5. Conductors

1. Conductors:

A conductor is a material having free charges free to move, which can conduct electricity.

In the metallic conductors, there are some free electrons moving at high speeds in random directions and collide with the fixed metallic ions, but do not leave the surface of the metal. Their behavior resembles that of gas molecules confined within a container This is why the collection of the metallic electros is called ‘electron gas’.

2. Electrostatic properties of a metallic solid conductor:

Due to the presence of the free moving electrons, the metals have the following electrostatic properties:

(i) In static condition, the electrostatic field inside the conductor is always zero (if conductor is given some charge or it is placed in an external static electric field).

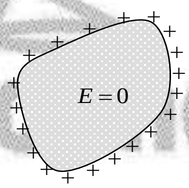
(ii) The surface and entire volume of a conductor is equipotential. This implies that the field lines are perpendicular to the surface of the conductor.

(iii) The interior of a metallic conductor cannot have net charge in static conditions. Therefore, the excess of charge must reside on the outer surface of the conductor.

(iv) Electric field at a point on the surface of a charged conductor is $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$, where σ is the local surface density of the charge and $\hat{n}$ is the normal to the surface at the point.

3. The field inside a conductor is zero:

If there were field inside a conductor in static condition, free electrons would have been moving inside the conductor, constituting a continuous current, hence producing heat without any supply of the other form of energy. This is not possible according to the *energy conservation principle*. Therefore, when some charge is given to a conductor; or the conductor is subjected to an external electric field, the charge careers (electrons) redistribute themselves in such a fashion that there is *no field inside* the conductor.



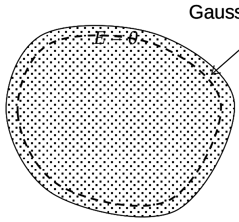
4. Every point of a conductor in an electric field or those of a charged conductor is at the same:

If a conductor will have different potentials at different points in the interior of it or on its surface, there will be a continuous current flowing between the points having different potentials. If there is no external source of energy supply, then such a continuous flow of charge will violate the energy conservation principle. This is why, when charge is given on a conductor or conductor is put in an external electric field, the charges move and redistribute themselves instantly to make the potential all over the volume of the conductor the same.

5. There is no charge in the interior of a charged conductor:

Let there be a charged conductor of any shape. A Gaussian surface just below the conductor’s outer surface is drawn.

By Gauss’s theorem, $\oint \vec{E}\cdot d\vec{s} = \frac{q_{inside}}{\varepsilon_0}$.



But E = 0, inside the conductor, hence $\frac{q_{inside}}{\varepsilon_0} = 0 \Rightarrow q_{inside} = 0$.

This implies that charge of the charged conductor is not anywhere inside so they must be on the outer surface.

[**If some charge is put on a conductor in the interior of it, would these charges migrate to the outer surface and the interior will get free of charge**]

6. Electric field near the surface of a charged conductor:

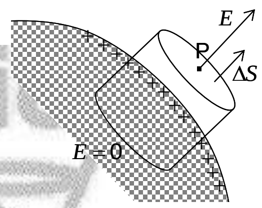
Let there be a charged conductor of charge per unit surface area σ. P is a point just outside the conductor surface. A 'pill-box' Gaussian surface across the conductor is drawn such that point P lies on the flat surface of the Gaussian surface.

The flat surface area is ΔS. Therefore charge enclosed by the Gaussian surface $q = \sigma \Delta S$.

The flux across the outer flat surface $\phi_{flat(out)} = E\,\Delta S$, where E is the field at P.

The flux across the flat surface inside the conductor is $\phi_{flat(in)} = 0$, because there is no field inside the conductor.

Flux across the curved surface is $\phi_{curved} = 0$, because the field lines are parallel to the curved surface.



Hence the net flux across the Gaussian surface will be, $\Phi = \phi_{flat(out)} + \phi_{flat(in)} + \phi_{curved} = E\,\Delta S$.

By Gauss's theorem $\Phi = \frac{q}{\varepsilon_0}$. $\Rightarrow E\Delta S = \frac{\sigma\,\Delta S}{\varepsilon_0}$. $\Rightarrow$ $\boxed{E = \frac{\sigma}{\varepsilon_0}}$.

If $\hat{n}$ is the unit vector perpendicular to the surface at the point P, then in vector form the field is $\boxed{\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}}$.

7. Cavity inside the conductor:

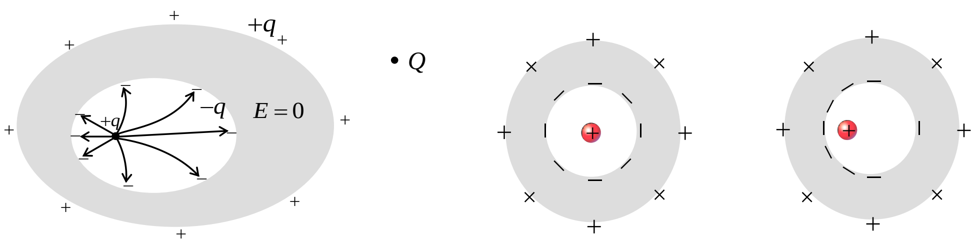
The following facts about cavity in a conductor are notable:

(i) The field inside a cavity in a conductor is also zero due to outer charges or fields, provided there is *no charge placed inside* the cavity.

(ii) There is no induced charge on the inner surface of the cavity due to external field or charge and all induced charges are on the outer surface, provided there is *no charge placed inside* the cavity.

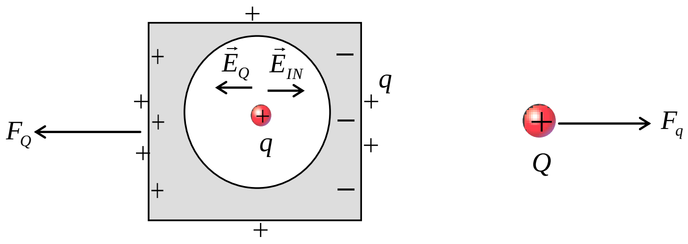
(iii) If there is a $+q$ charge inside cavity, it induces a total of $-q$ charge on the inner cavity surface and $+q$ charge appears on the outer surface of the conductor.

(iv) If the positioning of charge inside the cavity is asymmetrical, the charge induced on the inner surface is asymmetrical. But on the outer surface the induced charge $+q$ is distributed symmetrically.



8. Electrostatic Shielding:

A cavity inside a conductor is shielded from outside electric influence, i.e., the field in the cavity due to the outer charges or due to external field is always zero. This effect is called *electrostatic shielding*.



Use of electrostatic shielding:

(i) It is used to protect sensitive devices from out side electrical influences.
(ii) To protect human beings from lightening or electrical shocks, an "electric cage" is used near the high voltage devices, which works on the principle of 'electrostatic shielding'.

9. Potential of a conductor:

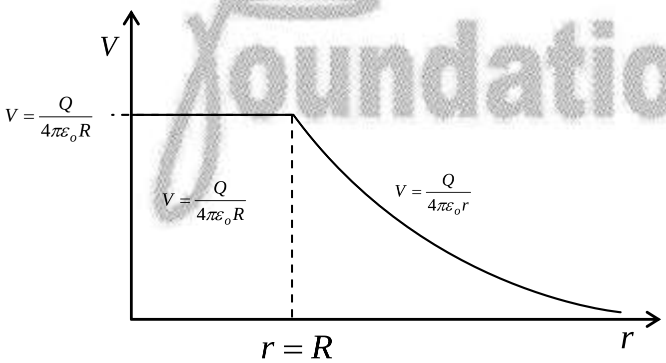
Potential at a point on the surface of a conductor is called **potential of the conductor** because every point in the conductor is at the same potential.

If a charge Q is given to a spherical conductor of radius R, it is distributed on the surface of the conductor uniformly.

The potential at the surface of the conductor is $V = \dfrac{Q}{4\pi\varepsilon_o R}$.

Since the volume of a conductor is equipotential, therefore, at every point on the surface and inside the sphere potential will be the same and equal to that on the surface, i.e., $V = Q/4\pi\varepsilon_o R$.

The potential due to the conductor falls off the surface with the distance from the center as shown in the following figure.



If a conductor is earthed i.e. it is connected to the earth, its potential becomes zero. To make the potential of the conductor zero, either electron may flow from the earth to the conductor, or to the earth from the conductor.