

**Q** Explain the concept of breakdown in capacitors. Calculate the maximum potential difference before breakdown for a cylindrical & plate capacitors. Using this, calculate the voltage of a lightning strike.

In a high voltage environment, free electrons in an insulator [there are always some present] gain energy from electric field. These high energy electrons can ionize [knock out electrons] the molecules of the insulator which causes the insulator to become a conductor and hence "breakdown".

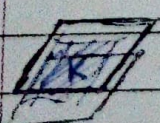
This breakdown is known as sparking.

Every dielectric material has two constants

↳ Dielectric constant (k)

↳ Dielectric unit strength  $V/m$

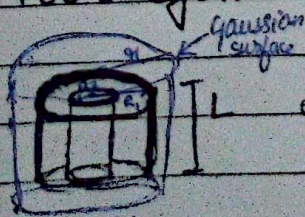
- For a parallel plate capacitor [Dielectric constant = k]  
Dielectric material's dielectric strength =  $E_0$

  $C = \frac{Q}{V}$   $E = \frac{k\sigma}{E_0}$   $V = Ed = \frac{\sigma d}{E_0} = \frac{Qd}{AE_0} \Rightarrow C = \frac{AE_0}{d}$

Area charge density

Maximum Voltage  $V_0 = E_0 d \Rightarrow V_0 = \frac{k\sigma d}{E_0}$

- For a cylindrical capacitor



$\oint E \cdot A = \frac{q}{\epsilon_0} \Rightarrow E(2\pi rL) = \frac{\lambda L}{\epsilon_0}$   
Gauss Law  $\Rightarrow E = \frac{k\lambda}{2\pi\epsilon_0 r}$   $\lambda = \frac{Q}{L}$

$V = \int_{R_2}^{R_1} E dr \Rightarrow V = \frac{k\lambda}{2\pi\epsilon_0} \int_{R_2}^{R_1} \frac{1}{r} = \frac{kQ}{L(2\pi\epsilon_0)} \ln\left(\frac{R_1}{R_2}\right)$

$C = \frac{Q}{V} = \frac{2\pi L\epsilon_0 k}{\ln\left(\frac{R_1}{R_2}\right)}$

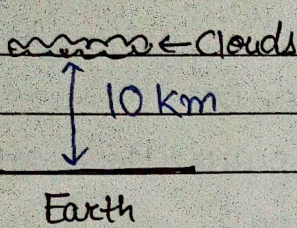
$V_0 = E_0 d \Rightarrow V_0 = \frac{2d}{2\pi\epsilon_0}$   
Maximum Voltage



$$\Rightarrow V_0 = E_0 \ln \left[ \frac{R_2}{R_1} \right]$$

Maximum Voltage  $\nearrow$

Now we assume the earth's surface and the clouds a parallel plate capacitor.



$$10 \text{ km} = d = 10^4 \text{ m}$$

$$\text{Dielectric Strength of Air} = 3 \times 10^8 \text{ V/m}$$

[ $E_0$ ]

$$V_0 = E_0 d \Rightarrow V_0 = (3 \times 10^8) \times 10^4$$

$$= 3 \times 10^{12} \text{ V}$$

$\therefore$  During a lightning strike the voltage <sup>difference</sup> b/w earth & cloud is  $3 \times 10^{12} \text{ V}$