10) In the following RC circuit with a switch S, two resistors $R_1$ and $R_2$ have the same resistance $R = 20 \Omega$. $C$ denotes a capacitor of capacitance $15 \mu F$, and $E$ denotes a 12 V battery.

Initially, switch S is open for a long time. After a switch S is closed, choose the best figure from below describing the time-dependence of the current $I$ through $R_2$. Do not forget that the battery $E$ is still connected.

The next two questions pertain to the situation described below.

In the following RC circuit with a switch S, two resistors $R_1$ and $R_2$ have the same resistance $R = 20 \Omega$. $C$ denotes a capacitor of capacitance $7 \mu F$, and $E$ denotes a 12 V battery.

11) Switch S has been closed for a long time. What is the current $I$ through $R_2$ immediately after S is opened? Pay attention to the direction of the current arrow in the figure.

When C is full $I = 0$ (S is closed)

- a. $I = -0.41 A$
- b. $I = 0.31 A$
- c. $I = 0.4 A$
- d. $I = -0.41 A$

12) What is the voltage $V_c$ across resistor $R_2$ at a time of $0.5$ ms after switch S is opened?

- a. $V_c = 2.2 V$
- b. $V_c = 0.51 V$
- c. $V_c = 1.8 V$

\[ V_c = \frac{Q(t)}{C} = Q_0 e^{\frac{-t}{RC}} \]

\[ \Rightarrow V_c(t) = V_c(0) e^{\frac{-t}{RC}} \]

\[ R_1 = R_2, \text{ so each resistor sees } \frac{1}{2} \text{ of total voltage drop around circuit} \]

\[ V(R_2) = V_c(0) = \frac{V_c}{2} \]

\[ RC = (56.52)(7 \times 10^{-4} F) \]

\[ t = 0.5 \text{ ms} \]
The next two questions pertain to the situation described below.

In the following figure, $E_1 = 12\, V$, $E_2 = 4\, V$, $R_1 = 3\, \Omega$, $R_2 = 12\, \Omega$, and $R_3 = 4\, \Omega$. Initially, the switch $S$ is open.

![Circuit Diagram]

13) At junction $P$ three currents $I_1$, $I_2$, and $I_3$ meet. Choose the correct relation among them from below.

- $I_1 + I_2 + I_3 = 0$
- $I_1 - I_2 - I_3 = 0$
- $-I_1 + I_2 - I_3 = 0$
- $I_1 - I_2 + I_3 = 0$
- $I_1 + I_2 - I_3 = 0$

with switch open, $I_3$ flows in to $P$

14) When the switch $S$ is closed, which is the current $I_2$?

- $I_2 = 0.4\, A$
- $I_2 = -0.57\, A$
- $I_2 = -0.33\, A$
- $I_2 = 0.7\, A$

15) Choose the correct formula(s) exhibiting Kirchhoff's loop law from the following formulas.

- $E_2 + I_2 R_2 + I_3 R_1 - E_1 = 0$
- $E_2 - I_2 R_2 - I_3 R_1 + E_1 = 0$
- $E_2 + I_2 R_2 + I_3 R_1 - E_1 = 0$
- $E_2 - I_2 R_2 - I_3 R_1 + E_1 = 0$
- $E_2 + I_2 R_2 + I_3 R_1 + E_1 = 0$

16) What is the current $I_3$? Pay attention to the direction of the current arrow in the figure.

- $I_3 = -0.4\, A$
- $I_3 = -1.2\, A$
- $I_3 = -2.3\, A$
- $I_3 = -2.4\, A$
- $I_3 = -2.5\, A$

17) The current $I_1$ is measured to be $-2.4\, A$. What is the current $I_2$? Pay attention to the direction of the current arrow in the figure.

- $I_1 = -2.5\, A$
- $I_1 = -2.6\, A$
- $I_1 = -2.7\, A$
- $I_1 = -5.5\, A$
- $I_1 = -5.6\, A$

$E_3 - I_3 R_4 = 0$

$I_4 = \frac{E_3}{R_4} \leftarrow 3\, \Omega$

$E_3 - I_4 R_4 = 0$

$I_4 = \frac{E_3}{R_4} \leftarrow 3\, \Omega$

$E_3 - I_4 R_4 = 0$

$I_4 = \frac{E_3}{R_4} \leftarrow 3\, \Omega$

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The next two questions pertain to the situation described below.

A current carrying loop of radius \( r = 14 \text{ cm} \) is oriented horizontally, with its area parallel to the \( xz \)-plane in the figure below, and a uniform magnetic field is applied that has no \( x \)-component. The \( x \)-component of the \( B \) field is \( 3 \text{T} \) and the \( y \)-component is \( 4 \text{T} \). The current \( I = 7 \text{A} \) is flowing into the \( (+x) \) direction at the rightmost point of the loop, as denoted in the figure that shows a side view of the loop. (The \((+z)\)-direction points into the page.)

![Diagram of a current carrying loop with magnetic field vectors]

18) What is the magnitude of the torque on the current loop?

- a. \( T = 17 \text{ Nm} \)
- b. \( T = 2500 \text{ Nm} \)
- c. \( T = 32 \text{ Nm} \)
- d. \( T = 0 \text{ Nm} \)

19) In which direction will the loop start to turn if left free?

- a. Clockwise about an axis parallel to the \( x \)-axis
- b. Counterclockwise about an axis parallel to the \( x \)-axis
- c. Around an axis that is not parallel to the \( x \)-axis

20) Four long straight wires carrying currents of equal magnitude \( (I_1 - I_2 - I_3 - I_4) \) are parallel or antiparallel to each other such that their cross sections form the corners of a square, as shown in the figure. The figures indicate the directions of the current in each wire. In which case is the magnitude of the total magnetic field at the center of the square \((O)\) the largest?

![Diagram of four parallel or antiparallel wires with magnetic field vectors]
21) A charged particle travels counterclockwise with speed $v$ on a circle in the plane of the page, while a uniform magnetic field $B$ is applied in a perpendicular direction, pointing into the page (as shown below). The period $T$ is the amount of time the particle takes to travel around one complete circle. How would the period change if the speed of the particle was doubled?

- $T$ would increase by a factor of 4.
- $T$ would remain unchanged.
- $T$ would decrease by a factor of 2.
- $T$ would decrease by a factor of 4.

$$\frac{R}{\gamma} = \frac{mv}{eb}$$

22) Three long, parallel straight wires A, B, and C carry a constant current of $I = 3 \text{ A}$ each. The direction of the current in each wire is as indicated in the figure below. The length of the wires is $L = 1 \text{ m}$ and the diameter is $D = 8 \text{ mm}$. Wires A and B are stuck to each other but electrically insulated from each other. We call the combination of wires A and B a "double wire AB". The distance from the center of C to the center of A is $r = 2 \text{ cm}$.

23) A particle of charge $-q$ moves in the positive $x$-direction with speed $v$. There is a uniform electric field $E$ of magnitude $|E|$ pointing in the positive $y$-direction and a uniform magnetic field $B$ pointing in the negative $y$-direction. What must be the magnitude of the magnetic field $|B|$ such that the particle does not accelerate? (Hint: Pay careful attention to the given directions of $E$ and $B$.

24) A negatively charged particle enters a uniform magnetic field from the south and is pushed to the east. In which direction does the magnetic field point?

The magnetic field points into the page.

The magnetic field points out of the page.

What is the net force on the double wire AB due to wire C?

- $F = 1.5 \times 10^{-3} \text{ N}$
- $F = 8 \text{ N}$
- $F = 2.5 \times 10^{-3} \text{ N}$

$$F_{\text{AB}} = F_A + F_B$$

$$I = \frac{\mu_0 I_A I_B}{2\pi r_{\text{AC}}} - \frac{\mu_0 I_A I_B}{2\pi r_{\text{BC}}}$$

$$I_A = 2, I_B = 3A$$

$$\Gamma_{\text{BC}} = 0.028 \text{ m}$$

$$\Gamma_{\text{AC}} = 0.02 \text{ m}$$

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The next two questions pertain to the situation described below.

A negatively charged particle with charge \( q = -1 \) e enters a uniform magnetic field \( B = 0.3 \) T pointing out of the page with a speed of \( v = 10^6 \) m/s and sweeps out a half circle of radius \( r = 5.0 \) cm before leaving the field.

25) What is the particle's mass?

- More information is required to determine the mass of the particle.
- \( m = 2.0 \times 10^{-9} \) kg
- \( m = 2.5 \times 10^{-9} \) kg
- \( m = 2.8 \times 10^{-9} \) kg
- \( m = 3.0 \times 10^{-9} \) kg

26) What is the speed \( v \) of the particle upon exiting the region with the \( B \) field?

- \( v = 10^6 \) m/s
- \( v = 0 \) m/s
- \( v = \) same as before
- \( v = 10^7 \) m/s
1. The picture above shows a top-down view of a solenoid. The current I in the solenoid flows clockwise. Which option does the magnetic field point at the center of the solenoid?
   a. Into the page
   b. Out of the page
   c. Along the +y direction
   d. Along the -y direction
   e. Along the +x direction

3. Suppose a smaller diameter solenoid is placed inside a larger diameter solenoid, as shown in the top-down view above. The first has current I and turns per unit length L. The second has current I and turns per unit length L. What is the magnitude of the magnetic field at the center of the solenoid?
   a. \( B = \mu_0 I \pi \frac{L}{n} \)
   b. \( B = \mu_0 I \pi \frac{L}{n} \)
   c. \( B = \mu_0 I \pi \frac{L}{n} \)
   d. \( B = \mu_0 I \pi \frac{L}{n} \)
   e. \( B = \mu_0 I \pi \frac{L}{n} \)

4. If you have a solenoid 3 m long that consists of 160 turns, what current must you put through it to produce a 0.1 T magnetic field at the center?
   a. 0.2 A
   b. 3.1 A
   c. 39.8 A
   d. 125 A
   e. 360 A

\[ B = \mu_0 \frac{I}{N} \frac{L}{\text{turns}} \]

\[ I = \frac{B \mu_0}{N} \frac{L}{\text{turns}} \]

So \( 10^{-6} \) m & 169
The next two questions refer to the following situation:

As shown in the picture below, two long, straight wires are separated by 2m. The point P lies at the midpoint of the line connecting the two wires.

5. If the current through wire A is 1 A and no current flows through wire B, what is the magnitude of the magnetic field at point P?
   a. $1 \times 10^{-7} \text{T}$
   b. $2 \times 10^{-7} \text{T}$
   c. $3 \times 10^{-7} \text{T}$
   d. $5 \times 10^{-7} \text{T}$
   e. $1 \times 10^{-7} \text{T}$

6. What is the direction of the magnetic field at point P if 1 A flows through wire B into the page?
   a. into the page
   b. Out of the page
   c. up direction
   d. down direction
   e. The magnetic field would be zero

The next two questions pertain to the same situation:

10. A square loop (connected to a battery not shown in the picture) has a current I flowing in the loop as indicated below and lies in the x-y plane. The loop is in an external uniform magnetic field B which points in the z direction. The left side of the loop is labeled a. In which direction does the loop rotate?

11. The current in the loop is I = 3.3 A, the side is 10 cm, the magnetic field B = 1 T and the number of turns in the loop N = 3. What is the magnitude of the torque on the loop?
   a. T = 0.023 N·m
   b. T = 0.074 N·m
   c. T = 0.127 N·m
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12. If we want current B to have a net force of zero on it, then in what direction should current C point?
   a. Out of the page
   b. Into the page
   c. No current is necessary

13. Assume the direction and magnitude of the current in wire C is such that the net force on wire B is zero. In which direction could an external magnetic field be applied so that there continues to be no net force on wire B?
   a. To the left
   b. To the right
   c. Up
   d. Down
   e. Other

14. Which direction should the magnetic field point to make it possible for the particle to travel in a straight line?
   a. Out of the page
   b. Into the page
   c. Up
   d. Down
   e. Other

15. What is the initial speed of this charge if it travels in a straight line?
   a. 40 m/s
   b. 50 m/s
   c. 100 m/s
   d. 200 m/s
   e. 60 m/s
The next question pertains to the following situation:

A charged particle with charge \( Q = 1 \text{ C} \) is travelling at \( v = 1 \text{ m/s} \) in the \( +z \)-direction toward a square with side length 5 m containing magnetic field \( B = 3 \text{ T} \) pointing into the page. The particle crosses the field at \( r = 2 \) meters above the bottom of the square. There is no magnetic field anywhere outside the square.

![Diagram of particle path]

17. The particle travels in a complete semi-circle. Given the direction of the magnetic field, this means that the particle exits at either point C or D, which you must determine. What is the mass of the particle?

\[
r = \frac{m v}{q B}
\]

a. 0.3 kg
b. 1 kg
c. 2.5 kg
d. 7.5 kg

17 of 16 pages
26 problems
The next two questions pertain to the following situation:

Two long straight wires are placed parallel to each other 9 cm apart, as shown in the figure. The current in wire 1 is oriented out of the page, and the current in wire 2 is oriented into the page. A point P is located 6 cm to the right of wire 2.

18. Calculate the net magnetic field in the y direction at the point P.
   a. \( B_y = 1.04 \times 10^{-3} \text{T} \)
   b. \( B_y = 3.99 \times 10^{-4} \text{T} \)
   c. \( B_y = 6.02 \times 10^{-3} \text{T} \)
   d. \( B_y = 5.34 \times 10^{-4} \text{T} \)
   e. \( B_y = -2.40 \times 10^{-4} \text{T} \)

19. The net magnetic field due to the two wires equals zero at a point in the region between the two wires.
   a. True
   b. False

The next three questions pertain to the following situation:

A particle of mass \( 5 \times 10^{-4} \) kg and speed \( v = 3000 \) m/s enters a region with a magnetic field \( B_{\text{top}} \) which is perpendicular to the plane of the paper. The magnitude of \( B_{\text{top}} \) is not known. The particle follows a quarter-circle trajectory and enters another region with a different magnetic field \( B_{\text{bottom}} \), which is also perpendicular to the plane of the paper. It again follows a quarter-circle trajectory. The magnitude of \( B_{\text{bottom}} \) is also not known. The radius of curvature for the motion in the top region is larger than that in the bottom region (\( r_{\text{top}} > r_{\text{bottom}} \)).

20. Given that the particle has charge \( q = 60 \mu C \), in which direction does \( B_{\text{top}} \) point?
   a. into the page
   b. out of the page

21. Which is true regarding the relationship between \( B_{\text{top}} \) and \( B_{\text{bottom}} \)?
   a. \( B_{\text{top}} < B_{\text{bottom}} \)
   b. \( B_{\text{top}} = B_{\text{bottom}} \)
   c. \( B_{\text{top}} > B_{\text{bottom}} \)

22. Calculate \( B_{\text{top}} \) if \( r_{\text{top}} \) is 1.35 meters.
   a. \( B_{\text{top}} = 4.9 \text{T} \)
   b. \( B_{\text{top}} = 18.5 \text{T} \)
   c. \( B_{\text{top}} = 68.4 \text{T} \)
   d. \( B_{\text{top}} = 173 \text{T} \)
   e. \( B_{\text{top}} = 557 \text{T} \)
The next two questions pertain to the following situation:

A square loop with sides of unknown length \( L \) is carrying a current \( I = 3 \, \text{A} \). The loop is oriented in space at a 35° angle with respect to the horizontal. The current flows into the page at the top of the loop and out of the page at the bottom of the loop, as shown in the picture below. A magnetic field of magnitude \( B = 2.8 \, \text{mT} \) is applied in an unknown direction.

23. In which direction could the magnetic field be oriented for the torque due to the magnetic field to cause the loop to rotate in the counter-clockwise (CCW) direction as viewed in the picture above?

\[ a. \, \text{out of the page} \]
\[ b. \, \text{in the plane of the page} \]
\[ c. \, \text{parallel to the page} \]

24. Present the magnetic field is now directed downward, in the -\( y \) direction. The torque on the loop is measured to be \( \tau = 6.4 \times 10^{-6} \, \text{N m} \). Calculate the length \( L \) of the sides of the square.

\[ a. \, L = 0.381 \, \text{m} \]
\[ b. \, L = 0.392 \, \text{m} \]
\[ c. \, L = 0.533 \, \text{m} \]
\[ d. \, L = 0.985 \, \text{m} \]

25. Calculate the charge \( Q \) of the particle:

\[ F = 9 \, q \, B \Rightarrow q = \frac{F}{9 \, B} \]

26. An electric field is now applied in the same region as the magnetic field. In which direction must the electric field be oriented so that the charge travels a straight-line trajectory through the region of the two fields?

\[ a. \, \text{down} \]
\[ b. \, \text{into the page} \]
\[ c. \, \text{out of the page} \]
\[ d. \, \text{right} \]

Check to make sure you bubbled in all your answers.
Did you bubble in your name, exam version and network-ID?
8. A 10^{-3} m long carbon nanotube with a mass of 2 \times 10^{-6} kg is used as a wire. As shown, the nanotube carries 10^{9} A of current in the right. If the Earth’s magnetic field is 5 \times 10^{-5} T and points into the page, what is the acceleration of the nanotube?

\[ F = I L B \sin \theta \]

\[ a = \frac{F}{m} = \frac{I L B v}{m} \]

\[ 10^{-9} A \quad 10^{-5} m \]

\[ m = 2 \times 10^{-6} kg \]
19. A long straight wire carries current, $I$, It produces a magnetic field, $B$, at a distance, $d$, from the wire. Now, both the current and the distance are doubled. Compare the new magnetic field, $B_2$, to the original field, $B_1$.

- $B_2 < B_1$
- $B_2 = B_1$
- $B_2 > B_1$

\[ B = \frac{\mu_0 I}{2\pi r} \]

20. Two wires carry current perpendicular to the page. The magnitudes of the two currents are equal, but one is into and one is out of the page, as shown. Where on the line is the magnetic field zero?

- Somewhere in region A
- Somewhere in region B
- At point C
- Somewhere in region D
- The magnetic field is not zero anywhere on the line.

Because currents are equal

21. The coil of an MRI solenoid is 8 cm long and has a 10.05 cm radius. There are 500 turns of wire. How much current is needed to produce a 3 T magnetic field inside the solenoid? (Note: This device images alive, not humans!)

\[ B = \frac{\mu_0 N I}{L} \]

- $I = 6.0 \times 10^{-17}$ A
- $I = 382$ A
- $I = 1774$ A
- $I = 1.01 \times 10^9$ A
- $I = 1.49 \times 10^9$ A
A charged dust particle, \( m = 3 \times 10^{-7} \text{ kg} \) and \( q = 1.6 \times 10^{-19} \text{ C} \), is accelerated through a 1000 V potential difference. The magnetic field is zero in the electric field region. It then enters a region that contains a uniform 1.5 T magnetic field that points into the page. \( E = 0 \) in the magnetic field region.

**Problem 22:** Which of the three paths shown in the figure does the dust particle follow?

a. Left
b. Straight
c. Right

**Problem 23:** What is the radius of curvature of the path of a proton in the magnetic field region?

\[ r = \frac{mv}{qB} \]

- a. \( r = 0.122 \text{ m} \)
- b. \( r = 0.129 \text{ m} \)
- c. \( r = 1.03 \text{ m} \)
- d. \( r = 1.09 \text{ m} \)
- e. \( r = 1.06 \text{ m} \)

**Problem 24:** A negatively charged particle, \( q \), is moving in the \( z \)-direction in a region that contains a uniform magnetic field along the \( x \)-direction. In which direction must an electric field point so that there is no net force on the particle?

a. Along \( y \)
b. Along \( x \)
c. Along \( \gamma \)
d. Along \( \rho \)
e. Along \( -x \)

**Problem 25:** An electron (mass \( m = 9.11 \times 10^{-31} \text{ kg} \), and charge \( q = -1.6 \times 10^{-19} \text{ C} \)) is initially at point \( P_0 \). It moves with speed \( v_0 = 3 \times 10^6 \text{ m/s} \) in a uniform magnetic field of strength \( B = 1.5 \text{ T} \). Now, the electron is the electron moving when it reaches point \( P_2 \), which is a. \( 2.5 \times 10^{-7} \text{ m} \) along \( B \) and \( d = 1.5 \times 10^{-7} \text{ m} \) perpendicular to \( B \) with respect to \( P_0 \).

- a. \( p_x = 5.1 \times 10^{-20} \text{ kg m/s} \)
- b. \( p_y = 3.1 \times 10^{-20} \text{ kg m/s} \)
- c. \( p_z = 5.1 \times 10^{-20} \text{ kg m/s} \)
- d. \( p_y = 6.7 \times 10^{-20} \text{ kg m/s} \)
- e. The electron does not have enough energy to reach point \( P_2 \).

**Problem 26:** The electron does not have enough energy to reach point \( P_2 \).
The next two questions pertain to this situation.

A square loop with sides, \( l = 0.1 \text{ m} \), lies in the
\( x-y \) plane and carries electric current, \( I = 3.7 \text{ A} \),
in the direction shown. The magnetic field,
\( B = 0.22 \text{ T} \), lies in the \( x-y \) plane, normal to the
plane of the loop, as shown in the diagram.

26. What value of \( \theta \) would make the torque on the loop equal to zero?

- a. \( \theta = 0^\circ \)
- b. \( \theta = 45^\circ \)
- c. \( \theta = 90^\circ \)
- d. \( \theta = 135^\circ \)
- e. The torque is never equal to zero.

27. For \( \theta = 37^\circ \), how much torque, \( \tau \), is exerted on the loop
in the direction shown?

- a. \( \tau = 4.90 \times 10^{-3} \text{ N m} \)
- b. \( \tau = 6.00 \times 10^{-3} \text{ N m} \)
- c. \( \tau = 8.14 \times 10^{-3} \text{ N m} \)
- d. \( \tau = 2.23 \times 10^{-3} \text{ N m} \)
- e. \( \tau = 8.14 \times 10^{-3} \text{ N m} \)
1. The velocity selector is set up to select positive charges only.

2. What is the magnitude of the magnetic field $B_1$ in the region of the velocity selector?

   - $B_1 = 0.13 \ T$
   - $B_1 = 1.1 \ T$
   - $B_1 = 1.6 \ T$
   - $B_1 = 84 \ T$
   - $B_1 = 160 \ T$

3. The selected charged particles are then sent into a mass spectrometer to identify the composition of the beam from the source. The magnetic field $B_2 = 2.5 \ T$ in this region is oriented such that the charged particles deflect in semicircular arcs as shown. For a certain particle to detour, the mass is measured to be $m = 1.56 \times 10^{-24} \ kg$ for following a path of radius $r = 3.5 \ mm$. What is the charge $q$ of the particle?

   - $q = 41.8 \ e$
   - $q = 56.2 \ e$
   - $q = 83.2 \ e$
   - $q = 0.348 \ e$
   - $q = 25.0 \ e$

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7. A proton is moving toward a bar magnet. What is the direction of the magnetic force on the proton if it travels in the $+z$ direction at the point $G$ indicated in the figure? (The proton $Q$ is directly below the center of the magnet.)

   - a. left
   - b. right
   - c. into the page
   - d. out of the page
   - e. There is no magnetic force on the proton
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The next three questions pertain to the following situation:

Three infinitely long current-carrying wires are placed in a horizontal line, with a distance of between each. The magnitudes of the currents in each of the wires are \( I_1 = I_2 = I_3 = I \). Point \( P \) is located a distance of directly under wire 2.

10. What is the general direction of the net magnetic field at point \( P \) due to the three wires?
   a. \( \) b. \( \) c. \( \) d. \( \) e. \( \)

11. What is the \( y \)-component of the magnetic field at point \( P \)?
   a. \( B_y = \frac{2I}{2\pi d} \)
   b. \( B_y = 0 \)
   c. \( B_y = \frac{2I}{3\pi d} \)
   d. \( B_y = \frac{2I}{4\pi d} \)
   e. \( B_y = \frac{2I}{5\pi d} \)

12. What is the magnitude of the net force on a 40 m length of wire 1 due to the other two wires?
   a. \( F_{\text{net}} = \frac{2I^2L}{\pi d} \)
   b. \( F_{\text{net}} = \frac{2I^2L}{2\pi d} \)
   c. \( F_{\text{net}} = \frac{2I^2L}{4\pi d} \)

\[ F_1 = F_3 = \frac{\mu_0 I^2 L}{2\pi d} \] (of 7 pages)

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The next two questions pertain to the following situation:

A single wire loop is placed in a uniform magnetic field as shown in the diagram. The loop has radius \( R = 15 \) cm. The current in the loop is measured to be \( I = 3.33 \) A in the counter-clockwise direction, as indicated in the figure. The net torque this loop experiences is measured to be \( \tau = 5.25 \times 10^{-3} \) Nm.

13. What is the magnitude of the magnetic field?
   a. \( B = 66.7 \) mT
   b. \( B = 22.3 \) mT
   c. \( B = 57.3 \) mT
   d. \( B = 312 \) mT
   e. \( B = 6.6 \) mT

\[ \tau = \frac{IAB\sin \theta}{2} \]

\[ B = \frac{\tau}{IA} \]

\[ B = \frac{5.25 \times 10^{-3}}{(0.15 \text{ m})^2} \]

14. Which picture below shows the direction of rotation of the loop if the loop is allowed to rotate freely?
   a. \( \) b. \( \) c. \( \) d. \( \)

\[ \text{No of 8 pages} \]

(20 problems)
The next three questions pertain to the situation described below.

A negatively charged particle, moving at a speed $v = 165 \text{ m/s}$, enters a region with $B = 0.07 \text{ T}$ that contains a uniform magnetic field of magnitude $B = 1.7 \text{ T}$ pointing out of the page, as shown in the figure. The mass and the magnitude of the charge of the particle are unknown.

1) In which direction will the particle be deflected? Show how annoy from figure (point in ___ and ___) 75%

2) What is the minimum mass-to-charge ratio ($m/q$) such that the particle can pass through the shaded region and exit through the right? Show work with $F = ma$, and solve.

- $m = 0.0064 \text{ kg}$
- $m = 0.0112 \text{ kg}$
- $m = 0.00427 \text{ kg}$
- $m = 0.00343 \text{ kg}$
- $m = 0.001956 \text{ kg}$

3) Now an electric field of magnitude $E = 78 \text{ N/C}$ is added to the shaded region. What should the speed of the particle be such that it travels in a straight line across the shaded region? Show work with $F = ma$.

- $v = 39.9 \text{ m/s}$
- $v = 1.22 \text{ m/s}$
- $v = 45.4 \text{ m/s}$
- $v = 75.6 \text{ m/s}$
- $v = 4.12 \text{ m/s}$
The next two questions pertain to the situation described below.

A rectangular loop of area \( A = 0.0053 \, \text{m}^2 \) and carrying a current \( I = 3.9 \, \text{A} \) is exposed to a uniform magnetic field of magnitude \( B = 4.6 \, \text{T} \), as shown in the figure.

4) What is the magnitude of the torque exerted on the loop?  
   \[ \Theta = 90^\circ - 18^\circ = 72^\circ \]  
   \[ \tau = IAB \sin \Theta \]
   
   a) 11.36 Nm  
   b) 11.53 Nm  
   c) 11.48 Nm

5) As seen from the front, in which direction will the loop rotate?  
   a) Clockwise  
   b) Counterclockwise

The next two questions pertain to the situation described below.

Three long, straight wires, each carrying a current \( I = 4.8 \, \text{A} \), are arranged as shown in the figure, with \( d = 8 \) m and \( \theta = 30 \) degrees.

6) What is the magnitude of the total magnetic field at the origin, \( \vec{B}_{\text{total}} \), due to the three wires?  
   \[ \vec{B} = \vec{B}_y + \vec{B}_x \]
   \[ B_y = \frac{\mu_0 I}{2r} \]  
   \[ B_x = 2 \frac{\mu_0 I}{2r} \frac{\sqrt{3}}{2} \]

7) What is the \( x \) component of the net force on one meter of the top wire due to the other two wires?  
   \[ \vec{F}_{\text{net}} = \left( F_{\text{net},y} + F_{\text{net},x} \right) \hat{x} \]  
   \[ F_{\text{net},y} = 2 \left( \frac{\mu_0 I}{2} \right) \frac{I}{2} \cos \theta \]
   \[ F_{\text{net},x} = 2 \frac{\mu_0 I}{2} \frac{I}{2} \cos \theta \]
   \[ F = \frac{\mu_0 I^2}{2 \pi d} \cos \theta \]
The next three questions pertain to the situation described below.

Mass spectrometers often contain a device called a velocity selector, which consists of a chamber with perpendicular \(E\) and \(B\) fields. The trajectories of the fields are such that only particles with speed \(v = 1 \times 10^8 \text{m/s}\) travel along a straight line trajectory \(\text{b}\) through the opening at the far end of the chamber.

7) Given the \(E\) field pointing up, which direction of the \(B\) field would give the observed trajectory \(\text{b}\)? You may assume that the particle charge \(Q\) is positive.

- out of the page
- to the right
- to the left
- into the page
- the \(B\) field is zero

8) Does your answer to the previous problem change if the charge \(Q\) is negative?

- Yes
- No

9) As shown in the figure, two other particles move along the dotted trajectories \(a\) and \(c\). Which of the following statements must be true? Again assume \(Q\) is positive.

- \(v_a > v_b > v_c\)
- \(v_a = v_b > v_c\)
- \(v_a = v_b = v_c\)
- \(v_a < v_b < v_c\)
The next three questions pertain to the situation described below.

Consider the following RC circuit: $R_1 = 4 \, \text{k} \Omega$, $R_2 = 6 \, \text{k} \Omega$, $C = 0.4 \, \mu \text{F}$, and $E = 9 \, \text{V}$. Initially, the capacitor is uncharged. At some time, the switch is closed.

![Circuit Diagram]

13) What is the current through the battery, $I_{\text{bat}}$, immediately after the switch is closed?
   - $I_{\text{bat}} = C \frac{dV}{dt}$
   - Initial condition: $V = 0$, so $I_{\text{bat}} = 0$

14) What is the current through the battery, $I_{\text{bat}}$, one second after the switch is closed?
   - $I = \frac{3}{2} \, \text{mA}$
   - $I = \frac{E}{R_1 + R_2} = \frac{9}{3000} = 0.003 \, \text{A} = 3 \, \text{mA}$

15) How much time does it take for the charge $Q$ to decrease to 50% of its initial value after the switch is re-opened?
   - $Q = Q_0 e^{-t/RC}$
   - $Q = \frac{1}{2} Q_0$
   - $t = RC \ln(2)$

The next three questions pertain to the situation described below.

![Loop Diagram]

A rectangular loop of length $L = 0.445 \, \text{m}$ and width $W = 0.235 \, \text{m}$ carries a current $I = 3.94 \, \text{A}$ is exposed to a uniform magnetic field of magnitude $B = 5.5 \, \text{T}$, as shown in the figure.

18) What is the magnitude of the force experienced on wire segment $AB$?
   - $F = BIL \sin \theta$ = $3.94 \times 0.445 \times 3.94 \times 5.5 \, \text{T}$

19) What is the magnitude of the torque exerted on the loop?
   - $T = IAB \sin \theta = 3.94 \times 0.445 \times 3.94 \times 5.5 \, \text{T}$

20) As seen from the front, in which direction will the loop rotate?
   - Counterclockwise
The next two questions pertain to the situation described below.

Consider a beam of identical particles with the same charge $q$ and mass $m$ travelling along the dotted trajectories as they enter a region containing a uniform $B$ field pointing into the page.

10. What is the sign of the charge of the particles?
   a. positive
   b. the sign cannot be determined
   c. negative

11. Particles moving along which trajectory have the largest kinetic energy?
   a. trajectory a
   b. trajectory b
   c. trajectory c

The next three questions pertain to the situation described below.

Consider the following circuit: $R_1 = 10 \Omega$, $R_2 = 4 \Omega$, $R_3 = 3 \Omega$, $E_1 = 17 \text{ V}$ and $E_2 = 8 \text{ V}$. Initially the switch is open.

![Circuit Diagram]

13. You connect a voltmeter at points $A$ and $B$ in the circuit. What is the electric potential difference, $V_{AB} = V_A - V_B$, measured between those points?
   a. $V_{AB} = 17 \text{ V}$
   b. $V_{AB} = 12 \text{ V}$
   c. $V_{AB} = 9 \text{ V}$

14. Now the switch is closed. Using the same voltmeter at points $A$ and $B$, measure the electric potential difference, $V_{AB} = V_A - V_B = 3.33 \text{ V}$ in which direction does the current flow through resistor $R_3$?
   a. no current flows
   b. up
   c. down

14. When is the current $I_2$ through resistor $R_3$ after the switch is closed?
   a. $I_2 = 1 \text{ A}$
   b. $I_2 = 3 \text{ A}$
   c. $I_2 = 2 \text{ A}$
The next three questions pertain to the situation described below.

Three long, straight wires are arranged as shown in the figure:

\( a = 3.5 \text{ m}, \ b = 2 \text{ m} \) and \( \theta = 30^\circ \). Each wire carries a current \( I = 3.3 \text{ A} \).

21) Which vector best represents the direction of the total magnetic field at the origin due to the three wires?

- a. Figure B
- b. Figure C
- c. Figure D
- d. Figure E
- e. Figure A

22) What is the magnitude of the total magnetic field at the origin, \( B_{\text{total}} \), due to the three wires?

\[ B_y = B_1 + B_2 = 2B_1 = 2\mu_0 I \]

\[ B_x = B_3 = \frac{\mu_0 I}{2\pi b} \]

\[ B^2 = B_x^2 + B_y^2 = \frac{\mu_0 I^2}{(2\pi b)^2} \left( \frac{4}{a^2} + \frac{1}{b^2} \right) \]

23) What is the direction of the net force on one meter of Wire 3 due to the other two wires?

- a. \( \theta \) direction
- b. \( 0 \) direction
- c. \( -\theta \) direction
- d. \( +\theta \) direction

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21. Which of the equations below correctly describe the circuit above?

I. \( V_0 - RFV - e = 0 \)
II. \( V_0 - \frac{1}{2}R^2 = 0 \)
III. \( V_0 + RFV - \frac{1}{2}R^2 = 0 \)

a. I and II
b. II and III
c. I and III

d. None of the above.

25. What is the current through the 5 \( \Omega \) resistor immediately after the switch is closed?

a. 0.9 A
b. 0.5 A
c. 0 A

d. 10 V

e. 10 V

26. What is the voltage across the capacitor after the switch has been closed for a long time?

a. 4.55 V
b. 2.45 V
c. 1.55 V
d. 3.5 V
e. 10 V

27. The switch has been closed for a long time, it is then opened again. What is the current through the 15\( \Omega \) after the switch has been open for 30s?

a. 0.26 A
b. 0.23 A
c. 0.13 A
d. 0.30 A
e. 0.16 A

Check to make sure you bubbled in all your answers. Did you bubble in your name, exam version and network-ID?
The next three questions pertain to the situation described below.

Consider the circuit shown below.

9) What is the resistance of resistor \( R_4 \)?
   - a. \( R_4 = 1 \Omega \)
   - b. \( R_4 = 2 \Omega \)
   - c. There is no value of \( R_4 \) for which \( I_V = 2 \text{ A} \).
   - d. \( R_4 = 10 \Omega \)
   - e. \( R_4 = 2 \Omega \)

10) Which of the following equations is a valid application of Kitchhoff's current law?
   - a. \( I_4 = I_5 \)
   - b. \( I_4 = I_3 = 0 \)
   - c. \( I_4 = I_3 + I_5 = 0 \)
   - d. \( I_4 = I_3 + I_5 = 0 \)
   - e. \( I_4 = I_3 + I_5 = 0 \)

11) Which of the following equations is NOT a valid application of Kitchhoff's voltage law?
   - a. \( V_4 + V_5 + (I_4)(R_4) + (I_5)(R_5) = 0 \)
   - b. \( V_4 - V_5 + (I_4)(R_4) = 0 \)
   - c. \( V_4 - V_5 + (I_4)(R_4) = 0 \)
   - d. \( V_4 - V_5 + (I_4)(R_4) = 0 \)
   - e. \( V_4 - V_5 + (I_4)(R_4) = 0 \)
The next four questions pertain to the situation described below.

Consider the circuit shown below. Initially, both switches are open and the capacitor has been charged to 10 V.

At time t=0, switch B is closed (switch A remains open).

12) What is the current through resistor R_3 just after the switch B is closed?
   \[ I = \frac{V}{R_1R_3} = \frac{10}{20} = 0.5 \text{ A} \]

13) Which of the following plots best represents the voltage V across resistor 2 starting just after switch B is closed? (The careful image is shown as answer choice)

Voltage drops across each resistor.

14) Figure repeated from previous page.

Consider the circuit shown below. Initially, both switches are open and the capacitor has been charged to 10 V. At time t=0, switch B is closed (switch A remains open).

If it takes 12 \( \mu \text{s} \) for the charge on the capacitor to drop 1/2 of its initial value, what is the capacitance of the capacitor C?
   \[ C = \frac{0.5 \times 10^{-6}}{2} = 2.5 \times 10^{-6} \text{ F} \]

15) After a very long time, switch A is closed. Switch B remains closed. What is the magnitude of the current I through resistor R_2 immediately after switch A is closed?

\[ I = \frac{30 \times 0.5}{30} = 0.5 \text{ A} \]
7. Consider the circuit below. Which of the following equations is incorrect?

\[ E_1 = E_2 \quad \frac{V}{R_1} / \frac{dR_1}{dt} = 0 \]

- a. \( E_1 = E_2 \)
- b. \( V / R_1 / \frac{dR_1}{dt} = 0 \)
- c. \( V / R_1 / \frac{dR_1}{dt} = 1 \)
- d. \( E_1 = E_2 \)
21. What is the current $I_1$ in resistor $R_1$?
   a. $I_1 = 0$ A
   b. $I_1 = 0.25$ A
   c. $I_1 = 1.30$ A
   d. $I_1 = 1.50$ A
   e. $I_1 = 17.5$ A

22. Now the switch $S$ is closed. What is the current $I_2$?
   a. $I_2 = 0$ A
   b. $I_2 = 0.25$ A
   c. $I_2 = 1.30$ A
   d. $I_2 = 1.50$ A
   e. $I_2 = 17.5$ A

At $t = 0$, the switch $S$ is flipped to position A.

23. What is the current $I_1$ in resistor $R_1$ immediately after setting the switch to A?
   a. $I_1 = 0$ A
   b. $I_1 = 0.67$ A
   c. $I_1 = 1.25$ A
   d. $I_1 = 6.75$ A
   e. $I_1 = 15$ A

24. At some time $t > 0$ later, the current through $R_1$ is found to be $I_1 = 1.25$ A. What is the charge $Q$ on the capacitor $C$ at that precise time?
   a. $Q = 30 \mu$C
   b. $Q = 31.4 \mu$C
   c. $Q = 35 \mu$C

$\Delta V = 5V - 1A(3\Omega) = 2V$

$Q = CV = 15 \times 10^{-6} \times 2V = 30 \mu$C

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(27 problems)
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The next three questions continue from the previous page.

After a long time, the switch S is reset to position B. The next three questions pertain to this situation.

25. What is the magnitude of the current \( I \) in resistor \( R_1 \) immediately after resetting the switch to B?
   a) \( I = 0 \) A
   b) \( I = 6.67 \) A
   c) \( I = 5.01 \) A
   d) \( I = 12.3 \) A
   e) \( I = 1.23 \) A

26. In what direction around the circuit does the current \( I \) flow immediately after resetting the switch?
   a) Clockwise
   c) Counterclockwise

27. Eventually, the current decays gradually to zero as shown in the figure below. Which formula best represents the time constant \( \tau \) for this decay?

   ![Graph with options: d) \( t = \frac{\tau}{e} \), c) \( t = (R_1 - R_0)C \), b) \( t = \frac{R_0}{R_1} \)]

Check to make sure you bubbled in all your answers.

Did you bubble in your name, exam version, and network ID?

14 of 15 pages
(27 problems)
The following situation pertains to the next four questions:

As shown in the diagram below, a circuit is constructed consisting of two batteries with emf $e_1$ and $e_2$ and resistors with resistance $R_1$, $R_2$, and $R_3$. Two currents $I_1$ and $I_2$ are labeled on the diagram.

1. Which equation is a correct application of Kirchhoff's laws?  
   a. $I_1 R_1 + I_2 (R_2 + R_3) = 0$  
   b. $I_1 R_1 - I_2 R_2 = 0$  
   c. $I_1 R_1 - I_2 R_3 = 0$  
   d. $I_1 R_1 + I_2 R_2 = 0$

2. Which equation is another correct application of Kirchhoff's laws?  
   a. $V_1 = e_1$  
   b. $V_2 = e_2$  
   c. $V_1 = e_1 - I_1 R_1$  
   d. $V_2 = e_2 - I_2 R_2$

5. Switch $A$ is closed at time $t=0$ and switch $B$ is left open. Which graph shown below best represents how the voltage $V_c$ across the capacitor changes with time $t$?
   a.  
   b.  
   c.  

6. After closing switch $A$ and waiting a long time, what is the charge on the capacitor?
   a.  
   b.  
   c. $Q = 6 \times 10^{-6} \text{ C} \cdot 5 \text{ V} = 30 \mu \text{C}$
The next two questions refer to the diagram on the previous page:

7. After closing switch A and waiting a long time, what is the current through the 10Ω resistor?
   - A. 0.5 A
   - B. 1.5 A
   - C. 2.5 A

   C acts like an open switch after a long time.

8. After switch A has been closed for a long time, switch A is opened and switch B is closed. Which graph best represents how the current I through the 5Ω resistor changes with time after switch B is closed?

   a) 1.25 A  
   b) 1.25 A  
   c) 1.25 A  
   d) 1.25 A  
   e) 1.25 A

   Initially, \( V_c = 5 \) V, \( \Rightarrow I = \frac{5V}{5Ω} = 1 \) A.

   (0.25 A goes through 20Ω resistor, so total \( I_{\text{tot}} = 1.25 \) A.
14. What is a valid Kirchhoff's loop rule for the circuit shown above?

- $i_1 + i_1 - i_1 R_1 = 0$
- $i_1 + i_1 - i_2 R_2 = 0$
- $i_1 - i_2 R_3 + i_1 R_4 = 0$

15. Switch A is opened. What is the current $i_1$ if switch A is left closed for a long time?

- $2 \text{ A}$ (Correct)
- $0.5 \text{ A}$

After a long time, both capacitors are fully charged.

16. Switch B is opened and switch A is left closed for a long time. Then switch A is opened and switch B is closed. What is the current $i_1$ immediately after switch B is closed?

- $2 \text{ A}$ (Correct)
- $0.5 \text{ A}$
- $0 \text{ A}$

Initially $V_{c_1} = V_{c_2} = 10 \text{ V}$

$10 \text{ V}$ across resistor $R_2$

$I = \frac{V}{R} = \frac{10 \text{ V}}{5 \Omega} = 2 \text{ A}$
KEY

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1. c
2. a
3. b
4. c
5. a
6. c
7. e
8. c
9. a
10. ae
11. d
12. a
13. b
14. b
15. c
16. a
17. b
18. shade
19. d
20. a
21. b
22. a
23. d
24. b
25. d
26. b