Basic Electricity Principle

Flow of Charge: Current

An electric current exists whenever electric charges are in motion.

In ionised gas or electrolytic solutions, both positive and negative ions migrate under the influence of electric field.

In Metallic conductors current is produced by motion of free electron.

In semiconductor current is produced by motion of electron & hole.

Current: The strength of the current passing through a given cross sectional area of the conductor is the amount of charge flowing per unit time through that area.

If net charge flow Q flows in time t, the current I is given by

$I = Q/t$

SI unit of current is ampere(A)

One ampere current as that current which transport one coulomb (or $6.241509074 \times 10^{19}$ electrons worth of charge) moving past a point in a second.

Electric Current is scaler quantity

If the rate of flow of charge is constant and does not vary with time, the current is said to be steady.

If the current is variable, then **instantaneous current** at any time is given by

$i = dQ/dt$

Current Density: Current flowing per unit area is known is known as current density. It is represented by J

$J = I/A$

Where A is the cross sectional area of conductor.

J is a vector quantity.

<u>Opposition to Current: Resistance</u>

When the same potential difference is applied across different conductors, different current flow. Some conductors offer less opposition or resistance to the passage of current than the others.

The resistance R of a conductor has been defined as the ratio of potential difference V across the ends of the conductor to the current I flowing through

$R= V/I$

The SI unit of resistance is ohm.

A conductor has a resistance of one ohm if it carries a current of one ampere when a potential difference of one volt is applied across its two ends.

i) The Current is the rate of flow of charges.

ii) The resistance is the opposition which regulates the flow.

iii) The voltages the motive force which causes the flow.

OHM'S LAW

One of the most basic and important laws of electric circuits is Ohm's law.

Ohm's law states that the voltage across a conductor is directly proportional to the current flowing through it, provided all physical conditions and temperatures remain constant.

Mathematically, this current-voltage relationship is written as,

$$V=IR$$

In the equation, the constant of proportionality, R, is called Resistance and has units of ohms, with the symbol Ω.

The same formula can be rewritten in order to calculate the current and resistance respectively as follows:

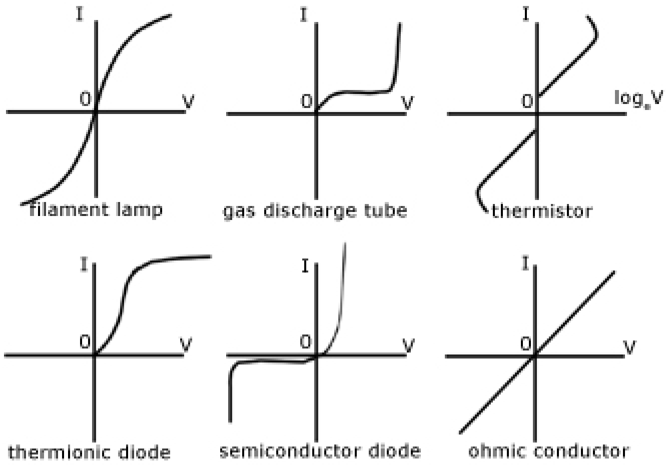
$$I = \frac{V}{R}$$

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

Metals and metallic alloys obey OHM's Law & are known as ohmic conductor. On the other hand many circuit element like pn junction diode, thyristor etc, do not obey Ohm's law and therefore known as non-ohmic conductors.

The resistance of ohmic conductor is constant, independent of current but the resistance of nonohmic conductor depends on current flowing. The V_I graph of a ohmic conductor is straight line while it is not so foe a non-ohmic conductor.

R=V/I is definition of resistance while R= constant is a statement of OHM's law.



DEPENDENCE OF RESISTANCE ON GEOMETRICAL SIZE: RESISTIVITY

The resistance, R of a wire has been found to depend

(1) directly on the length l of the wire;

(2) inversely on the cross-sectional area A of the wire.

R$\propto l/A$
R = *p* l/A

where *p* is a constant whose value depends on the material of the wire. We call *p* as the resistivity or specific resistance. When /= 1m. A = 1 m, we find R = *p,* hence resistivity is defined as follows:

Resistivity or specific resistance of a material is numerically equal to the resistance offered by a piece of conductor whose length is one metre and area of cross- section is one square metre.

The unit of resistivity is ohm-m. The resistivity of metals increases with temperature, so does the resistance of a metallic wire. "At 0°C, the resistivity of copper is 1.7 x 10^{-8} ohm-m and that of aluminium 2.8 x 10^{-8} ohm-m.

OHM'S LAW IN TERMS OF MATERIAL PARAMETERS

We know that for a ohmic conductor

I$\propto$ V

or, I = V/R ...(i)

where resistance R is independent of current I. If the conductor is in the form of a wire of length / and cross sectional area A, then

$R = p \frac{l}{A}$ ...(ii)

A where p is known as the resistivity. From (i) and (ii) we find that

$I = V\ (\frac{A}{pl})$

$\frac{I}{A} = \frac{1}{p}\frac{V}{l}$

We know that I/A (=J) is the current density and $\frac{V}{l}$(= E) is the electric field inside the conductor. The above relation can, therefore, be written in the following form

$\mathbf{J} = \sigma E$

Where σ=$\frac{1}{p}$ is known as the conductivity of the material.

This is an alternative way of expressing ohm's law

MODEL OF ELECTRIC CONDUCTION

In a metallic conductor, current is carried by electrons. In absence of any external potential difference ie. V= 0 (no internal field, ie., E=0), these electrons move at random and collide with atoms of the conductor .We call this motion of electrons as thermal motion. Like gas molecules electrons move in all directions with all possible velocities u_1, u_2 , …u_n and hence at any instant the average velocity of electrons (u_1+u_2+ …u_n) /n = 0

Hence there is no net flow of charge in any particular direction. In other words no steady current results on account of the thermal motion of electrons The random velocity of electrons due to the thermal motion is known as the thermal velocity. It is temperature dependent. A typical value of thermal velocity is 10 m s at room temperature. No net current is produced due to the thermal velocities of the electrons.

(1) PHYSICAL BASIS OF RESISTANCE

When an external potential difference is applied i.e., V=0 (internal field **E** appears inside the conductor), the electrons are accelerated towards the positive terminal. Thus they increase their velocities in a particular direction. But this does not continue for long. Soon these electrons collide with the atoms of the conductor. Whatever energy they have gained from the field is lost and they start again. The effect of collisions is thus to introduce a viscous or fractional force which inhibits the continuous acceleration. Larger the number of collisions per second larger is the opposition and higher is the resistance.

Liberation of heat due to resistance. As a result of the collisions, the electrons lose energy. However in the process of collisions, the vibrational energy of the atoms of the conductor increases. This is manifested as the liberation of heat. Higher the resistance, greater is the heat liberated,

2.DRIFT VELOCITY AND CURRENT

As a result of collisions electrons are not able to accelerate continuously and they acquire a constant average drift velocity v_d in the direction of the positive terminal. The drift motion of electrons is superposed on their thermal motion.

Consider a metallic wire of cross-sectional area A in which a current I is flowing. Let the number of electron in metallic wire of cross-sectional area A electrons per unit volume be n. When p.d. is applied, all those electrons which are contained in a cylinder of length d will pass through the section t second

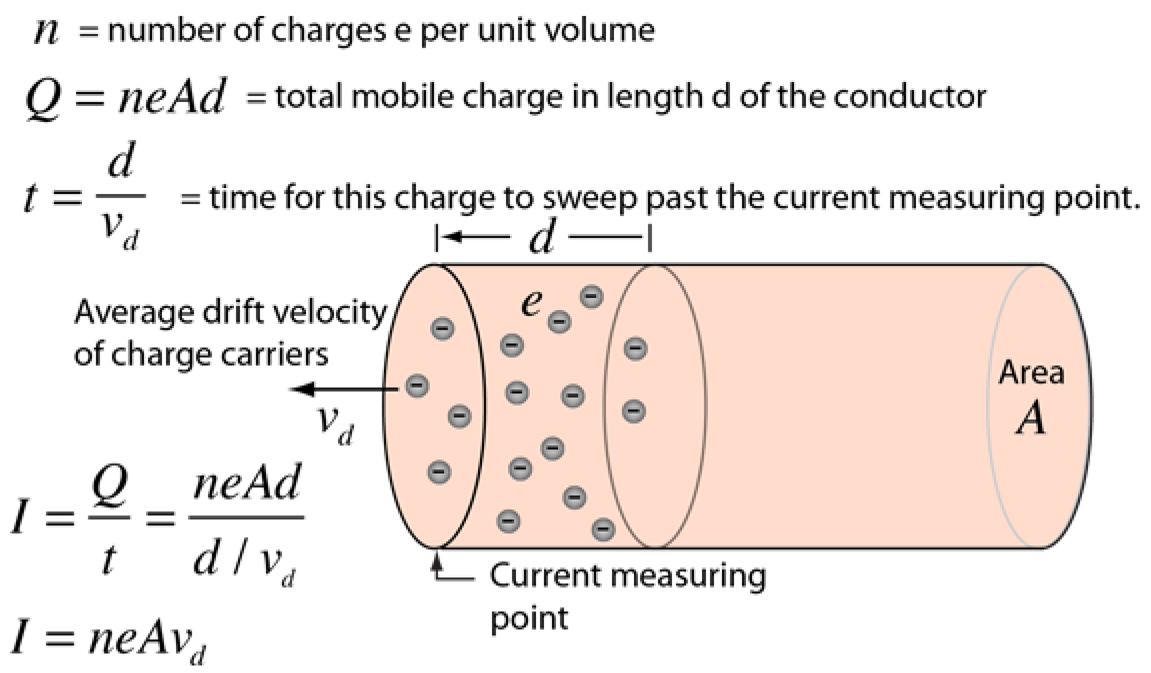


Fig. Electric current as flow of electrons

$$I = ne\,Av_d \qquad [a]$$

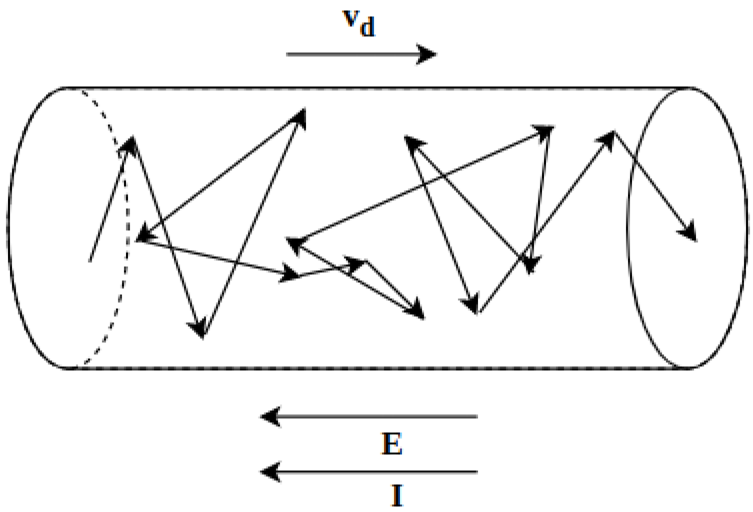
Typical value of v_d in a copper wire ($n = 10^{29} m^{-3}$). of area of cross-section $1x\ 10^{-7}\ m^2$ is 0.625 mm s^1. This is very low speed. With this speed electrons will take about half an hour to drift 1 m. It must be emphasised here that the drift speed of electrons is not the speed with which electric field travels inside the wire The speed with which the electric field travels inside a wire is close to the velocity of light and it is because of this that we get practically instantaneous response when we switch on the current.

(3) DRIFT VELOCITY AND ELECTRIC FIELD: MOBILITY

Net Velocity of Electrons

The random motion of free electrons moving around in the conductor can also be used to understand drift velocity. The electrons continue to move randomly as a result of this field, but their random motion will shift them toward a higher potential. This indicates that the electrons are drifting toward the conductor's higher potential end. As a result, each electron will have a net velocity toward the conductor's end. The Drift current is the current generated by the motion of electrons inside a conductor.

Drift velocity is defined as "Average velocity with which the free electrons get drifted towards the positive end of the conductor under the influence of an external electric field."



Let's consider the charge of an electron to be (-e).
Hence, the force on the electron is equal to

$$F=-eE$$

We can find the acceleration of the electron by,

$$a=F/m=-eE/m \quad (1)$$

Where m is the mass of the electron.
Now, let us introduce a quantity called the relaxation time. It is the average time between two consecutive collisions.
Let's assume there are 'n' number of electrons in the conductor at any given time.
The relaxation time is given by,

$$\tau=(\tau 1+\tau 2+\tau 3+\tau 4+...)/ n......(2)$$

Where, [τ1,τ2,τ3,τ4,....] are the collision times of n electrons.
We can say that the drift velocity is the average velocity of all the electrons.
So, we can write,

$$vd= (v1+v2+v3+v4+v5+....)/ n ....(3)$$

We can use the general kinematics equation,

$$v=u+at \quad .... (4)$$

(Where, v is the final velocity ,u is the initial velocity, a is the acceleration, and t is the time duration.)

So the instantaneous velocity of these electron after suffering one collision each will be

$v_1 = u_1 + a\,\tau_1$

$v_2 = u_2 + a\,\tau_2$

$v_n = u_n + a\,\tau_n$ ....(5) (a is same as m, e & E is same for each electron)

Where $u_1, u_2..........u_n$ are random (thermal) velocities & $\tau_1. \tau_2.....$are relaxation time

Using equation(1) & (2) ,(3) & (4) we get,

$$vd=\{(u1+u2+...+un)+a(\tau 1+\tau 2+...+\tau n)\} / n$$

$\Rightarrow vd=0 + a(\tau 1+\tau 2+...+\tau n)/n$ (as Initial average velocity is zero)

$\Rightarrow vd= a(\tau 1+\tau 2+...+\tau n)/n$

$\Rightarrow vd= a\tau$

$\Rightarrow vd=(-\frac{eE}{m})\tau$ (6)

The expression of drift velocity is,
vd$= \frac{(-e\,\tau)}{m}$ **E**

which shows that (i) drift velocity is directly proportional to |**E**| & (ii) it is directed opposite to **E**

The magnitude of $|v_d| = \mu\,|E|$

Where $\boldsymbol{\mu} = \frac{(e\,\tau)}{m}$ **(constant)**

This is known as mobility of electron.

Mobility of electron is defined as the drift velocity imparted to an electron by an electric field of unit strength. **Unit is $m^2V^{-1}s^{-1}$.**

Note:
The mobility of electrons as a charge carrier is greater than holes. Mobility can also be defined as the ability to move freely.

Derivation of OHM's law (From Drift Velocity)

From eq (a) & (6)

I = enAv_d = enA $\frac{(e\,\tau)}{m}$ E = enA $\frac{(e\,\tau)}{m}\frac{V}{l}$

I =($\frac{n\tau e^2}{m}\,\frac{A}{l}$)$V$

I ∝ V (OHM'S Law)

Where R =$\frac{m}{n\tau e^2}\,\frac{l}{A}$ = $p\,\frac{l}{A}$

Conductivity σ = 1/ p = $\frac{n\tau e^2}{m}$

Which shows conductivity depends on the number of charge carriers.

Resistance vs Temperature

The general rule says that resistance increases in conductors with increasing temperature and decreases with increasing temperature in semiconductor & insulators. In the case of semiconductors, typically, the resistance of the semiconductor decreases with the increasing temperature.

Resistivity vs Temperature

The resistivity of materials depends on the temperature as
$p_t = \rho_0 [1 + \alpha (T - T_0)$. This is the equation that shows the relationship between the resistivity and the temperature.
$P_t = \rho_0 [1 + \alpha (T - T_0)]$

- ρ_0 is the resistivity at a standard temperature
- ρ_t is the resistivity at t^0 C
- T_0 is the reference temperature
- α is the temperature coefficient of the resistivity

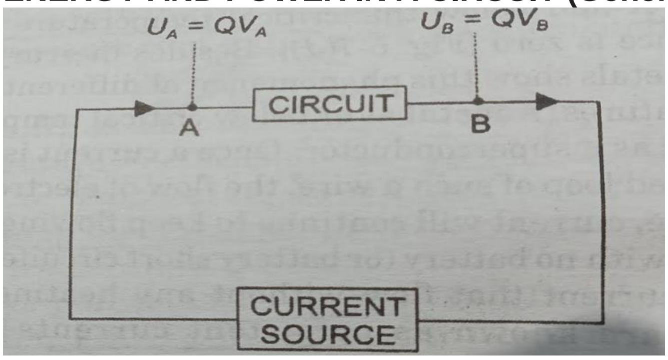
1. **For Conductors:** It is said that conductors have a positive co-temperature-efficient for metals or conductors. The positive value is α. For most metals, the resistivity increases linearly with temperature increases of around 500 K.

2. **For Semiconductors:** The resistivity of the semiconductor decreases with the increasing temperature. It is said that they have a negative temperature coefficient. The temperature coefficient of resistivity, α, is therefore negative.
3. **Insulators:** For insulators, as the temperature increases, the material conductivity is increased. When the material's conductivity increases, we know that the resistivity decreases, and the current flow increases thereby. And certain insulators convert to conductors at high temperatures at room temperature. They have a negative temperature coefficient.

What is Meant by Electric Power?

Power is commonly defined as the rate at which the work is done. When this is done with respect to time and in an electrical circuit, it is known as electric power. Alternately, electric power is defined as the rate at which electric energy is transferred across an electrical circuit per unit time. Electric power is versatile - it can be produced in generators in our houses and can be supplied to electric batteries used in devices.

ENERGY AND POWER IN A CIRCUIT (General Case)



Let a current I flow through a circuit AB (in a special case AB may be a pure resistor) The amount of positive charge Q that is transported in t seconds from A to B is given by Q = It (i)
Potential energy of +Q charge at A and B.

Let the potential of the point A be V_a and that of B be V_b. When the charge was at A it possessed a potential energy $U_A=QV_a$. However, when it arrives at the other A end B of the circuit, its potential energy is reduced to $U_B=QV_b$. The decrease in the potential energy of charge is given by

$(U_A-U_B) = Q(V_a– V_b) = QV$ (ii)
where $V = (V_a-V_b)$ is the potential difference across the circuit.
Now as Q = It so from (i) and (ii)

$(U_A-U_B) = Vit$ ...(iii)

To maintain circulation of current in the circuit; the current source has to supply energy W given by

$W=(U_A-U_B) = VIt$
The rate of supply of energy is called as power P.

So the power in a circuit carrying current I at a potential difference V is given by

$$\mathbf{P} = \frac{W}{t} = \frac{VIt}{t} = \mathbf{VI} = \mathbf{I^2R} = \mathbf{V^2/R}$$

The unit of electric power is J/s which is known as Watt. The wattage of any electrical circuit is given by the product of voltage across its terminals multiplied by the current

Since W = Pt, the unit of electric energy is watt x sec. However, this unit is too small for practical work. For commercial purposes a bigger unit, known as kilowatt-hour is found more convenient. One kilowatt- hour is the amount of energy consumed by a circuit (or device) in one hour when it takes one kilowatt of p for working. Thus power

Energy in kW-hr = Power in kW x time in hr.

POWER DISSIPATION IN A RESISTOR, JOULE'S LAWS

Consider a circuit containing a pure resistor R. When a current I flows through it at a potential difference V, the source of current has to supply energy at the rate of

P = VI (True for all circuits)

What happens to this energy supplied per second by the current source to a resistor? energy supplied is liberated as heat energy. So the amount of heat energy liberated in t seconds is given by

W = Pt = VIt

Since for a resistor V = IR, so for a resistor only

W = VIt = I^2Rt

If the heat energy is measured in calories then

H = $I^2Rt / 4.2$ (in calories)

The above relation tells us that amount of heat produced in a conductor is
(i) directly proportional to the square of the current when the resistance and time duration remain constant.
(ii) directly proportional to the resistance when the current and the time duration remain constant
(iii) directly proportional to the time duration when the current and resistance remain constant.
The above results were experimentally discovered by Joule and are known as Joule’s Laws of Heating.

EMF & Power of Cell

Charge flows from higher potential to lower. To maintain continuous circulation of charge Q through a circuit, it is necessary to pump the charge from lower potential

to higher. This is done by a device like cell or dynamo.
While pumping the charge Q from lower potential to higher, the cell or dynamo consumes certain amount of energy.
Therefore the device that maintains the circulation of charge in the circuit has to supply energy by chemical reactions or otherwise for (i) the energy lost in the external circuit, (ii) the energy lost in the device itself. Thus-

Energy supplied to circulate Q charge = Energy lost in external circuit+ Energy lost internally in the device

$W = I^2Rt + I^2rt$

where r is a resistance such that when multiplied by I^2, it gives the power lost internally in the device while maintaining the circulation of the charge. We call this resistance as the internal resistance of the cell (or generator).

Therefore, the energy supplied per coulomb of charge is given by

$\varepsilon = W/Q = (I^2Rt+I^2rt)/It = I(R+r)$ ...(i)

where ε is known as **the electromotive force of the cell**. Thus:

The electromotive force & of a device (such as a cell or generator) is defined as the ratio of the non-electrical energy W needed to pump a charge Q from its lower potential terminal to its higher potential terminal, to the charge Q i.e. $\varepsilon = W/Q$. In other words emf of a device is the amount of non-electrical energy needed per unit charge to pump it from lower potential terminal to its higher potential terminal.

Power Of a Cell

For a voltage source, such as cell with emf ε together with an internal resistance r, connected with external resistance R we get the following result

Current $I = \frac{\varepsilon}{R+r}$

Terminal voltage $V = IR = \frac{\varepsilon R}{R+r}$

Power developed in R ,

$P = VI = \frac{\varepsilon^2 R}{(R+r)^2}$

Maximum power developed in the load R is when

dP/dR = 0

$$\frac{\varepsilon^2}{(R+r)^2}\left[1 - \frac{2}{R+r}\right] = 0$$

R=r

Maximum power is developed in the load when the external resistance R has a value equal to the internal resistance r of the source.

Series & Parallel Combination

Series circuits are sometimes referred to as current-coupled. The current in a series circuit goes through every component in the circuit. Therefore, all of the components in a series connection carry the same current.

A series circuit has only one path through which its current can flow. Opening or breaking a series circuit at any point causes the entire circuit to "open" or stop operating. For example, if even one of the light bulbs in an older-style string of Christmas tree lights burns out or is removed, the entire string becomes inoperable until the faulty bulb is replaced.

Current[

In a series circuit, the current is the same for all of the elements.

Voltage

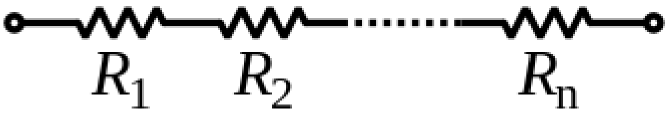
In a series circuit, the voltage is the sum of the voltage drops of the individual components (resistance units).

$V = V_1 + V_2 \ldots\ldots V_n$

Series circuit can be used as Voltage divider.

Resistance units

The total resistance of two or more resistors connected in series is equal to the sum of their individual resistances:



$V = V_1 + V_2 \ldots\ldots V_n$

$IR_{eq} = IR_1 + IR_2 + IR_3 \ldots\ldots + IR_n$

$R_{eq} = R_1 + R_2 + R_3 \ldots\ldots\ldots + R_n$

Here, the subscript *s* in R_s denotes "series", and R_s denotes resistance in a series.

Conductance

Electrical conductance presents a reciprocal quantity to resistance. Total conductance of a series circuits of pure resistances, therefore, can be calculated from the following expression:

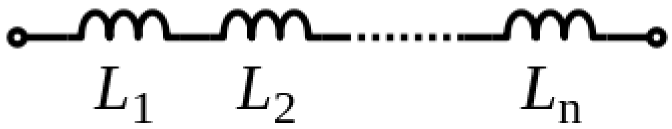
$$\frac{1}{G_{total}} = \frac{1}{G_1} + \frac{1}{G_2} + \cdots + \frac{1}{G_n}.$$

For a special case of two conductances in series, the total conductance is equal to:

$$G_{\text{total}} = \frac{G_1 G_2}{G_1 + G_2}.$$

Inductors

Inductors follow the same law, in that the total inductance of non-coupled inductors in series is equal to the sum of their individual inductances:



$$L_{\text{total}} = L_1 + L_2 + \cdots + L_n$$

However, in some situations, it is difficult to prevent adjacent inductors from influencing each other as the magnetic field of one device couples with the windings of its neighbors. This influence is defined by the mutual inductance M. For example, if two inductors are in series, there are two possible equivalent inductances depending on how the magnetic fields of both inductors influence each other.

When there are more than two inductors, the mutual inductance between each of them and the way the coils influence each other complicates the calculation. For a larger number of coils the total combined inductance is given by the sum of all mutual inductances between the various coils including the mutual inductance of each given coil with itself, which is termed self-

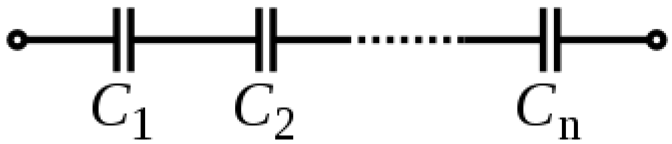
inductance or simply inductance. For three coils, there are six mutual inductances , M_{12},M_{13}, M_{23} and M_{21},M_{31},M_{32} . There are also the three self-inductances of the three coils:M_{11} ,M_{22},M_{33} Therefore

$$L_{\text{total}} = (M_{11} + M_{22} + M_{33}) + (M_{12} + M_{13} + M_{23}) + (M_{21} + M_{31} + M_{32})$$

By reciprocity, $M_{ij} = M_{ji}$ so that the last two groups can be combined. The first three terms represent the sum of the self-inductances of the various coils. The formula is easily extended to any number of series coils with mutual coupling. The method can be used to find the self-inductance of large coils of wire of any cross-sectional shape by computing the sum of the mutual inductance of each turn of wire in the coil with every other turn since in such a coil all turns are in series.

Capacitors

Capacitors follow the same law using the reciprocals. The total capacitance of capacitors in series is equal to the reciprocal of the sum of the reciprocals of their individual capacitances:



$$\frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}.$$

Equivalently using elastance (the reciprocal of capacitance), the total series elastance equals the sum of each capacitor's elastance.

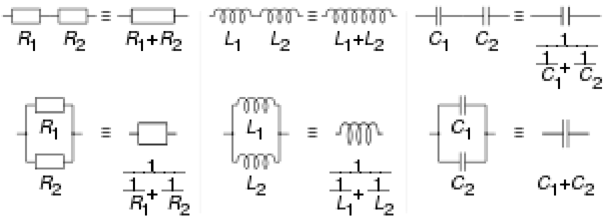
Switches

Two or more switches in series form a logical AND; the circuit only carries current if all switches are closed. See AND gate.

Cells and batteries

A battery is a collection of electrochemical cells. If the cells are connected in series, the voltage of the battery will be the sum of the cell voltages. For example, a 12 volt car battery contains six 2-volt cells connected in series. Some vehicles, such as trucks, have two 12 volt batteries in series to feed the 24-volt system.

Parallel circuits



Comparison of effective resistance, inductance and capacitance of two resistors, inductors and capacitors in series and parallel

If two or more components are connected in parallel, they have the same difference of potential (voltage) across their ends. The potential differences across the components are the same in magnitude, and they also have identical polarities. The same voltage is applied to all circuit components connected in parallel. The total current is the sum of the currents through the individual components, in accordance with Kirchhoff's current law.

Voltage

In a **parallel circuit**, the voltage is the same for all elements.

$$V = V_1 = V_2 = \cdots = V_n$$

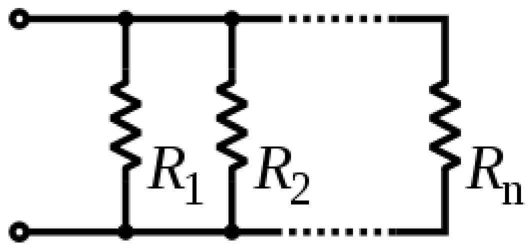
Current

The current in each individual resistor is found by Ohm's law. Factoring out the voltage gives

$$I_{\text{total}} = I_1 + I_2 + \cdots + I_n = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}\right).$$

Resistance units

To find the total resistance of all components, add the reciprocals of the resistances of each component and take the reciprocal of the sum. Total resistance will always be less than the value of the smallest resistance:



$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}.$$

For only two resistances, the unreciprocated expression is reasonably simple:

$$R_{\text{total}} = \frac{R_1 R_2}{R_1 + R_2}.$$

This sometimes goes by the mnemonic *product over sum*.

For *N* equal resistances in parallel, the reciprocal sum expression simplifies to:

$$\frac{1}{R_{\text{total}}} = N\frac{1}{R}.$$

and therefore to:

$$R_{\text{total}} = \frac{R}{N}.$$

To find the current in a component with resistance R_i, use Ohm's law again:

$$I_i = \frac{V}{R_i}\,.$$

The components divide the current according to their reciprocal resistances, so, in the case of two resistors,

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}.$$

Parallel circuit can be used as current divider

An old term for devices connected in parallel is *multiple*, such as multiple connections for arc lamps.

Conductance

Since electrical conductance G is reciprocal to resistance, the expression for total conductance of a parallel circuit of resistors is simply:

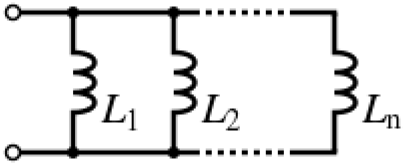
$$G_{\text{total}} = G_1 + G_2 + \cdots + G_n.$$

The relations for total conductance and resistance stand in a complementary relationship: the expression for a series connection of resistances is the same as for parallel connection of conductances, and vice versa.

Inductors

Inductors follow the same law, in that the total inductance of non-coupled inductors in parallel is equal to the reciprocal of the sum of the reciprocals of their individual inductances:

$$\frac{1}{L_{\text{total}}} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots + \frac{1}{L_n}.$$



If the inductors are situated in each other's magnetic fields, this approach is invalid due to mutual inductance. If the mutual inductance between two coils in parallel is M, the equivalent inductor is:

$$\frac{1}{L_{\text{total}}} = \frac{L_1 + L_2 - 2M}{L_1 L_2 - M^2}$$

If $L_1 = L_2$

$$L_{\text{total}} = \frac{L + M}{2}$$

The sign of M depends on how the magnetic fields influence each other. For two equal tightly coupled coils the total inductance is close to that of every single coil. If the polarity of one coil is reversed so that M is negative, then the parallel inductance is nearly zero or the combination is almost non-inductive. It is assumed in the "tightly coupled" case M is very nearly equal to L. However, if the inductances are not equal and the coils are tightly coupled there can be near short circuit conditions and high circulating currents for both positive and negative values of M, which can cause problems.

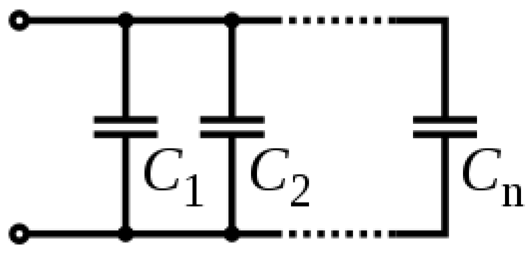
More than three inductors become more complex and the mutual inductance of each inductor on each other inductor and their influence on each other must be considered. For three coils, there are three mutual inductances M_{12}, M_{13} and M_{23}. This is best handled by matrix methods and summing the terms of the inverse of the L matrix (3×3 in this case).

The pertinent equations are of the form:

$$v_i = \sum_j L_{i,j} \frac{di_j}{dt}$$

Capacitors

The total capacitance of capacitors in parallel is equal to the sum of their individual capacitances:



$$C_{\text{total}} = C_1 + C_2 + \cdots + C_n.$$

The working voltage of a parallel combination of capacitors is always limited by the smallest working voltage of an individual capacitor.

Switches

Two or more switches in parallel form a logical OR; the circuit carries current if at least one switch is closed. See OR gate.

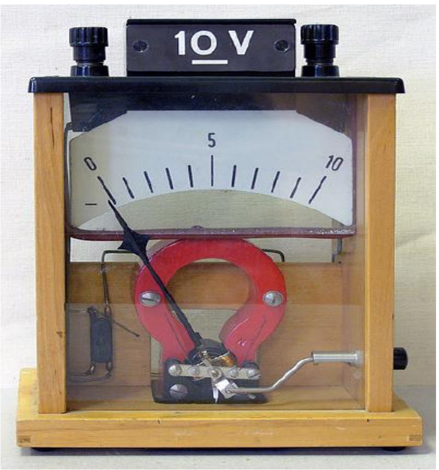
Cells and batteries

If the cells of a battery are connected in parallel, the battery voltage will be the same as the cell voltage, but the current supplied by each cell will be a fraction of the total current. For example, if a battery comprises four identical cells connected in parallel and delivers a current of 1 ampere, the current supplied by each cell will be 0.25 ampere. If the cells are not identical in voltage, cells with higher voltages will attempt to charge those with lower ones, potentially damaging them.

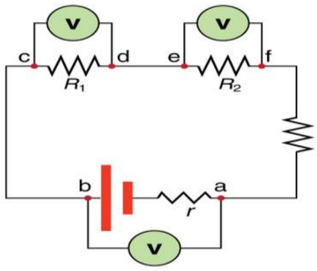
Parallel-connected batteries were widely used to power the valve filaments in portable radios. Lithium-ion rechargeable batteries (particularly laptop batteries) are often connected in parallel to increase the ampere-hour rating. Some solar electric systems have batteries in parallel to increase the storage capacity; a close approximation of total amp-hours is the sum of all amp-hours of in-parallel batteries.

Voltmeters

A voltmeter is an instrument that measures the difference in electrical potential between two points in an electric circuit. An analog voltmeter moves a pointer across a scale in proportion to the circuit's voltage; a digital voltmeter provides a numerical display.

.

In order for a voltmeter to measure a device’s voltage, it must be connected in parallel to that device. This is necessary because objects in parallel experience the same potential difference.



(a)

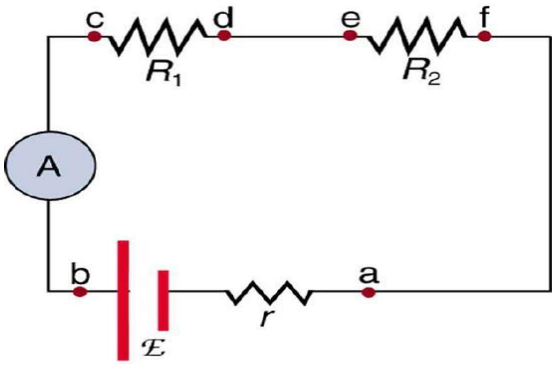
(b)

Voltmeter in Parallel: (a) To measure the potential difference in this series circuit, the voltmeter (V) is placed in parallel with the voltage source or either of the resistors. Note that terminal voltage is measured between points a and b. It is not possible to connect the voltmeter directly across the EMF without including its internal resistance, r. (b) A digital voltmeter in use

Ammeters

An ammeter measures the electric current in a circuit. The name is derived from the name for the SI unit for electric current, amperes (A).

In order for an ammeter to measure a device's current, it must be connected in series to that device. This is necessary because objects in series experience the same current. They must not be connected to a voltage source — ammeters are designed to work under a minimal burden, (which refers to the voltage drop across the ammeter, typically a small fraction of a volt).



Ammeter in Series: An ammeter (A) is placed in series to measure current. All of the current in this circuit flows through the meter. The ammeter would have the same reading if located between points d and e or between points f and a, as it does in the position shown. (Note that the script capital E stands for EMF, and r stands for the internal resistance of the source of potential difference.)

What is a Galvanometer?

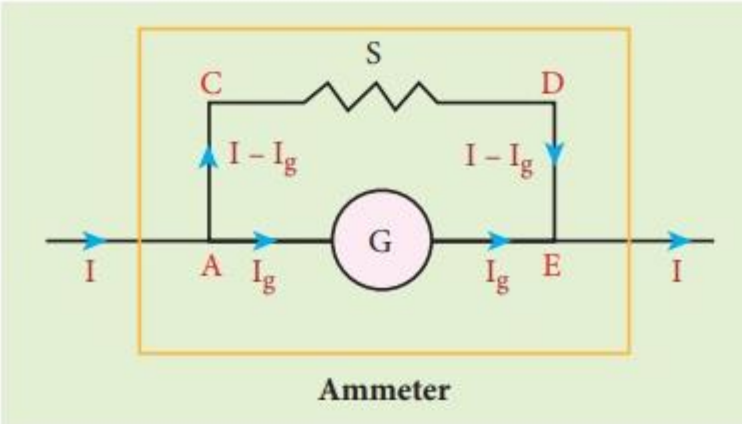
A galvanometer is a device or an instrument that is used to measure small currents in an electric circuit. It can be used as both ammeter and voltmeter by adding resistance to it in parallel or series. A galvanometer consists of a coil which is placed between the poles of a horseshoe magnet. When an electric current passes through this coil, the pointer of the galvanometer deflects. Most popular and frequently used galvanometer today is the D'Arsonal type.

As mentioned earlier, a galvanometer is an instrument used to measure small electric currents. To measure high currents and high potential difference in an electric circuit, galvanometers are usually converted to ammeter or voltmeter depending on the required usage.

Galvanometer to Ammeter Formula

The conversion of a galvanometer into an ammeter and a voltmeter is achieved by adding a resistor of a particular value in series or in parallel. A galvanometer can only measure small currents. Thus, for it to measure large currents, we convert it into an ammeter by connecting a resistor in parallel. Ammeter, as we know, is an instrument used to measure the value of current. The ammeter must have low resistance, so that the current passing through it does not change. A low resistance value is connected in the shunt, so that the overall current passing through the ammeter does not change.

Conversion of Galvanometer to Ammeter



The value of shunt S can be calculated using the circuit above. G is the resistance of the galvanometer, I_g is the current through the galvanometer, I is the total current through the circuit and ($I-I_g$) is the current passing through the shunt resistor (S).

Now, for a parallel circuit we know that the potential difference is equal. Thus, we get:

$I_g \times G = (I - I_g)S$ (i)

$\therefore S = I_g G/(I - I_g)$ (ii)

$S = G / [(I/I_g) - 1]$

$S = G / [m-1]$

Where $m = I/I_g$ is known as multiplying factor.

The above relation shows if we want to measure current which is 10,100,1000 times the current required for full scale deflection then value of shunt should be G/9, G/99,G/999.

How to increase range?

In order to increase range of a given ammeter an additional shunt of resistance S_{add} must be put across so that effective Shunt resistance is S_{eff} . If the range is to be increase from I to nI ,then from (ii)

$S_{eff} = I_g G / (nI - I_g)$

$1/S_{eff} = 1/S + 1/S_{sdd}$

$\therefore$ **$1/S_{add} = (n-1) \frac{(\frac{I}{Ig})}{G}$**

Now, if θ is assumed to be the deflection in the galvanometer, then it can be denoted as:

$$\theta \propto I_g$$

$$\theta \propto I_g . m, \text{ where } m = \frac{I}{I_g}$$

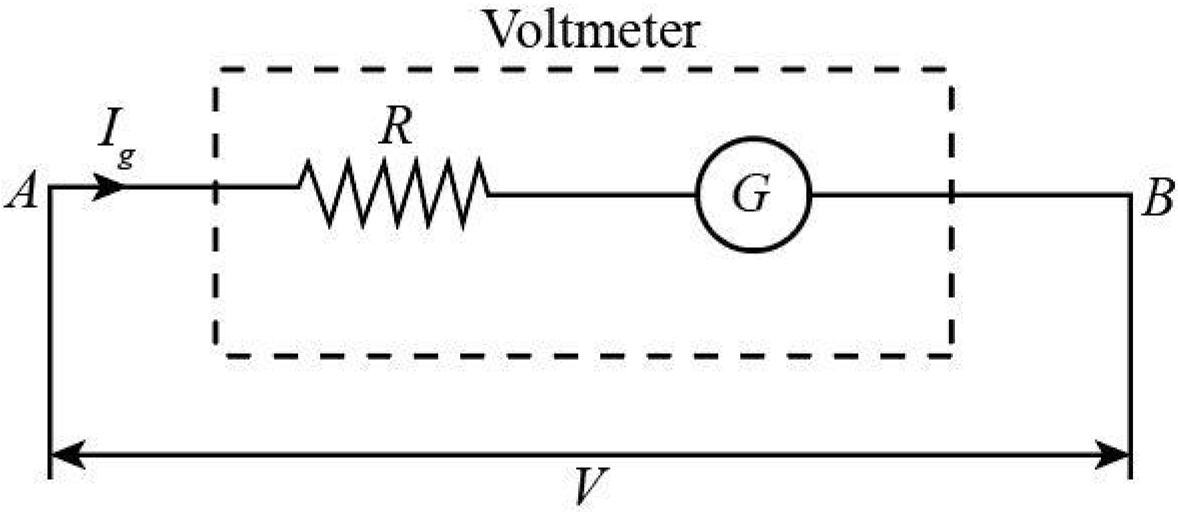
$$\theta \propto I_g \cdot \frac{I}{I_g}$$

$$\theta \propto I$$

Thus, deflection in the galvanometer is equal to the current passing through it. Additionally, the value of shunt resistance will be in milliohms.

Conversion of Galvanometer to Voltmeter

A galvanometer can be converted into a voltmeter by connecting a large resistance in series to the galvanometer which is shown in diagram.



Let the resistance of the galvanometer be G and current require for full scale deflection in it be I_g. Suppose we want to convert this galvanometer to read voltage upto V volts Let R be the resistance of a conductor connected in series with it . The value of R must be such that when a potential difference V is applied to the voltmeter so formed, a current passing through the galvanometer is I_g so that full scale deflection is obtained. Let V volt be the potential difference to be measured by the voltmeter and Ig, be the current. Now potential difference between point A and B :

$V= I_gR+I_gG= I_g(R+G)$

$\therefore R+G = V/ I_g$

$\therefore \quad R=[(V/I_g)-G]$

This is the required value of resistance which must be connected in series to the galvanometer to convert it into a voltmeter of range 0-V volt.

Voltmeter is a high resistance device. Resistance of an ideal voltmeter is infinite. A voltmeter is always connected in parallel to the circuit component across which voltage is to be measured.

If we connect a simple galvanometer in parallel to the circuit, it will draw some current and hence the potential difference of the circuit will change and the measurement will not be accurate. For accurate measurement of the potential difference, it is essential that current between the two points should remain the same after connecting a measuring device. This is possible if the resistance of the device is infinite.

Conclusion

The article presents a thorough overview of how a galvanometer is converted to an ammeter and a voltmeter respectively. Being a sensitive device, a galvanometer can only measure feeble currents in the circuit. Thus, to extend its range, we use resistors in series and in parallel, to control the flow of current through the galvanometer. Also, the branches of resistors to be connected depends on how much the range of ammeter or voltmeter is to be increased. To increase the range of ammeter n times, the value of shunt resistor to be used is $S = G/(n-1)$, whereas for voltmeter, it will be $R = (n-1)\cdot G$.

FAMILIARIZATION OF MULTIMETER

A **multimeter** (also known as a **volt-ohm-milliammeter**, **volt-ohmmeter** or **VOM**) is a measuring instrument that can measure multiple electrical properties. A typical multimeter can measure voltage, resistance, and current, in which case can be used as a voltmeter, ammeter, and ohmmeter. Some feature the measurement of additional properties such as temperature and capacitance.

multimeters can measure many values. The most common are:

- Voltage, alternating and direct, in volts.
- Current, alternating and direct, in amperes. The frequency range for which AC measurements are accurate is important, depends on the circuitry design and construction, and should be specified, so users can evaluate the readings they take. Some meters measure currents as low as milliamps or even microamps
- Resistance in ohms.
- Capacitance in farads,.
- Frequency in hertz
- Inductance in henries. Like capacitance measurement, this is usually better handled by a purpose designed inductance / capacitance meter.
- Continuity tester; a buzzer sounds when a circuit's resistance is low enough (just how low is enough varies from meter to meter), so the test must be treated as inexact.

- Diodes (measuring forward drop of diode junctions).
- Transistors (measuring current gain and other parameters in some kinds of transistors)

A digital multumeter is made from the basic digital voltmeter. For the measurment of current , the voltage drop across a precision resistance is measured. DVM cam be converted to an ohmmeter by using an accurate current source. It measures the voltage drop across the resistance being measured.

Measurements Using analog multimeter

Zero adjustment of multimeter: Before the measurment are taken, make sure that the pointer of the meter is at zero position of the scale. If the pointer is not on the zero position , bring th pointer to.exact position by turning th screw located just below the scale window , using a small srew driver.

The face of a digital multimeter typically includes four components: ♣ Display: Where measurement readouts can be viewed. ♣ Buttons: For selecting various functions; the options vary by model. ♣ Dial (or rotary switch): For selecting primary measurement values (volts, amps, ohms). ♣ Input jacks: Where test leads are inserted.

(a) Voltage *V* (b) Resistance *Ω* (c) Current *A*

Multimeters. The meter can measure voltage, resistance and current. Note two things:

- which connectors at the bottom are used
- where the dial points (your dial might look different from the one shown here, but somewhere it will have *V*, *Ω*, and *A* for measuring voltage, resistance, and current).

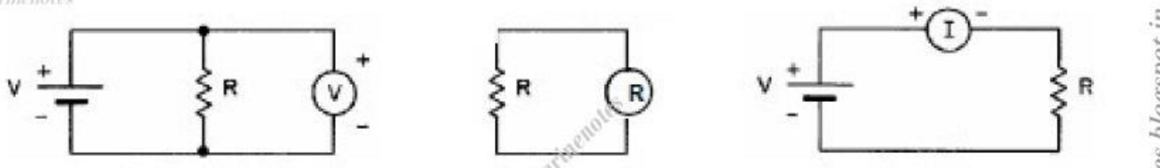


Figure 1-4. Using a multimeter (shown by the circle with a *V*) to measure voltage.

Figure 1-3. Using a multimeter (shown by the circle with a *R*) to measure resistance.

Figure 1-5. Using a multimeter (shown by the circle with an *I*) to measure current.

DIGITAL MULTIMETER Digital Multimeter is a combination of Ammeter, Voltmeter, Ohmmeter and Continuity meter. Sometimes, there is also a terminal to check the transistor whether it is PNP or NPN. It is used for measurement of resistance, AC & DC voltage and current, continuity of a wire etc. It has separate AC and DC voltage and current ranges, resistance ranges, continuity, diode circuit. Some points should be kept in mind during measurements. • Voltage should always be measured in parallel. • Current should always be measured in series. • Switch off circuit supply before measuring resistance of a resistor connected in circuit, and take out the resistor from circuit.

Digital multimeter is constructed with:

- Sensing element connected to probes,
- Analog to digital converter,
- Rectifier circuit,
- Range selector and converter,
- Digital display, and
- Amplifier.

Most digital multimeters are supplied by a pair of AA batteries.

Digital multimeters

All digital meters contain a battery to power the display so they use virtually no power from the circuit under test. This means that on their DC voltage ranges they have a very high resistance (usually called input impedance) of 1MΩ or more, usually 10MΩ, and they are very unlikely to affect the circuit under test.

Digital meters have a special diode test setting because their resistance ranges cannot be used to test diodes and other semiconductors.

How to Measure Resistance

.

1. Plug the red probe's terminal to the multimeter's socket indicated by the symbol "Ω". Plug the black probe's terminal to the multimeter's socket indicated by the ground symbol "≑" or COM.
2. Rotate the rotary switch to the symbol "Ω". This symbol is Omega and used to represent Ohm in electricity.
3. Use the bigger scale first (MΩ or kΩ) if you have no idea how big the resistance will be. You may lower it if the result shows zero in the first digit. That indicates that the scale is too big. Don't worry, using a small scale won't harm your multimeter.
4. Turn off or cut off the power supply from the circuit.
5. Touch one end of the resistor with the red probe and another end with the black probe. Since resistance doesn't have polarity then we don't need to think about which one should be connected to the red probe.
6. **6.** Read the number in the digital display and take note of the scale you use.

Basic principle of Measurement of Resistance

When the multimeter is used to measure resistance, it uses its reference voltage source inside it. The voltage is applied to the measured point and the voltage drop is generated. This voltage drop is calculated using a calibrated value to produce resistance on the measured points.The current will flow through the resistor and produce a voltage. Using the basic Ohm's Law (R=V/I), it will result in the resistance value and be displayed on the digital display.

How to Measure Voltage

1. Plug the red probe's terminal to the multimeter's socket indicated by the symbol "V". Plug the black probe's terminal to the multimeter's socket indicated by the ground symbol "≐" or COM.
2. Determine whether the voltage is AC or DC. Some multimeters have auto-ranging indicated by DC and AC symbols in a single mode but some of them only measure mV.
3. Assume that we don't have auto-ranging then we need to manually choose DC or AC.
4. Rotate the rotary switch to the voltage symbol.
5. We start with the highest scale for safety if we don't have an idea how high the voltage is.
6. Connect the red probe to the hot line or positive line and black probe to the ground line or negative line.
7. If the measured voltage is AC then we don't need to specifically determine the polarity. If we measure DC voltage then connecting the wrong probe to the wrong polarity will show a negative value.
8. Read the displayed value. Reduce the scale if the result is too small, indicating the scale is too big.

Principle of Measurement of Voltage

The voltage measured by the multimeter will be calibrated and converted by the ADC (analog to digital converter) to show in the digital display.

How to Measure Current

1. Plug the red probe's terminal to the multimeter's socket indicated by the symbol "mA" for milliamps or "A" for Amps. Plug the black probe's terminal to the multimeter's socket indicated by the ground symbol "≐" or COM.

2. If you are not sure how high the measured current is, just use the “Amps” first. If the result is too low, maybe it is within milliamps and you need to use the mA.
3. Determine whether the voltage is AC or DC. Some multimeters have auto-ranging indicated by DC and AC symbols in a single mode but some of them only measure mA.
4. Assume that we don’t have auto-ranging then we need to manually choose DC or AC.
5. Rotate the rotary switch to the “A” symbol.
6. We start with the highest scale for safety if we don’t have an idea how high the voltage is.
7. Turn off the circuit or cut off its power supply.
8. Break the circuit at the point you want to measure the current.
9. Connect the red probe to the positive side and black probe to the negative side. These two sides we connect with the probes are the result when we broke the circuit. Remember that an ammeter should be connected in series right?
10. If the measured voltage is AC then we don’t need to specifically determine the polarity. If we measure DC voltage then connecting the wrong probe to the wrong polarity will show a negative value.
11. Turn on the circuit or connect the power supply.
12. Read the displayed value. Reduce the scale if the result is too small, indicating the scale is too big.

Basic Principle of Measurement of Current

While doing current measurement in series, the probes will sense the current. If the measured current is DC then we will not have any problem, but if it is AC then it is converted to DC first by the AC to DC converter (rectifier circuit).This measurement will convert the current into equivalent voltage from its internal resistance in the multimeter. Keep in mind that every measurement given by the multimeter is processed in the form of voltage. Digital multimeter has a low resistance resistor with the set value. This low resistor acts as close as a conductor wire to minimize resistance that can disturb the measurement.

Later on, the current flows through this resistor and the multimeter measures the voltage across this resistor. This value is then calculated and calibrated by the multimeter using Ohm’s Law (I = V/R) and displayed digitally.

How to Test Diode

1. Plug the red probe’s terminal to the multimeter’s socket indicated by the symbol diodes (an arrow). Plug the black probe’s terminal to the multimeter’s socket indicated by the ground symbol “≟” or COM.
2. Rotate the rotary switch to the diode symbol.
3. Turn off the circuit or cut off its power supply.

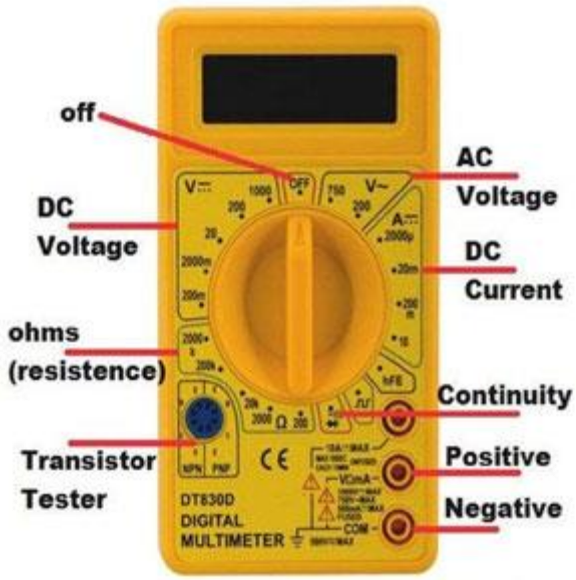
4. To test the **forward bias**, connect the red probe to the positive terminal of the diode and black probe to the negative terminal.
5. If the displayed number is more than 0 then the forward bias is good (more than 0 less than 1). If the displayed number is OL (OverLoad) or 0 then the forward bias is bad.
6. To test the **reverse bias**, connect the red probe to the negative terminal of the diode and black probe to the positive terminal.
7. If the displayed number is 0 or OL then the reverse bias is good. If the displayed number is more than 0 and less than 1 then the reverse bias is bad.
8. To conclude whether the diode is good or bad, the results for both forward bias and reverse bias should be good.
9. Turn on the circuit or connect the power supply.
10. Read the displayed value. Reduce the scale if the result is too small, indicating the scale is too big.

How to Test Continuity

We can use the same probe configuration as the resistance measurement. We simply connect the probes to the desired connection and if it shows any value in Ohm then it is good. If it shows OL then the continuity is bad.

Most of the multimeter will beep if the continuity is good. But if it is not beep that doesn't mean the connection is bad, maybe the impedance is too high.

This test is useful for checking the fuse, switch, conductors, and many more.
CategoriesArticles



Parts of digital multimeter

- A multimeter is a simple but useful device that has only three parts
- Display screen
- Selection knob
- Ports.

Display screen

- Display screen-It has an illuminated display screen for better visualization.
- It has five digits display screen; one represents significant value and the other four are for number representation.

Selection knob

- As we know a single multimeter performs so many tasks like reading voltage, resistance, and current.
- The selection knob allows the user to select the different jobs.

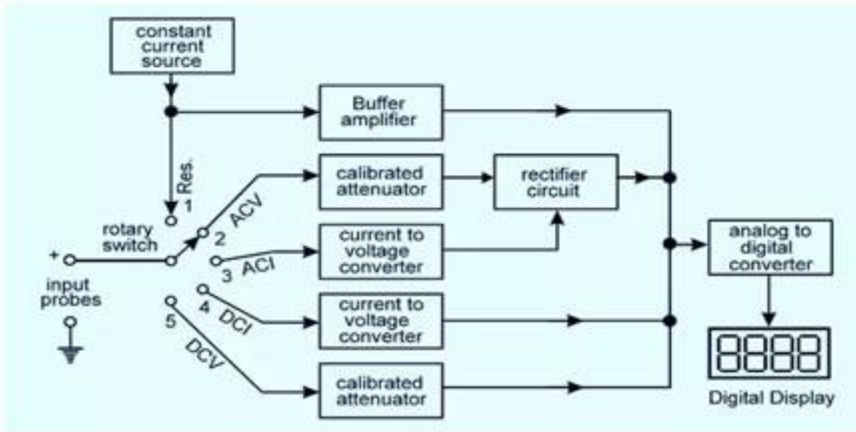
Port

- There are two ports on the front of the unit. One is the mAVΩ port which allows the measurement of all the three units: current up to 200 mA, voltage, and resistance. The red probe is plugged into this port.
- · The other is COM port which means common and it normally connected to -ev of a circuit and a black probe is plugged into it. There is one particular port is 10A, which is used to measures a large current in the circuit.

Features of digital multimeter

- Auto-Rang
- A Back-Lit LCD
- Auto-Off
- Decent Probes
- Auto Polarity

BLOCK DIAGRAM



Diode Check By Using a Digital Multimeter

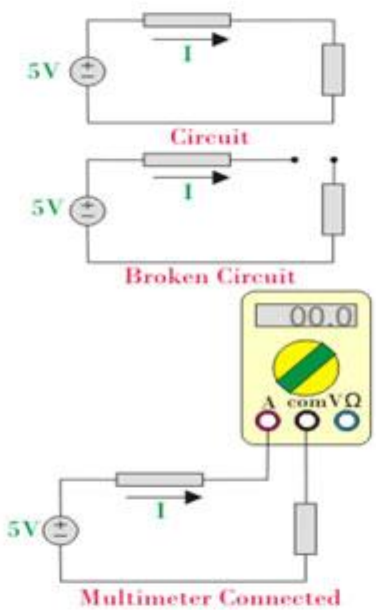
Function Switch Dial

● There are eight different functions to choose from on the function switch.
● The first is OFF. The meter should always be returned to this position when not in use.
● The V markings are for measuring DC and AC voltage.
● The Ω marking is for measuring resistance.

● The A marking is for measuring current.

Function Switch Measuring Resistance and Current

● The Ω is used to measure electrical resistance in ohms.
● The A setting is used to measure DC current in amps.



or Direct Current (DC) circuits. Alternatively, Radio Frequency (RF) voltage can also be measured by specialised voltmeters.