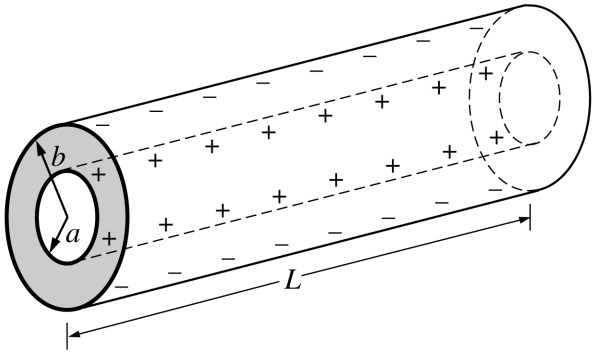
2000 AP® PHYSICS C FREE-RESPONSE QUESTIONS

(b) Explain why the x-component of the total electric field is zero at any point on the y-axis.

(c) Write a general expression for the electric potential V at any point on the y-axis inside the triangle in terms of Q, ℓ, and y.

(d) Describe how the answer to part (c) could be used to determine the y-coordinates of points P_1 and P_2 at which the electric field is zero. (You do not need to actually determine these coordinates.)



E & M 3.

A capacitor consists of two conducting, coaxial, cylindrical shells of radius a and b, respectively, and length $L >> b$. The space between the cylinders is filled with oil that has a dielectric constant κ. Initially both cylinders are uncharged, but then a battery is used to charge the capacitor, leaving a charge $+Q$ on the inner cylinder and $-Q$ on the outer cylinder, as shown above. Let r be the radial distance from the axis of the capacitor.

(a) Using Gauss's law, determine the electric field midway along the length of the cylinder for the following values of r, in terms of the given quantities and fundamental constants. Assume end effects are negligible.

i. $a < r < b$

ii. $b < r << L$

(b) Determine the following in terms of the given quantities and fundamental constants.

i. The potential difference across the capacitor

ii. The capacitance of this capacitor

2000 Physics C Solutions | **Distribution of points**

E&M. 3 (15 points)

(a)

i. 3 points

For a correct statement of Gauss's law — 1 point

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon}$$

For expressing the permittivity of the oil in terms of the dielectric constant κ — 1 point

$$\epsilon = \kappa\epsilon_0$$

For a correct expression for the electric field in the oil — 1 point

$$E(2\pi rL) = \frac{Q}{\kappa\epsilon_0}$$

$$E = \frac{Q}{2\pi\kappa\epsilon_0 rL}$$

ii. 2 points

For a correct statement of Gauss's law in the space outside the outer shell — 1 point

$$\oint \mathbf{E} \cdot d\mathbf{A} = 0$$

For stating that the electric field is zero in this region — 1 point

$$\mathbf{E} = 0$$

(b)

i. 3 points

For an expression for the electric potential between the two shells — 1 point

$$\Delta V = V_b - V_a = \int_a^b E_r\, dr$$

For substituting the expression for the electric field between the shells — 1 point

$$\Delta V = \frac{Q}{2\pi\kappa\epsilon_0 L}\int_a^b \frac{dr}{r}$$

For a correct expression for the electric potential difference between the shells — 1 point

$$\Delta V = \frac{Q}{2\pi\kappa\epsilon_0 L}\ln\left(\frac{b}{a}\right)$$

E&M. 3 (continued)

(b) (continued)

ii. 2 points

For an expression for the capacitance in terms of Q and ΔV — 1 point

$$C = \frac{Q}{\Delta V}$$

Substituting the expression for ΔV from (b)i:

$$C = \frac{Q}{\frac{Q}{2\pi\kappa\epsilon_0 L}\ln\left(\frac{b}{a}\right)}$$

For a correct expression for the capacitance — 1 point

$$C = \frac{2\pi\kappa\epsilon_0 L}{\ln\left(\frac{b}{a}\right)}$$

(c)

i. 3 points

For a correct statement of Ampere's law — 1 point

$$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$$

For substituting the current through the inner shell — 1 point

$$B(2\pi r) = \mu_0\left(\frac{\mathcal{E}}{R}\right)$$

For a correct expression for the magnetic field between the shells — 1 point

$$B = \frac{\mu_0 \mathcal{E}}{2\pi r R}$$

ii. 2 points

For the correct substitution of the total current through both shells in to Ampere's law — 1 point

$$B(2\pi r) = \mu_0\left(\frac{4\mathcal{E}}{R}\right)$$

For a correct expression for the magnetic field around the outer shell — 1 point

$$B = \frac{2\mu_0 \mathcal{E}}{\pi r R}$$