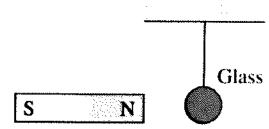
29 The Magnetic Field

29.1 Magnetism

1. A lightweight glass sphere hangs by a thread. The north pole of a bar magnet is brought near the sphere.



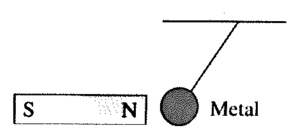
   a. Suppose the sphere is electrically neutral. How does it respond?
      i. It is strongly attracted to the magnet.
      ii. It is weakly attracted to the magnet.
      iii. It does not respond.
      iv. It is weakly repelled by the magnet.
      v. It is strongly repelled by the magnet.
      Explain your choice.

Glass experiences no force from the magnet.

   b. How does the sphere respond if it is positively charged? Explain.

The glass sphere swings toward the magnet due to a weak electrical attraction between the charged sphere and the neutral magnet. Even though there are no magnetic forces between the glass and magnet, the magnet becomes polarized near the charged sphere and exerts a polarization force on the sphere.

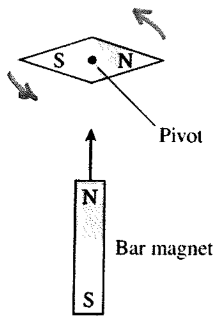
2. A metal sphere hangs by a thread. When the north pole of a bar magnet is brought near, the sphere is strongly attracted to the magnet. Then the magnet is reversed and its south pole is brought near the sphere. How does the sphere respond? Explain.



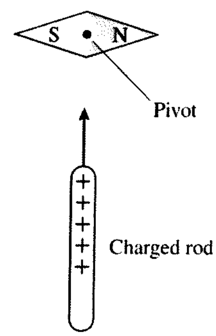
The sphere is still strongly attracted to the magnet. Magnetic materials are attracted to both poles of a magnet. This is analagous to how neutral objects are attracted to both postively charged and negatively charged objects.

3. The compass needle below is free to rotate in the plane of the page. Either a bar magnet or a charged rod is brought toward the *center* of the compass. Does the compass rotate? If so, in which direction? If not, why not?

a.



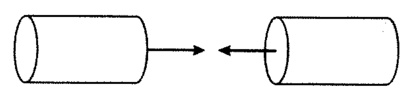
b.



a. The compass will rotate CCW so that its south end faces the north pole of the bar magnet.

b. No rotation. The charged rod exerts weak polarization forces on both ends of the compass, but the net torque on the compass remains zero.

4. You have two electrically neutral metal cylinders that exert strong attractive forces on each other. You have no other metal objects. Can you determine if *both* of the cylinders are magnets, or if one is a magnet and the other just a piece of iron? If so, how? If not, why not?



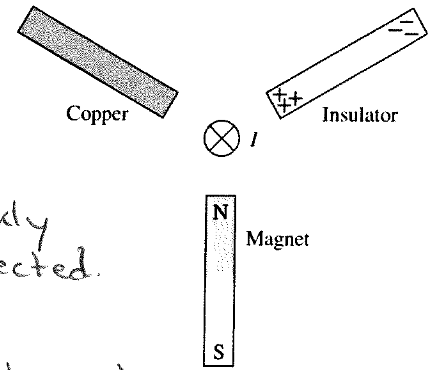
Yes. Rotate one of the cylinders 180° and if the cylinders repel each other then they both are magnets. However, if they still attract each other after the rotation then one of them is just a piece of iron.

5. Can you think of any kind of object that is repelled by *both* ends of a bar magnet? If so, what? If not, what prevents this from happening?

No. Magnets will be attracted to one end and repelled by the other. Magnetic material (e.g., iron) will be attracted to both ends of a magnet. Non-magnetic materials (e.g., wood) experience no magnetic force.

29.2 The Discovery of the Magnetic Field

6. A neutral copper rod, a polarized insulator, and a bar magnet are arranged around a current-carrying wire as shown. For each, will it stay where it is? Move toward or away from the wire? Rotate clockwise or counterclockwise? Explain.



a. Neutral copper rod

Copper rod stays put. Copper is so weakly magnetic that any effect is likely undetected.

b. Polarized insulator

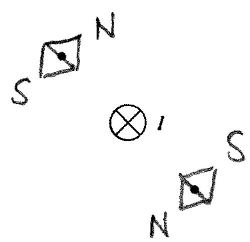
Insulator stays put. Wire may become polarized, but polarization forces are likely too weak to be detected.

c. Bar magnet

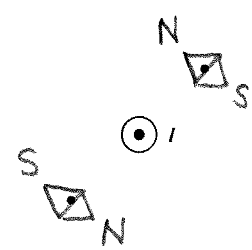
Bar magnet will rotate counterclockwise to align with the direction of the magnetic field vector generated by the current.

7. For each of the current-carrying wires shown, draw a compass needle in its equilibrium position at the positions of the dots. Label the poles of the compass needle.

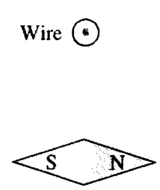
a.



b.

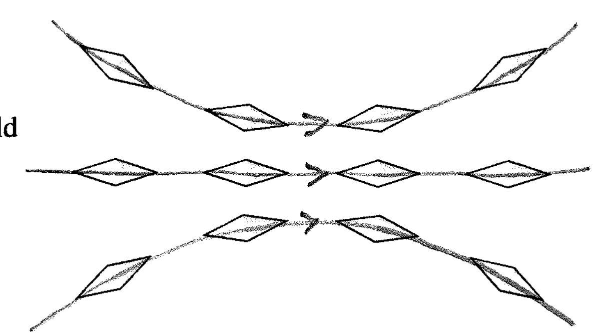


8. The figure shows a wire directed into the page and a nearby compass needle. Is the wire's current going into the page or coming out of the page? Explain.



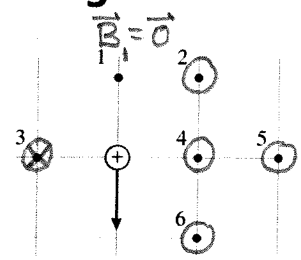
The compass needle indicates the current's magnetic field is CCW about the wire, so by the right-hand rule the current is coming out of the page.

9. A compass is placed at 12 different positions and its orientation is recorded. Use this information to draw the magnetic *field lines* in this region of space. Draw the field lines on the figure.



29.3 The Source of the Magnetic Field: Moving Charges

10. A positively charged particle moves toward the bottom of the page.



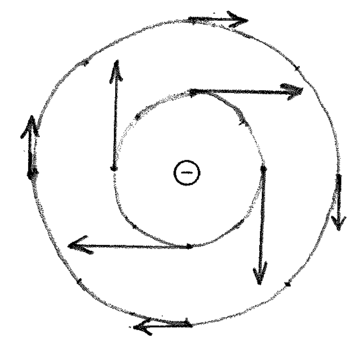
a. At each of the six number points, show the direction of the magnetic field or, if appropriate, write $\vec{B} = \vec{0}$.

b. Rank in order, from strongest to weakest, the magnetic field strengths B_1 to B_6 at these points.

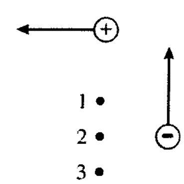
Order: $B_3 = B_4 > B_2 = B_6 > B_5 > B_1$

Explanation: The strength of $\vec{B}$ is largest for points closest to the moving charge. Use the right-hand rule to find the direction of $\vec{B}$ from a moving charge (similar to that used for current in a wire). By RHR, $\vec{B}$ points out of the page for locations to the right of the charge and into the page for locations to the left. $\vec{B} = \vec{0}$ along the line of motion (point 1).

11. The negative charge is moving out of the page, coming toward you. Draw the magnetic field lines in the plane of the page.



12. Two charges are moving as shown. At this instant of time, the net magnetic field at point 2 is $\vec{B}_2 = \vec{0}$.



a. Is the unlabeled moving charge positive or negative? Explain.

Negative. The field at point 2 due to the moving positive charge is out of the page (by RHR) so the field due to the second moving charge must be into the page so $\vec{B}_2 = \vec{0}$.

b. What is the magnetic field direction at point 1? Explain.

$\vec{B}_1$ is out of page. In comparison to point 2, point 1 is now closer to the moving ⊕ charge but farther from the moving ⊖ charge. So at point 1, the field from the moving ⊕ charge is now larger but the field from the moving ⊖ charge is now weaker.

c. What is the magnetic field direction at point 3?

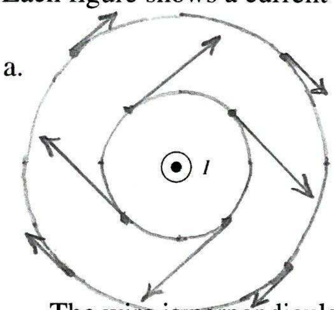
The net field is into the page.

29.4 The Magnetic Field of a Current

29.5 Magnetic Dipoles

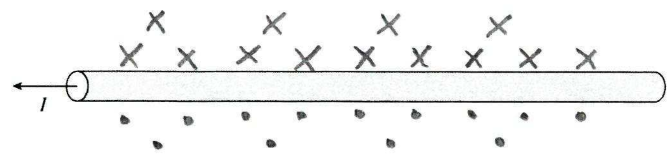
13. Each figure shows a current-carrying wire. Draw the magnetic field diagram:

a.



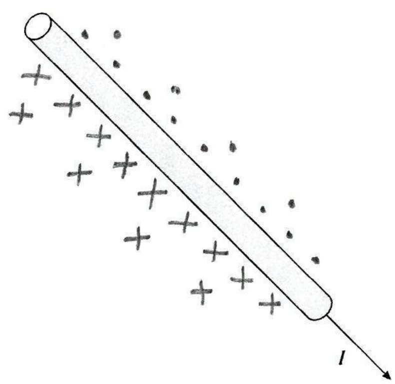
The wire is perpendicular to the page. Draw magnetic field *lines*, then show the magnetic field *vectors* at a few points around the wire.

b.

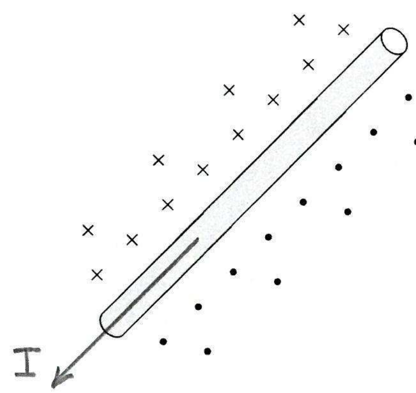


The wire is in the plane of the page. Show the magnetic field above and below the wire.

14. This current-carrying wire is in the plane of the page. Draw the magnetic field on both sides of the wire.

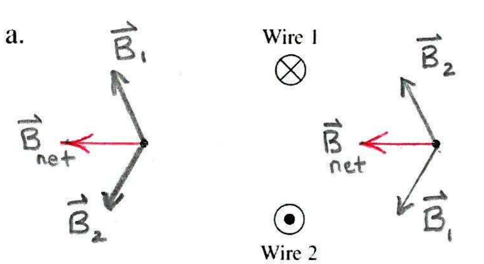


15. Use an arrow to show the current direction in this wire.

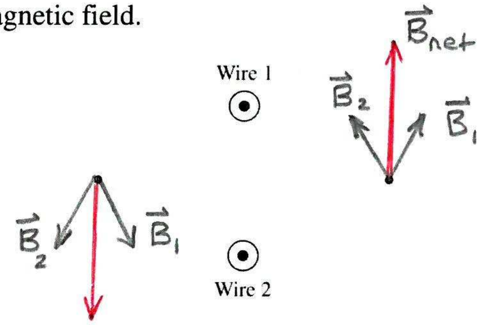


16. Each figure below shows two long straight wires carrying equal currents into or out of the page. At each of the dots, use a **black** pen or pencil to show and label the magnetic fields $\vec{B}_1$ and $\vec{B}_2$ due to each wire. Then use a **red** pen or pencil to show the net magnetic field.

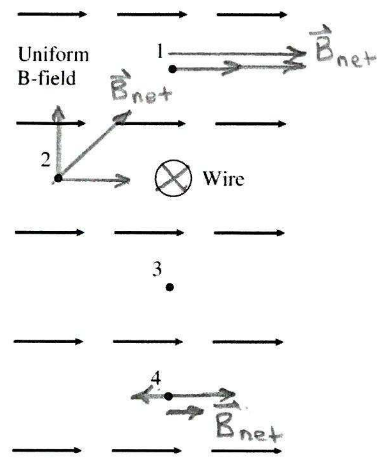
a.



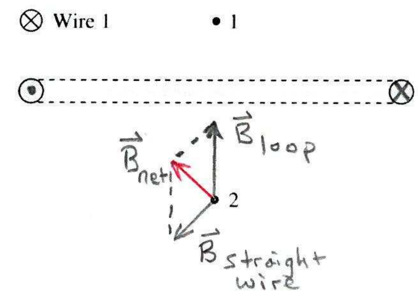
b.



17. A long straight wire, perpendicular to the page, passes through a uniform magnetic field. The *net* magnetic field at point 3 is zero.
   a. On the figure, show the direction of the current in the wire.
   b. Points 1 and 2 are the same distance from the wire as point 3, and point 4 is twice as distant. Construct vector diagrams at points 1, 2, and 4 to determine the net magnetic field at each point.



18. A long straight wire passes above one edge of a current loop. Both are perpendicular to the page. $\vec{B}_1 = \vec{0}$ at point 1.
   a. On the figure, show the direction of the current in the loop.
   b. Use a vector diagram to determine the net magnetic field at point 2.

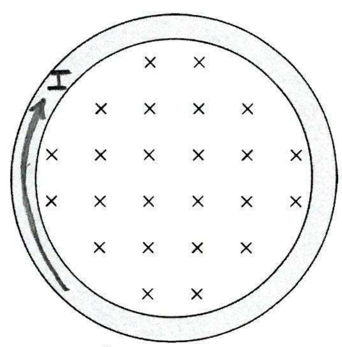


In strength, $B_{loop\,1} = B_{loop\,2}$

but $(B_{straight\ wire})_1 > (B_{straight\ wire})_2$

19. The figure shows the magnetic field seen when facing a current loop in the plane of the page.
   a. On the figure, show the direction of the current in the loop.
   b. Is the north pole of this loop at the upper surface of the page or the lower surface of the page? Explain.

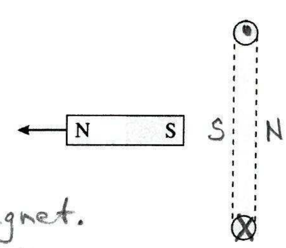
The lower surface of the page.
The north pole is the end from which the magnetic field emerges.



C.W. current

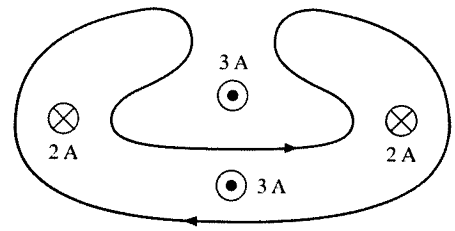
20. The current loop exerts a repulsive force on the bar magnet. On the figure, show the direction of the current in the loop. Explain.

The current loop is a magnetic dipole.
Since like poles repel, the south pole of this dipole must face the south pole of the bar magnet.
Using the right-hand rule, the $\vec{B}$-field direction of the current loop (which is to the right at the loop's center) reveals the direction of the current as shown.



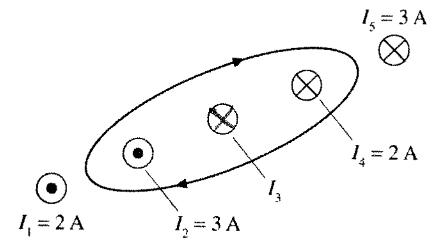
29.6 Ampère's Law and Solenoids

21. What is the total current through the area bounded by the closed curve?



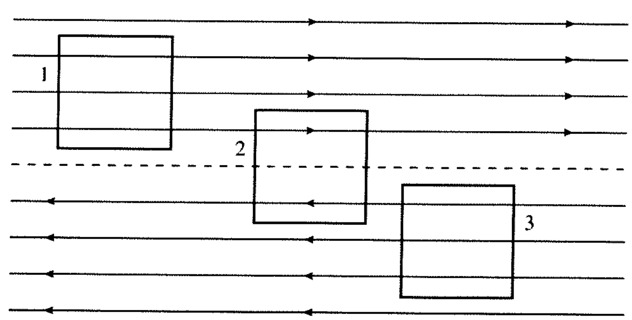
1 A into the page.

22. The total current through the area bounded by the closed curve is 2 A. What are the size and direction of I_3?



I_3 is 3A into the page.

23. The magnetic field above the dotted line is $\vec{B} = (2\text{ T, right})$. Below the dotted line the field is $\vec{B} = (2\text{ T, left})$. Each closed loop is $1\text{ m} \times 1\text{ m}$. Let's evaluate the line integral of $\vec{B}$ around each of these closed loops by breaking the integration into four steps. We'll go around the loop in a *clockwise* direction. Pay careful attention to signs.

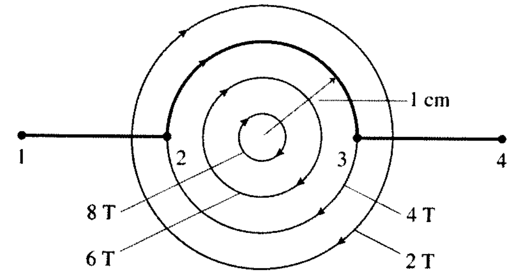


	Loop 1	Loop 2	Loop 3
$\int \vec{B} \cdot d\vec{s}$ along left edge	0	0	0
$\int \vec{B} \cdot d\vec{s}$ along top	+ 2T·m	+ 2T·m	− 2T·m
$\int \vec{B} \cdot d\vec{s}$ along right edge	0	0	0
$\int \vec{B} \cdot d\vec{s}$ along bottom	− 2T·m	+ 2T·m	+ 2T·m

The line integral *around* the loop is simply the sum of these four separate integrals:

	Loop 1	Loop 2	Loop 3
$\oint \vec{B} \cdot d\vec{s}$ around the loop	0	+ 4T·m	0

24. The strength of a circular magnetic field decreases with increasing radius as shown.



a. What is $\int_1^2 \vec{B} \cdot d\vec{s}$? 0

Explain or show your work.

$\vec{B}$ is perpendicular to the line from to 1 to 2, so the dot product is zero.

b. What is $\int_2^3 \vec{B} \cdot d\vec{s}$? 0.13 T · m Explain or show your work.

$\vec{B}$ is parallel to the path from 2 to 3.

$BL = B(\pi R) = 4T\,(\pi)(0.01m)$ ($L = \frac{1}{2}$ circumference)

c. What is $\int_3^4 \vec{B} \cdot d\vec{s}$? 0 Explain or show your work.

$\vec{B}$ is perpendicular to the line from 3 to 4, so the dot product is zero.

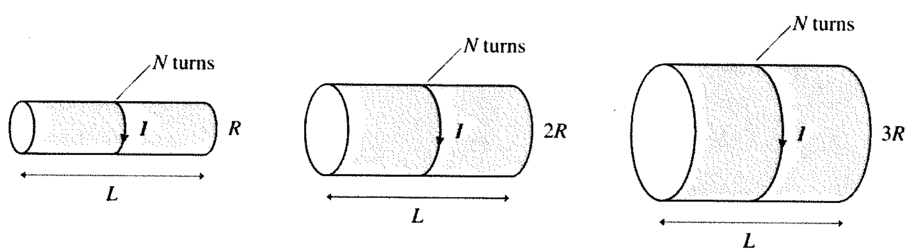
d. Combining your answers to parts a to c, what is $\int_1^4 \vec{B} \cdot d\vec{s}$? 0.13 T · m

25. A solenoid with one layer of turns produces the magnetic field strength you need for an experiment when the current in the coil is 3 A. Unfortunately, this amount of current overheats the coil. You've determined that a current of 1 A would be more appropriate. How many additional layers of turns must you add to the solenoid to maintain the magnetic field strength? Explain.

Add 2 more layers of turn.

$B_{solenoid} = \mu_0 n I$ where n is the number of turns per unit length. If I decreases by a factor of 3, then n must increase by a factor of 3 to keep $\vec{B}$ unchanged.

26. Rank in order, from largest to smallest, the magnetic fields B_1 to B_3 produced by these three solenoids.



Order: $B_1 = B_2 = B_3$

Explanation:

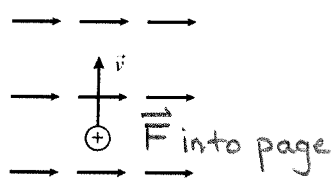
$B = \mu_0 n I$ where $n = N/L$.

B is independent of R.

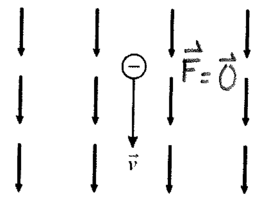
29.7 The Magnetic Force on a Moving Charge

27. For each of the following, draw the magnetic force vector on the charge or, if appropriate, write "$\vec{F}$ into page," "$\vec{F}$ out of page," or "$\vec{F} = \vec{0}$."

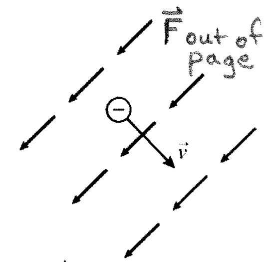
a.



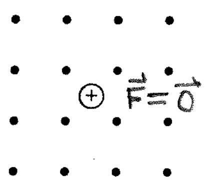
b.



c.

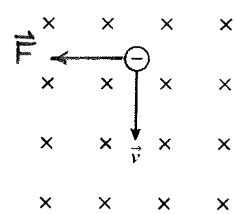


d.

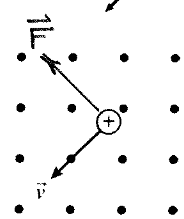


$\vec{v}$ out of page

e.

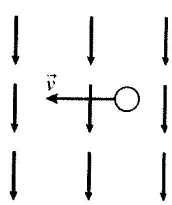


f.



28. For each of the following, determine the sign of the charge (+ or −).

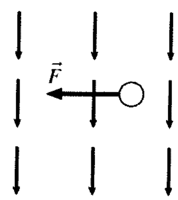
a.



$\vec{F}$ into page

$q =$ −

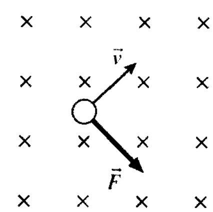
b.



$\vec{v}$ into page

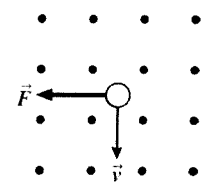
$q =$ +

c.



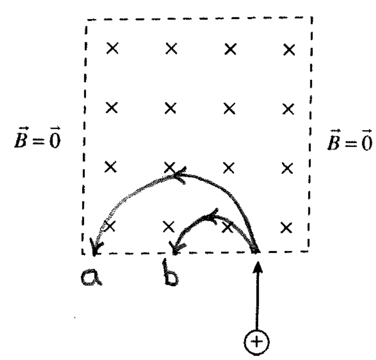
$q =$ −

d.



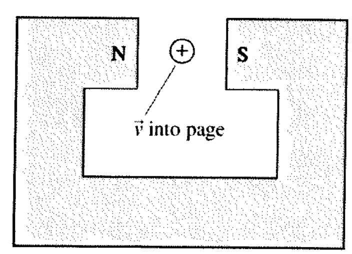
$q =$ +

29. The magnetic field has constant magnitude inside the dashed lines and is zero outside. Sketch and label the trajectory of the charge for
   a. A weak field.
   b. A strong field.



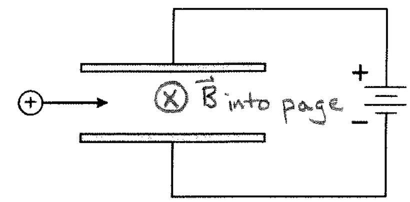
Paths are semicircles.

30. A positive ion, initially traveling into the page, is shot through the gap in a horseshoe magnet. Is the ion deflected up, down, left, or right? Explain.



Down. The $\vec{B}$-field is left to right from N pole to S pole.
Use RHR to find $\vec{F}$ direction.

31. A positive ion is shot between the plates of a parallel-plate capacitor.



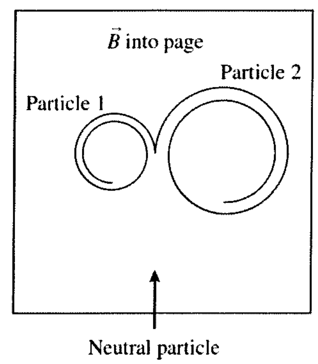
a. In what direction is the electric force on the ion?

Down.

b. Could a magnetic field exert a magnetic force on the ion that is opposite in direction to the electric force? If so, show the magnetic field on the figure.

Yes.

32. In a high-energy physics experiment, a neutral particle enters a bubble chamber in which a magnetic field points into the page. The neutral particle undergoes a collision inside the bubble chamber, creating two charged particles. The subsequent trajectories of the charged particles are shown.



a. What is the sign (+ or −) of particle 1? +

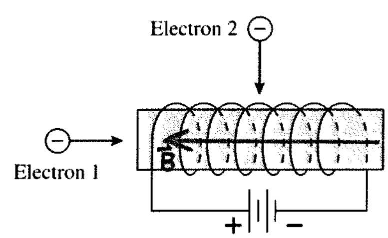
What is the sign (+ or −) of particle 2? −

b. Which charged particle leaves the collision with a larger momentum? Explain. (Assume that $|q| = e$ for both particles.)

Particle 2.

$F = qvB = \frac{mv^2}{r}$ so $mv = rqB$ The larger radius implies larger momentum.

33. A hollow solenoid is wound as shown and attached to a battery. Two electrons are fired into the solenoid, one from the end and one through a very small hole in the side.



a. In what direction does the magnetic field inside the solenoid point? Show it on the figure.

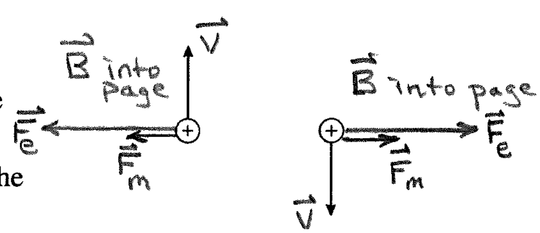
b. Is electron 1 deflected as it moves through the solenoid? If so, in which direction? If not, why not?

No. $\vec{F} = q\vec{v} \times \vec{B}$ but the angle between $\vec{v}$ and $\vec{B}$ is 180° and $\sin(180°) = 0$

c. Is electron 2 deflected as it moves through the solenoid? If so, in which direction? If not, why not?

Yes. Out of the page (by RHR).

34. Two protons are traveling in the directions shown.



a. Draw and label the electric force on each proton due to the other proton.

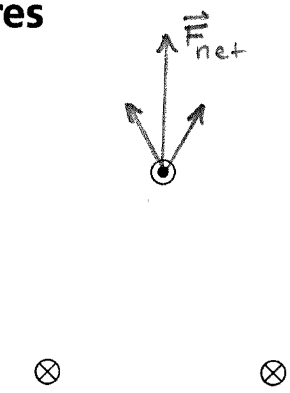
b. Draw and label the magnetic force on each proton due to the other proton. Explain how you determined the directions.

First find the direction of $\vec{B}$ from each moving charge by using the right-hand rule for fields. Then use the right-hand rule for magnetic forces where $\vec{F} = q\vec{v} \times \vec{B}$.

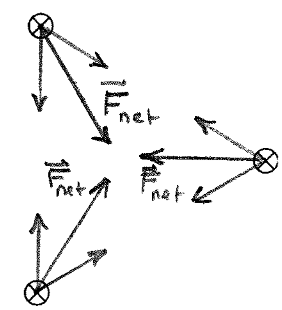
29.8 Magnetic Forces on Current-Carrying Wires

29.9 Forces and Torques on Current Loops

35. Three current-carrying wires are perpendicular to the page. Construct a force vector diagram on the figure to find the net force on the upper wire due to the two lower wires.

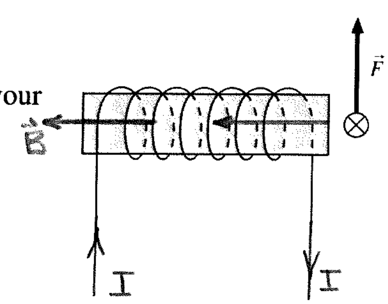


36. Three current-carrying wires are perpendicular to the page.
   a. Construct a force vector diagram on each wire to determine the direction of the net force on each wire.
   b. Can three *charges* be placed in a triangular pattern so that their force diagram looks like this? If so, draw it below. If not, why not?



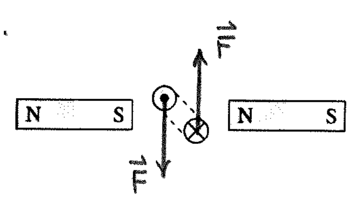
No. Charges must be different to attract each other. Here 3 different charges would be needed but only 2 different charges are known to exist.

37. A current-carrying wire passes in front of a solenoid that is wound as shown. The wire experiences an upward force. Use arrows to show the direction in which the current enters and leaves the solenoid. Explain your choice.



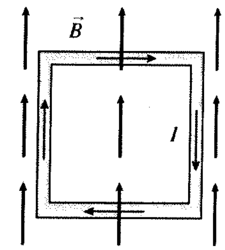
To experience an upward force, the straight wire must be in a $\vec{B}$-field that points to the left. To generate this field in the solenoid the current direction must be as shown, using RHR.

38. A current loop is placed between two bar magnets. Does the loop move to the right, move to the left, rotate clockwise, rotate counterclockwise, some combination of these, or none of these? Explain.



The loop rotates counterclockwise.
The $\vec{B}$-field created by the bar magnets points to the left. From $I\vec{\ell} \times \vec{B}$ and the RHR, we can find the direction of forces on the loop current. These forces give nonzero net torque (but $\vec{F}_{net} = \vec{0}$).

39. A square current loop is placed in a magnetic field as shown.



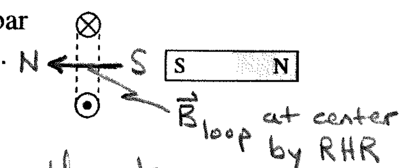
a. Does the loop undergo a displacement? If so, is it up, down, left, or right? If not, why not?

The loop will rotate but it will not undergo translational displacement since the sum of forces acting on the loop is zero.

b. Does the loop rotate? If so, which edge rotates out of the page and which edge into the page? If not, why not?

Yes. A magnetic force causes the top edge to rotate out of the page, and another magnetic force causes the bottom edge to rotate into the page.

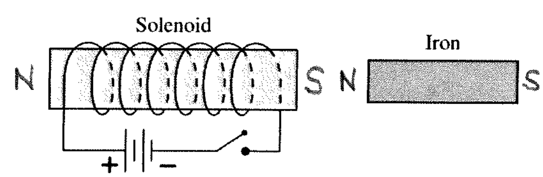
40. The south pole of a bar magnet is brought toward the current loop. Does the bar magnet attract the loop, repel the loop, or have no effect on the loop? Explain.



Repel. The current loop is a magnetic dipole with its south pole facing the south pole of the bar magnet.

29.10 Magnetic Properties of Matter

41. A solenoid, wound as shown, is placed next to an unmagnetized piece of iron. Then the switch is closed.



a. Identify on the figure the north and south poles of the solenoid.

b. What is the direction of the solenoid's magnetic field as it passes through the iron?

The solenoid $\vec{B}$-field that passes through the iron points to the left (toward the S pole of the solenoid).

c. What is the direction of the induced magnetic dipole in the iron?

The induced magnetic dipole in the iron points to the left to align with the external field from the solenoid.

d. Identify on the figure the north and south poles of the induced magnetic dipole in the iron.

e. When the switch is closed, does the iron move left or right? Does it rotate? Explain.

The iron moves to the left since opposite poles attract each other.