On my honor, I have neither given nor received unauthorized aid on this examination.

YOUR TEST NUMBER IS THE 5-DIGIT NUMBER AT THE TOP OF EACH PAGE.

DIRECTIONS

(1) Code your test number on your answer sheet (use 76–80 for the 5-digit number). Code your name on your answer sheet. **DARKEN CIRCLES COMPLETELY**. Code your student number on your answer sheet.

(2) Print your name on this sheet and sign it also.

(3) Do all scratch work anywhere on this exam that you like. At the end of the test, this exam printout is to be turned in. No credit will be given without both answer sheet and printout with scratch work most questions demand.

(4) **Blacken the circle of your intended answer completely, using a #2 pencil or blue or black ink.** Do not make any stray marks or the answer sheet may not read properly.

(5) The answers are rounded off. Choose the closest to exact. There is no penalty for guessing.

>>>GETTING STARTED<<<

Hand in the answer sheet separately.

<table>
<thead>
<tr>
<th>Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m</td>
</tr>
<tr>
<td>$k = 8.99 \times 10^9$ N m$^2$/C$^2$</td>
</tr>
<tr>
<td>milli $= 10^{-3}$</td>
</tr>
</tbody>
</table>
PHY2054 Exam 1 Formula Sheet

**Vectors**

\[ \vec{a} = a_x \hat{x} + a_y \hat{y} + a_z \hat{z} \quad \vec{b} = b_x \hat{x} + b_y \hat{y} + b_z \hat{z} \]

**Magnitudes:**

\[ |\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad |\vec{b}| = \sqrt{b_x^2 + b_y^2 + b_z^2} \]

**Scalar Product:**

\[ \vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z = |\vec{a}| |\vec{b}| \cos \theta \quad (\theta = \text{angle between} \ \vec{a} \ \text{and} \ \vec{b}) \]

**Electrostatic Force and Electric Field**

**Electrostatic Force (vector):**

\[ \vec{F} = k \frac{q_1 q_2}{r^2} \hat{r} \quad (r = \text{distance between charge} \ q_1 \ \text{and charge} \ q_2, \ \text{units} = \text{N}) \]

\[ k = 1/(4\pi\varepsilon_0) = 8.99 \times 10^9 \ \text{N} \cdot \text{m}^2/\text{C}^2 \quad \varepsilon_0 = 8.85 \times 10^{-12} \ \text{C}^2/(\text{N} \cdot \text{m}^2) \]

**Electric Field (at} q_2 \ \text{due to} q_1):**

\[ \vec{E} = \frac{\vec{F}}{q_2} = k \frac{q_1}{r^2} \hat{r} \quad (\text{units} = \text{N/C} = \text{V/m}) \]

**Electric Flux (through the infinitesimal surface area} dA):**

\[ d\Phi_E = \vec{E} \cdot d\vec{A} \quad (\text{units} = \text{Nm}^2/\text{C}) \]

**Vector Area (directed area):**

\[ \vec{A} = A \hat{n} \quad (\text{where} \ \hat{n} = \text{normal to the surface}) \]

**Gauss’ Law** (net flux through closed surface} S):

\[ \Phi_E = \int_S \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\varepsilon_0} \quad (Q_{\text{enclosed}} = \text{charge enclosed}) \]

**Gauss’ Law:** Net flux through closed surface} S = the charge enclosed by surface S divided by \( \varepsilon_0 \)

**Electric Potential and Potential Energy**

**Electric Potential Energy:** work done against a constant field} E in moving charge} q a distance d along straight line path from A to B, \( \Delta U = U_B - U_A = -q \vec{E} \cdot d\vec{A} \quad (\text{units} = \text{J}) \)

**Electric Potential:** Work done per unit charge against a constant field} E in moving charge} q a distance d along straight line path from A to B, \( \Delta V = \Delta U / q = -\vec{E} \cdot d\vec{A} \quad (\text{units} = \text{J/C} = \text{V}) \)

**Electric Potential** (distance r from a point charge} q):

\[ V(r) = k \frac{q}{r} \quad (\text{N point charges}) \quad V(r) = \sum_{i=1}^{N} k \frac{q_i}{r_i} \]

**Electric Potential Energy (N point charges):**

\[ U = \frac{1}{2} \sum_{i=1}^{N} q_i V_i, \quad \text{where} \ V_i = \text{the electric potential at} \ q_i \ \text{due to the other charges} \]

**Stored Electric Potential Energy** (N conductors with charge} Q_i and electric potential} V_i):

\[ U = \frac{1}{2} \sum_{i=1}^{N} Q_i V_i \]

**Capacitance** (definition):

\[ C = \frac{Q}{V} = \frac{Q}{\Delta V} \quad (\text{units} = \text{C/V} = \text{F}) \]

**Energy Density of the Electric Field:**

\[ u = \frac{1}{2} \varepsilon_0 E^2 \quad (\text{units} = \text{J/m}^3) \]

**Electric Current and Circuits**

**Current** (through directed area A):

\[ I = \frac{dQ}{dt} = \vec{J} \cdot \vec{A} = n q \vec{v}_{\text{drift}} \cdot \vec{A} \quad (\text{units} = \text{C/s} = \text{A}) \]

\( n \) is the number of charged particles} q per unit volume, \( \vec{v}_{\text{drift}} \) is the average velocity of the charged particles).

**Conducting Wire** (length L, cross sectional area A):

\[ J = \sigma E, \quad I = \sigma E A / \rho, \quad |\Delta V| = EL \]

**Ohm’s Law**:

\[ |\Delta V| = IR, \quad R = \rho L / A \quad (\text{Resistance} \ R \ \text{units} = \text{V/A} = \Ω) \]

**Resistivity** (at temperature} T in °C):

\[ \rho(T) = \rho_0 (1 + \alpha T) \quad \text{where} \ \Delta T = T - T_0 \]

**Power** (supplied by EMF} \( \varepsilon \)):

\[ P = \varepsilon I \]

**Power** (dissipated in resistor} R):

\[ P = I^2 R \quad (\text{units} = \text{J/s} = \text{W}) \]

**RC Circuits** (charging capacitor C through resistor R with EMF} \( \varepsilon \)):

\[ Q(t) = \varepsilon C (1 - e^{-t/\tau}) \]

**RC Circuits** (discharging capacitor C with initial charge} \( Q_0 \) through resistor} R):

\[ Q(t) = Q_0 e^{-t/\tau} \]

**RC Circuits** (time constant):

\[ \tau = RC \quad (\text{units} = \Ω \cdot \text{F} = \text{s}) \]
PHY2054 Exam 2 Formula Sheet

**Vectors**

\[ \vec{a} = a_x \hat{x} + a_y \hat{y} + a_z \hat{z} \quad \vec{b} = b_x \hat{x} + b_y \hat{y} + b_z \hat{z} \]

Cross Product Magnitude:  
\[ |\vec{a} \times \vec{b}| = |\vec{a}| |\vec{b}| \sin \theta_{ab} \]

Cross Product Vector:  
\[ \vec{c} = \vec{a} \times \vec{b} = (a_y b_z - a_z b_y) \hat{x} - (a_z b_x - a_x b_z) \hat{y} + (a_x b_y - a_y b_x) \hat{z} \]

**Electromagnetic Force**

Electromagnetic Force (vector): \[ \vec{F}_{EM} = \vec{F}_E + \vec{F}_B = q \vec{E} + q \vec{v} \times \vec{B} \]
\[ \vec{F}_E = q \vec{E} \quad \vec{F}_B = q \vec{v} \times \vec{B} \]

(\(r\) = distance between charge Q and charge q, \(v\) = velocity of charge q, \(V\) = velocity of charge Q)

\[ \vec{F}_E = k \frac{Qq}{r^2} \hat{r} \text{ (units = N)} \quad \vec{F}_B = k \frac{Qq}{c^2 r^2} \hat{V} \times \hat{r} \text{ (units = N)} \]

\[ k = \frac{1}{4 \pi \varepsilon_0} \approx 8.99 \times 10^9 \text{ N m}^2 / \text{C}^2 \]
\[ \varepsilon_0 \approx 8.85 \times 10^{-12} \text{ C}^2 / (\text{N m}^2) \]
\[ k_B = k/c^2 = \mu_0/(4 \pi) \approx 10^{-7} \text{ T m/A} \]
\[ \mu_0 \approx 4 \pi \times 10^{-7} \text{ T m/A} \]
\[ c \approx 3 \times 10^8 \text{ m/s} \text{ (speed of light)} \]

**Electric Field (due to Q):** \[ \vec{E} = k \frac{Q}{r^2} \hat{r} \text{ (units = N/C = V/m)} \]

**Magnetic Field (due to Q):** \[ \vec{B} = k_B \frac{Q}{r^2} \hat{V} \times \hat{r} \text{ (units = N/(C m/s) = T)} \]

**Magnetic Field (due to current I):** \[ \vec{B} = k_B \frac{I}{r^2} \hat{L} \times \hat{r} \text{ (units = N/(C m/s) = T)} \]

**Energy Density (Electric & Magnetic Field):** \[ u_E = \frac{1}{2} \varepsilon_0 E^2 \quad u_B = \frac{1}{2} \mu_0 B^2 \text{ (units = J/m³)} \]

**Magnetic Force (on a long straight wire carrying current I):** \[ \vec{F}_B = I \hat{L} \times \vec{B} \text{ (units = N)} \]

**Magnetic Dipole Moment (N loops, current I, area A):** \[ \vec{\mu}_B = NI \hat{A} \text{ (units = A m²) \quad \hat{A} = A \hat{\mathbf{n}}} \]

**Magnetic Torque on a Magnetic Dipole:** \[ \vec{\tau} = \vec{\mu}_B \times \vec{B} \text{ (units = N m)} \]

**Ampere’s Law:** \[ \oint_C \vec{B} \cdot d\vec{L} = \sum_{C} B || \Delta l = \mu_0 I_{\text{enclosed}} \text{ (around a closed loop)} \]

**Magnetic Field (Examples)**

Infinite Straight Wire Carrying Current I: \[ |\vec{B}| = 2 k_B I / r_{perp} \text{ (units = T)} \]

Center of a Circular Loop Carrying Current I: \[ |\vec{B}| = 2 \pi k_B I / R \text{ (units = T)} \]

Infinite Solenoid (current I, n loops per unit length): \[ |\vec{B}| = \mu_0 n I \text{ (units = T)} \]

**Electromagnetic Induction, RL Circuits, and LC Circuits**

**Magnetic Flux** (uniform B, surface A): \[ \Phi_B = \vec{B} \cdot \hat{A} = BA \cos \theta = B_{\text{perp}} A \quad \text{units = T m² = Wb} \]

**Faraday’s Law of Induction:** \[ \varepsilon = -\frac{\Delta \Phi_B}{\Delta t} \text{ (\varepsilon = induced EMF, units = V)} \]

**Inductor** (inductance L units = H): \[ \Delta V_L = -L \frac{\Delta I}{\Delta t} \text{ (potential difference) \quad U_L = \frac{1}{2} LI^2 \text{ (stored energy)}} \]

**RL Circuits** (time constant): \[ \tau_L = L/R \text{ (units = H/Ω = s)} \]

**RL Circuits** (EMF \(\varepsilon\), Resistor R, Inductor L, switch closed at \(t = 0\)): \[ I(t) = \varepsilon (1 - e^{-t/\tau_L}) / R \]

**Oscillating LC Circuit** (no resistance): \[ U_{\text{tot}} = \frac{1}{2} Q^2 / C + \frac{1}{2} LI^2 \text{ (stored energy) \quad \omega = 1/\sqrt{LC}} \]

**Oscillating LC Circuit** (no resistance): \[ Q(t) = Q_0 \sin(\omega t + \phi) \quad I(t) = I_0 \cos(\omega t + \phi) \]

**Oscillating LC Circuit** (no resistance): \[ f = \omega / 2\pi \text{ (frequency of oscillations in Hz)} \]
1. Two identical charged particles, separated by a distance \( d \), are moving parallel to each other in the x-direction with velocity \( V \) as shown in the figure. If \( V = c/2 \), what is the ratio of the magnitude of the magnetic force \( F_B \) to the magnitude of the electric force \( F_E \) (e.g., what is \( F_B/F_E \)) that one of the particles exerts on the other? Note that \( c \approx 3 \times 10^8 \) m/s is the speed of light in a vacuum.

(1) 1/4  
(2) 1/9  
(3) 1/16  
(4) 1/2  
(5) 1/3

2. Two identical charged particles, separated by a distance \( d \), are moving parallel to each other in the x-direction with velocity \( V \) as shown in the figure. If \( V = c/3 \), what is the ratio of the magnitude of the magnetic force \( F_B \) to the magnitude of the electric force \( F_E \) (e.g., what is \( F_B/F_E \)) that one of the particles exerts on the other? Note that \( c \approx 3 \times 10^8 \) m/s is the speed of light in a vacuum.

(1) 1/9  
(2) 1/4  
(3) 1/16  
(4) 1/2  
(5) 1/3

3. Two identical charged particles, separated by a distance \( d \), are moving parallel to each other in the x-direction with velocity \( V \) as shown in the figure. If \( V = c/4 \), what is the ratio of the magnitude of the magnetic force \( F_B \) to the magnitude of the electric force \( F_E \) (e.g., what is \( F_B/F_E \)) that one of the particles exerts on the other? Note that \( c \approx 3 \times 10^8 \) m/s is the speed of light in a vacuum.

(1) 1/16  
(2) 1/4  
(3) 1/9  
(4) 1/2  
(5) 1/3

4. An infinitely long straight wire lies on the x-axis and carries a current \( I_0 = 10 \) mA to the right as shown in the figure. A circular loop of wire with radius \( R \) carrying a current \( I \) in the clockwise direction lies in the xy-plane. If the center of the circular loop is located a perpendicular distance \( y = 3R/2 \) from the straight wire, and if the net magnetic field at the center of the circular loop is zero, what is \( I \) (in mA)?

(1) 2.12  
(2) 1.59  
(3) 1.06  
(4) 0.47  
(5) 0.63

5. An infinitely long straight wire lies on the x-axis and carries a current \( I_0 = 10 \) mA to the right as shown in the figure. A circular loop of wire with radius \( R \) carrying a current \( I \) in the clockwise direction lies in the xy-plane. If the center of the circular loop is located a perpendicular distance \( y = 2R \) from the straight wire, and if the net magnetic field at the center of the circular loop is zero, what is \( I \) (in mA)?

(1) 1.59  
(2) 2.12  
(3) 1.06  
(4) 0.47  
(5) 0.63

6. An infinitely long straight wire lies on the x-axis and carries a current \( I_0 = 10 \) mA to the right as shown in the figure. A circular loop of wire with radius \( R \) carrying a current \( I \) in the clockwise direction lies in the xy-plane. If the center of the circular loop is located a perpendicular distance \( y = 3R \) from the straight wire, and if the net magnetic field at the center of the circular loop is zero, what is \( I \) (in mA)?

(1) 1.06  
(2) 2.12  
(3) 1.59  
(4) 0.47  
(5) 0.94
7. Two infinitely long parallel wires lie in the yz-plane and are located at $y = d/2$ and $y = -d/2$ as shown in the figure. The top wire ($y = d/2$) carries a current $I$ (out of the page), while the bottom wire ($y = -d/2$) carries a same current $I$ (into the page). What is the magnitude of the net magnetic field on the x-axis a distance $x = d/2$ from the origin? (Note: $k_B = \mu_0/(4\pi)$.)

(1) $4.0 \frac{k_B I}{d}$  (2) $1.6 \frac{k_B I}{d}$  (3) $0.8 \frac{k_B I}{d}$  (4) $5.7 \frac{k_B I}{d}$  (5) $3.6 \frac{k_B I}{d}$

8. At what point on the positive y-axis is the magnitude of net magnetic field the same as it was on x-axis at $x = d/2$ in the previous problem?

(1) $y = 0.866d$  (2) $y = 1.225d$  (3) $y = 1.658d$  (4) $y = 0.659d$  (5) nowhere

9. Two infinitely long parallel wires lie in the yz-plane and are located at $y = d/2$ and $y = -d/2$ as shown in the figure. The top wire ($y = d/2$) carries a current $I$ (out of the page), while the bottom wire ($y = -d/2$) carries a same current $I$ (into the page). What is the magnitude of the net magnetic field on the x-axis a distance $x = d$ from the origin? (Note: $k_B = \mu_0/(4\pi)$.)

(1) $1.6 \frac{k_B I}{d}$  (2) $4.0 \frac{k_B I}{d}$  (3) $0.8 \frac{k_B I}{d}$  (4) $5.7 \frac{k_B I}{d}$  (5) $3.6 \frac{k_B I}{d}$

10. At what point on the positive y-axis is the magnitude of net magnetic field the same as it was on x-axis at $x = d$ in the previous problem?

(1) $y = 1.225d$  (2) $y = 0.866d$  (3) $y = 1.658d$  (4) $y = 0.659d$  (5) nowhere

11. Two infinitely long parallel wires lie in the yz-plane and are located at $y = d/2$ and $y = -d/2$ as shown in the figure. The top wire ($y = d/2$) carries a current $I$ (out of the page), while the bottom wire ($y = -d/2$) carries a same current $I$ (into the page). What is the magnitude of the net magnetic field on the x-axis a distance $x = 3d/2$ from the origin? (Note: $k_B = \mu_0/(4\pi)$.)

(1) $0.8 \frac{k_B I}{d}$  (2) $4.0 \frac{k_B I}{d}$  (3) $1.6 \frac{k_B I}{d}$  (4) $5.7 \frac{k_B I}{d}$  (5) $3.6 \frac{k_B I}{d}$

12. At what point on the positive y-axis is the magnitude of net magnetic field the same as it was on x-axis at $x = 3d/2$ in the previous problem?

(1) $y = 1.658d$  (2) $y = 0.866d$  (3) $y = 1.225d$  (4) $y = 0.659d$  (5) nowhere

13. Two circular current loops have their centers at the origin (i.e., $x = y = z = 0$). Loop 1 lies in the xy-plane and has radius $R$ and carries current $3I$. Loop 2 lies in the yz-plane and has radius $2R$ and carries current $8I$. What is the magnitude of the net magnetic field at the origin?

(1) $\frac{5\mu_0 I}{2R}$  (2) $\frac{5\mu_0 I}{R}$  (3) $\frac{15\mu_0 I}{2R}$  (4) $\frac{2\mu_0 I}{R}$  (5) $\frac{4\mu_0 I}{R}$
14. Two circular current loops have their centers at the origin \((i.e., x = y = z = 0)\). Loop 1 lies in the xy-plane and has radius \(R\) and carries current \(6I\). Loop 2 lies in the yz-plane and has radius \(2R\) and carries current \(16I\). What is the magnitude of the net magnetic field at the origin?

\[
\begin{align*}
\text{(1)} & \quad \frac{5\mu_0 I}{R} \\
\text{(2)} & \quad \frac{5\mu_0 I}{2R} \\
\text{(3)} & \quad \frac{15\mu_0 I}{2R} \\
\text{(4)} & \quad \frac{2\mu_0 I}{R} \\
\text{(5)} & \quad \frac{4\mu_0 I}{R}
\end{align*}
\]

15. Two circular current loops have their centers at the origin \((i.e., x = y = z = 0)\). Loop 1 lies in the xy-plane and has radius \(R\) and carries current \(9I\). Loop 2 lies in the yz-plane and has radius \(2R\) and carries current \(24I\). What is the magnitude of the net magnetic field at the origin?

\[
\begin{align*}
\text{(1)} & \quad \frac{15\mu_0 I}{2R} \\
\text{(2)} & \quad \frac{5\mu_0 I}{2R} \\
\text{(3)} & \quad \frac{5\mu_0 I}{R} \\
\text{(4)} & \quad \frac{2\mu_0 I}{R} \\
\text{(5)} & \quad \frac{4\mu_0 I}{R}
\end{align*}
\]

16. A positively charged particle with a charge to mass ratio \(\frac{q}{m} = 1 \text{ C/kg}\) is traveling to the right along the x-axis with speed \(V = 1 \text{ m/s}\). At \(t = 0\) and \(x = 0\) it encounters uniform parallel electric and magnetic fields that point in the x-direction as shown in the figure. If the magnitudes of the E and B fields are \(1.0 \text{ V/m}\) and \(0.2 \text{ T}\), respectively, what is the particle’s speed (in m/s) at \(t = 2\) s?

\[
\begin{align*}
\text{(1)} & \quad 3 \\
\text{(2)} & \quad 4 \\
\text{(3)} & \quad 5 \\
\text{(4)} & \quad 1 \\
\text{(5)} & \quad 2
\end{align*}
\]

17. A positively charged particle with a charge to mass ratio \(\frac{q}{m} = 1 \text{ C/kg}\) is traveling to the right along the x-axis with speed \(V = 2 \text{ m/s}\). At \(t = 0\) and \(x = 0\) it encounters uniform parallel electric and magnetic fields that point in the x-direction as shown in the figure. If the magnitudes of the E and B fields are \(1.0 \text{ V/m}\) and \(0.2 \text{ T}\), respectively, what is the particle’s speed (in m/s) at \(t = 2\) s?

\[
\begin{align*}
\text{(1)} & \quad 4 \\
\text{(2)} & \quad 3 \\
\text{(3)} & \quad 5 \\
\text{(4)} & \quad 1 \\
\text{(5)} & \quad 2
\end{align*}
\]

18. A positively charged particle with a charge to mass ratio \(\frac{q}{m} = 1 \text{ C/kg}\) is traveling to the right along the x-axis with speed \(V = 3 \text{ m/s}\). At \(t = 0\) and \(x = 0\) it encounters uniform parallel electric and magnetic fields that point in the x-direction as shown in the figure. If the magnitudes of the E and B fields are \(1.0 \text{ V/m}\) and \(0.2 \text{ T}\), respectively, what is the particle’s speed (in m/s) at \(t = 2\) s?

\[
\begin{align*}
\text{(1)} & \quad 5 \\
\text{(2)} & \quad 3 \\
\text{(3)} & \quad 4 \\
\text{(4)} & \quad 1 \\
\text{(5)} & \quad 2
\end{align*}
\]

19. An infinitely long wire carrying a current \(I\) forms a partial circle of radius \(R\) as shown in the figure. If the missing part of the circle corresponds to \(\theta = 30^\circ\), what is the magnitude of the magnetic field at the center of the partial circle?

\[
\begin{align*}
\text{(1)} & \quad \frac{5.76 k_B I}{R} \\
\text{(2)} & \quad \frac{5.50 k_B I}{R} \\
\text{(3)} & \quad \frac{5.24 k_B I}{R} \\
\text{(4)} & \quad \frac{6.28 k_B I}{R} \\
\text{(5)} & \quad \frac{3.14 k_B I}{R}
\end{align*}
\]
20. An infinitely long wire carrying a current $I$ forms a partial circle of radius $R$ as shown in the figure. If the missing part of the circle corresponds to $\theta = 45^\circ$, what is the magnitude of the magnetic field at the center of the partial circle?

(1) $5.50 \frac{k_B I}{R}$  (2) $5.76 \frac{k_B I}{R}$  (3) $5.24 \frac{k_B I}{R}$  (4) $6.28 \frac{k_B I}{R}$  (5) $3.14 \frac{k_B I}{R}$

21. An infinitely long wire carrying a current $I$ forms a partial circle of radius $R$ as shown in the figure. If the missing part of the circle corresponds to $\theta = 60^\circ$, what is the magnitude of the magnetic field at the center of the partial circle?

(1) $5.24 \frac{k_B I}{R}$  (2) $5.76 \frac{k_B I}{R}$  (3) $5.50 \frac{k_B I}{R}$  (4) $6.28 \frac{k_B I}{R}$  (5) $3.14 \frac{k_B I}{R}$

22. Three infinitely long straight wires lie in a plane and carry current in the same direction as shown in the figure. The top wire carries current $I$ and is a distance $d$ from the center wire which carries current $2I$. The bottom wire carries current $3I$ and is a distance $d$ from the center wire. What is the magnitude of the net force on a length $L = d/4$ of the center wire due to the other two wires?

(1) $2k_B I^2$  (2) $4k_B I^2$  (3) $6k_B I^2$  (4) $8k_B I^2$  (5) $k_B I^2$

23. Three infinitely long straight wires lie in a plane and carry current in the same direction as shown in the figure. The top wire carries current $I$ and is a distance $d$ from the center wire which carries current $2I$. The bottom wire carries current $3I$ and is a distance $d$ from the center wire. What is the magnitude of the net force on a length $L = d/2$ of the center wire due to the other two wires?

(1) $4k_B I^2$  (2) $2k_B I^2$  (3) $6k_B I^2$  (4) $8k_B I^2$  (5) $k_B I^2$

24. Three infinitely long straight wires lie in a plane and carry current in the same direction as shown in the figure. The top wire carries current $I$ and is a distance $d$ from the center wire which carries current $2I$. The bottom wire carries current $3I$ and is a distance $d$ from the center wire. What is the magnitude of the net force on a length $L = 3d/4$ of the center wire due to the other two wires?

(1) $6k_B I^2$  (2) $2k_B I^2$  (3) $4k_B I^2$  (4) $8k_B I^2$  (5) $k_B I^2$

25. The figure shows a mass spectrometer in which negatively charged particles of different masses enter a region through a slit and travel perpendicular to a uniform magnetic field (pointing out of the page). The particles are accelerated through the same potential difference, $\Delta V$, before entering the spectrometer and are measured by a detector when they strike the bottom wall. If a particle with charge $-Q$ and mass $M$ hits the bottom wall a distance $d$ from the slit, at what distance will a particle with charge $-4Q$ and mass $4M$ hit the bottom wall?

(1) $d$  (2) $2d/3$  (3) $d/2$  (4) $2d$  (5) $3d/2$
26. The figure shows a mass spectrometer in which negatively charged particles of different masses enter a region through a slit and travel perpendicular to a uniform magnetic field (pointing out of the page). The particles are accelerated through the same potential difference, $\Delta V$, before entering the spectrometer and are measured by a detector when they strike the bottom wall. If a particle with charge $-Q$ and mass $M$ hits the bottom wall a distance $d$ from the slit, at what distance will a particle with charge $-9Q$ and mass $4M$ hit the bottom wall?

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

27. The figure shows a mass spectrometer in which negatively charged particles of different masses enter a region through a slit and travel perpendicular to a uniform magnetic field (pointing out of the page). The particles are accelerated through the same potential difference, $\Delta V$, before entering the spectrometer and are measured by a detector when they strike the bottom wall. If a particle with charge $-Q$ and mass $M$ hits the bottom wall a distance $d$ from the slit, at what distance will a particle with charge $-16Q$ and mass $4M$ hit the bottom wall?

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

28. A current loop in the shape of a right triangle with a base of 3 m and a height of 4 m lies in the xy-plane and carries a current $I = 2$ A in the clockwise direction as shown in the figure. The current loop is immersed in a uniform external 0.5 T magnetic field which points in the x-direction. What is the magnitude of the magnetic force on the hypotenuse of the right triangle due to the external magnetic field (in N)?

(1) 4.0  (2) 6.0  (3) 8.0  (4) 3.0  (5) 4.5

29. In the previous problem, what is the magnitude of the torque on the current loop (in N·m) due to the external magnetic field?

(1) 6.0  (2) 9.0  (3) 12.0  (4) 3.0  (5) 4.0

30. A current loop in the shape of a right triangle with a base of 3 m and a height of 4 m lies in the xy-plane and carries a current $I = 3$ A in the clockwise direction as shown in the figure. The current loop is immersed in a uniform external 0.5 T magnetic field which points in the x-direction. What is the magnitude of the magnetic force on the hypotenuse of the right triangle due to the external magnetic field (in N)?

(1) 6.0  (2) 4.0  (3) 8.0  (4) 3.0  (5) 4.5

31. In the previous problem, what is the magnitude of the torque on the current loop (in N·m) due to the external magnetic field?

(1) 9.0  (2) 6.0  (3) 12.0  (4) 3.0  (5) 4.0
32. A current loop in the shape of a right triangle with a base of 3 m and a height of 4 m lies in the xy-plane and carries a current $I = 4 \, \text{A}$ in the clockwise direction as shown in the figure. The current loop is immersed in a uniform external 0.5 T magnetic field which points in the x-direction. What is the magnitude of the magnetic force on the hypotenuse of the right triangle due to the external magnetic field (in N)?

(1) 8.0  (2) 4.0  (3) 6.0  (4) 3.0  (5) 4.5

33. In the previous problem, what is the magnitude of the torque on the current loop (in N·m) due to the external magnetic field?

(1) 12.0  (2) 6.0  (3) 9.0  (4) 3.0  (5) 4.0

34. A moveable (massless and frictionless) rod with a length of $L = 0.25$ meters is being moved at a constant speed along two conducting rails by a constant external force $F_{\text{ext}} = 3 \, \text{N}$, as shown in the figure. The entire system is immersed in a uniform constant magnetic field (z-axis out of the paper) with $B = 2 \, \text{T}$. What is the magnitude of the induced current (in A) in the $R = 4 \, \text{Ohm}$ resistor?

(1) 6.0  (2) 3.0  (3) 1.0  (4) 9.0  (5) 0.5

35. What is the speed (in m/s) of the moveable rod in the previous problem?

(1) 48.0  (2) 12.0  (3) 1.33  (4) 24.0  (5) 36.0

36. A moveable (massless and frictionless) rod with a length of $L = 0.5$ meters is being moved at a constant speed along two conducting rails by a constant external force $F_{\text{ext}} = 3 \, \text{N}$, as shown in the figure. The entire system is immersed in a uniform constant magnetic field (z-axis out of the paper) with $B = 2 \, \text{T}$. What is the magnitude of the induced current (in A) in the $R = 4 \, \text{Ohm}$ resistor?

(1) 3.0  (2) 6.0  (3) 1.0  (4) 9.0  (5) 0.5

37. What is the speed (in m/s) of the moveable rod in the previous problem?

(1) 12.0  (2) 48.0  (3) 1.33  (4) 24.0  (5) 36.0

38. A moveable (massless and frictionless) rod with a length of $L = 1.5$ meters is being moved at a constant speed along two conducting rails by a constant external force $F_{\text{ext}} = 3 \, \text{N}$, as shown in the figure. The entire system is immersed in a uniform constant magnetic field (z-axis out of the paper) with $B = 2 \, \text{T}$. What is the magnitude of the induced current (in A) in the $R = 4 \, \text{Ohm}$ resistor?

(1) 1.0  (2) 6.0  (3) 3.0  (4) 9.0  (5) 0.5
39. What is the speed (in m/s) of the moveable rod in the previous problem?

(1) 1.33  (2) 48.0  (3) 12.0  (4) 24.0  (5) 36.0

40. A conducting circular wire loop with radius $R = 0.2$ m lies in the plane of the paper as shown in the figure. The loop is immersed in a uniform magnetic field (pointing out of the page) that varies with time according to $B(t) = bt$, where $b$ is a constant (i.e., it varies linearly with time). If $b = 500$ mT/s, what is the induced EMF in the loop (in mV) at time $t = 5$ s?

(1) 62.8  (2) 251.3  (3) 565.5  (4) 15.7  (5) 125.3

41. A conducting circular wire loop with radius $R = 0.4$ m lies in the plane of the paper as shown in the figure. The loop is immersed in a uniform magnetic field (pointing out of the page) that varies with time according to $B(t) = bt$, where $b$ is a constant (i.e., it varies linearly with time). If $b = 500$ mT/s, what is the induced EMF in the loop (in mV) at time $t = 5$ s?

(1) 251.3  (2) 62.8  (3) 565.5  (4) 15.7  (5) 125.3

42. A conducting circular wire loop with radius $R = 0.6$ m lies in the plane of the paper as shown in the figure. The loop is immersed in a uniform magnetic field (pointing out of the page) that varies with time according to $B(t) = bt$, where $b$ is a constant (i.e., it varies linearly with time). If $b = 500$ mT/s, what is the induced EMF in the loop (in mV) at time $t = 5$ s?

(1) 565.5  (2) 62.8  (3) 251.3  (4) 15.7  (5) 125.3

43. Consider the LR circuit shown in the figure. The inductor has inductance $L = 0.2$ mH and no initial stored energy. If $\epsilon = 12$ V, what is the current through the 4 M resistor (in Amps) immediately after the switch is closed?

(1) 2  (2) 4  (3) 6  (4) 3  (5) 9

44. In the previous problem, how much magnetic energy (in mJ) is stored in the inductor a long time after the switch is closed (i.e., steady state)?

(1) 0.90  (2) 3.6  (3) 8.1  (4) 0.55  (5) 9.8

45. Consider the LR circuit shown in the figure. The inductor has inductance $L = 0.2$ mH and no initial stored energy. If $\epsilon = 24$ V, what is the current through the 4 M resistor (in Amps) immediately after the switch is closed?

(1) 4  (2) 2  (3) 6  (4) 3  (5) 9
46. In the previous problem, how much magnetic energy (in mJ) is stored in the inductor a long time after the switch is closed (i.e., steady state)?

(1) 3.6   (2) 0.90   (3) 8.1   (4) 0.55   (5) 9.8

47. Consider the LR circuit shown in the figure. The inductor has inductance \( L = 0.2 \, \text{mH} \) and no initial stored energy. If \( \epsilon = 36 \, \text{V} \), what is the current through the 4\( \Omega \) resistor (in Amps) immediately after the switch is closed?

(1) 6   (2) 2   (3) 4   (4) 3   (5) 9

48. In the previous problem, how much magnetic energy (in mJ) is stored in the inductor a long time after the switch is closed (i.e., steady state)?

(1) 8.1   (2) 0.90   (3) 3.6   (4) 0.55   (5) 9.8

49. What magnetic field strength (in \( \mu \text{T} \)) has the same energy density (in J/m\(^3\)) as does a 1,200 V/m electric field?

(1) 4.0   (2) 5.0   (3) 6.0   (4) 7.0   (5) 2.0

50. What magnetic field strength (in \( \mu \text{T} \)) has the same energy density (in J/m\(^3\)) as does a 1,500 V/m electric field?

(1) 5.0   (2) 4.0   (3) 6.0   (4) 7.0   (5) 2.0

51. What magnetic field strength (in \( \mu \text{T} \)) has the same energy density (in J/m\(^3\)) as does a 1,800 V/m electric field?

(1) 6.0   (2) 4.0   (3) 5.0   (4) 7.0   (5) 2.0

52. Two 60 W light bulbs differ in that one is designed for the United States (US) 120 V rms alternating current and the other is designed for the European 220 V rms alternating current. Which bulb has the greater resistance, and what is that resistance?

(1) Europe, 806.7 \( \Omega \)   (2) Europe, 645.3 \( \Omega \)   (3) Europe, 484.0 \( \Omega \)   (4) US, 240.0 \( \Omega \)   (5) US, 192.0 \( \Omega \)

53. Two 75 W light bulbs differ in that one is designed for the United States (US) 120 V rms alternating current and the other is designed for the European 220 V rms alternating current. Which bulb has the greater resistance, and what is that resistance?

(1) Europe, 645.3 \( \Omega \)   (2) Europe, 806.7 \( \Omega \)   (3) Europe, 484.0 \( \Omega \)   (4) US, 240.0 \( \Omega \)   (5) US, 192.0 \( \Omega \)

54. Two 100 W light bulbs differ in that one is designed for the United States (US) 120 V rms alternating current and the other is designed for the European 220 V rms alternating current. Which bulb has the greater resistance, and what is that resistance?

(1) Europe, 484.0 \( \Omega \)   (2) Europe, 806.7 \( \Omega \)   (3) Europe, 645.3 \( \Omega \)   (4) US, 240.0 \( \Omega \)   (5) US, 192.0 \( \Omega \)
55. Consider an oscillating LC circuit consisting of a capacitor with \( C = 1 \text{ mF} \), no resistance, and an unknown inductor \( L \) as shown in the figure. At a certain moment of time the charge on the capacitor is 4 mC and the current is 2 A. At a later time the charge on the capacitor is 10 mC and the current is 1 A. What is the frequency \( f \) of the oscillations (in Hz)?

(1) 30.1  (2) 14.1  (3) 6.93  (4) 50.2  (5) 20.3

56. What is the inductance (in mH) of the unknown inductor \( L \) in the previous problem?

(1) 28  (2) 128  (3) 528  (4) 228  (5) 328

57. Consider an oscillating LC circuit consisting of a capacitor with \( C = 1 \text{ mF} \), no resistance, and an unknown inductor \( L \) as shown in the figure. At a certain moment of time the charge on the capacitor is 4 mC and the current is 2 A. At a later time the charge on the capacitor is 20 mC and the current is 1 A. What is the frequency \( f \) of the oscillations (in Hz)?

(1) 14.1  (2) 30.1  (3) 6.93  (4) 50.2  (5) 20.3

58. What is the inductance (in mH) of the unknown inductor \( L \) in the previous problem?

(1) 128  (2) 28  (3) 528  (4) 228  (5) 328

59. Consider an oscillating LC circuit consisting of a capacitor with \( C = 1 \text{ mF} \), no resistance, and an unknown inductor \( L \) as shown in the figure. At a certain moment of time the charge on the capacitor is 4 mC and the current is 2 A. At a later time the charge on the capacitor is 40 mC and the current is 1 A. What is the frequency \( f \) of the oscillations (in Hz)?

(1) 6.93  (2) 30.1  (3) 14.1  (4) 50.2  (5) 20.3

60. What is the inductance (in mH) of the unknown inductor \( L \) in the previous problem?

(1) 528  (2) 28  (3) 128  (4) 228  (5) 328

THE FOLLOWING QUESTIONS, NUMBERED IN THE ORDER OF THEIR APPEARANCE ON THE ABOVE LIST, HAVE BEEN FLAGGED AS CONTINUATION QUESTIONS: 8 10 12 29 31 33 35 37 39 44 46 48 56 58 60 FOLLOWING GROUPS OF QUESTIONS WILL BE SELECTED AS ONE GROUP FROM EACH TYPE

TYPE 1
Q# S 1
Q# S 2
Q# S 3
TYPE 2
Q# S 4
Q# S 5
Q# S 6
TYPE 3
Q# S 7 8
Q# S 9 10
Q# S 11 12
TYPE 4
Q# S 13
Q# S 14
Q# S 15
TYPE 5
Q# S 16
Q# S 17
Q# S 18
TYPE 6
Q# S 19
Q# S 20
Q# S 21
TYPE 7
Q# S 22
Q# S 23
Q# S 24
TYPE 8
Q# S 25
Q# S 26
Q# S 27
TYPE 9
Q# S 28 29
Q# S 30 31
Q# S 32 33
TYPE 10
Q# S 34 35
Q# S 36 37
Q# S 38 39
TYPE 11
Q# S 40
Q# S 41
Q# S 42
TYPE 12
Q# S 43 44
Q# S 45 46
Q# S 47 48
TYPE 13
Q# S 49
Q# S 50
Q# S 51
TYPE 14
Q# S 52
Q# S 53
Q# S 54
TYPE 15
Q# S 55 56
Q# S 57 58
Q# S 59 60