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## Conductors and Insulators:

1. **Conductors** are material in which electric charges move quite freely. Conductors are essentially metals, e.g. copper, aluminum, they contain **free** electrons which move freely in the conductor and can transfer the electric charge.
2. **Insulators** are materials that do not readily transport charge, e.g. glass, rubber, wood. Their electrons are tightly bound to their atoms and can not move freely.

## Properties of a conductor in electrostatic equilibrium:

1. The excess charge resides entirely on its surface.
2. The electric field is zero everywhere inside it.
3. The electric field just outside it is perpendicular to its surface and has a magnitude ($\frac{\sigma}{\varepsilon_o}$), where σ is the charge per unit area at that point.
4. On an irregularly shaped conductor, the concentration of charge on it is greatest where the surface is most sharply curved (radius of curvature of the surface is the smallest).

## EXAMPLES

1. The electric field everywhere on the surface of a hollow sphere of radius $r$ =0.7 m is measured to be equal to $9.80\times10^2$ (N/C) and points radially toward the center of the sphere.

a- What is the net charge within the sphere's surface? [$\boxed{E = k\frac{Q}{r^2}}$]

Since the electric field points radially inward towards the center of the sphere, then one can expect a **negative charge inside**. Using Gauss' law, we can have

**Ans**: $E = k\frac{-Q}{r^2} \quad \Rightarrow \quad Q = -\frac{(9.8\times10^2)(0.7)^2}{(9.0\times10^9)} = \underline{-5.3\times10^{-8}\ \text{C}}$

b- What can you conclude about the nature and distribution of the charge inside the sphere?
Negative charge has spherically symmetric distribution.

2.The electric field everywhere on the surface of a hollow sphere of radius r=11 cm is measured to be equal to $3.8\times10^4$ N/C and points radially inward towards the center of the sphere. How much charge is enclosed by this surface?

$$\Phi = EA = E(4\pi r^2) = 3.8\times10^4\times(4\pi)\times(0.11)^2 = \underline{5.78\times10^3\ \frac{\text{N.m}^2}{\text{C}}}$$

then

$$Q_{in} = -\varepsilon_o \Phi = \underline{-5.11\times 10^{-8}\ \text{C}}$$

It is a **negative charge inside** because the electric field points radially inward towards the center of the sphere.

**Example:** A point charge of $q_{center} = -50e$ lies at the center of a hollow spherical metal shell that has a net charge of $q_{net} = -100e$, as seen in figure (4). Calculate the charge on the (a) shell's inner surface, and (b) on its outer surface. [e is the magnitude of the charge on the electron.]

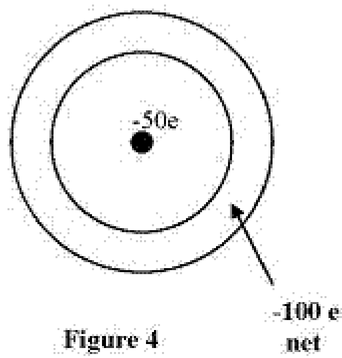



Figure 4

$$q_{inner} = -q_{center} = 50e,$$
$$q_{out} = q_{inner} + q_{net} = -50e + (-100e) = -150e$$

# CAPACITORS and DIELECTRIC

A capacitor is an electronic device, which is used to store electric charge, and hence electrical energy. A capacitor stores electric charge on its plates. There are many types of capacitors available; one of them is the parallel plate capacitor. A parallel-plate capacitor consists of two metal plates separated by an insulator (e.g. air, waxed paper, etc.). When it is connected to a battery (charging), the two plates are charged with equal and opposite charges.

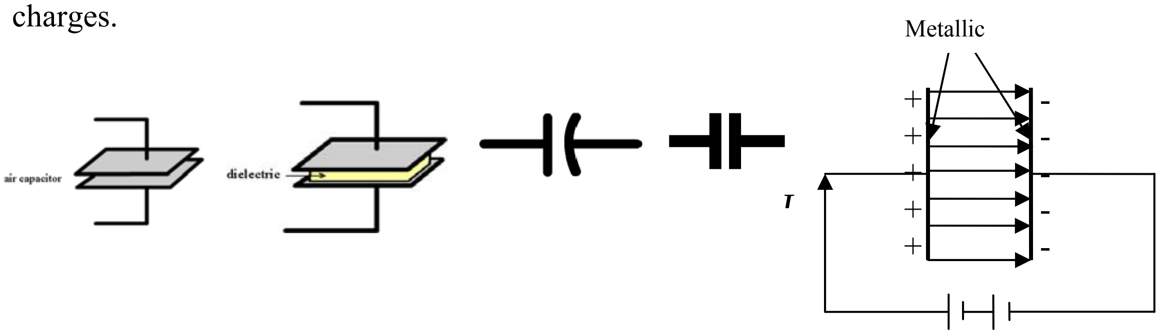



Figure 1 – Air capacitor, ceramic or paper capacitor, and schematic symbol.

**<u>Capacitance</u>**: is <u>*the ability to store charge*</u>- and measured in farads (F). "*A capacitance of one farad can store charge of one coulomb when the potential difference across it is one volt*". It could be written as:

$$\text{Capacitance } (C) = \frac{\text{Charge stored } (Q)}{\text{Potential difference } (V)}$$

In symbols

$$C = \frac{Q}{V}$$

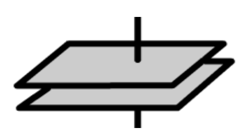
If charge is measured in coulombs and potential in volts, capacitance is measured in $\frac{\text{Coulombs}}{\text{Volts}} \equiv \text{ Farad [F]}$. Capacitance of one Farad is enormous. Most small electronic components are measured in microfarads (μF), 1 μF = $10^{-6}$ F.

**EX.: A** capacitor of capacitance 10 μF is charged to a P.D. of 5 volt. How much charge is stored on each plate?

$$\Rightarrow \quad Q = CV = 10\times10^{-6}\times5 = 50\times10^{-6}\text{ C} = 50\ \mu\text{C}$$

**Ex**: find the capacitance of the parallel-plate capacitor, with the separation *d*, area *A* and carries a charge *Q*, in vacuum.

$$\Rightarrow \quad C = \frac{Q}{V} = \frac{Q}{E\,d} = \frac{Q}{(\sigma\,/\,\varepsilon_o)\,d} = \frac{Q}{(Q\,/\,A\varepsilon_o)\,d} = \varepsilon_o\,\frac{A}{d}$$



**H.W**. A parallel-plate capacitor has a capacitance of 2.0 μF. If the plates are 2.0 mm apart, what is the area of the plates? [Ans: 4.4 x $10^2$ $m^2$].

**Example:** A parallel-plate capacitor has a plate area of 0.2 m$^2$ and a plate separation of 0.1 mm. If the charge on each plate has a magnitude of $4.0\times10^{-6}$ C the electric field between the plates is approximately:
**Answr:**

$$\because C = \frac{q}{V} = \varepsilon_o \frac{A}{d} \quad \therefore V = \frac{qd}{\varepsilon_o A}$$

$$\because |E| = \frac{V}{d} \quad \therefore |E| = \frac{\sigma}{A} = \frac{q}{\varepsilon_o A} = \frac{4.0\times10^{-6}}{8.85\times10^{-12}\times0.2} = \underline{2.3\times10^{6}\ \frac{\text{V}}{\text{m}}}$$

**Ex**: find the capacitance of the spherical shell capacitor of radius *R*.

$$\Rightarrow \qquad C = \frac{Q}{V} = \frac{Q}{(kQ/R)} = \frac{R}{k} = 4\pi\varepsilon_o R$$

Note: For one Farad, the radius of the sphere will be $R = k = 9\text{x}10^9$ m !!!

**H.W**. Find the capacitance of two concentric spherical conducting shells (of radii $a$ and $b$, $b > a$) and they are separated by vacuum. [Ans: $C = 4\pi\varepsilon_o \frac{ab}{b-a}$]

The capacitance can be increased by:

1. Increasing the area of the plates. By increasing the area, more charge is stored, so the capacitance is increased.
2. Decreasing the separation of the plates
3. Adding an insulator material (a dielectric) between the plates. The electric field between the plates distorts the atoms of dielectric material, and the displaced electrons and nuclei lower the potential, so the capacitance increases.