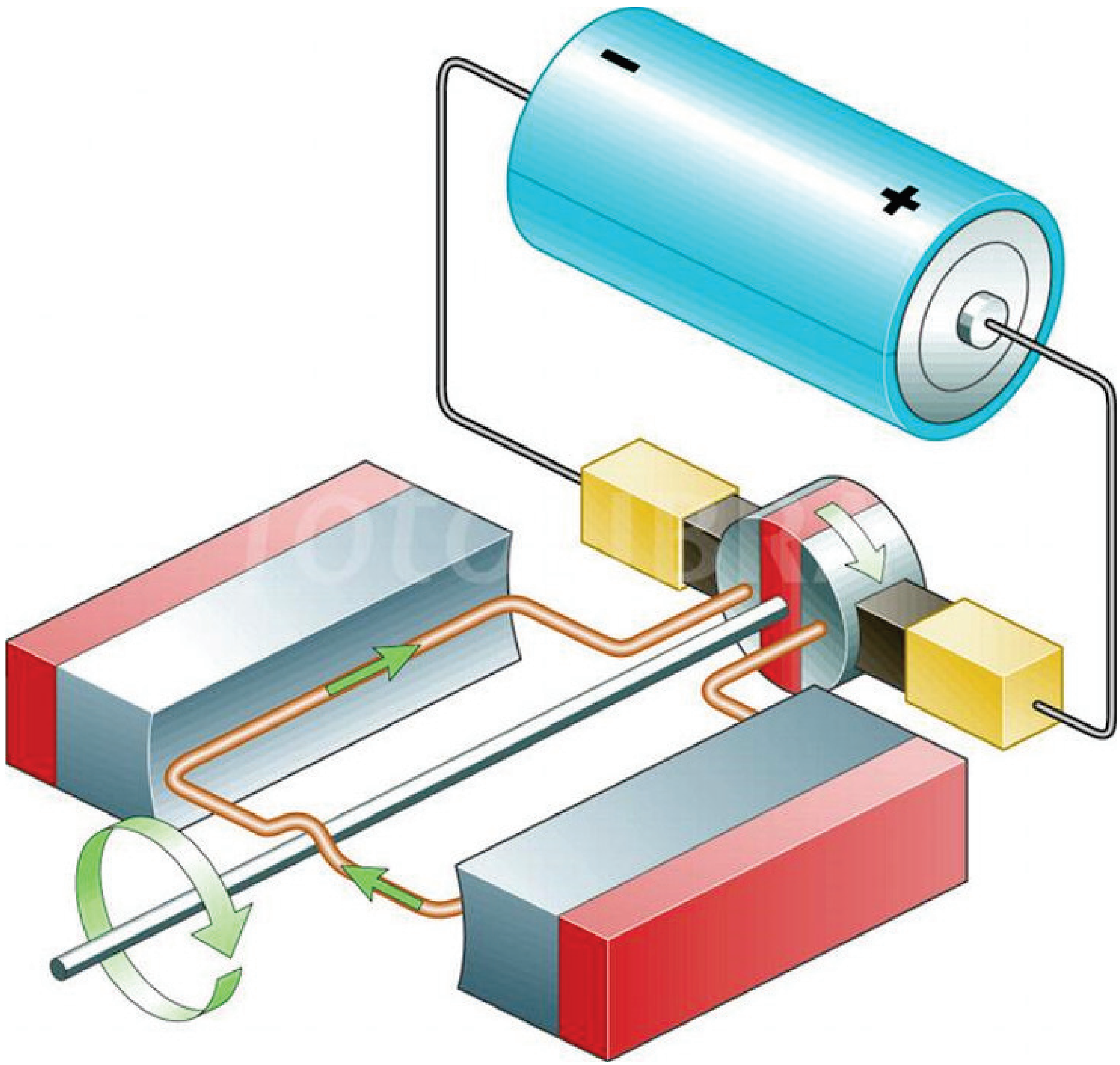
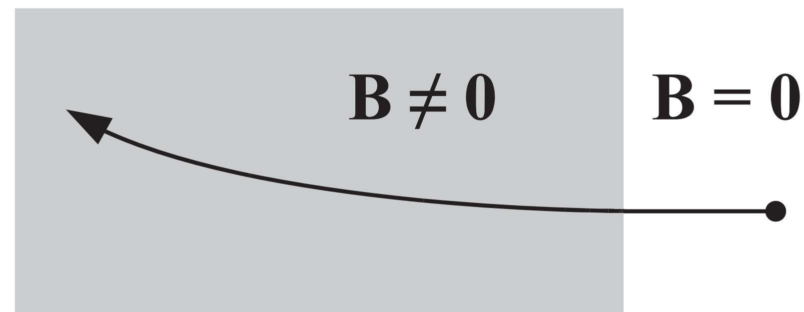
Magnetic Forces



A beam of electrons enters a region with a non-zero magnetic field and follows a trajectory as shown below. The magnetic field must be pointed



A. downward

B. upward

C. into the plane

D. out of the plane

E. leftward

F. rightward

G. at some odd angle

H. It depends on position

ANS: C—The magnetic field must point into the plne.

Confirm this by using the right-hand rule, which gives $\vec{v} \times \vec{B}$ downward. Because they're electrons (negative charge), the direction is reversed and the path bends upward.

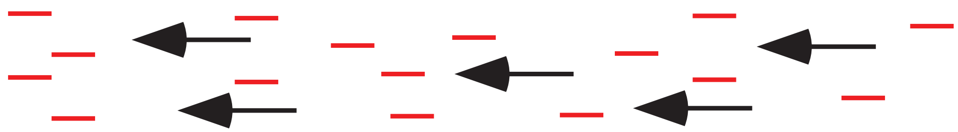
A current is formed by a stream of leftward moving electrons, as shown below. In what direction is the electric current?

A. Left

B. Right

C. There is no current

D. more information needed



ANS: B—The current points to the right.

Electric current is a measure of the flow of positive charge through a circuit. The direction of current is always opposite the direction of electron flow in a wire.

A current is formed by a stream of positively charged particles flowing rightward through a wire, as shown below. In what direction is the magnetic force on the wire?

A. Left

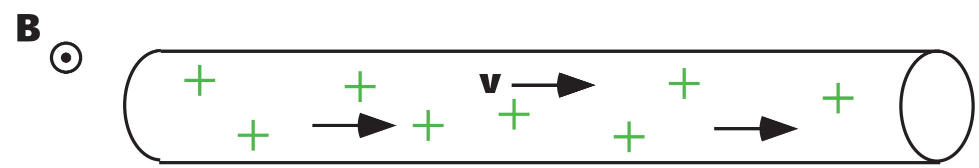
B. Right

C. Up

D. Down

E. There is no magnetic force

F. more information needed

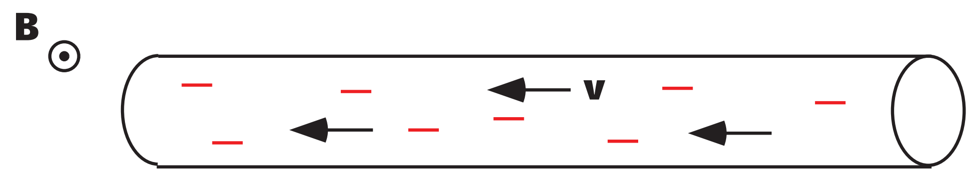


ANS: D—For force points downward.

The force on each particle is $\vec{F}_B = q\vec{v} \times \vec{B}$, where $\vec{v}$ points to the right and $\vec{B}$ points out of the page. Therefore, $\vec{v} \times \vec{B}$ points downward. The charges are positive, so the force points downward, as well. This force on the charges eventually translates into force on the wire because the charges are constrained to move within the wire.

A current is formed by a stream of negatively charged particles flowing leftward through a wire, as shown below. In what direction is the magnetic force on the wire?

A. Left
B. Right
C. Up
D. Down
E. There is no magnetic force
F. More information needed



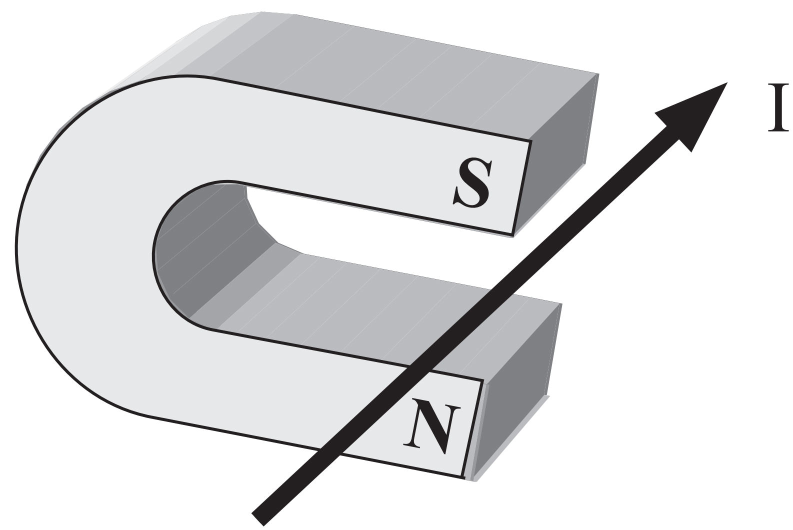
ANS: D—The force points downward.

This time it is negative charges moving to the left, with the field still pointing out of the page. In this case, $\vec{v} \times \vec{B}$ points upward. However, the force still points downward because the charges are negative so the force vector is anti-parallel to $\vec{v} \times \vec{B}$.

Note: This and the previous question have the same answer because, when looked at from the perspective of current, they are effectively the same question. In these two questions, we have electric current flowing to the right in the diagram. Instead of looking at the forces on individual charges, you can look at the force on the current. The force on a current-carrying wire of length l is $\vec{F}_B = I\vec{l} \times \vec{B}$, where $\vec{l}$ is a vector of magnitude l and pointing in the direction of the current flow. In both cases, the current and field point in the same direction so they should have the same force.

A wire is placed between the poles of a horseshoe magnetic. When the power supply is turned on, current travels into along the wire in the direction shown. In what direction is the magnetic force on the wire?

A. Left, into the horseshoe
B. Right, out from the horseshoe
C. Up
D. Down
E. None of the above
F. Need more information

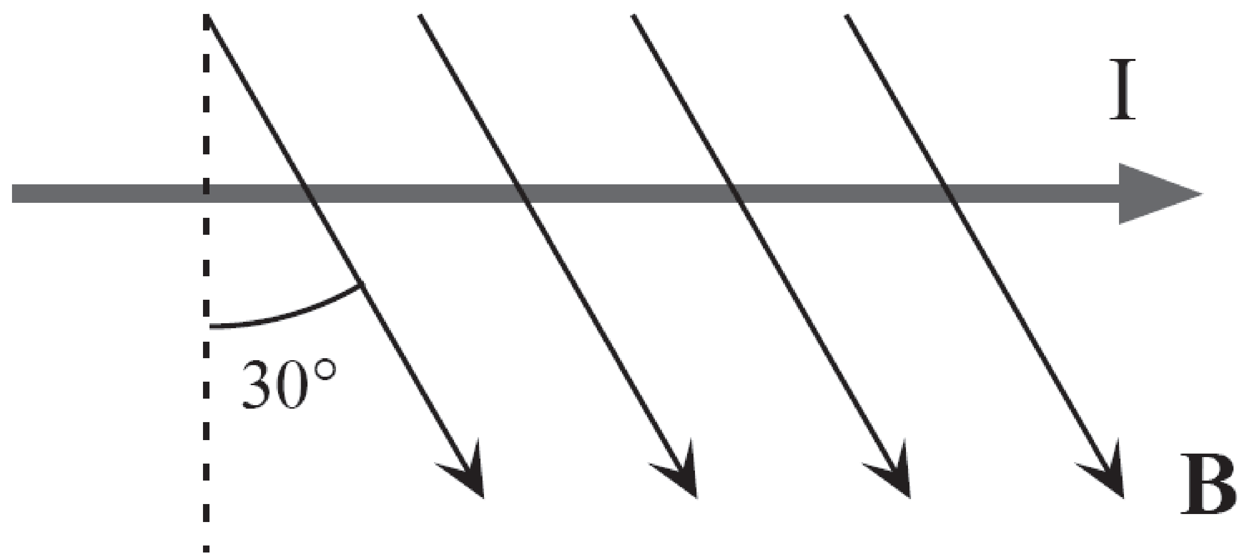


ANS: B—The force points to the right.

The current points into the page, while the magnetic field points upward (away from the North and toward the South pole). The right-hand rule applied to $\vec{F}_B = I\vec{l} \times \vec{B}$, therefore, gives a force to the right.

A horizontal wire carries a Northward current in a region where the Earth's magnetic field is $B = 50\,\mathrm{mT}$ and makes an angle of 30° to the vertical. If the magnitude of the force per length on the wire is $100\,\mathrm{mN/m}$, what is the current in the wire?

A. $2.0\,\mathrm{A} \times \sin 30^\circ$
B. $2.0\,\mathrm{A} \times \sin 60^\circ$
C. $2.0\,\mathrm{A}/\sin 30^\circ$
D. $2.0\,\mathrm{A}/\sin 60^\circ$
E. $0.5\,\mathrm{A}/\sin 30^\circ$
F. $0.5\,\mathrm{A}/\sin 60^\circ$

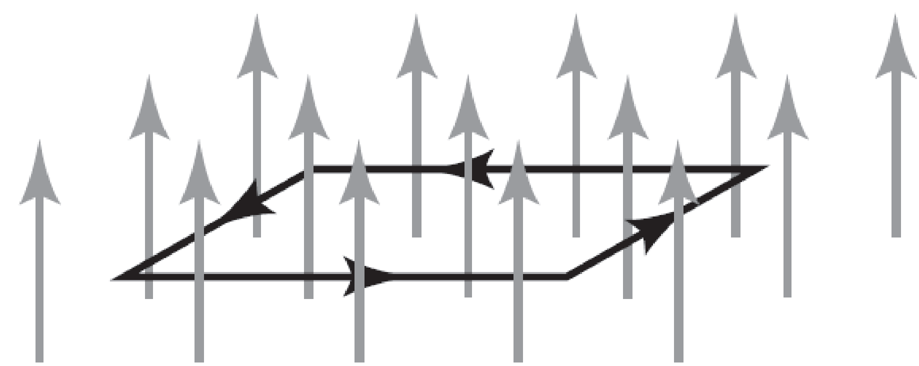


ANS: Answer **D** is correct.

The easiest way to see this is to note that, from $\vec{F}_B = I\,\vec{l} \times \vec{B}$, the magnitude of the force on a current carrying wire is $F_B = IlB\sin\phi$, where ϕ is the angle between the current and the field. In this diagram, $\phi = 60^\circ$, although this is not explicitly stated. You are given the complimentary angle instead. Therefore, $F_B = IlB\sin 60^\circ$. You are given $F_B/l = 100\,\text{mN/m}$, and $B = 50\,\text{mT}$, so $F_B/lB = 2.0\,\text{A}$. Therefore, the current through the wire is $I = 2.0\,\text{A}/\sin 60^\circ$.

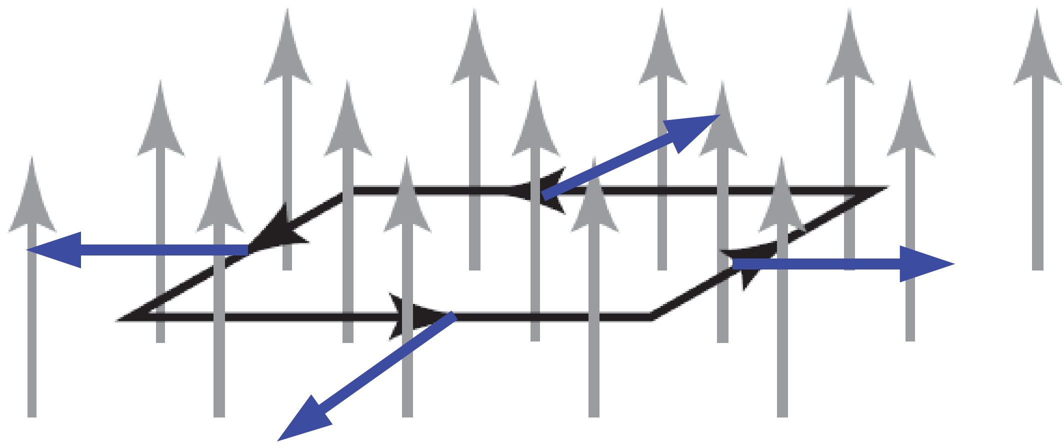
A rectangular loop is placed in a uniform magnetic field with the plane of the loop perpendicular to the direction of the field. If a current is made to flow through the loop in the sense shown by the arrows, the field exerts on the loop:

A. a net force.
B. a net torque.
C. a net force and a net torque.
D. neither a net force nor a net torque.



ANS: D—There is no net force or net torque on the loop.

The diagram below shows the forces on each segment of the wire. The two horizontal forces are equal and opposite, as are the two forces into/out of the page. Therefore, the net force on the loop is zero. Also, the torques due to these forces around any axis will sum to zero, so there is no net torque on the loop. The forces on this loop will seek to stretch the loop, but not really do anything else.



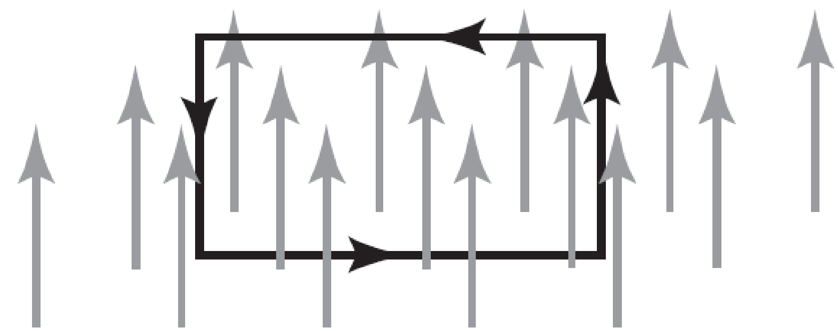
A rectangular loop is placed in a uniform magnetic field with the plane of the loop parallel to the direction of the field. If a current is made to flow through the loop in the sense shown by the arrows, the field exerts on the loop:

A. a net force.

B. a net torque.

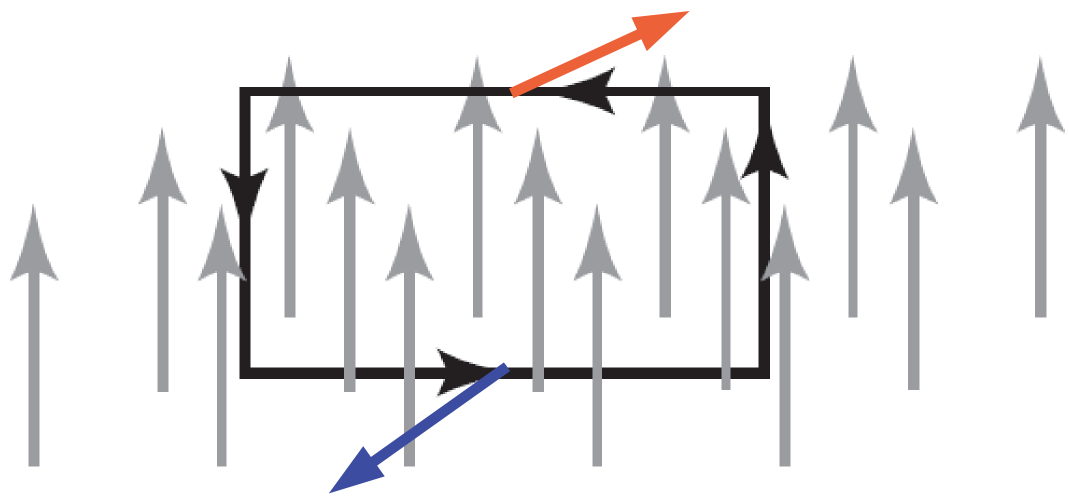
C. a net force and a net torque.

D. neither a net force nor a net torque.



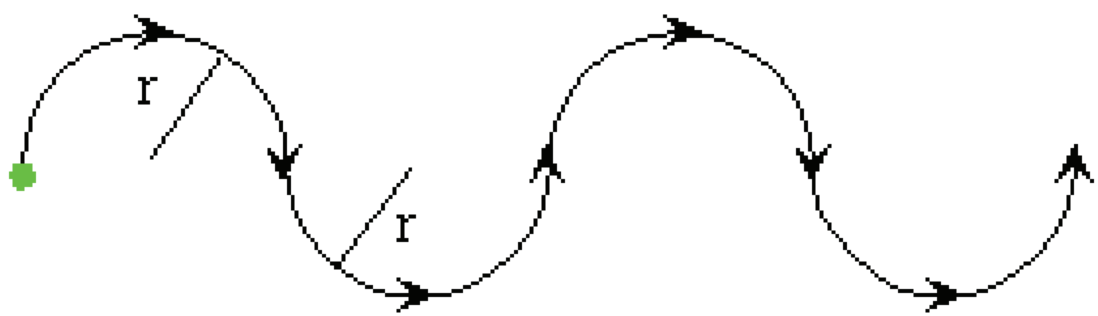
ANS: B—The field exerts a net torque on the loop.

The diagram below shows the forces on each segment of the wire. There is not a force on either of the side segments because those currents are co-linear with the field. The force on the top segment (red) points into the page. The force on the bottom segment (blue) points out of the page. Because these segments are the same length, carry the same current, and are both perpendicular to the same field, they will have the same magnitude. Therefore, the net force on the loop is zero. However, there certainly is a torque around an axis that runs horizontally through the picture. This torque will seek to turn the loop so that the face currently pointing out of the page will be turned upward.

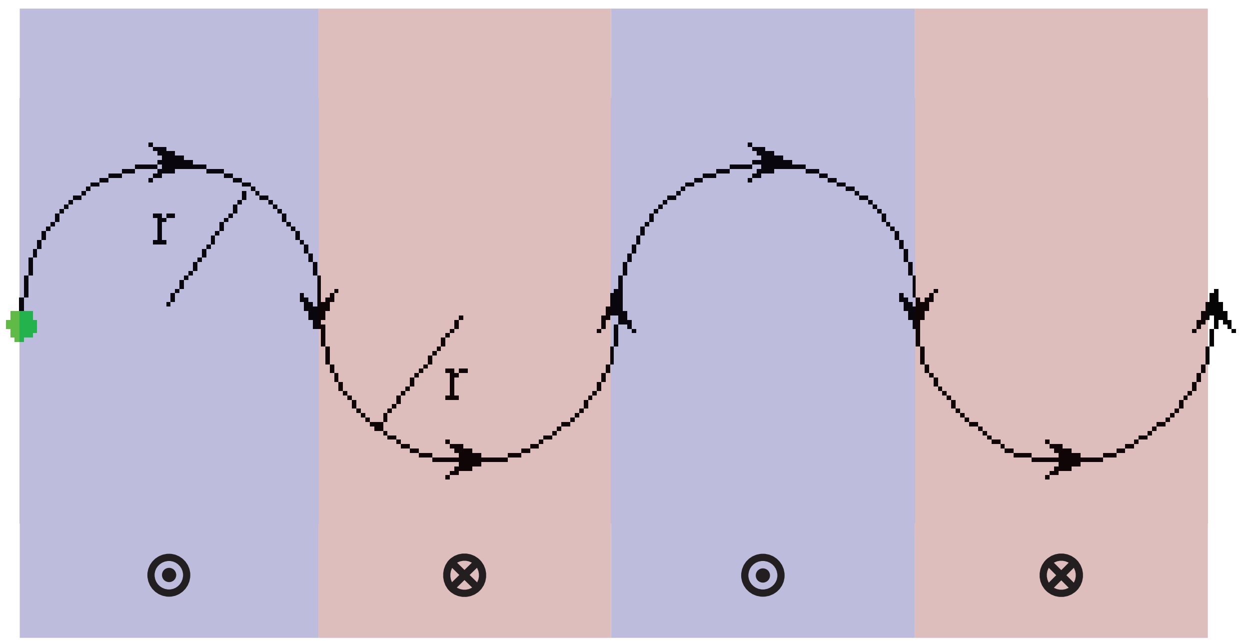


Warmup Question

Suppose a positively charged particle executes a trajectory like the one in the figure, a connected series of half circles (not a sine curve!). The half circles have the equal radii but the curvature is alternately up then down, and the particle remains in the plane of the page. If there is no other influence acting on the particle, describe an example of a nonuniform magnetic field configuration that could be produce this path.



ANS: The field appears to be a set of bands of uniform fields that alternately point out of the page and then into the page. For each semicircle, the force must be constant and must point toward the center of the circle. For the semicircles in which the positive charge follows a clockwise curve, the field must point out of the screen to give the centripetal force. For the semicircles in which the positive charge follows a counter-clockwise curve, the field must point into the screen to give the centripetal force. The forces in each region are constant, so the fields of each region must be uniform. Below is a diagram, with the fields included. The blue regions have a uniform magnetic field pointing out of the page. The red regions have a uniform magnetic field pointing into the page.



Warmup Question

The surface magnetic field of the Earth is about $0.10\,\mathrm{mT}$. If you dropped an electron from rest in the Earth's gravitational field and let it accelerate in free fall, estimate how long would it have to fall before the magnetic force equaled the gravitational force? (An electron has charge $e = 1.6 \times 10^{-19}\,\mathrm{C}$ and mass $9.11 \times 10^{-31}\,\mathrm{kg}$.) I would prefer to see no evidence of calculator usage. Brain usage, yes, calculator usage, no. Please explain your work.

ANS: Let's use nice, round numbers: $g = 10\,\mathrm{N/kg}$, $B = 10^{-4}\,\mathrm{T}$, $m = 10^{-30}\,\mathrm{kg}$, $q = 10^{-19}\,\mathrm{C}$.

We want the magnitudes of the forces to equal, or $qvB = mg$.

Substitute $v = gt$ to get $t = (mg)/(qgB) = m/(qB)$.

(Hey, we didn't even need g!).

This gives

$$t = (10^{-30}\,\mathrm{kg})/(10^{-19}\,\mathrm{C} \times 10^{-4}\,\mathrm{T}) = 10^{-7}\,\mathrm{s}\,.$$

Warmup Question

A current loop in a magnetic field tends to orient itself such that

A. it will maximize the total amount of magnetic field going through it.

B. it will minimize the total amount of magnetic field going through it.

C. it will make the total amount of magnetic field going through it equal to zero.

ANS: A—The loop will orient itself such that the total amount of magnetic field going through the loop is maximum.