Multiple Choice Questions
(Choose only one answer and label your answer clearly.)

1. A constant current density \( j \) flows perpendicular to the circular cross-sectional area of a wire. The current \( I \) contained in a cross-sectional area of radius \( r \) varies as
   (a) \( r^2 \)
   (b) \( r \)
   (c) \( 1/r^2 \)
   (d) \( 1/r \)
   (e) the current is constant

\[
\begin{align*}
\int_S \mathbf{j} \cdot d\mathbf{A} &= \int_S j \mathbf{dA} = \int_S j \mathbf{dA} \\
\Rightarrow I &= \text{constant} \cdot r^2
\end{align*}
\]

2. A parallel-plate capacitor is attached to a battery that maintains a constant potential difference \( V \) between the plates. While the battery is still connected, a glass slab is inserted so as to just fill the space between the plates. Which statement is FALSE?
   (a) The energy stored in the capacitor increases.
   (b) The capacitance of the capacitor increases.
   (c) The potential difference across the capacitor remains the same.
   (d) The charge on the capacitor plates increases.
   (e) The electric field between the capacitor plates increases.

3. The current density is the same in two wires made of different material. Wire A has half the number density of conduction electrons as wire B. The drift speed of electrons in A is:
   (a) twice that of the electrons in B
   (b) four times that of the electrons in B
   (c) half that of the electrons in B
   (d) one-fourth that of the electrons in B
   (e) the same as that of the electrons in B
4. A 10-volt battery, a 600 Ω resistor and a 300 Ω resistor are all connected in parallel. The power delivered by the battery is:

(a) 0.112 Watts 
(b) 0.332 Watts 
(c) 0.400 Watts 
(d) 0.500 Watts 
(e) cannot be determined from the given information

![Battery Circuit Diagram](image)

\[ R_{eq} = \left( \frac{1}{R_1} + \frac{1}{R_2} \right)^{-1} = \left( \frac{1}{300} + \frac{1}{600} \right)^{-1} = 200 \Omega \]

\[ I = \frac{V_{batt}}{R_{eq}} = \frac{10}{200} = \frac{1}{20} \ A \]

\[ P = I \cdot V = \left( \frac{1}{20} \right) \cdot 10 = \frac{1}{2} \ \text{Watts} \]

5. A point charge is placed at the center of a spherical ‘Gaussian’ surface. Which of the following is true? The electric flux \( \Phi_E \) is changed

(a) if the sphere is replaced by a cube of the same volume.
(b) if the sphere is replaced by one of one-tenth the volume.
(c) if the point charge is moved off center but still inside the original sphere.
(d) if the point charge is moved to just outside the sphere.
(e) if a second point charge is placed just outside the sphere.

![Gaussian Surface Diagram](image)

Gauss' Law: \( \oint_S \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed by } S}}{\epsilon_0} \)

If point charge \( q \) is moved from inside \( S \) to outside \( S \), then \( Q_{\text{enclosed}} \) changes from \( q \) to zero. Consequently, the electric flux through \( S \) changes from \( \frac{q}{\epsilon_0} \) to zero. Otherwise, \( \Phi_E \) is unchanged.

Problems

6. In the figure, a long wire of length \( L \) is coaxial with a conducting shell of inner radius \( R_1 \) and outer radius \( R_2 \), and length \( L \) (where \( L \) is assumed to be large). The wire carries linear charge density \( \lambda \) uniformly distributed along its length. The conducting shell is neutral.

![Coaxial Wire Diagram](image)

(a) Determine the electric field (magnitude and direction) at \( r < R_1, \ R_1 < r < R_2 \), and \( r > R_2 \).
(b) What is the surface charge density on the inner surface of the conducting shell?
(c) What is the surface charge density on the outer surface of the conducting shell?
   (Hint: What is the total charge on the inner surface? What is the total charge on the outer surface?)
(d) Will the your answer in (b) change if the charged wire is moved off-axis?
(e) Will the your answer in (c) change if the charged wire is moved off-axis?
(c) \[ Q_{diel} = Q_{inner} + Q_{outer} = 0 \]
\[ \frac{Q}{\pi R^2} = \frac{Q_{inner}}{\pi R^2} = \frac{Q_{outer}}{\pi R^2} \]
\[ Q_{inner} = -Q_{outer} = -Q_{diel} \]

(d) \[ Q_{inner} = -Q_{outer} = -Q_{diel} \]

(c) Due to the charge on the inner surface being conserved, the charge distribution on the surface of a charged conductor is that of a point charge at the center:

\[ E = \frac{2e}{r^2} \text{ (radially outward)} \]

\[ R > R_c : E = \frac{2e}{R_c^2} \text{ (radially outward)} \]

\[ R < R_c : E = \frac{\epsilon_0 \chi r}{g} = \frac{\epsilon_0 \chi L}{R} \text{ (radially outward)} \]

\[ E = \frac{2e}{L} \text{ (radially outward)} \]

\[ \frac{g}{R_c} \frac{\epsilon_0 \chi L}{R} = \frac{\epsilon_0 \chi L}{R} \]

(e) Draw Gaussian surface E = \epsilon_0 \chi L / R
7. The figure shows a network consisting of three resistors, of resistance $R_1$, $R_2$ and $R_3$, a capacitor, $C$, a battery with emf $V_0$, and a switch $S$. Initially, the capacitor is uncharged, and the switch is open.

(a) Determine the equivalent resistance $R_{23}$ between points $A$ and $B$.
(b) Using this equivalent resistance, redraw the circuit as two loops. Write down the loop rules and junction rule.
(c) What is the current through $R_1$ at $t = 0$ just after the switch is closed?
(d) What is the current through $R_1$ at $t = oo$ when the capacitor is fully charged?
(e) Obtain a differential equation describing the charge on the capacitor $C$ as a function of time. (Hint: Relate the charge on the capacitor to the current in that loop.)
\[ O = \frac{1}{2} \left( \frac{1}{y} - \frac{1}{x} \right) + \frac{1}{2} \left( \frac{1}{y} + \frac{1}{x} \right) \]

\[ O = \frac{1}{2} R - \frac{1}{2} \left( \frac{1}{y} + \frac{1}{x} \right) \]

\[ \frac{2}{y} \frac{dy}{dt} = I \]

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The circuit consists of two changing capacitors: \( C_{1} \) and \( C_{2} \). The right loop:

\[ V_{o} - V_{c} - \frac{1}{2} I_{2} R_{2} - \frac{1}{2} I_{1} R_{1} = 0 \]

\[ V_{o} = \frac{1}{2} I_{2} R_{2} - \frac{1}{2} I_{1} R_{1} \]

\[ I_{2} = \frac{V_{o}}{R_{2}} \]

\[ I_{1} = \frac{V_{o}}{R_{1}} \]

The null loop rule and Mason's method:

\[ \frac{V_{2}}{V_{1}} = -I \]

\[ -I = -I_{1} - I_{2} \]

\[ V_{2} = -V_{1} \]