1. An isolated conductor made of grey metal has a cavity that contains a particle of charge $q = +3 \, \mu C$, as shown in the figure. The net charge on the conductor itself (that is, not including the charged particle in the cavity) is $+10 \, \mu C$. What is the total charge on the outer surface of the conductor?

- total charge on inner surface = $-3 \, \mu C$
- net charge on inner + outer surfaces = $10 \, \mu C$
- so total on outer surface is $+13 \, \mu C$

   a) $+10 \, \mu C$
   b) $+3 \, \mu C$
   c) $-3 \, \mu C$
   d) $+13 \, \mu C$
   e) $+7 \, \mu C$

2. The current through the $3\Omega$ resistor is:

   a) $4.7 \, A$
   b) $2.0 \, A$
   c) $0.67 \, A$
   d) $8.2 \, A$
   e) $0.50 \, A$

   outer loop: $6i_1 = 12i_2 \implies i_1 = 2i_2$

   right side loop: $14V = 12i_2 + 3(3i_2) = 21i_2 \implies i_2 = 0.67A, i_1 = 1.33A$

3. The potential difference between two plates of a parallel plate capacitor of area $25 \, \text{cm}^2$ is $3.0 \, \text{V}$ when the charge on the capacitor is $66 \, \text{pC}$. What is the separation of the plates?

   a) $1.0 \, \text{cm}$
   b) $0.3 \, \text{cm}$
   c) $0.2 \, \text{cm}$
   d) $0.1 \, \text{cm}$
   e) $0.05 \, \text{cm}$

   $\frac{66 \, \text{pC}}{V} = 22 \, \text{pF}$

   $C = \frac{Q}{V} = \frac{66 \, \text{pC}}{3 \, \text{V}} = 22 \, \text{pF}$

   $C = \frac{\varepsilon_0 A}{d} \implies d = \frac{\varepsilon_0 A}{C}$

   $= 8.85 \times 10^{-12} \times 0.0025$

   $= 1.0 \times 10^{-3} \, \text{m}$
4. A proton is traveling in the negative y-direction. It enters a uniform magnetic field pointing in the positive z-direction. The force on the proton is in the
   a) positive x-direction
   b) positive y-direction
   c) negative z-direction
   d) negative x-direction
   e) positive z-direction

\[ \vec{F} = q \vec{v} \times \vec{B} \]

5. For the four charges arranged as in the figure, what is the net electric potential at P, taking V = 0 at infinity?

\[ \begin{align*}
   &a) \quad 0 \text{ V} \\
   &b) \quad +\frac{kq}{d} \\
   &c) \quad -\frac{kq}{d} \\
   &d) \quad +\frac{kq}{(2d)} \\
   &e) \quad -\frac{kq}{(2d)} \\
\end{align*} \]

6. A segment of a wire is in the shape of an arc of a circle of radius R, and carries current I in the direction shown. The arc subtends a 45° angle. What is the contribution to the magnetic field at the center C by the current in this arc?

\[ B = \frac{\mu_0 I}{4\pi R} \Rightarrow B = \frac{\mu_0 I}{\pi R} \]

for circular arc, \( B = \frac{\mu_0 I \phi}{4\pi R} \)

\( \phi = \frac{\pi}{4} \Rightarrow B = \frac{\mu_0 I}{16R} \)

right hand rule ⇒ out of paper
7. An infinite uniform line of charge produces an electric field of magnitude $4.5 \times 10^4 \text{ N/C}$ at a point that is $2.0 \text{ m}$ away from the line. What is the linear charge density of the line of charge? Assume the charge is positive.

\[
E = \frac{\lambda}{2\pi \epsilon_0 r} \Rightarrow \lambda = \frac{4.5 \times 10^4 \cdot 2\pi \cdot 8.85 \times 10^{-12}}{2 \pi \epsilon_0 \cdot 2} \approx 5.0 \times 10^{-6} \text{ C/m}
\]

8. Consider a uniform electric field and $d = 0.50 \text{ m}$. The values of the potential at the origin $D$, at point $A$ at $(0,0,d)$ and point $B$ at $(d,0,0)$ are equal, and $20 \text{ V}$ higher than the value of the potential at point $C$ at $(0,d,0)$. The magnitude and direction of the electric field are

\[
\begin{align*}
V_A & = V_D \Rightarrow E_z = 0 \\
V_B & = V_D \Rightarrow E_x = 0 \\
V_C - V_D & = -20 \text{ V} \Rightarrow -E_y \cdot 0.5 \text{ m} = -20 \text{ V} \\
E_y & = 40 \text{ V/m}
\end{align*}
\]

9. An electron at point $A$ in the figure has a speed $v_0$ of $1.4 \times 10^6 \text{ m/s}$. Recall that the mass is $9.1 \times 10^{-31} \text{ kg}$ and the electron charge is $-1.6 \times 10^{-19} \text{ C}$. For the electron to follow the semicircular path of radius $5.0 \text{ cm}$ from $A$ to $B$, the magnetic field must be

For negative particle to bend right, $\mathbf{v} \times \mathbf{B}$ is left $\Rightarrow \mathbf{B}$ into page

\[
\begin{align*}
\mathbf{v} \times \mathbf{B} & \text{ is left} \Rightarrow \mathbf{B} \text{ into page} \\
\mathbf{r} & = \frac{mv}{qB} \Rightarrow \mathbf{B} = \frac{mv}{q |r|} = \frac{9.1 \times 10^{-31} \cdot 1.4 \times 10^6}{1.6 \times 10^{-19} \cdot 0.05} = 1.6 \times 10^{-4} \text{ T}
\end{align*}
\]
10. A plastic rod has been bent into a circle of radius $R = 3.0 \text{ cm}$. If a charge $Q = 6.0 \text{ pC}$ is uniformly distributed around the circle, what is the electric potential at point $P$ on the central axis of the circle at distance $D = 4.0 \text{ cm}$ from the center? Take $V = 0$ at infinity.

\[
\frac{kQ}{0.05} = \frac{6.0 \text{ pC}}{0.05} = 120 \text{ V}
\]

11. Consider the circuit shown in the figure. The circuit element at the top is a battery with internal resistance $i$, and $R = 5.30 \text{ } \Omega$ for the resistor at the bottom. If the terminal voltage of the battery is $21.2 \text{ V}$, what is the power dissipated in the resistor $R$?

\[
P = \frac{V^2}{R} = \frac{(21.2 \text{ V})^2}{5.30 \text{ } \Omega}
\]

12. At $x = 0$, a long straight wire carries current $2I$ out of the plane of the paper. At $x = -D$, another long straight wire carries current $3I$ into the plane of the paper. What is the direction of the force on the wire at $x = -D$ (the wire on the left)?

- in the positive $x$-direction
- in the negative $x$-direction
- in the positive $y$-direction
- in the negative $y$-direction
- the force is zero

Opposite currents repel
13. Consider a conductor in electrostatic equilibrium. Then,
   a) the values of the electric potential at two different points on the surface are the same.
   b) the magnitude of the electric field at the surface of the conductor is \( \sigma/(2\varepsilon_0) \), where \( \sigma \) is the surface charge density.
   c) the electric field at the surface of the conductor cannot have a component perpendicular to the surface.
   d) the electric potential must be zero inside the conductor.
   e) work is done by the electric field to move a charge along the surface.

14. Two capacitors have capacitances of 5.0 \( \mu F \) and 4.0 \( \mu F \) respectively. They are connected in parallel to a battery. After the battery has charged them, the 5.0 \( \mu F \) capacitor has a stored energy of \( 2.5 \times 10^{-4} \) J. What is the charge on the other capacitor, i.e. the 4.0 \( \mu F \) capacitor?
   a) 10 \( \mu C \)
   b) 20 \( \mu C \)
   c) 30 \( \mu C \)
   d) 40 \( \mu C \)
   e) 50 \( \mu C \)

\[
U = \frac{1}{2} CV^2 \\
2.5 \times 10^{-4} J = \frac{1}{2} (5 \times 10^{-6}) E^2 \Rightarrow E = 10 \text{ V} \\
Q = CV = 4 \times 10^{-6} \times 10 \text{ C} = 40 \mu C
\]

15. A potential difference of 4.0 V is applied between the ends of a wire, resulting in a current of 16 A. If the wire is 2.5 m in length and 0.60 mm in radius, then the resistivity of the material of which the wire is made is
   a) 4.0 \( \Omega \)
   b) 1.1 \times 10^{-7} \( \Omega m \)
   c) 4.5 \times 10^{-7} \( \Omega m \)
   d) 2.8 \times 10^{-8} \( \Omega m \)
   e) 0.25 \( \Omega \)

\[
R = \frac{V}{I} = 0.25 \Omega \\
0.25 \Omega = \frac{\rho L}{A} \Rightarrow \rho = \frac{0.25 \Omega \cdot A}{L} = \frac{0.25 \pi (6 \times 10^{-3})^2}{2.5}
\]

16. Consider the combination of capacitors shown in the figure, where \( C_1 = 3.0 \mu F \), \( C_2 = 2.0 \mu F \), \( C_3 = 3.0 \mu F \), and \( C_4 = 1.0 \mu F \). What is the equivalent capacitance of this network?

\[
\left( \frac{1}{3} + \frac{1}{6} \right)^{-1} = 2
\]