VINAYAKAR MATRICULATION HIGHER SECONDARY SCHOOL, SIVAKASI.

12th Standard - PHYSICS

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UNIT 1 ELECTROSTATICS

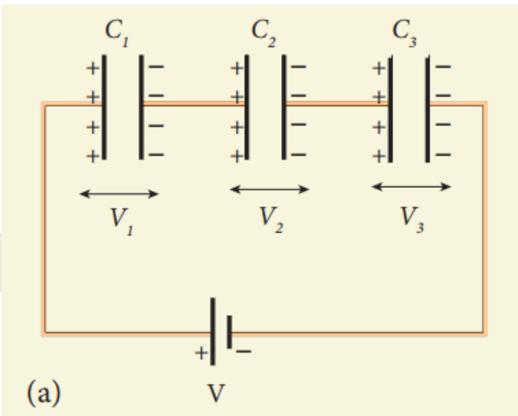
Warm greetings:

Dear students

Welcome all. In this section of physics class you get to learn about capacitors and distribution of charges in a conductor and action at points.

- Capacitors
  - Capacitor in series
  - Capacitor in parallel
- Distribution of charges in a conductor and action at points
  - Distribution of charges in a conductor
  - Action of points or Corona discharge
  - Lightning arrester or lightning conductor
  - Van de Graaff Generator

(i) Capacitor in series:



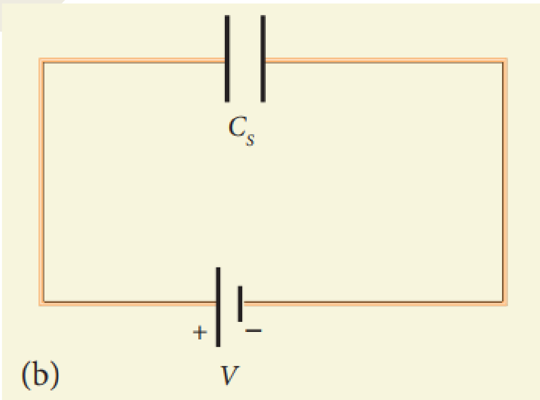


Figure 1.58 (a) Capacitors connected in series (b) Equivalent capacitors C_s

- Consider three capacitors of capacitance C_1, C_2 and C_3 connected in series with a battery of voltage V as shown in the Figure 1.58 (a).
- As soon as the battery is connected to the capacitors in series, the electrons of charge $-Q$ are transferred from negative terminal to the right plate of C_3 which pushes the electrons of same amount $-Q$ from left plate of C_3 to the right plate of C_2 due to electrostatic induction.
- Similarly, the left plate of C_2 pushes the charges of $-Q$ to the right plate of C_1 which induces the positive charge $+Q$ on the left plate of C_1.

- At the same time, electrons of charge $-Q$ are transferred from left plate of C_1 to positive terminal of the battery.
- By these processes, each capacitor stores the same amount of charge Q.
- The capacitances of the capacitors are in general different, so that the voltage across each capacitor is also different and are denoted as V_1, V_2 and V_3 respectively.
- The sum of the voltages across the capacitor must be equal to the voltage of the battery.

$$V = V_1 + V_2 + V_3 \qquad (1.103)$$

$$\text{Since, } Q = CV, \text{ we have } V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$= Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right) \qquad (1.104)$$

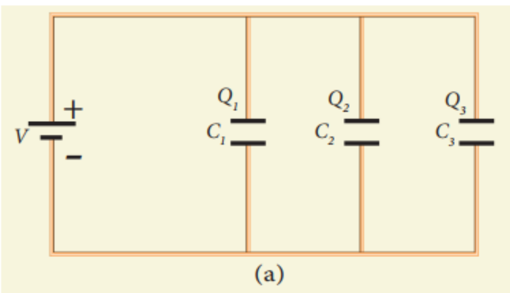
- If three capacitors in series are considered to form an equivalent single capacitor C_s shown in Figure 1.58(b), then we have $V = Q/C_S$. Substituting this expression into equation (1.104), we get

$$\frac{Q}{C_S} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \qquad (1.105)$$

- Thus, the inverse of the equivalent capacitance C_S of three capacitors connected in series is equal to the sum of the inverses of each capacitance.
- This equivalent capacitance C_S is always less than the smallest individual capacitance in the series.

(ii) Capacitance in parallel:



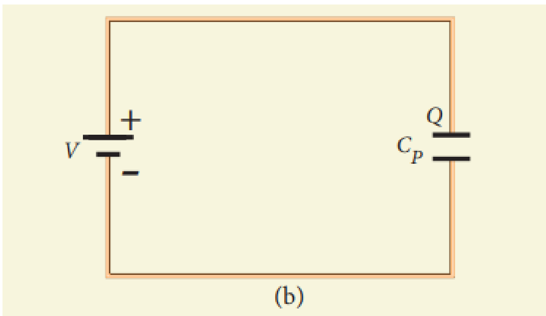


Figure 1.59 (a) capacitors in parallel (b) equivalent capacitance with the same total charge

- Consider three capacitors of capacitance C_1, C_2 and C_3 connected in parallel with a battery of voltage V as shown in Figure 1.59 (a).
- Since corresponding sides of the capacitors are connected to the same positive and negative terminals of the battery, the voltage across each capacitor is equal to the battery's voltage.
- Since capacitances of the capacitors are different, the charge stored in each capacitor is not the same.
- Let the charge stored in the three capacitors be Q_1, Q_2, and Q_3 respectively.
- According to the law of conservation of total charge, the sum of these three charges is equal to the charge Q transferred by the battery,

$$Q = Q_1 + Q_2 + Q_3 \quad (1.106)$$

Since $Q = CV$, we have

$$Q = C_1V + C_2V + C_3V \quad (1.107)$$

- If these three capacitors are considered to form a single equivalent capacitance C_P which stores the total charge Q as shown in the Figure 1.59(b), then we can write $Q = C_PV$. Substituting this in equation (1.107), we get

$$C_PV = C_1V + C_2V + C_3V$$

$$C_P = C_1 + C_2 + C_3 \quad (1.108)$$

- Thus, the equivalent capacitance of capacitors connected in parallel is equal to the sum of the individual capacitances.
- The equivalent capacitance C_P in a parallel connection is always greater than the largest individual capacitance.
- In a parallel connection, it is equivalent as area of each capacitance adds to give more effective area such that total capacitance increases.

Distribution of charges in a conductor:

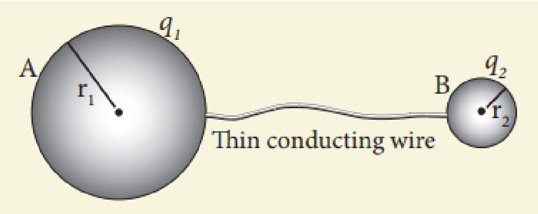


Figure 1.60 Two conductors are connected through conducting wire

- Consider two conducting spheres A and B of radii r_1 and r_2 respectively connected to each other by a thin conducting wire as shown in the Figure 1.60.
- The distance between the spheres is much greater than the radii of either spheres.
- If a charge Q is introduced into any one of the spheres, this charge Q is redistributed into both the spheres such that the electrostatic potential is same in both the spheres.
- They are now uniformly charged and attain electrostatic equilibrium.
- Let q_1 be the charge residing on the surface of sphere A and q_2 is the charge residing on the surface of sphere B such that $Q = q_1 + q_2$.
- The charges are distributed only on the surface and there is no net charge inside the conductor.
- The electrostatic potential at the surface of the sphere A is given by

$$V_A = \frac{1}{4\pi\epsilon_\circ}\frac{q_1}{r_1} \qquad (1.110)$$

- The electrostatic potential at the surface of the sphere B is given by

$$V_B = \frac{1}{4\pi\epsilon_\circ}\frac{q_2}{r_2} \qquad (1.111)$$

- The surface of the conductor is an equipotential. Since the spheres are connected by the conducting wire, the surfaces of both the spheres together form an equipotential surface. This implies that

$$V_A = V_B$$

$$\text{or} \quad \frac{q_1}{r_1} = \frac{q_2}{r_2} \qquad (1.112)$$

- Let the charge density on the surface of sphere A be σ_1 and that on the surface of sphere B be σ_2. This implies that $q_1 = 4\pi r_1^2\sigma_1$ and $q_2 = 4\pi r_2^2\sigma_2$.
- Substituting these values into equation (1.112), we get b

$$\sigma_1 r_1 = \sigma_2 r_2 \qquad (1.113)$$

from which we conclude that

$$\sigma r = \text{constant} \qquad (1.114)$$

Thus the surface charge density σ is inversely proportional to the radius of the sphere. For a smaller radius, the charge density will be larger and vice versa.

Action of points or Corona discharge:

- Consider a charged conductor of irregular shape as shown in Figure 1.61 (a).
- We know that smaller the radius of curvature, the larger is the charge density.
- The end of the conductor which has larger curvature (smaller radius) has a large charge accumulation as shown in Figure 1.61 (b).
- As a result, the electric field near this edge is very high and it ionizes the surrounding air.
- The positive ions are repelled at the sharp edge and negative ions are attracted towards the sharper edge.
- This reduces the total charge of the conductor near the sharp edge. This is called action of points or corona discharge.

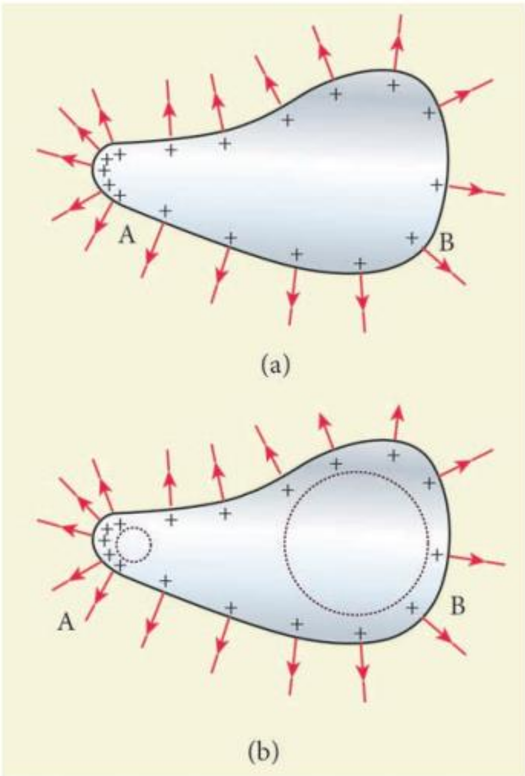


Figure 1.61 Action of points or corona discharge

Lightning arrester or lightning conductor:

- ✓ This is a device used to protect tall buildings from lightning strikes.
- ✓ It works on the principle of action at points or corona discharge.
- ✓ This device consists of a long thick copper rod passing from top of the building to the ground.
- ✓ The upper end of the rod has a sharp spike or a sharp needle as shown in Figure 1.62 (a) and (b).
- ✓ The lower end of the rod is connected to copper plate which is buried deep into the ground.

- ✓ When a negatively charged cloud is passing above the building, it induces a positive charge on the spike.
- ✓ Since the induced charge density on thin sharp spike is large, it results in a corona discharge.
- ✓ This positive charge ionizes the surrounding air which in turn neutralizes the negative charge in the cloud. The negative charge pushed to the spikes passes through the copper rod and is safely diverted to the Earth.
- ✓ The lightning arrester does not stop the lightning; rather it diverts the lightning to the ground safely.

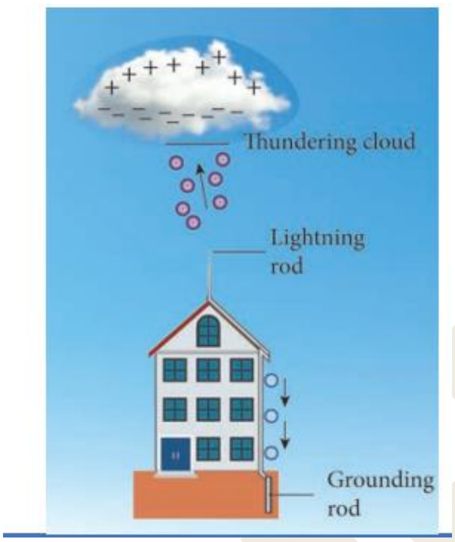
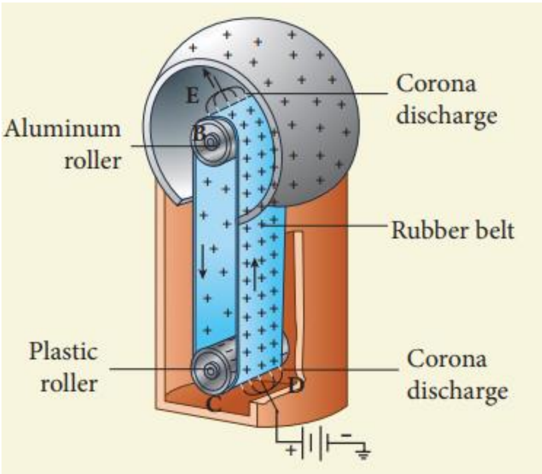


Figure 1.62 (a) Schematic diagram of a lightning arrestor. (b) A house with a lightning arrestor

Van de Graaff Generator:

- ✓ Introduction: In the year 1929, Robert Van de Graaff designed a machine which produces a large amount of electrostatic potential difference, up to several million volts (10^7 V).
- ✓ Principle: This Van de Graff generator works on the principle of electrostatic induction and action at points.
- ✓ Diagram:



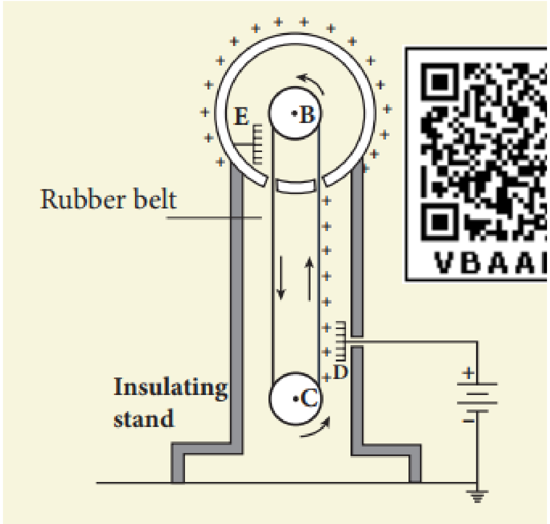


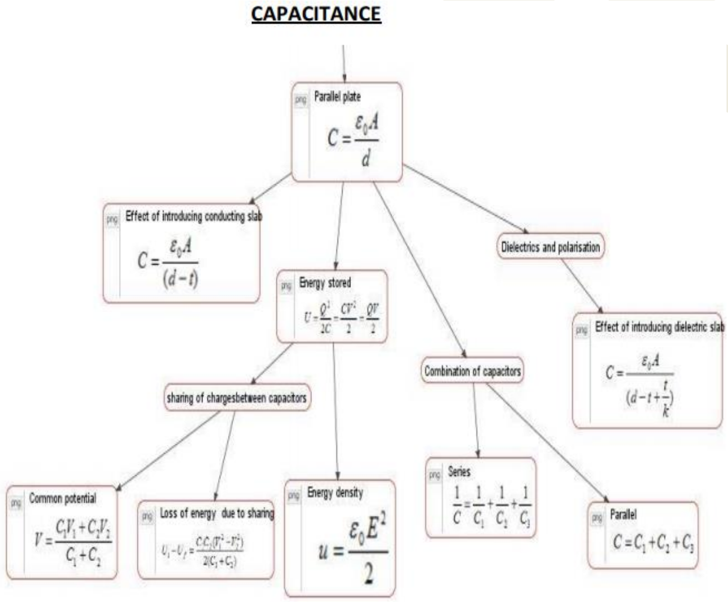
Figure 1.63 Van de Graaff generator

✓ Construction:

- A large hollow spherical conductor is fixed on the insulating stand as shown in Figure 1.63.
- A pulley B is mounted at the centre of the hollow sphere and another pulley C is fixed at the bottom.
- A belt made up of insulating materials like silk or rubber runs over both pulleys.
- The pulley C is driven continuously by the electric motor.
- Two comb shaped metallic conductors E and D are fixed near the pulleys.
- The comb D is maintained at a positive potential of 10^4 V by a power supply.
- The upper comb E is connected to the inner side of the hollow metal sphere.
- Due to the high electric field near comb D, air between the belt and comb D gets ionized by the action of points.
- The positive charges are pushed towards the belt and negative charges are attracted towards the comb D.
- The positive charges stick to the belt and move up.
- When the positive charges on the belt reach the point near the comb E, the comb E acquires negative charge and the sphere acquires positive charge due to electrostatic induction.
- As a result, the positive charges are pushed away from the comb E and they reach the outer surface of the sphere. Since the sphere is a conductor, the positive charges are distributed uniformly on the outer surface of the hollow sphere.
- At the same time, the negative charges nullify the positive charges in the belt due to corona discharge before it passes over the pulley.
- When the belt descends, it has almost no net charge. At the bottom, it again gains a large positive charge.

- The belt goes up and delivers the positive charges to the outer surface of the sphere.
- This process continues until the outer surface produces the potential difference of the order of 10^7 which is the limiting value.
- We cannot store charges beyond this limit since the extra charge starts leaking to the surroundings due to ionization of air.
- The leakage of charges canbe reduced by enclosing the machine in a gas filled steel chamber at very high pressure.
- The high voltage produced in this Van de Graaff generator is used to accelerate positive ions (protons and deuterons) for nuclear disintegrations and other applications.

Conclusion:



For reference: https://youtu.be/BmbhU_a7tjs?t=20