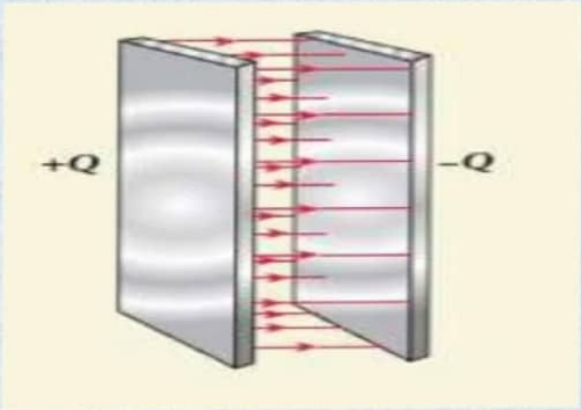
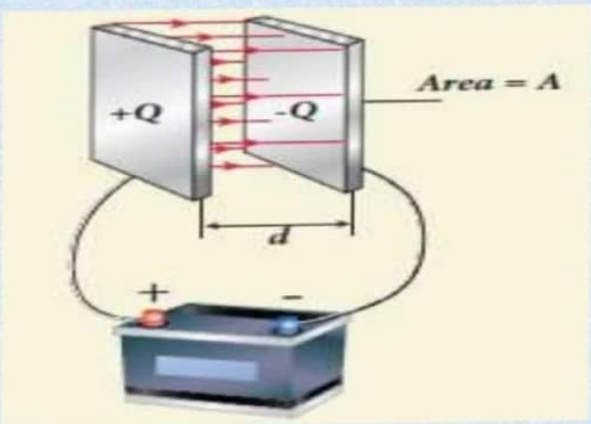
Capacitor

- Capacitor is a device used to store electric charge and electrical energy.
- It consists of two conducting objects (usually plates or sheets) separated by some distance.
- Capacitors are widely used in many electronic circuits and have applications in many areas of science and technology.
- A simple capacitor consists of two parallel metal plates separated by a small distance

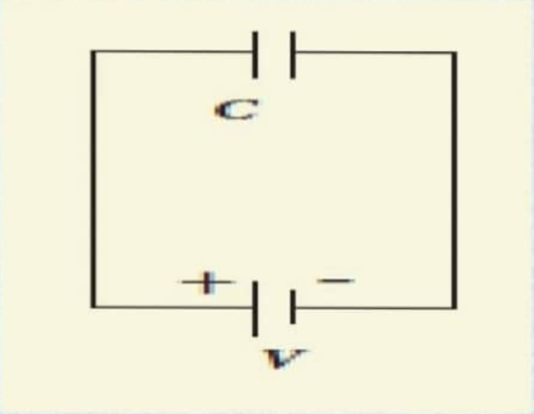
Parallel plate capacitor



Capacitor connected with a battery



Symbolic representation of capacitor



- When a capacitor is connected to a battery of potential difference V, the electrons are transferred from one plate to the other plate by battery so that one plate becomes negatively charged with a charge of –Q and the other plate positively charged with +Q.
- The potential difference between the plates is equivalent to the battery's terminal voltage.
- If the battery voltage is increased, the amount of charges stored in the plates also increase

- In general, the charge stored in the capacitor is proportional to the potential difference between the plates $Q \alpha V$

  so that Q = CV

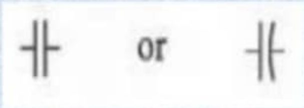
  where the C is the proportionality constant called capacitance. **The capacitance C of a capacitor is defined as the ratio of the magnitude of charge on either of the conductor plates to the potential difference existing between the conductors.**

Scanned with CamScanner

C=Q/V

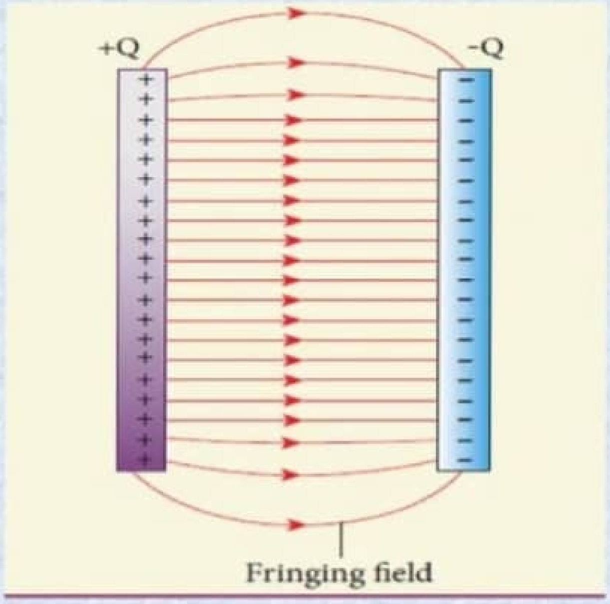
The SI unit of capacitance is *coulomb per volt or farad (F) in honor of Michael Faraday. Farad is a very large unit of capacitance.*

In practice, capacitors are available in the range of microfarad (1μF = 10^{-6} F) to picofarad (1pf = 10^{-12} F). A capacitor is represented by the symbol



- Note that the total charge stored in the capacitor is zero (Q - Q = 0).
- When we say the capacitor stores charges, it means the amount of charge that can be stored in any one of the plates.
- Nowadays there are capacitors available in various shapes (cylindrical, disk) and types (tantalum, ceramic and electrolytic), These capacitors are extensively used in various kinds of electronic circuits.

Various types of capacitors



- It is evident that capacitance is directly proportional to the area of cross section and is inversely proportional to the distance between the plates
- (i) If the area of cross-section of the capacitor plates is increased, more charges can be distributed for the same potential difference. As a result, the capacitance is increased

- Sometimes we notice that the ceiling fan does not start rotating as soon as it is switched on. But when we rotate the blades, it starts to rotate as usual. Why it is so?

- We know that to rotate any object, there must be a torque applied on the object.
- For the ceiling fan, the initial torque is given by the capacitor widely known as a condenser. If the condenser is faulty, it will not give sufficient initial torque to rotate the blades when the fan is switched on.

Energy stored in the capacitor

- Capacitor not only stores the charge but also it stores energy.
- When a battery is connected to the capacitor, electrons of total charge -Q are transferred from one plate to the other plate.
- To transfer the charge, work is done by the battery.
- This work done is stored as electrostatic potential energy in the capacitor

- To transfer an infinitesimal charge dQ for a potential difference V, the work done is given by

$$dW = V\,dQ$$

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

- The total work done to charge a capacitor is

$$W = \int_0^Q \frac{Q}{C}\,dQ = \frac{Q^2}{2C}$$

- This work done is stored as electrostatic potential energy (U_E) in the capacitor.

$$U_E = \frac{Q^2}{2C} = \frac{1}{2}CV^2 \quad (\because Q = CV)$$

- where Q = CV is used. This stored energy is thus directly proportional to the capacitance of the capacitor and the square of the voltage between the plates of the capacitor

- The equation is rewritten as follows using the

$$C = \frac{\varepsilon_0 A}{d} \text{ and } V = Ed$$

$$U_E = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}\varepsilon_0 (Ad) E^2$$

- where Ad = volume of the space between the capacitor plates. **The energy stored per unit volume of space is defined as energy density**

Applications of capacitors

Flash capacitor in camera

- Most people are now familiar with the digital camera.
- The flash which comes from the camera when we take photographs is due to the energy released from the capacitor, called a flash capacitor

Heart defibrillator

- During cardiac arrest, a device called heart defibrillator is used to give a sudden surge of a large amount of electrical energy to the patient's chest to retrieve the normal heart function.
- This defibrillator uses a capacitor of 175 μF charged to a high voltage of around 2000 V

- Capacitors are used in the ignition system of automobile engines to eliminate sparking
- Capacitors are used to reduce power fluctuations in power supplies and to increase the efficiency of power transmission.

Combinations of Capacitors

Capacitors are manufactured with different standard capacitances, and by combining them in series or in parallel, we can get any desired value of the capacitance.

(i) Capacitors in Parallel

In this combination, the left plate of each capacitor is connected to the positive terminal of the battery by a conducting wire. In the same way, the right plate of each capacitor is connected to the negative terminal of the battery (Fig. 13.14).

This type of combination has the following characteristics:

1. Each capacitor connected to a battery of voltage V has the same potential difference V across it. i.e., $V_1 = V_2 = V_3 = V$
2. The charge developed across the plates of each capacitor will be different due to different value of capacitances.
3. The total charge Q supplied by the battery is divided among the various capacitors. Hence,

$$Q = Q_1 + Q_2 + Q_3$$

$$Q = C_1V + C_2V + C_3V$$

or $$\frac{Q}{V} = C_1 + C_2 + C_3$$

or

4. Thus, we can replace the parallel combination of capacitors with one equivalent capacitor having capacitance C_{eq}, such that $C_{eq} = C_1 + C_2 + C_3$

For your information

Farad is a bigger unit of capacitance. We generally use the following submultiples:

1 micro farad = 1 μF = 1×10^{-6} F

1 nano farad = 1 nF = 1×10^{-9} F

1 pico farad = 1 pF = 1×10^{-12} F

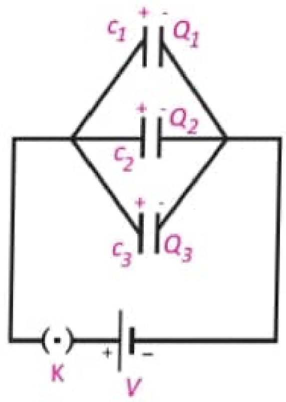


Fig.13.14: Capacitors in parallel combination

For your information

Three factors affect the ability of a capacitor to store charge.

1. Area of the plates
2. Distance between the plates
3. Type of insulator used between the plates.

In the case of 'n' capacitors connected in parallel, the equivalent capacitance is given by

$$C_{eq} = C_1 + C_2 + C_3 + \ldots\ldots + C_n \quad \ldots\ldots(13.9)$$

5. The equivalent capacitance of a parallel combination of capacitors is greater than any of the individual capacitances.

Quick Quiz

Is the equivalent capacitance of parallel capacitors larger or smaller than the capacitance of any individual capacitor in the combination?

(ii) Capacitors in Series

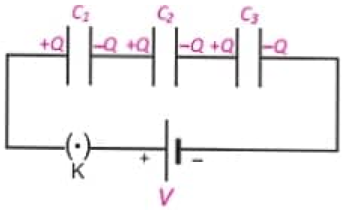


Fig.13.15: capacitors in series combination.

In this combination, the capacitors are connected side by side i.e., the right plate of one capacitor is connected to the left plate of the next capacitor (Fig. 13.15). This type of combination has the following characteristics:

1. Each capacitor has the same charge across it. If the battery supplies $+Q$ charge to the left plate of the capacitor C_1, due to induction $-Q$ charge is induced on its right plate and $+Q$ charge on the left plate of the capacitor C_2 i.e.,

$$Q_1 = Q_2 = Q_3 = Q$$

2. The potential difference across each capacitor is different due to different values of capacitances.
3. The voltage of the battery has been divided among the various capacitors. Hence

$$V = V_1 + V_2 + V_3$$
$$= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$
$$= Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$
$$\frac{V}{Q} = \left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$

Quick Quiz

Is the equivalent capacitance of series capacitors larger or smaller than the capacitance of any individual capacitor in the combination?

4. Thus, we can replace series combination of capacitors with one equivalent capacitor having capacitance C_{eq} i.e.,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

In the case of 'n' capacitors connected in series, we have

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots\cdots + \frac{1}{C_n} \qquad \text{.......(13.10)}$$