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

In a high voltage environment, free electrons in an ~~insutl~~ insulator (there are always some present) gain energy from electric field. These high energy electrons can ionize (i.e. knockout 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 2 constants.
- Dielectric constant (K)
- Dielectric strength — units: $\frac{V}{m}$

* For Parallel plate capacitor -

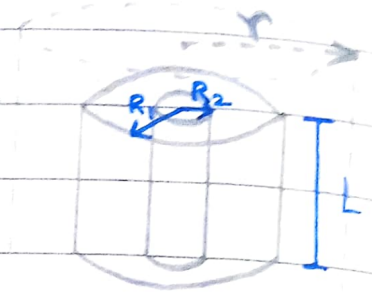
$$C = \frac{Q}{V} \quad ; \quad E = \frac{K\sigma}{\varepsilon_0}$$

(σ → Area Charge Density.)

$$V = Ed = \frac{\sigma d}{\varepsilon_0} = \frac{Qd}{A\varepsilon_0} \Rightarrow C = \frac{A\varepsilon_0}{d}$$

$$\boxed{V_M = E_M d}$$ → Maximum voltage

* For Cylindrical capacitor :



$$\oint E \cdot A = \frac{q_{enc}}{\varepsilon_0}$$

$$\Rightarrow E(2\pi r L) = \frac{\lambda L}{\varepsilon_0}$$

$$\Rightarrow E = \frac{k\lambda}{2\pi\varepsilon_0 r}$$

$$V = \int_{R_2}^{R_1} E\,dr \Rightarrow V = \frac{k\lambda}{2\pi\varepsilon_0}\int_{R_2}^{R_1}\frac{1}{r} = \frac{kQ}{L}\left[\frac{\ln(R_1/R_2)}{2\pi\varepsilon_0}\right]$$

$$C = \frac{Q}{V} = \frac{2\pi L\varepsilon_0 k}{\ln(R_1/R_2)}$$

$$\boxed{V_M = E_M \ln\left(\frac{R_2}{R_1}\right)} \longrightarrow \text{Maximum voltage}$$

- Now assuming the Earth's surface & the clouds to be a parallel plate capacitor.

10 km = d = 10^4 m

Dielectric strength of Air = $3 \times 10^8 \ \frac{V}{m}$

$V_M = Emd$

$V_M = (3 \times 10^8) \times 10^4$

$\boxed{V_M = 3 \times 10^{12}\ V}$

∴ During a lighning strike the voltage difference between earth and cloud is 3×10^{12} V