A proton traveling due north enters a region that contains both a magnetic field and an electric field. The electric field lines point due west. It is observed that the proton continues to travel in a straight line due north. In which direction must the magnetic field lines point?

A. up
B. down
C. east
D. west
E. south

Correct answer (A).
A sort of “projectile launcher” is shown in Fig 20-46. A large current moves in a closed loop composed of fixed rails, a power supply, and a very light, almost frictionless bar touching the rails. A magnetic field is perpendicular to the plane of the circuit. If the bar has a length of 20 cm, a mass of 1.5 g, and is placed in a field of 4.0 T, what constant current flow is needed in order for it to accelerate to 30 m/s in a distance of 1.0 m? In what direction must the field point?

\[ v_f = \sqrt{2as} \]
\[ 30 \text{ m/s} = \sqrt{2 \cdot a \cdot 1 \text{ m}} \Rightarrow a = \frac{900}{2} = 450 \text{ m/s}^2 \]
\[ F = ma = ILB; \]
\[ I = \frac{ma}{LB} = \frac{1.5 \times 10^{-3} \text{ kg} \cdot 450 \text{ m/s}^2}{0.2 \text{ m} \cdot 4 \text{ T}} \]
\[ = 0.844 \text{ A} \]

Magnetic field is down.
A wire loop with a current \( I \) is placed in a magnetic field of a permanent magnet bar as shown in Figure; the loop is in the \( x-y \) plane and the current \( I \) flows as shown (view for looking in the negative \( x \)-axis direction). Assume that the loop wires are very light and the loop is allowed to rotate around axis \( x, y \) or \( z \). What is the direction of the torque exerted on the loop by the magnetic field of the magnet?

a) Positive X direction  
b) Negative X direction  
c) Positive Y direction  
d) Negative Y direction  
e) Positive Z direction  
f) Negative Z direction

For the setup of the previous question, which axis would the loop rotate around?

a) X axis  
b) Y axis  
c) Z axis
Two long wires are perpendicular to the plane of the paper as shown in the figure below. Each wire carries a current of magnitude $I$. The currents are directed out of the paper toward you. Which one of the following expressions correctly gives the magnitude of the total magnetic field at the origin of the $(x, y)$ coordinate system?

\[ B_{\text{tot}} = \sqrt{B_1^2 + B_2^2} = \sqrt{\left(\frac{\mu_0 I}{2\pi d}\right)^2 + \left(\frac{\mu_0 I}{\pi d}\right)^2} = \frac{\mu_0 I}{\sqrt{2\pi d}} \]

a) $\frac{\mu_0 I}{2d}$  

b) $\frac{\mu_0 I}{\sqrt{2d}}$  

c) $\frac{\mu_0 I}{2\pi d}$  

d) $\frac{\mu_0 I}{\pi d}$  

e) $\frac{\mu_0 I}{\sqrt{2\pi d}}$
Solution: Interaction of wires

A long, straight wire carries a 10.0-A current in the $+y$ direction as shown in Fig. 2. Next to the wire is a square copper loop that carries a 2.00-A current as shown. The length of each side of the square is 1.00 m.

\[ F_1 = \frac{\mu_0 I_1 I_2}{2\pi d} \cdot \frac{2\pi I_0 - 2\pi I_0}{2\pi} \cdot \frac{10A \cdot 2A \cdot 1m}{0.2m} = 200 \times 10^{-7} N \]

\[ F_2 = 2 \times 10^{-7} \cdot \frac{10.2 \cdot 1m}{1.2} = 33.3 \times 10^{-7} N \]

Other sides do not influence.

Total force:

\[ F = (200 - 33.3) \times 10^{-7} = 166.7 \times 10^{-7} N \]

Force on the loop is to the left, negative $x$ direction.
A circular loop of wire rests on a table. A long, straight wire rests on the loop, directly over its center, as shown. There is no electrical contact between the wires. The current $I$ in the straight wire is decreasing.

(a) In what direction is the induced current?

(b) If a CW current $I_{loop}$ is set in the circular wire and the straight wire is mechanically fixed, which way will the circ. wire move in the magnetic field created by the straight wire?

(c) If the circular wire is fixed instead, which way the straight wire will move?
Solutions/Answers

(a) There will no induced current in the loop b/c total change of the magnetic flux is zero (positive change in one half of the loop is compensated by negative change in the other)

(b) The loop will be shifting down

(c) The wire will be shifting up
Transformer

Which one of the following statements concerning transformers is false?

(a) Their operation makes use of mutual induction.
(b) They are an application of Faraday's and Lenz's laws.
(c) A transformer can function with either an ac current or a steady dc current.
(d) A transformer that steps down the voltage, steps up the current.
(e) A transformer that steps up the voltage, steps down the current.

Correct answer is (c).
Transformer

For delivery of electrical power to a customer, a power-supply company decided to use a step-up (100:1) transformer. This would roughly

a) increase power losses in transmission lines by 100
b) increase power losses in transmission lines by 10000
c) decrease power losses in transmission lines by 100
d) decrease power losses in transmission lines by 100000
e) none of the above is the correct expectation

Correct answer is (d). Current will be decreased by 100 times, but the power losses are proportional to $i^2$, so the decreases in losses is $10^4$ times.
A 3 \( \mu \text{F} \) capacitor has a voltage of 35 V between its plates. What must be the current in 5 mH inductor, such that the energy stored in the inductor equals the energy stored in the capacitor?

\[
\frac{CV^2}{2} = \frac{Li^2}{2} \quad \Rightarrow \quad i = V\sqrt{C/L} = 0.857 \text{ A}
\]
At time t=0, the switch is closed for the bar and rail shown below. The 300 volt DC supply has an internal resistance of 4 ohms as shown. The rails have negligible resistance. The 20.4 kg bar has an internal resistance of 2 \( \Omega \). The dynamic coefficient of friction is 0.3. There is a uniform perpendicular magnetic field of density 0.6 T acting downward throughout the region between the rails, which are separated by 1.5 m. A constant external force of 40 N acts to the right on the bar.

(a) Show the electrical equivalent circuit and free body diagram for the system.

(b) For the steady-state condition, determine:

(i) Direction of motion of the bar
(ii) Direction and magnitude of the current
(iii) Velocity of the bar
(iv) Polarity and magnitude of voltage between the rails
(v) Complete power balance of the system
(vi) Complete energy conversion analysis
(vii) Is the bar motor or generator? Explain

(c) After steady-state is reached, the magnetic field density suddenly increases to 1.25 T downward. Determine new velocity and direction of bar’s motion
Problem setup

\[ R = 4 \Omega \]
\[ W \]
\[ R = 2 \text{bar} W \]
\[ E = 300V \]
\[ m = 0.3 \text{ kg} \]
\[ B = 20.4 \text{ kg} \]
\[ B = 0.6 \text{ T} \]
\[ l = 1.5 \text{ m} \]
\[ F = 40 \text{ N} \]
\[ \mu = 0.3 \]
(i) Assume that the bar is moving to the left. Then, the polarity of motional e.m.f. $\epsilon_m$, and electric equivalent circuits $\frac{\epsilon}{R}$, $\frac{E_m}{E}$.

Both batteries, $\epsilon = 300V$ and $E_m$, provide $CW$ current. Magnetic force on the bar is oriented to the right, so that the free body diagram looks as follows:

There are no forces to support motion to the left $\Rightarrow$ assumption that the bar is moving to the left is wrong. We have to consider the problem assuming that the bar is moving to the right.

(ii) Electric circuit: $\frac{\epsilon}{R}$, $\frac{E_m}{E}$.

Free body diagram:
(b) We have to assume that the current in the circuit is CW directed. We are not sure about this since $E = 300\, V$ and $E_m$ are acting in opposite directions. But... if the current is in CCW direction, then the free body diagram is

\[ F_{fric} = \mu N = \mu mg \approx 60\, N \]

\[ F_{ext} = 40\, N \]

$F_{fric} > F_{ext}$ and for the bar to move to the right there is not enough force $\Rightarrow$ $F_m$ must be directed to the right, as shown on free body diagram.

Newton's law for motion in horizontal direction:

$F_{ext} + F_m = F_{fric} \Rightarrow F_m = F_{fric} - F_{ext} = 60 - 40 = 20\, N$

$F_m = IEB = 20\, N \Rightarrow I = \frac{EB}{I_m} = \frac{EB}{1.5} \approx 22.2\, A$

(iii) KVL for the circuit (\#):$E - I(4.2 + 2.2) - E_m = 0 \Rightarrow E_m = E - I \cdot 6 = 300 - 22.2 \cdot 6 \approx 166.7\, V$

$E_m = EVB \Rightarrow V = E_m/EB = 166.7/1.5 \approx 111\, V$

(iv) Voltage across the bar:

\[ V_{bar} = E_m + I \cdot 2.3 \approx 211\, V \]
(v) Power balance

Supplied by battery: $\epsilon \cdot I = 6660 \text{W}

Supplied by external force: $F_{\text{ext}} \cdot v = 7408 \text{W}

Delivered to resistors: $I^2 (4R + 2R) = 2957 \text{W}

Losses due to friction: $F_{\text{fric}} \cdot v = 1111 \text{W}

$P_{\text{in}} = 6660 + 7408 = 14068 \text{W}$

$P_{\text{out}} = 2957 + 1111 = 14068 \text{W}$

$P_{\text{in}} = P_{\text{out}}$

Summary diagram:

(vi) Power conversion:

Electric power in: $+6660 \text{W}$

Electric power out: $-2957 \text{W}$

Net electric power: $+3703 \text{W}$
Solution

Mechanical power in: +7408W
Mechanical power out: -11112W
Net mechanical power: -3704W < 0

Net electric power = Net mechanical power

(vii) By looking at the forces and the velocity directions, one can conclude that this setup is either a generator with electrical support or a motor with mechanical support.

By looking at energy conversion, we see that there is access of electrical power and deficiency in mechanical power so that overall electric energy goes to mechanical energy. This is typical for a motor setup.

One preferably should classify this setup as a motor with mechanical support.

(c) After B-jump to 1.25 T, a new steady state has the same free-body diagram and electric equivalent

\[ I = 10.7 A \]
\[ E_m = 235.9 V \]
\[ v = 25.8 \text{ m/s} \]
Solution

TRANSITION TO NEW EQUILIBRIUM STATE

\[ t = 0^- \]
\[ F_2 = 60N \quad F_\text{app} = 40N \quad F_m = 20N \]
\[ V = 185.2 \text{ m/s} \quad I = 22.2 \text{ A} \]

\[ t = 0^+ \]
\[ F_m = 14.8N \quad F_\text{app} = 40N \quad V = 185.2 \text{ m/s} \]
\[ I = \frac{347.3 - 300}{6} = 7.9 \text{ A} \]

At certain time \( t^* \)

no current, \( I = 0 \)
\[ F_m = 0 \quad V = 160 \text{ m/s} \]
\[ 60N \quad 40N \]

\( F_m = 7.9 \times 1.5 \times 1.25 = 14.8N \)
\[ \varepsilon_m = 1.5 \times 185.2 \times 1.25 = 347.3V \]
\[ \varepsilon = \frac{347.3}{1.5 \times 1.25} = 160 \text{ m/s} \]

At time \( t^* \)

at the new equilibrium state
\[ V = 125.8 \text{ m/s} \]
\[ F_m = 20N \]
\[ I = 10.7 \text{ A} \]
\[ 60N \quad 40N \]

\[ \varepsilon_m \approx 236V \]