USEFUL CONCEPTS/INFORMATION

1. When a conductor (*e.g.* copper, silver, aluminium etc.) is placed in an electric field, there is movement of charge carriers (free electrons) within the conductor. The adjustment of charge on the conductor takes place quickly. When there is no net motion of charge within the conductor, the conductor is said to be in *electrostatic equilibrium*.

2. A conductor (hollow or solid) in *electrostatic equilibrium* has the following properties (See Fig. 5.50).

(*i*) The electric field is zero $(\vec{E} = 0)$ everywhere inside the charged conductor.

(*ii*) There is no net charge inside the material of the charged conductor. This means that charge resides entirely on the surface of the conductor.

(*iii*) The electric field $(\vec{E})$ on the surface or just outside the charged conductor is perpendicular to the surface of the conductor at every point.

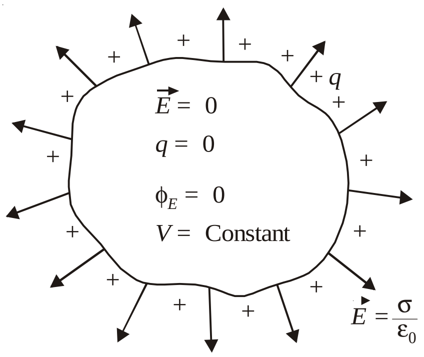

Fig. 5.50

(*iv*) The magnitude of electric field just outside the conductor is σ/ε_0 where σ is surface charge per unit area at that point (*i.e.* surface charge density). This applies to any conductor shape.

(*v*) The electric potential (*V*) is the same (*i.e.* constant) at the surface and inside a charged conductor.

Note that these rules presume the freedom of electrons to move and hence do not apply to insulators.

3. Fig. 5.51 illustrates the result of placing two uncharged shells around a positively charged (+*q*) body on an insulation support.

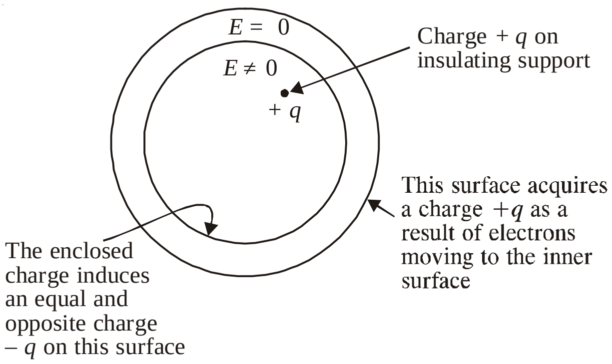

Fig. 5.51

(*i*) The net charge within the sphere is zero.

(*ii*) The total charge is the same as it was before the charged body was enclosed—an example of conservation of charge.

(*iii*) *Outside* the sphere, the field and the potential are as if the total charge (+*q*) were concentrated at the centre of the sphere.

(*iv*) The position of the enclosed charge (+*q*) does not affect points (*i*), (*ii*) and (*iii*) above.

4. A **capacitor** (the old name is **condenser**) is a device which is used to store electric charge. All capacitors consist of a pair of conducting plates separated by an insulator. The insulator is called *dielectric* and is often air, oil or paper.

5. The capacitance *C* of any capacitor is defined to be the ratio of charge *q* stored on either plate to the resulting voltage *V* between the plates *i.e.*

$$\text{Capacitance, } C = \frac{q}{V}$$

(*i*) The SI unit of capacitance is coulomb per volt or farad (F) and 1F = 1C/V.

(*ii*) Once the dimensions and the shape of a capacitor are given, its capacitance can be determined.

(*iii*) A large value of *C* indicates that the device can store large amounts of charge without building up a large voltage. Small values of *C* indicate a large potential difference for relatively small amounts of charge stored.

6. The capacitance of several geometries is summarised in table below. The formulas apply when the charged metal surfaces are separated by vacuum/air.

S. No.	Geometry	Capacitance
1.	Isolated charged sphere of radius r.	$C = 4\pi\varepsilon_0 r$ ....in vacuum/air
2.	Spherical capacitor with inner radius r_A and outer radius r_B.	$C = \dfrac{4\pi\varepsilon_0 r_A r_B}{(r_B - r_A)}$ ....in vacuum/air
3.	Parallel-plate capacitor of plate area A and plate separation d.	$C = \dfrac{\varepsilon_0 A}{d}$ ....in vacuum/air
4.	Cylindrical capacitor with inner and outer radii a and b respectively.	$C = \dfrac{2\pi\varepsilon_0 l}{\log_e\left(\dfrac{b}{a}\right)}$ ....in vacuum/air Here l = length of cylindrical capacitor

Note. If vacuum/air is replaced by a dielectric of relative permittivity K, then substitute $K\varepsilon_0$ in place of ε_0 in the above formulas.

7. If a dielectric is placed between the plates of a charged capacitor, the field between the plates distorts the molecules of the dielectric. The positive nuclei are slightly shifted in the direction of field (*i.e.* away from the positive plate) and negative electrons are shifted in the opposite direction. The molecules are said to be *polarised*.

8. The effect of dielectric between the plates of a capacitor can be studied under two conditions.

(*i*) When the **capacitor** is **isolated** and dielectric slab is introduced between the plates as shown in Fig. 5.52 (*i*), this results in the following effects:

(*a*) Since the capacitor is isolated, there can be no change in the amount of charge (q) on either plate.

(*b*) The potential difference between plates decreases.

(*c*) $E = V/d$. Since V decreases and d remains the same, the electric field within the dielectric decreases.

(*d*) $C = q/V$. Since q remains same but V decreases, the capacitance increases.

(*e*) The stored energy decreases.

(*ii*) When the **capacitor is connected to a battery** and dielectric slab is introduced between the plates as shown in Fig. 5.52 (*ii*), this results in the following effects:

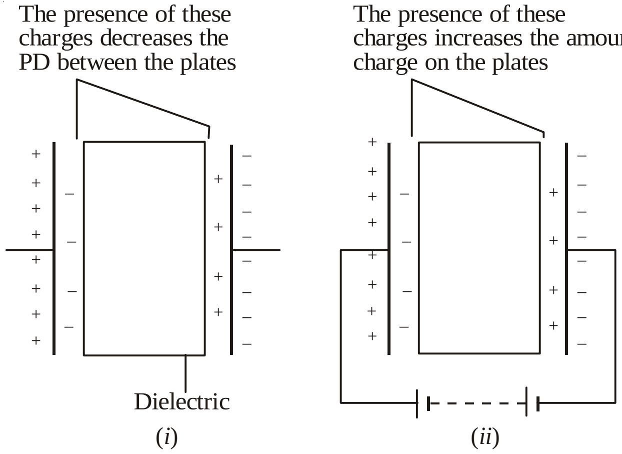

Fig. 5.52

(*a*) The potential difference (V) between plates cannot change since battery is connected.

(*b*) The charge on the plates is increased.

(*c*) The electric field is unchanged.

(*d*) $C = q/V$. Since q is increased but V remains same, C is increased.

(*e*) The stored energy increases.

9. If the space between the plates is **entirely** filled with a dielectric of dielectric constant K, the effects are illustrated in the table below :

S. No.	Without dielectric	With dielectric (Isolated Capacitor)	With dielectric (Capacitor connected to battery)
1.	E	$\frac{E}{K}$	E
2.	q	q	Kq
3.	V	$\frac{V}{K}$	V
4.	$C = \frac{q}{V}$	$C = \frac{q}{V/K} = KC$	$C = \frac{Kq}{V} = KC$
5.	Energy, $U_0 = \frac{q^2}{2C}$	$U = \frac{U_0}{K}$	$U = KU_0$

10. Dielectric constant, $K = \frac{\text{Field is Vacuum}}{\text{Field in dielectric}}$

(*i*) Value of K is equal to or greater than 1.

(*ii*) Materials which are easily polarised have larger values of K.

11. The capacitance of a parallel-plate capacitor (plate area = A, plate separation = d) with metal plate of thickness t ($t < d$) between the plates is

$$C = \frac{A\varepsilon_0}{d - t}$$

Note that introduction of metal plate increases the capacitance of the capacitor.

12. The capacitance of parallel-plate capacitor (plate area = A, plate separation = d) with dielectric slab (dielectric constant = K) of thickness t ($t < d$) between the plates is

$$C = \frac{A\varepsilon_0}{d - t\left(1 - \frac{1}{K}\right)}$$

Note that introduction of dielectric slab *increases* the capacitance of the capacitor.

13. The equivalent capacitance (C_S) of n capacitors in series is

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$$

The equivalent capacitance (C_P) of n capacitors in parallel is

$C_P = C_1 + C_2 + C_3 + ...+ C_n$

(*i*) Each capacitor in a series combination carries the same charge. Each has a different voltage across it (unless they have the same C).

(*ii*) Each capacitor in a parallel combination has the same voltage across it. Each carries a different charge (unless they have the same C).

(*iii*) In a series combination, the equivalent capacitance (C_S) is smaller than the least value of the individual capacitors.

(*iv*) If two capacitors of capacitances C_1 and C_2 are connected in series, then equivalent capacitance C_S is given by ;

$$C_S = \frac{C_1 C_2}{C_1 + C_2} \textit{ i.e. } \frac{\text{Product}}{\text{Sum}}$$

14. Work is required to charge a capacitor, since the charging process consists of transferring charges (free electrons) from one plate at a *lower potential* to another plate at a *higher potential*.

15. The work done in charging a capacitor to a charge q is equal to the electrostatic potential energy U stored in the capacitor.

$$\text{Work done} = U = \frac{q^2}{2C} = \frac{1}{2}qV = \frac{1}{2}CV^2$$

16. The energy density (energy per unit volume) associated with a region of electric field strength E is

$$\text{Energy density, } u = \frac{1}{2}\varepsilon_0 E^2 \text{ ....in vacuum/air}$$

$$= \frac{1}{2} K \varepsilon_0 E^2 \text{ .... in a medium}$$

Note that K is the dielectric constant of the material filling the volume. The unit of energy density is J/m^3.

17. Fig. 5.53 shows the two charged capacitors. When switch S is closed, charge flows until the potential difference across each capacitor is the same.

(*i*) There is no change in the total amount of charge.

(*ii*) The two capacitors acquire the same potential difference

(*iii*) Since the capacitors are in parallel, the total capacitance C of the combination is given by $C = C_1 + C_2$.

Note. Unless the initial potential differences of the two capacitors are the same, the total energy stored by the capacitors decreases when they are joined together. Energy is dissipated as heat in the connecting wires when charge (free electrons) flows from one capacitor to the other and this accounts for the decrease in stored energy.