1. How long does it take to charge an initially uncharged capacitor to half of its maximum charge of 24 μC if it is connected in series with a 15 kΩ resistor to a 12 V EMF source?

(1) 0.04 s  (2) 0.06 s  (3) 0.02 s  (4) 0.4 s  (5) 0.03 s

2. Determine the drift velocity \( v_d \) of free electrons in a copper wire carrying a current of 1 A, if the wire has a cylindrical cross section of radius \( r = 0.005 \) m. The number density of free electrons in copper is \( n = 8.5 \times 10^{28} \) m\(^{-3}\). The current density is related to the drift velocity by \( j = nev_d \).

(1) \( 1.5 \times 10^{-25} \) m/s  (2) \( 1.1 \times 10^6 \) m/s  (3) \( 3 \times 10^8 \) m/s  (4) \( 7.4 \times 10^{-11} \) m/s  (5) \( 9.4 \times 10^{-7} \) m/s

3. Consider an infinite solenoid which is made by winding 6000 turns per meter of a wire which carries 3 Amps. Inside the solenoid there is a loop of radius 0.1 m which carries a current of 3 Amps. How much energy is required to flip the loop from its lowest energy orientation to its highest energy orientation?

(1) 0.21 mJ  (2) 0.43 mJ  (3) 0 J  (4) 0.034 mJ  (5) 0.071 μJ

4. A square metal loop of side length \( \ell = 1.5 \) m is pulled out of a uniform magnetic field with a velocity of magnitude \( v = 2 \) m/s. The magnetic field has a strength of \( B = 0.5 \) T and is directed out of the page and perpendicular to the surface of the loop. One side of the square is aligned with the edge of the field region when the pulling first starts. What is the magnitude of the force that must be applied to pull the loop with this velocity if the resistance of the loop is 0.2 Ω?

(1) 5.6 N  (2) 1.1 N  (3) 1.5 N  (4) 3.8 N  (5) 7.5 N
5. Two cylindrical wires are made from copper. The second wire has twice the diameter and twice the length of the first wire. What is the ratio of the resistance of the second wire to that of the first?

(1) 1  
(2) 1/2  
(3) 2  
(4) 4  
(5) 1/4

6. Suppose a charged particle moves with velocity \( (2\hat{i} - 3\hat{k}) \text{ m/s} \) in a magnetic field of \( 8\hat{j} \text{ nano-Tesla} \). What must be the electric field (in nano-Volt/meter) in order for the particle to move freely with constant velocity?

(1) \(+24\hat{i} + 16\hat{k}\)  
(2) \(+24\hat{i} - 16\hat{k}\)  
(3) Must know the charge to answer.  
(4) \(-24\hat{i} - 16\hat{k}\)  
(5) \(-24\hat{i} + 16\hat{k}\)

7. Two light bulbs each with a resistance of 250 \( \Omega \) can be connected in parallel or in series to a source of EMF with \( \varepsilon = 120 \text{ V} \). What is the ratio of the brightness of one of the light bulbs when it is in the parallel circuit to that of one of the light bulbs when it is in the series circuit? (The two light bulbs have the same brightness in each circuit since they are identical.)

(1) 4  
(2) 2  
(3) 16  
(4) 1/2  
(5) 1/4

8. In the circuit shown, the EMF source maintains a potential difference of \( \varepsilon = 6 \text{ V} \) and the resistances are \( R_1 = 10 \Omega, R_2 = 20 \Omega, \) and \( R_3 = 30 \Omega \). If the electric potential at point \( a \) is \( V_a = -3 \text{ V} \), what is the electric potential \( V_b \) at point \( b \)?

(1) +4 V  
(2) +1 V  
(3) -1 V  
(4) +2 V  
(5) 6 V

9. A large appliance consumes 10 kW of electrical power from a utility company that delivers that power with an EMF of 400 V. What is the internal resistance of the appliance?

(1) 40 \( \Omega \)  
(2) 16,000 \( \Omega \)  
(3) 25 \( \Omega \)  
(4) 0.04 \( \Omega \)  
(5) 16 \( \Omega \)

10. Consider three parallel wires which are arranged from top to bottom carrying currents in the same direction. Suppose the top wire carries four times the current of the bottom wire and the middle wire carries twice the current of the bottom wire. If the distance between the top wire and the middle one is \( d \), what must be the distance between the middle wire and the bottom one in order that the force on the middle wire is zero?

(1) \( d/2 \)  
(2) \( d/16 \)  
(3) \( d/32 \)  
(4) \( d/8 \)  
(5) \( d/4 \)

11. Find the equivalent resistance of the circuit connected to the source of EMF as shown in the figure if every resistor has the same resistance 60 \( \Omega \).

(1) 80\( \Omega \)  
(2) 150\( \Omega \)  
(3) 120\( \Omega \)  
(4) 60\( \Omega \)  
(5) 15\( \Omega \)
12. Find the magnitude of the current in amperes through resistor \( R_3 \) in the circuit shown if \( \varepsilon_1 = \varepsilon_2 = 9 \, \text{V} \) and \( R_1 = R_2 = 40 \, \Omega \) and \( R_3 = 10 \, \Omega \).

(1) 0.3  
(2) 0.05  
(3) 0.15  
(4) 0.1  
(5) 0

13. In the figure, a uniform magnetic field points out of the page and varies in time according to \( B(t) = 0.1 t + 0.01 t^2 \), with \( t \) measured in seconds and \( B \) in Tesla. What is the magnitude of \( \oint \vec{E} \cdot d\vec{s} \) when \( t = 2 \, \text{s} \) along a closed path in the plane of the page that traces an equilateral triangle of side length \( s = 1 \, \text{cm} \) as shown in the figure?

(1) \( 1.0 \times 10^{-5} \, \text{V} \)  
(2) \( 6.1 \times 10^{-6} \, \text{V} \)  
(3) 0  
(4) \( 0.14 \, \text{V} \)  
(5) \( 8.7 \times 10^{-7} \, \text{V} \)

14. A circular conducting loop is immersed in a uniform magnetic field \( B \) pointing out of the page with a constant magnitude of 5 T. If the loop suddenly contracts from its initial radius of 0.2 m with a radial velocity \( dr/dt = -0.2 \, \text{m/s} \), what is the induced current and its direction immediately after it starts contracting if the loop has a constant resistance of 0.1 \( \Omega \)? A clockwise direction is considered positive, counter-clockwise is negative.

(1) \( -12.5 \, \text{A} \)  
(2) 0  
(3) \( -6.3 \, \text{A} \)  
(4) \( +6.3 \, \text{A} \)  
(5) \( +12.5 \, \text{A} \)

15. 100 turns of wire are wound around the frame of a door of height 2 meters and width 1 meter. The wire carries a current of 5 Amps up its hinge. Suppose a constant magnetic field of magnitude 0.003 Tesla is applied parallel to the door's hinge. What is the magnitude of the torque (in N·m) on the door, and which way does it make the door turn as viewed from above?

(1) 0, the door doesn't turn  
(2) 0.03, clockwise  
(3) 3, counter-clockwise  
(4) 3, clockwise  
(5) 0.03, counter-clockwise

16. The current through an inductor with inductance \( L = 0.05 \, \text{H} \) is shown by the graph, with the direction from left to right through the inductor as shown. What is the EMF across the inductor \((V_L = V_{\text{right}} - V_{\text{left}})\), including sign, at \( t = 4 \, \text{ms} \)?

(1) 0.1 \, \text{V}  
(2) \( -25 \, \text{V} \)  
(3) 33 \, \text{V}  
(4) \( -70 \, \text{V} \)  
(5) \( -670 \, \text{V} \)

17. Consider an unknown conductor in the shape of a rectangular bar along the \( y \) axis. Suppose the conductor carries a current directed along the positive \( y \) axis. A magnetic field is applied along the positive \( z \) axis, and the resulting Hall voltage is measured to be positive from the \(-x\) side of the bar to the \(+x\) side. What is the sign of the conductor's charge carriers and the direction of their average motion?

(1) \( q < 0 \) and \( v_y > 0 \)  
(2) \( q > 0 \) and \( v_y < 0 \)  
(3) \( q < 0 \) and \( v_y < 0 \)  
(4) \( q > 0 \) and \( v_y > 0 \)  
(5) Insufficient information
18. Consider a charged particle of mass $2 \times 10^{-9}$ kg which moves in a region of zero electric field and a constant magnetic field of magnitude 5 Tesla and directed straight up from the paper. Suppose the particle moves at a constant speed of 1000 m/s counter-clockwise around a circle of radius 3 m. What is the particle's charge in Coulombs?

(1) $+1.3 \times 10^{-7}$    (2) $-8.4 \times 10^{-7}$    (3) $-1.3 \times 10^{-7}$    (4) $+2.1 \times 10^{-8}$    (5) $+8.7 \times 10^{-7}$

19. A cable of radius $R$ carries a current density directed along its axis whose magnitude grows linearly with the distance from the cable's central axis. If the total current in the cable is $i_0$, what is the magnitude of the magnetic field a distance $r = R/2$ from the central axis?

(1) $\mu_0 i_0 / 4\pi R$    (2) $\mu_0 i_0 / 2\pi R$    (3) $\mu_0 i_0 / \pi R$    (4) $\mu_0 i_0 / 6\pi R$    (5) $\mu_0 i_0 / 8\pi R$

20. What is the magnetic field (in nano-Tesla) at a point 4 meters along the positive $x$ axis by a wire segment of length 3 meters which carries a current of 5 Amps along the positive $z$ axis?

(1) $6j$    (2) $-13j$    (3) $+75j$    (4) $+13j$    (5) $-75j$