- $\epsilon_r = 2$ or 3
- dielectric Strength = 30kv/mm.
- Resistivity of insulation = 10^{17} Ω/cm.
- Drawback : - Absorbs moisture
  - Max safe temp is low (about 38°C)
  - Soft & liable to damage.
  - Ages when exposed to light.

② Vulcanised India Rubber (VIR):

- pure rubber mixed with mineral such as zinc oxide, red lead etc. & 3-5% of sulphur.
- The compound is rolled into thin sheets & cut into strips.
- Applied to conductor, heated at 150°c
- Process is known vulcanisation
- Advantages : - ↑ mechanical strength
  - ↑ durability
  - ↑ resistant property.
- Drawback - Sulphur reacts very quickly with copper
  - Hence its used for tinned copper conductor
- Used for low or moderate voltage levels

③ Impregnated paper :

- Chemically pulped paper from wood chipping & impregnated with compound like ... material.

- Advantages (i) Low cost
  (ii) ↑ High dielectric strength.
  (iii) ↑ insulation resistance
- Disadvantage : (i) Paper is hygroscopic
  (ii) ↓ Insulation 'R'

(4) Varnished Cambric :
- Cotton cloth, impregnated, coated with varnish.
- Also known as empire tape.
- lapped on conductor & coated with petroleum jelly compound

Disadvantag - Hygroscopic.

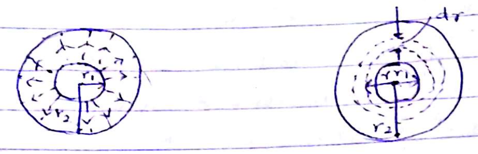
- Dielectric strength is 4kv/mm
- $\epsilon_r = 2.5 - 3.8$

(5) Polyvinyl Chloride (PVC) :
- obtained from polymerisation acetylene. & is in the form of white powder.

- Advantages : - ↑ Insulation Resistance
  - ↑ Dielectric strength
  - ↑ Mechical toughness

* Module 5

· Insulation Resistance of single core cable.



→ Consider a single core cable of conductor radius r_1 and sheath radius r_2, length l & insulation material resistivity 'ρ'.

→ length through which the leakage 'I' will flow is dr & Area of cross-section is $2\pi r l$

Area of a cylinder $= 2\pi r^2 + 2\pi r l$

$= (2\pi r''^2 + 2\pi r'' l) - (2\pi r'^2 + 2\pi r' l)$

$= 2\pi (r''^2 + r'' l) - 2\pi (r'^2 + r' l)$

$= 2\pi [r''^2 + r'' l - r'^2 - r' l]$

$= 2\pi [r''^2 - r'^2 + l(r'' - r')]$

$= 2\pi [(dr)^2 + dr\, l]$

$= 2\pi\, dr\, (dr + l)$

→ $R_{ins} = \rho \dfrac{dr}{2\pi r l}$

→ R_{ins} (of entire cable) $= \displaystyle\int_{r_1}^{r_2} \rho \frac{dr}{2\pi r l}$

$= \rho \dfrac{1}{2\pi l} [\log_e r]_{r_1}^{r_2}$

$= \rho \dfrac{1}{2\pi l} [\log_e r_2 - \log_e r_1]$

$= \dfrac{\rho}{2\pi l} \log_e \dfrac{r_2}{r_1}$.

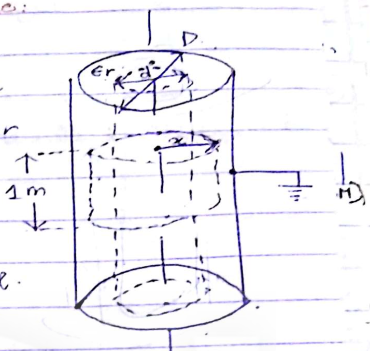
→ R_{inst} varies inversely as the length of the cable.

* Capacitance of a single core cable:

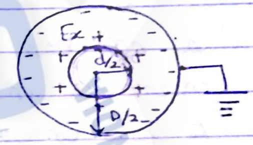
→ The cable can be considered as two co-axial cylinders of inner diameter d & outer diameter D.

d → represents diameter of core

D → represents diameter of lead sheath at Ground Potential.



→ let the charge/m length on the outer surface of core be +Q coulombs & the charge/m length on the inner surface of the lead sheath be −Q coulombs.



→ consider a co-axial cylinder of radius x meters & of length 1m.

The surface area would be $= 2\pi r l$

$= 2\pi x(1)\ m^2$

→ ∴ Electric field intensity at a point x meters from the center of inner cylinder.

$$E_x = \frac{Q}{2\pi\epsilon_0\epsilon_r x}\ V/m$$

→ Potential difference between capacitor plates (between core & the sheath).

$$V = \int_{d/2}^{D/2} \frac{Q}{2\pi\epsilon_0\epsilon_r x}\,dx = \frac{Q}{2\pi\epsilon_0\epsilon_r}\left(\log_e D/2 - \log_e d/2\right).$$

$$= \frac{Q}{2\pi\epsilon_0\epsilon_r} \log_e \frac{D/2}{d/2} = \frac{Q}{2\pi\epsilon_0\epsilon_r} \log_e \frac{D}{d}$$

→ Capacitance of cable $= \frac{Q}{V} = \frac{Q}{\frac{Q}{2\pi\epsilon_0\epsilon_r}\log_e \frac{D}{d}}$ F/m

$$= \frac{2\pi\epsilon_0\epsilon_r}{\log_e D/d} \text{ F/m.}$$

* Grading of Cables

→ It has been observed that the electrostatic stress is max near the surface of the conductor & goes on reducing as we move away from the cable.

→ The process of achieving uniformity in dielectric stress is known as grading of cables.

(i) Capacitance grading:

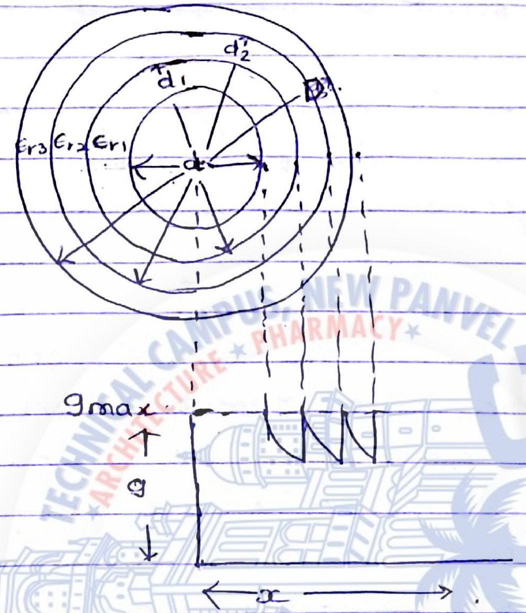
→ In this method, the uniformity in dielectric stress is achieved by using various layers of diff dielectrics in such a manner that ϵ_r is inversely proportional to x i.e. the distance from center

$$\epsilon_r \propto \frac{1}{x} \quad \text{or} \quad \epsilon_r x = \text{constant e.g.} \propto \frac{Q}{2\pi\epsilon_0}.$$

→ Consider a cable with 3 layers of dielectrics of outer diameters d_1, d_2, and D & the relative permittivity $\epsilon_{r1}, \epsilon_{r2}, \epsilon_{r3}$ have been used

→ $\epsilon_{r1} > \epsilon_{r2} > \epsilon_{r3}$.

→ $\epsilon_{r1} \, d/_2 = \epsilon_{r2} \, d_1/_2 = \epsilon_{r3} - d_2/_2$



→ For the pd across the inner layer we have;

$$V_1 = \int_{d/2}^{d_1/2} g \, dx = \int_{d/2}^{d_1/2} \frac{Q}{2\pi\epsilon_0\epsilon_{r1}x} dx.$$

$$= \frac{Q}{2\pi\epsilon_0} \frac{1}{\epsilon_{r1}} (\log_e d_1/_2 - \log_e d/_2)$$

$$= \frac{Q}{2\pi\epsilon_0} \frac{d}{2} \log_e \frac{d_1}{d}.$$

$$= g_{max} \frac{d}{2} \log_e \frac{d_1}{d}.$$

$$V_2 = g_{max} \frac{d_1}{2} \log_e \cdot \frac{d_2}{d_1}.$$

$$V_3 = g_{max} \frac{d_2}{2} \log_e \frac{D}{d_2}.$$

→ P.d between core & earthed sheath.

$$V = V_1 + V_2 + V_3.$$

$$= \frac{g_{max}}{2}\left[\frac{d}{2}\log_e\frac{d_1}{d} + \frac{d_1}{2}\log_e\frac{d_2}{d_1} + \frac{d_2}{2}\log_e\frac{D}{d_2}\right]$$

(ii) <u>Intersheath grading</u>:

→ A homogenous di-electric is used, divided into various layers by placing metallic intersheaths.

→ These metallic intersheaths are held at certain potentials which are in between the inner core potential & the earth potential.

→ There is thus a definite potential difference between the inner & outer layers of each sheath so that each sheath can be treated like a homogeneous single core cable. we have;

$$g_1 max = \frac{V_1}{\frac{d}{2}\log_e\frac{d_1}{d}}$$

$$g_2 max = \frac{V_2}{\frac{d_1}{2}\log_e\frac{d_2}{d_1}}$$

$$g_3 max = \frac{V_3}{\frac{d_3}{2}\log_e\frac{D}{d_2}}$$

→ For homogenous dielectric we have;

$g_1 max = g_2 max = g_3 max. = g_{max}$ (say).

→ ∴ $V = V_1 + V_2 + V_3$.

$$V_1 = \int_{d/2}^{d_1/2} \frac{Q}{2\pi\epsilon_0\epsilon_{r1} x}\, dx = \int_{d/2}^{d_1/2} \frac{Q}{2\pi\epsilon_0\epsilon_{r1}} \frac{1}{x}\, dx$$

$$= \frac{Q}{2\pi\epsilon_0\epsilon_{r1}} \left[\log_e x\right]_{d/2}^{d_1/2}$$

$$= \frac{Q}{2\pi\epsilon_0\epsilon_{r1}} \left(\log_e \frac{d_1}{2} - \log_e \frac{d}{2}\right)$$

$$= \frac{Q}{2\pi\epsilon_0\epsilon_{r1}} \log_e \frac{d_1}{d}$$

$$= \frac{Q}{2\pi\epsilon_0} \cdot \frac{d}{2} \cdot \log_e \frac{d_1}{d}$$

$$= g_{max} \frac{d}{2} \log_e \frac{d_1}{d}$$