Q1

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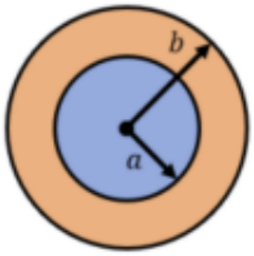
1. The coaxial cable shown below is $10m$ long, and has a $5V$ potential applied across it. The inner cylinder is made of silicon and the outer cylinder is made of carbon. If the outer shell is to be twice the diameter of the inner cylinder, find the radii a and b for which a current of $0.2A$ would be expected.



$R = l/\sigma A$ $\qquad l = 10\ m \qquad A_1 = \pi a^2$

$R = V/I$ $\qquad A_2 = \pi(b^2 - a^2)$

$R = (5\,V)/(0.2\,A)$ $\qquad \sigma_1 = \sigma_{silicon}$

$= 5/\frac{1}{5}$ $\qquad \sigma_2 = \sigma_{carbon}$

$R = 25\,\Omega$

$$R = \left[\frac{1}{R_{out}} + \frac{1}{R_{in}}\right]^{-1} = \left[\frac{\sigma_1 A_1}{l} + \frac{\sigma_2 A_2}{l}\right]^{-1}$$

$$= \frac{l}{\sigma_1 A_1 + \sigma_2 A_2}$$

$$= \frac{l}{\sigma_1 \pi a^2 + \sigma_2 \pi (b^2 - a^2)}$$

$$= \frac{}{\sigma_1 \pi a^2 + \sigma_2 \pi (b^2 - a^2)}$$

$$= \frac{l}{\pi(\sigma_1 a^2 + \sigma_2 (b^2 - a^2))}$$

☆ $2d_{in} = d_{out}$

$$4a = 2b$$

$$2a = b$$

$$= \frac{l}{\pi(\sigma_1 a^2 + \sigma_2(4a^2 - a^2))}$$

$$= \frac{l}{a^2 \pi(\sigma_1 + 3\sigma_2)}$$

sub $\sigma_1 = \sigma_{silicon} = 4.4 \times 10^{-4}$ S/m

$\sigma_2 = \sigma_{carbon} = 3 \times 10^4$ S/m

$R = 25\,\Omega$, $l = 10$

$$25 = \frac{10}{a^2 \pi (4.4 \times 10^{-4} + 9 \times 10^4)}$$

$$a^2 = \frac{10}{7.06858 \times 10^6}$$

$$a = \sqrt{1.41471 \times 10^{-6}\,m}$$

$$\boxed{a = 1.19\,mm}$$

$$b = 2a$$

$$\boxed{b = 2.38\,mm}$$

Q2

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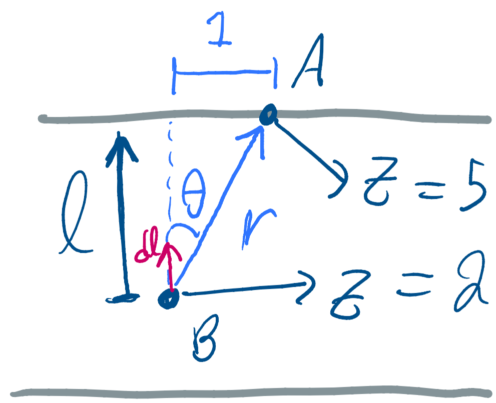
2. A uniform sheet of charge with $\rho_{S1} = 1\frac{nC}{m^2}$ lies on the $z = 0$ plane, and a second sheet with $\rho_{S2} = -1\frac{nC}{m^2}$ occupies the $z = 5m$ plane. Find the scalar potential V_{AB} between the points $A(0,0,5m)$ and $B(0,-1m,2m)$. Explain what this scalar potential means in physical terms, in the context of this problem.

$V = Ed$ $\quad\quad \rho_{S1} = -\rho_{S2} \quad\quad d = 5$

$E = \frac{Q}{\varepsilon_0 A} = \frac{\rho}{\varepsilon_0} \quad\quad Q/A = \rho$

$E = \frac{\rho}{\varepsilon_0} = \frac{(10^{-9})}{(8.854\times10^{-12})}$



$E = 112.94 \ V/m$

$V_{AB} = -\int_B^A \vec{E}\, d\vec{l} = \int_A^B \vec{E}\, d\vec{l}$

$= \int_2^5 (112.94 \tfrac{V}{m})\, d\vec{l}$

$= 112.94 \,[r]_5^2$

$= 112.94(-3)$

$\boxed{V_{AB} = -338.82 \ V}$

$$\boxed{V_{AB} = -338{,}82 \text{ V}}$$

In this case, the scalar potential represents the difference in electrical potential energy stored at point A vs point B.

Q3

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3. A cable with a uniform square cross-section has a length of $200m$, and there is an $8V$ potential applied across it. If the current density through it is determined to be $1.4 \times 10^6\ A/m^2$, find the conductivity of its material. Name a material that could be used here.

$l = 200m$

$V = 8V$

$j = 1.4 \times 10^6\ A/m^2$

$\sigma = ?$

$I = jA$ ← cross-sectional area

$* j = \sigma \cdot E$

$I = \sigma E A$

$* E = V/l$

$I = \frac{\sigma A V}{l}$

$j\cancel{A} = \frac{\sigma \cancel{A} V}{l}$

$\frac{jl}{V} = \sigma$

$\sigma = \frac{(1.4 \times 10^6)(200m)}{8V}$

$\boxed{\sigma = 3.5 \times 10^7\ S/m}$

$\therefore \sigma = 3.5 \times 10^7\ S/m$, a material that

could be used here is Aluminum

could be used here is Aluminum

Q4

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4. In class, we discussed the concept of *dielectric breakdown* using the example of lightning. Research another example of dielectric breakdown. Explain your example in 5 sentences or fewer, and as always, cite your sources. Make sure you capture the following:

   - What is the mechanism or mechanisms by which breakdown occurs?
   - Is it ever desirable? What are potential consequences (or benefits)?
   - What factors contribute to the likelihood of this breakdown occurring?

A common example of a tool that harnesses dielectric breakdowns is a spark plug, found in most combustion engines, where an ignition system will send a high voltage (approximately 20 kV) to the spark plug. When the voltage in the spark plug exceeds the dielectric strength of the gases in the combustion chamber, dielectric breakdown occurs causing a spark to form and the fuel gases to be ignited, allowing the each piston to "fire".

This is very desirable, as it is one of the primary components in the function of a conventional combustion engine. However, this process causes a small explosion to happen within the combustion chamber, and any small error can cause an explosion that is larger than expected, which can potentially damage the engine or injure the driver if there is a critical failure.

Factors contributing to this breakdown include the compression of the gas in the combustion chamber, increasing density, which also increases the dielectric constant.

References:

W. Scraba, “How do spark plugs work?: Mobil™ Motor Oils,” *How do spark plugs work?* [Online]. Available: https://www.mobil.com/en/lubricants/for-personal-vehicles/auto-care/vehicle-maintenance/how-do-spark-plugs-work. [Accessed: 14-Mar-2022].

“How spark plugs work,” *How Spark Plugs Work*. [Online]. Available: https://e3sparkplugs.com/blog/the-role-spark-plugs-play-in-your-engine/. [Accessed: 14-Mar-2022].