CHAPTER 21 | *Magnetism*

CONCEPTUAL QUESTIONS

Cutnell & Johnson 7E

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3. ssm A charged particle, passing through a certain region of space, has a velocity whose magnitude and direction remain constant, (a) If it is known that the external magnetic field is zero every where in this region, can you conclude that the external electric field is also zero? Explain. (b) If it is known that the external electric field is zero everywhere, can you conclude that the external magnetic field is also zero? Explain.

3. **SSM** ***REASONING AND SOLUTION*** A charged particle, passing through a certain region of space, has a velocity whose magnitude and direction remain constant.

a. If it is known that the external magnetic field is zero everywhere in the region, we can conclude that the electric field is also zero. Any charged particle placed in an electric field will experience a force given by **F** = *q***E**, where *q* is the charge and **E** is the electric field. If the magnitude and direction of the velocity of the particle are constant, then the particle has zero acceleration. From Newton's second law, we know that the net force on the particle is zero. But there is no magnetic field and, hence, no magnetic force. Therefore, the net force is the electric force. Since the electric force is zero, the electric field must be zero.

b. If it is known that the external electric field is zero everywhere, we *cannot* conclude that the external magnetic field is also zero. In order for a moving charged particle to experience a magnetic force when it is placed in a magnetic field, the velocity of the moving charge must have a component that is perpendicular to the direction of the magnetic field. If the moving charged particle enters the region such that its velocity is parallel or antiparallel to the magnetic field, it will experience no magnetic force, even though a magnetic field is present. In the absence of an external electric field, there is no electric force either. Thus, there is no net force, and the velocity vector will not change in any way.

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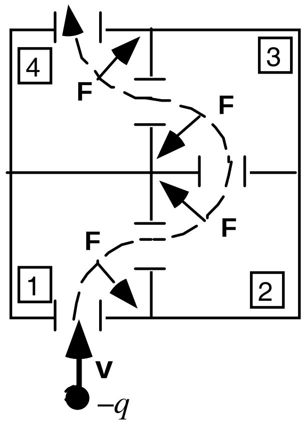
7. The drawing shows a top view of four interconnected chambers. A negative charge is fired into chamber 1. By turning on separate magnetic fields in each chamber, the charge can be made to exit from chamber 4, as shown. (a) Describe how the magnetic field in each chamber should be directed. (b) If the speed of the charge is *v* when it enters chamber 1, what is the speed of the charge when it exits chamber 4? Why?

7. ***REASONING AND SOLUTION*** The drawing shows a top view of four interconnected chambers. A negative charge is fired into chamber 1. By turning on separate magnetic fields in each chamber, the charge is made to exit from chamber 4.



a. In each chamber the path of the particle is one-quarter of a circle. The drawing at the right also shows the direction of the centripetal force that must act on the particle in each chamber in order for the particle to traverse the path. The charged particle can be made to move in a circular path by launching it into a region in which there exists a magnetic field that is perpendicular to the velocity of the particle.

Using RHR-1, we see that if the palm of the right hand were facing in the direction of **F** in chamber 1 so that the thumb points along the path of the particle, the fingers of the right hand must point out of the page. This is the direction that the magnetic field must have to make a *positive* charge move along the path shown in chamber 1. Since the particle is *negatively* charged, the field must point opposite to that direction or into the page. Similar reasoning using RHR-1, and remembering that the particle is negatively charged, leads to the following conclusions: in region 2 the field must point out of the page, in region 3 the field must point out of the page, and in region 4 the field must point into the page.

b. If the speed of the particle is v when it enters chamber 1, it will emerge from chamber 4 with the same speed v. The magnetic force is always perpendicular to the velocity of the particle; therefore, it cannot do work on the particle and cannot change the kinetic energy of the particle, according to the work-energy theorem. Since the kinetic energy is unchanged, the speed remains constant.

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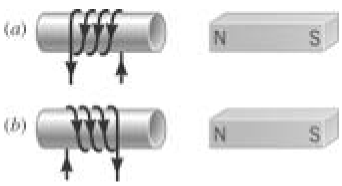
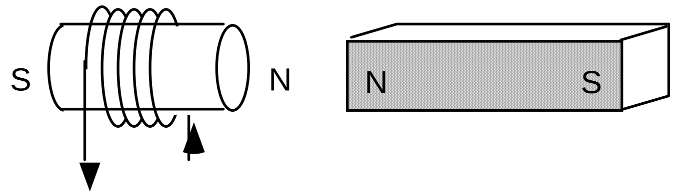
15. For each electromagnet at the left of the drawing, explain whether it will be attracted to or repelled from the permanent magnet at the right.

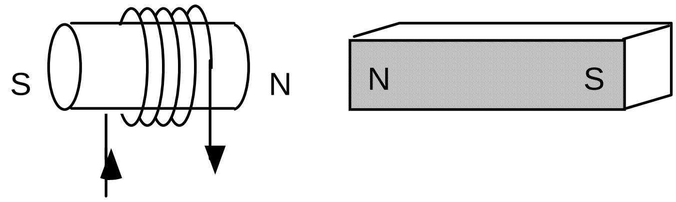


15**.** ***REASONING AND SOLUTION*** The figure below shows the arrangements of electro-magnets and magnets.

(a)



(b)



We can determine the polarity of the electromagnets by using RHR-2. Imagine holding the current-carrying wire of the electromagnet in the right hand as the wire begins to coil around the iron core. The thumb points in the direction of the current. For the electromagnet in figure (*a*), the fingers of the right hand wrap around the wire on the left end so that they point, inside the coil, toward the right end. Thus, the right end of the coil must be a north pole. Similar reasoning can be used to identify the north and south poles of the electromagnet in figure (*b*). The results are shown in the figure above. Since the like poles of two different magnets repel each other and the dissimilar poles of two different magnets attract each other, we can conclude that in both arrangements, the electromagnet is repelled from the permanent magnet at the right.

CHAPTER 21 | *MAGNETIC FORCES AND MAGNETIC FIELDS*

Samples of solutions to Problems from chapter 21Cutnell & Johnson 7E

4. When a charged particle moves at an angle of 25° with respect to a magnetic field, it experiences a magnetic force of magnitude F. At what angle (less than 90°) with respect to this field will this particle, moving at the same speed, experience a magnetic force of magnitude $2F$?

4. ***REASONING*** According to Equation 21.1, the magnetic force has a magnitude of $F = |q| vB \sin\theta$, where $|q|$ is the magnitude of the charge, B is the magnitude of the magnetic field, v is the speed, and θ is the angle of the velocity with respect to the field. As θ increases from 0° to 90°, the force increases. Therefore, the angle we seek must lie between 25° and 90°.

SOLUTION Letting θ_1 = 25° and θ_2 be the desired angle, we jcan apply Equation 21.1 to both situations as follows:

$$\underbrace{F = |q| vB \sin\theta_1}_{\text{Situation 1}} \quad \text{and} \quad \underbrace{2F = |q| vB \sin\theta_2}_{\text{Situation 2}}$$

Dividing the equation for situation 2 by the equation for situation 1 gives

$$\frac{2F}{F} = \frac{|q| vB \sin\theta_2}{|q| vB \sin\theta_1} \quad \text{or} \quad \sin\theta_2 = 2\sin\theta_1 = 2\sin 25° = 0.85$$

$$\theta_2 = \sin^{-1}(0.85) = \boxed{58°}$$

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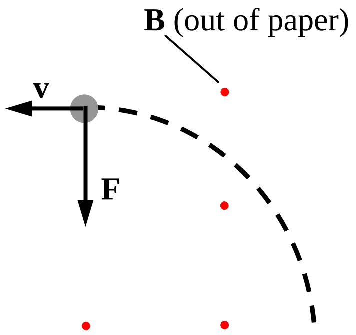
11. A charged particle enters a uniform magnetic field and follows the circular path shown in the drawing. (a) Is the particle positively or negatively charged? Why? (b) The particle's speed is 140 m/s, the magnitude of the magnetic field is 0.48 T, and the radius of the path is 960 m. Determine the mass of the particle, given that its charge has a magnitude of 8.2×10^{-4} C.

11. ***REASONING***

a. The drawing shows the velocity **v** of the particle at the top of its path. The magnetic force **F**, which provides the centripetal force, must be directed toward the center of the circular path. Since the directions of **v**, **F**, and **B** are known, we can use Right-Hand Rule No. 1 (RHR-1) to determine if the charge is positive or negative.



b. The radius of the circular path followed by a charged particle is given by Equation 21.2 as $r = mv/|q|B$. The mass m of the particle can be obtained directly from this relation, since all other variables are known.

SOLUTION

a. If the particle were positively charged, an application of RHR-1 would show that the force would be directed straight up, opposite to that shown in the drawing. Thus, the charge on the particle must be $\boxed{\text{negative}}$.

b. Solving Equation 21.2 for the mass of the particle gives

$$m = \frac{|q| Br}{v} = \frac{(8.2\times10^{-4}\ \text{C})(0.48\ \text{T})(960\ \text{m})}{140\ \text{m/s}} = \boxed{2.7\times10^{-3}\ \text{kg}}$$

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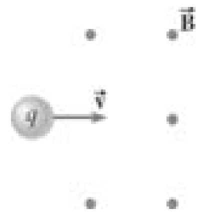
19. ssm Review Conceptual Example 2 as an aid in understanding this problem. The drawing shows a positively charged particle entering a 0.52-T magnetic field (directed out of the paper). The particle has a speed of 270 m/s and moves perpendicular to the magnetic field. Just as the particle enters the magnetic field, an electric field is turned on. What must be the magnitude and direction of the electric field such that the *net* force on the particle is twice the magnetic force?



19. SSM ***REASONING AND SOLUTION*** According to Right-Hand Rule No. 1, the magnetic force on the positively charged particle is toward the bottom of the page in the drawing in the text. If the presence of the electric field is to double the magnitude of the net force on the charge, the electric field must also be $\boxed{\text{directed toward the bottom of the page}}$. Note that this results in the electric field being perpendicular to the magnetic field, even though the electric force and the magnetic force are in the same direction.

Furthermore, if the magnitude of the net force on the particle is twice the magnetic force, the electric force must be equal in magnitude to the magnetic force. In other words, combining Equations 18.2 and 21.1, we find $|q|E = |q|vB\sin\theta$, with $\sin\theta = \sin\ 90.0° = 1.0$. Then, solving for E

$$E = vB\sin\theta = (270\ \text{m/s})(0.52\ \text{T})(1.0) = \boxed{140\ \text{V/m}}$$

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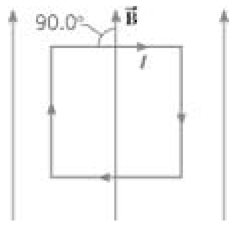
29. A square coil of wire containing a single turn is placed in a uniform 0.25-T magnetic field, as the drawing shows. Each side has a length of 0.32 m, and the current in the coil is 12 A. Determine the magnitude of the magnetic force on each of the four sides.



29. ***REASONING AND SOLUTION*** The force on each side can be found from $F = ILB\sin\theta$. For the top side, $\theta = 90.0°$, so

$$F = (12\ \text{A})(0.32\ \text{m})(0.25\ \text{T})\sin 90.0° = \boxed{0.96\ \text{N}}$$

The force on the bottom side ($\theta = 90.0°$) is the same as that on the top side, $F = \boxed{0.96\ \text{N}}$.

For each of the other two sides $\theta = 0°$, so that the force is $F = \boxed{0\ \text{N}}$.

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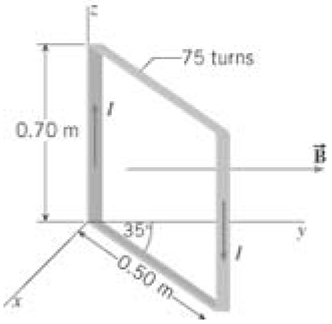
41. ssm www The rectangular loop in the drawing consists of 75 turns and carries a current of I = 4.4 A. A 1.8-T magnetic field is directed along the $+y$ axis. The loop is free to rotate about the z axis. (a) Determine the magnitude of the net torque exerted on the loop and (b) state whether the 35° angle will increase or decrease.



41. SSM WWW ***REASONING*** The torque on the loop is given by Equation 21.4, $\tau = NIAB\sin\phi$. From the drawing in the text, we see that the angle ϕ between the normal to the plane of the loop and the magnetic field is $90° - 35° = 55°$. The area of the loop is $0.70\text{ m} \times 0.50\text{ m} = 0.35\text{ m}^2$.

SOLUTION

a. The magnitude of the net torque exerted on the loop is

$$\tau = NIAB\sin\phi = (75)(4.4\text{ A})(0.35\text{ m}^2)(1.8\text{ T})\sin 55° = \boxed{170\text{ N}\cdot\text{m}}$$

b. As discussed in the text, when a current-carrying loop is placed in a magnetic field, the loop tends to rotate such that its normal becomes aligned with the magnetic field. The normal to the loop makes an angle of 55° with respect to the magnetic field. Since this angle decreases as the loop rotates, the $\boxed{35°\text{ angle increases}}$.

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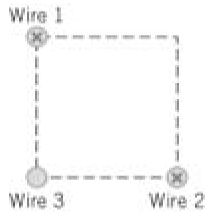
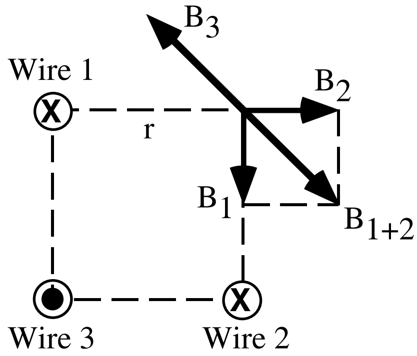
59. The drawing shows an end-on view of three wires. They are long, straight, and perpendicular to the plane of the paper. Their cross sections lie at the corners of a square. The currents in wires 1 and 2 are $I_1 = I_2 = I$ and are directed into the paper. What is the direction of the current in wire 3, and what is the ratio I_3/I, such that the net magnetic field at the empty corner is zero?



59. ***REASONING AND SOLUTION*** The currents in wires 1 and 2 produce the magnetic fields B_1 and B_2 at the empty corner, as shown in the following drawing. The directions of these fields can be obtained using RHR-2. Since there are equal currents in wires 1 and 2 and since these wires are each the same distance r from the empty corner, B_1 and B_2 have equal magnitudes. Using Equation 21.5, we can write the field magnitude as $B_1 = B_2 = \mu_0 I/(2\pi r)$. Since the fields B_1 and B_2 are perpendicular, it follows from the Pythagorean theorem that they combine to produce a net magnetic field that has the direction shown in the drawing at the right and has a magnitude B_{1+2} given by



$$B_{1+2} = \sqrt{B_1^2 + B_2^2} = \sqrt{\left(\frac{\mu_0 I}{2\pi r}\right)^2 + \left(\frac{\mu_0 I}{2\pi r}\right)^2} = \frac{\sqrt{2}\,\mu_0 I}{2\pi r}$$

The current in wire 3 produces a field B_3 at the empty corner. Since B_3 and B_{1+2} combine to give a zero net field, B_3 must have a direction opposite to that of B_{1+2}. Thus, B_3 must point upward and to the left, and RHR-2 indicates that

$\boxed{\text{the current in wire 3 must be directed out of the plane of the paper}}$.

Moreover, the magnitudes of B_3 and B_{1+2} must be the same. Recognizing that wire 3 is a distance of $d = \sqrt{r^2 + r^2} = \sqrt{2}\,r$ from the empty corner, we have

$$B_3 = B_{1+2} \qquad \text{or} \qquad \frac{\mu_0 I_3}{2\pi\left(\sqrt{2}\,r\right)} = \frac{\sqrt{2}\,\mu_0 I}{2\pi r} \qquad \text{so that} \qquad \boxed{\frac{I_3}{I} = 2}$$

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60. The wire in Figure 21.40 carries a current of 12 A. Suppose that a second long, straight wire is placed right next to this wire. The current in the second wire is 28 A. Use Ampère's law to find the magnitude of the magnetic field at a distance of r = 0.72 m from the wires when the currents are (a) in the same direction and (b) in opposite directions.

60. ***REASONING*** Since the two wires are next to each other, the net magnetic field is everywhere parallel to $\Delta\ell$ in Figure 21.40. Moreover, the net magnetic field **B** has the same magnitude B at each point along the circular path, because each point is at the same distance from the wires. Thus, in Ampère's law (Equation 21.8), $B_{||} = B$, $I = I_1 + I_2$, and we have

$$\Sigma B_{||}\Delta\ell = B\left(\Sigma\Delta\ell\right) = \mu_0\left(I_1 + I_2\right)$$

But $\Sigma\Delta\ell$ is just the circumference ($2\pi r$) of the circle, so Ampère's law becomes

$$B\left(2\pi r\right) = \mu_0\left(I_1 + I_2\right)$$

This expression can be solved for B.

SOLUTION
a. When the currents are in the same direction, we find that

$$B = \frac{\mu_0 \left(I_1 + I_2\right)}{2\pi r} = \frac{\left(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}\right)\left(28\ \mathrm{A} + 12\ \mathrm{A}\right)}{2\pi\left(0.72\ \mathrm{m}\right)} = \boxed{1.1 \times 10^{-5}\ \mathrm{T}}$$

b. When the currents have opposite directions, a similar calculation shows that

$$B = \frac{\mu_0 \left(I_1 - I_2\right)}{2\pi r} = \frac{\left(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}\right)\left(28\ \mathrm{A} - 12\ \mathrm{A}\right)}{2\pi\left(0.72\ \mathrm{m}\right)} = \boxed{4.4 \times 10^{-6}\ \mathrm{T}}$$

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65. ssm A long solenoid has 1400 turns per meter of length, and it carries a current of 3.5 A. A small circular coil of wire is placed in side the solenoid with the normal to the coil oriented at an angle of 90.0° with respect to the axis of the solenoid. The coil consists of 50 turns, has an area of 1.2×10^{-3} m^2, and carries a current of 0.50 A. Find the torque exerted on the coil.

65. **SSM** ***REASONING*** The coil carries a current and experiences a torque when it is placed in an external magnetic field. Thus, when the coil is placed in the magnetic field due to the solenoid, it will experience a torque given by Equation 21.4: $\tau = NIAB\sin\phi$, where N is the number of turns in the coil, A is the area of the coil, B is the magnetic field inside the solenoid, and ϕ is the angle between the normal to the plane of the coil and the magnetic field. The magnetic field in the solenoid can be found from Equation 21.7: $B = \mu_0 nI$, where n is the number of turns per unit length of the solenoid and I is the current.

SOLUTION The magnetic field inside the solenoid is

$$B = \mu_0 nI = (4\pi \times 10^{-7}\ \mathrm{T \cdot m/A})\left(1400\ \mathrm{turns/m}\right)(3.5\ \mathrm{A}) = 6.2 \times 10^{-3}\ \mathrm{T}$$

The torque exerted on the coil is

$$\tau = NIAB\sin\phi = (50)(0.50\ \mathrm{A})(1.2 \times 10^{-3}\ \mathrm{m^2})(6.2 \times 10^{-3}\ \mathrm{T})(\sin 90.0°) = \boxed{1.9 \times 10^{-4}\ \mathrm{N \cdot m}}$$