1. A tiny current of $10^{-9}$ A exists in a copper wire whose diameter is 2 mm. Assuming the current is uniform over the wire cross section, calculate the electron drift speed in m/s. Take the free electron density to be $7 \times 10^{28}$ electrons/m$^3$.

**Solution:** The current can be written as $i = nev_dA$, where $n$ is the free electron density, $e$ is the electron charge and $v_d$ is the drift velocity. Substituting yields $v_d = 2.8 \times 10^{-14}$ m/s.

2. In the circuit shown $E = 12$ V, $R_1 = 16$ Ω, and $R$ is variable. If the value of $R$ is chosen so that the ideal battery will transfer energy to the resistors at the maximum possible rate, what is that rate (in watts)?

![Diagram of a circuit with a battery, resistor $R_1$, and variable resistor $R$.]

**Solution:** The total resistance is $R_1 + RR_1/(R + R_1)$. Clearly the value of $R$ must be zero to minimize the resistance and therefore maximize the power. The total resistance is 16Ω so the total power delivered is $P = E^2/16 = 9$ watts.

3. An electron is accelerated from rest by a potential difference of 2.0 kV. It then enters a uniform magnetic field of magnitude 1.0 T with its velocity perpendicular to the direction of the field. Calculate the radius in meters of its path in the magnetic field.

**Solution:** The radius can be determined from the equation equating the centripetal force to the magnetic force, or $mv^2/r = evB$ (using obvious notation), which yields $r = mv/eB$. The velocity can be found from the equation relating the potential difference and kinetic energy, or $eV = \frac{1}{2}mv^2$, where $V$ is the potential difference. Solving for the radius in terms of the given quantities, we obtain $r = \sqrt{2mV/eB^2}$, which yields $r = 1.5 \times 10^{-4}$ m.
4. The figure shows a cross section of a long cylindrical conductor of radius $a = 5.0 \text{ cm}$, carrying a uniformly distributed current $i = 50 \text{ A}$. Find the magnitude of the magnetic field $B$ (in tesla) at a distance $r = 1 \text{ cm}$ from the center of the cylinder.

Solution: This problem can be solved easily with Ampere’s law. If the current is distributed uniformly, then the current within 1/5 of the total radius is 1/25 of the total current, or 2 A. Ampere’s law gives $B(2\pi r) = \mu_0 i_{\text{enc}}$, where $i_{\text{enc}} = 2 \text{ A}$. This yields for the magnetic field strength $B = 4 \times 10^{-5} \text{ T}$.

5. A resistor ($R \text{ ohms}$) is connected between the terminals of a 24 V battery, and energy is found to be dissipated in the resistor at the rate of 2 W. The same resistor is then connected between the terminals of a 6 V battery. At what rate in watts is energy now dissipated in the resistor?

Solution: The power dissipation is $\mathcal{E}^2/R$. Since the new battery has 4 times lower emf, the power dissipated is reduced by a factor of 16 to 0.125 W.

6. A 1 MΩ resistor and a 15 μF capacitor are connected in series with an ideal battery of emf $\mathcal{E} = 6.00 \text{ V}$. At $t = 2 \text{ s}$ after the connection is made, what is the rate at which the charge of the capacitor is increasing (in amperes)?

Solution: This problem requires use of RC circuits. The charging rate is given by $i = i_0 e^{-t/RC}$, where the initial current $i_0$ is given by $i_0 = \mathcal{E}/R = 6 \times 10^{-6} \text{ A}$. The RC time is 15.0 sec, so the exponential has the value $2/15 = 0.1333$. The current is thus $6 \times 10^{-6} e^{-0.1333} = 5.25 \times 10^{-6} \text{ A}$.

7. A straight wire of 50 cm length and 15 g mass is suspended horizontally by a pair of flexible leads in a uniform magnetic field of 2.0 T. The magnetic field points horizontally and perpendicular to the wire. What is the magnitude of the current through the wire, in amperes, required to remove the tension in the supporting leads?

Solution: The balancing force are gravity and the magnetic force lifting the wire, or $mg = iLB$, where $i$ is the current and $L$ is the length of the wire. Solving for the current yields $i = 0.15 \text{ A}$.

8. A wire is formed into a closed circuit with radii $a = 5 \text{ cm}$ and $b = 15 \text{ cm}$, as shown in the figure, and carries a current $i = 20 \text{ A}$. What is the magnitude (in tesla) of the magnetic field at point $P$?
Solution: The field can be found by repeatedly applying the formula for the magnetic field of an arc, \( B = \mu_0 i \phi / 4 \pi r \), where \( \phi \) is the angle of the arc and \( r \) is the radius. The arcs are both equal to \( \pi \) radians and the magnetic fields caused by the currents add. Substituting \( r = a \) and \( r = b \) for the radii of the two arcs yields \( B = 1.7 \times 10^{-4} \) T.

9. A negatively charged particle is released from rest between the plates of a capacitor, under the combined influence of a magnetic field \( B \) (directed into the page) and the electric field in the capacitor. Which of the paths shown best represents the trajectory of the particle? (Ignore gravity.)

Solution: It is trajectory 4. The particle accelerates from rest, so it is not bent to the side by the magnetic field until it picks up some speed. It bends to the right because it is a negative charge.

10. A positively charged particle enters a uniform magnetic field at an angle \( \theta \) relative to the field direction. What happens to the kinetic energy of the particle?

Solution: The kinetic energy is unchanged since the force is always perpendicular to the direction of motion.