segments insulated from each other and the armature shaft by pieces of mica. Insulated wedge rings hold the segments inplace.

Field Assembly

The field assembly consists of the field frame, the pole pieces and thefieldcoils.Thefieldframeislocatedalongtheinnerwallof the motor housing. It contains laminated soft steel pole pieces on which the field coil is wound. A coil,consisting of several turns of insulated wire, fits over each pole piece and, together with the pole, constitutes a field pole. Some motors have as few astwo poles, others as many as eight.