Chapter 29. Magnetism and the Electric Field

Magnetic Fields

29-1. The area of a rectangular loop is 200 cm^2 and the plane of the loop makes an angle of 41^0 with a 0.28-T magnetic field. What is the magnetic flux penetrating the loop?

$$A = 200\text{ cm}^2 = 0.0200\text{ m}^2; \quad \theta = 41^0; \quad B = 0.280\text{ T}$$

$$\phi = BA\sin\theta = (0.280\text{ T})(0.0200\text{ m}^2)\sin 41^0; \quad \boxed{\phi = 3.67\text{ mWb}}$$

29-2. A coil of wire 30 cm in diameter is perpendicular to a 0.6-T magnetic field. If the coil turns so that it makes an angle of 60^0 with the field, what is the change in flux?

$$A = \frac{\pi D^2}{4} = \frac{\pi(0.30\text{ m})^2}{4}; \quad A = 7.07 \times 10^{-2}\text{ m}^2; \quad \Delta\phi = \phi_f - \phi_o$$

$$\phi_0 = BA\sin 90^0 = (0.6\text{ T})(0.0707\text{ m}^2)(1); \quad \phi_0 = 42.4\text{ mWb}$$

$$\phi_f = BA\sin 60^0 = (0.6\text{ T})(0.0707\text{ m}^2)(1); \quad \phi_f = 36.7\text{ mWb}$$

$$\Delta\phi = \phi_f - \phi_o = 36.7\text{ mWb} - 42.4\text{ mWb}; \quad \boxed{\Delta\phi = -5.68\text{ mWb}}$$

29-3. A constant horizontal field of 0.5 T pierces a rectangular loop 120 mm long and 70 mm wide. Determine the magnetic flux through the loop when its plane makes the following angles with the **B** field: 0^0, 30^0, 60^0, and 90^0. [Area = 0.12 m)(0.07 m) = 8.40 x 10^{-3} m^2]

$$\phi = BA\sin\theta; \quad BA = (0.5\text{ T})(8.4 \times 10^{-3}\text{ m}^2) = 4.2 \times 10^{-3}\text{ T m}^2$$

$\phi_1 = (4.2 \times 10^{-3}\text{ T m}^2)\sin 0^0 = \boxed{0\text{ Wb};}$ $\phi_2 = (4.2 \times 10^{-3}\text{ T m}^2)\sin 30^0 = \boxed{2.10\text{ mWb};}$

$\phi_3 = (4.2 \times 10^{-3}\text{ T m}^2)\sin 60^0 = \boxed{3.64\text{ mWb};}$ $\phi_1 = (4.2 \times 10^{-3}\text{ T m}^2)\sin 90^0 = \boxed{4.20\text{ mWb}}$

29-4. A flux of 13.6 mWb penetrates a coil of wire 240 mm in diameter. Find the magnitude of the magnetic flux density if the plane of the coil is perpendicular to the field.

$$A = \frac{\pi D^2}{4} = \frac{\pi(0.240\text{ m})^2}{4}; \quad A = 4.52 \times 10^{-2}\text{ m}^2; \quad \phi = BA\sin\theta$$

$$B = \frac{\phi}{A\sin\theta} = \frac{0.0136\text{ Wb}}{(4.52 \times 10^{-2}\text{m}^2)(1)}; \quad \boxed{B = 0.300\text{ T}}$$

29-5. A magnetic flux of 50 μWb passes through a perpendicular loop of wire having an area of 0.78 m^2. What is the magnetic flux density?

$$B = \frac{\phi}{A\sin\theta} = \frac{50 \times 10^{-6}\text{ Wb}}{(0.78\text{ m}^2)(1)}; \quad \boxed{B = 64.1\ \mu\text{T}}$$

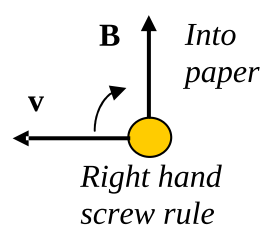
29-6. A rectangular loop 25 x 15 cm is oriented so that its plane makes an angle θ with a 0.6-T **B** field. What is the angle θ if the magnetic flux linking the loop is 0.015 Wb?

$$A = (0.25\text{ m})(0.15\text{ m}) = 0.0375\text{ m}^2; \quad \phi = 0.015\text{ Wb}$$

$$\phi = BA\sin\theta; \quad \sin\theta = \frac{\phi}{BA} = \frac{0.015\text{ Wb}}{(0.6\text{ T})(0.0375\text{ m}^2)}; \quad \boxed{\theta = 41.8^0}$$

The Force on Moving Charge

29-7. A proton (q = +1.6 x 10^{-19} C) is injected to the right into a **B** field of 0.4 T directed upward. If the velocity of the proton is 2 x 10^6 m/s, what are the magnitude and direction of the magnetic force on the proton?



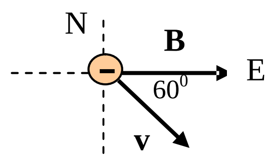
$F = qvB_\perp = (1.6 \times 10^{-19}\text{ C})(2 \times 10^6\text{ m/s})(0.4\text{ T})$

$\boxed{F = 1.28 \times 10^{-13}\text{ N, into paper}}$

29-8. An alpha particle (+2e) is projected with a velocity of 3.6 x 10^6 m/s into a 0.12-T magnetic field. What is the magnetic force on the charge at the instant its velocity is directed at an angle of 35^0 with the magnetic flux? [q = 2 (1.6 x 10^{-19} C) = 3.2 x 10^{-19} C]

$F = qvB \sin\theta$ = (3.2 x 10^{-19} C)(3.6 x 10^6 m/s)(0.12 T) sin 35^0; **F = 7.93 x 10^{-14} N**

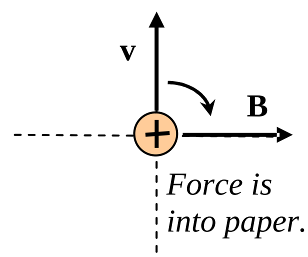
29-9. An electron moves with a velocity of 5 x 10^5 m/s at an angle of 60^0 with an eastward B field. The electron experiences an force of 3.2 x 10^{-18} N directed into the paper. What are the magnitude of B and the direction the velocity v?



In order for the force to be INTO the paper for a NEGATIVE charge, the 60^0 angle must be S of E. **$\theta = 60^0$ S of E**

$$B = \frac{F}{qv\sin\theta} = \frac{3.2 \text{ x } 10^{-18}\text{N}}{(1.6 \text{ x } 10^{-19}\text{C})(5 \text{ x } 10^5 \text{ m/s})};$$ **B = 46.3 μT**

29-10. A proton (+1e) is moving vertically upward with a velocity of 4 x 10^6 m/s. It passes through a 0.4-T magnetic field directed to the right. What are the magnitude and direction of the magnetic force?



$F = qvB_\perp$ = (1.6 x 10^{-19}C)(4 x 10^6m/s)(0.4 T) ;

F = 2.56 x 10^{-13} N, *directed into paper.*

29-11. What if an electron replaces the proton in Problem 29-10. What is the magnitude and direction of the magnetic force?

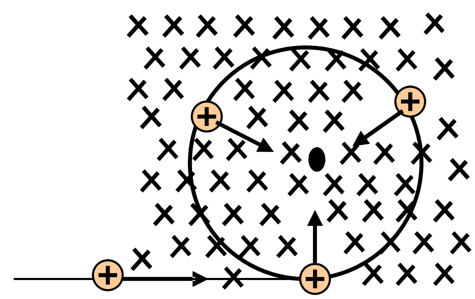
The direction of the magnetic force on an electron is opposite to that of the proton, but the magnitude of the force is unchanged since the magnitude of the charge is the same.

F_e = 2.56 x 10^{-13} N, *out of paper.*

*29-12. A particle having a charge *q* and a mass *m* is projected into a **B** field directed into the paper. If the particle has a velocity *v*, show that it will be deflected into a circular path of radius:

$$R = \frac{mv}{qB}$$

Draw a diagram of the motion, assuming a positive charge entering the **B** field from left to right. Hint: The magnetic force provides the necessary centripetal force for the circular motion.



$$F_C = \frac{mv^2}{R}; \quad F_B = qvB; \quad \frac{mv^2}{R} = qvB$$

$$\text{From which:} \quad R = \frac{mv}{qB}$$

The diagram shows that the magnetic force is a centripetal force that acts toward the center causing the charge to move in a counterclockwise circle of radius R.

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*29-13. A deuteron is a nuclear particle consisting of a proton and a neutron bound together by nuclear forces. The mass of a deuteron is 3.347 x 10^{-27} kg, and its charge is +1e. A deuteron projected into a magnetic field of flux density 1.2 T is observed to travel in a circular path of radius 300 mm. What is the velocity of the deuteron? *See Problem 29-12.*

$$F_C = \frac{mv^2}{R}; \quad F_B = qvB; \quad \frac{mv^2}{R} = qvB; \quad v = \frac{qRB}{m}$$

$$v = \frac{qRB}{m} = \frac{(1.6 \times 10^{-19}\text{C})(0.3 \text{ m})(1.2 \text{ T})}{3.347 \times 10^{-27} \text{ kg}}; \quad \boxed{v = 1.72 \times 10^{7} \text{ m/s}}$$

Note: This speed which is about 6% of the speed of light is still not fast enough to cause significant effects due to relativity (see Chapter 38.)

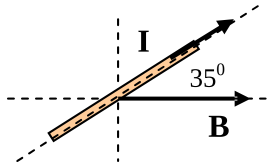
Force on a Current-Carrying Conductor

29-14. A wire 1 m in length supports a current of 5.00 A and is perpendicular to a **B** field of 0.034 T. What is the magnetic force on the wire?

$F = I B_{\perp} l = (5\text{ A})(0.034\text{ T})(1\text{ m})$; $\boxed{F = 0.170\text{ N}}$

29-15. A long wire carries a current of 6 A in a direction 35^0 north of an easterly 40-mT magnetic field. What are the magnitude and direction of the force on each centimeter of wire?

$F = Il\,B\sin\theta = (6\text{ A})(0.040\text{ T})(0.01\text{ m})\sin 35^0$



$\boxed{F = 1.38 \times 10^{-3}\text{ N, } \textit{into paper}}$

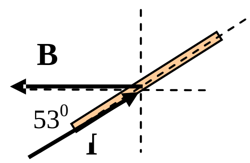
The force is into paper as can be seen by turning I into B to advance a screw inward.

29-16. A 12-cm segment of wire carries a current of 4.0 A directed at an angle of 41^0 north of an easterly **B** field. What must be the magnitude the **B** field if it is to produce a 5 N force on this segment of wire? What is the direction of the force?

$$B = \frac{F}{Il\sin\theta} = \frac{5.00\text{ N}}{(4.0\text{ A})(0.12\text{ m})\sin 41^0}; \quad \boxed{B = 15.9\text{ T}}$$

The force is directed inward according to the right-hand rule.

29-17. An 80 mm segment of wire is at an angle of 53^0 south of a westward, 2.3-T **B** field. What are the magnitude and direction of the current in this wire if it experiences a force of 2 N directed out of the paper?



$B = 2.30$ T; $l = 0.080$ m; $\theta = 53^0$; F = 2.00 N

$$I = \frac{F}{Bl\sin\theta} = \frac{2.00\text{ N}}{(2.3\text{ T})(0.080\text{ m})\sin 53^0}; \quad \boxed{I = 13.6\text{ A}}$$

The current must be directed 53^0 N of E *if I turned into B produces outward force.*

*29-18. The linear density of a certain wire is 50.0 g/m. A segment of this wire carries a current of 30 A in a direction perpendicular to the **B** field. What must be the magnitude of the magnetic field required to suspend the wire by balancing its weight?

$$\lambda = \frac{m}{l}; \quad m = \lambda l; \quad W = mg = \lambda l\,\text{g}; \quad F_B = W = \lambda l\,\text{g} \quad F_B = I\,lB$$

$$\lambda lg = IlB; \quad B = \frac{\lambda g}{I} = \frac{(0.050\text{ kg/m})(9.8\text{ m/s}^2)}{30\text{ A}}; \quad \boxed{B = 16.3\text{ mT}}$$

Calculating Magnetic Fields

29-19. What is the magnetic induction **B** in air at a point 4 cm from a long wire carrying a current of 6 A?

$$B = \frac{\mu_0 I}{2\pi l} = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(6\text{ A})}{2\pi(0.04\text{ m})}; \quad \boxed{B = 30.0\ \mu\text{T}}$$

29-20. Find the magnetic induction in air 8 mm from a long wire carrying a current of 14.0 A.

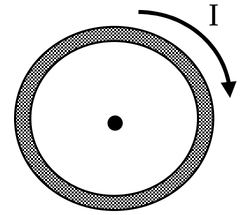
$$B = \frac{\mu_0 I}{2\pi l} = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(14\text{ A})}{2\pi(0.008\text{ m})}; \quad \boxed{B = 350\ \mu\text{T}}$$

29-21. A circular coil having 40 turns of wire in air has a radius of 6 cm and is in the plane of the paper. What current must exist in the coil to produce a flux density of 2 mT at its center?

$$B = \frac{\mu_0 NI}{2r}; \quad I = \frac{2rB}{\mu_0 N}$$

$$I = \frac{2(0.06\text{ m})(0.002\text{ T})}{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(40)}; \quad \boxed{I = 4.77\text{ A}}$$

29-22. If the direction of the current in the coil of Problem 29-21 is clockwise, what is the direction of the magnetic field at the center of the loop?



If you grasp the loop with your right hand so that the thumb points in the direction of the current, it is seen that the B field will be directed OUT of the paper at the center of the loop.

29-23. A solenoid of length 30 cm and diameter 4 cm is closely wound with 400 turns of wire around a nonmagnetic material. If the current in the wire is 6 A, determine the magnetic induction along the center of the solenoid.

$$B = \frac{\mu_0 NI}{l} = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(400)(6 \text{ A})}{0.300 \text{ m}}; \quad \boxed{B = 10.1 \text{ mT}}$$

29-24. A circular coil having 60 turns has a radius of 75 mm. What current must exist in the coil to produce a flux density of 300 μT at the center of the coil?

$$I = \frac{2rB}{\mu_0 N} = \frac{2(0.075 \text{ m})(300 \text{ x } 10^{-6}\text{T})}{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(60)}; \quad \boxed{I = 0.597 \text{ A}}$$

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*29-25. A circular loop 240 mm in diameter supports a current of 7.8 A. If it is submerged in a medium of relative permeability 2.0, what is the magnetic induction at the center?

$$r = ½(240 \text{ mm}) = 120 \text{ mm}; \quad \mu = 2\mu_0 = 8\pi \text{ x } 10^{-7} \text{ T m/A}$$

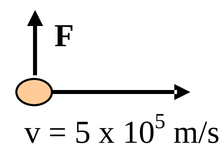
$$B = \frac{\mu NI}{2r} = \frac{(8\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(1)(7.8 \text{ A})}{2(0.120 \text{ m})}; \quad \boxed{B = 81.7 \ \mu\text{T}}$$

***29-26.** A circular loop of radius 50 mm in the plane of the paper carries a counterclockwise current of 15 A. It is submerged in a medium whose relative permeability is 3.0. What are the magnitude and direction of the magnetic induction at the center of the loop?

$$B = \frac{\mu NI}{2r} = \frac{3(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(1)(15 \text{ A})}{2(0.050 \text{ m})}; \quad \boxed{B = 565\ \mu\text{T}}$$

Challenge Problems

29-27. A +3-μC charge is projected with a velocity of 5 x 10^5 m/s along the positive x axis perpendicular to a **B** field. If the charge experiences an upward force of 6.0 x 10^{-3} N, what must be the magnitude and direction of the **B** field?

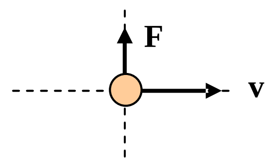


$$F = qvB \sin\theta; \quad B = \frac{F}{qv} = \frac{6 \text{ x } 10^{-3}\text{N}}{(3 \text{ x } 10^{-6}\text{C})(5 \text{ x } 10^{5}\text{m/s})}$$

$\boxed{B = 4.00 \text{ mT, } \textit{directed into paper.}}$ *Direction from right-hand rule.*

29-28. An unknown charge is projected with a velocity of 4 x 10^5 m/s from right to left into a 0.4-T **B** field directed out of the paper. The perpendicular force of 5 x 10^{-3} N causes the particle to move in a clockwise circle. What are the magnitude and sign of the charge?

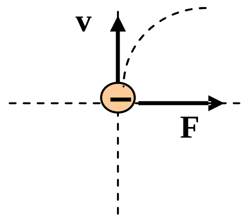
If the charge were positive, the force should be downward by the right-hand rule. Since in is upward, the charge must be negative. We find the magnitude as follows:



$$F = qvB \sin\theta; \quad q = \frac{F}{vB} = \frac{5 \text{ x } 10^{-3} \text{ N}}{(4 \text{ x } 10^{5}\text{m/s})(0.4 \text{ T})}; \quad q = 31.2 \text{ nC}$$

The charge is therefore: $\boxed{q = -31.2 \text{ nC}}$

29-29. A –8-nC charge is projected upward at 4×10^5 m/s into a 0.60-T **B** field directed into the paper. The field produces a force ($F = qvB$) that is also a centripetal force *(mv^2/R)*. This force causes the negative charge to move in a circle of radius 20 cm. What is the mass of the charge and does it move clockwise or counterclockwise?

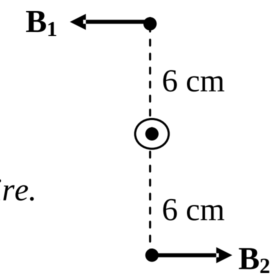


$$\frac{mv^2}{R} = qvB; \quad m = \frac{qBR}{v} = \frac{(8 \times 10^{-9})(0.6\text{ T})(0.20\text{ m})}{4 \times 10^5\text{ m/s}}$$

$$\boxed{m = 2.40 \times 10^{-15}\text{ kg}}$$

Since the charge is negative, the magnetic force is to the left and the motion is clockwise.

29-30. What is the magnitude and direction of the **B** field 6 cm above a long segment of wire carrying a 9-A current directed out of the paper? What is the magnitude and direction of the **B** field 6 cm below the segment?



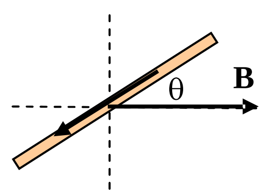
Wrapping the fingers around the wire with thumb pointing outward shows that the direction of the B field is counterclockwise around wire.

$$B_1 = \frac{\mu_0 I}{2\pi l_1} = \frac{(4\pi \times 10^{-7}\text{T}\cdot\text{m/A})(9\text{ A})}{2\pi(0.06\text{ m})}; \quad \boxed{B_1 = 30\ \mu\text{T, to left}}$$

$$B_2 = \frac{\mu_0 I}{2\pi l_2} = \frac{(4\pi \times 10^{-7}\text{T}\cdot\text{m/A})(9\text{ A})}{2\pi(0.06\text{ m})}; \quad \boxed{B_1 = 30\ \mu\text{T, to right}}$$

29-31. A 24 cm length of wire makes an angle of 32^0 above a horizontal B field of 0.44 T along the positive x axis. What are the magnitude and direction of the current required to produce a force of 4 mN directed out of the paper?

The current must be 32^0 downward and to the left.



$$I = \frac{F}{lB\sin\theta} = \frac{4 \times 10^{-3}\text{N}}{(0.24\text{ m})(0.44\text{ T})\sin 32^0}; \quad \boxed{I = 71.5\text{ mA}}$$

*29-32. A velocity selector is a device (Fig. 29-26) that utilizes crossed E and B fields to select ions of only one velocity v. Positive ions of charge q are projected into the perpendicular fields at varying speeds. Ions with velocities sufficient to make the magnetic force equal and opposite to the electric force pass through the bottom of the slit undeflected. Show that the speed of these ions can be found from

$$v = \frac{E}{B}$$

The electric force (qE) must balance the magnetic force (qvB) for zero deflection:

$$qE = qvB; \quad \boxed{v = \frac{E}{B}}$$

29-33. What is the velocity of protons (+1e) injected through a velocity selector (see Problem 29-32) if E = 3 x 10^5 V/m and B = 0.25 T?

$$v = \frac{E}{B} = \frac{3 \text{ x } 10^5 \text{ V/m}}{0.25 \text{ T}}; \quad \boxed{v = 1.20 \text{ x } 10^6 \text{ m/s}}$$

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*29-34. A singly charged Li^7 ion (+1e) is accelerated through a potential difference of 500 V and then enters at right angles to a magnetic field of 0.4 T. The radius of the resulting circular path is 2.13 cm. What is the mass of the lithium ion?

First we find the entrance velocity from energy considerations: Work = Δ(K.E.)

$$qV = ½mv^2; \quad v = \sqrt{\frac{2qV}{m}}; \text{ and } \quad \frac{mv^2}{R} = qvB; \quad v = \frac{qBR}{m} \quad \text{set } v = v$$

$$\sqrt{\frac{2qV}{m}} = \frac{qBR}{m} \quad \text{or} \quad \frac{2qV}{m} = \frac{q^2B^2R^2}{m^2} \quad \text{and} \quad m = \frac{qB^2R^2}{2V}$$

$$m = \frac{qB^2R^2}{2V} = \frac{(1.6 \text{ x } 10^{-19}\text{C})(0.4 \text{ T})^2(0.0213 \text{ m})^2}{2(500 \text{ V})}; \quad \boxed{m = 1.16 \text{ x } 10^{-26} \text{ kg}}$$

*29-35. A singly charged sodium ion (+1e) moves through a B field with a velocity of 4 x 10^4 m/s. What must be the magnitude of the B field if the ion is to follow a circular path of radius 200 mm? (The mass of the sodium ion is 3.818 x 10^{-27} kg).

$$\frac{mv^2}{R} = qvB; \quad B = \frac{mv}{qR} = \frac{(3.818 \text{ x } 10^{-27}\text{kg})(4 \text{ x } 10^4\text{m/s})}{(1.6 \text{ x } 10^{-19}\text{C})(0.200 \text{ m})}; \quad \boxed{B = 4.77 \text{ mT}}$$

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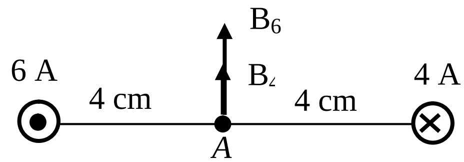
*29-36. The cross sections of two parallel wires are located 8 cm apart in air. The left wire carries a current of 6 A out of the paper and the right wire carries a current of 4 A into the paper. What is the resultant magnetic induction at the midpoint *A* due to both wires?

Applying right thumb rule, both fields are UP.



$$B_6 = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(6 \text{ A})}{2\pi(0.04 \text{ m})} = 30.0 \ \mu\text{T}, \textit{ up}$$

$$B_4 = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(4 \text{ A})}{2\pi(0.04 \text{ m})} = 20.0 \ \mu\text{T}, \textit{ up}; \quad B_R = 30 \ \mu\text{T} + 20 \ \mu\text{T}; \quad \boxed{B_R = 50 \ \mu\text{T}, \textit{ up}}$$

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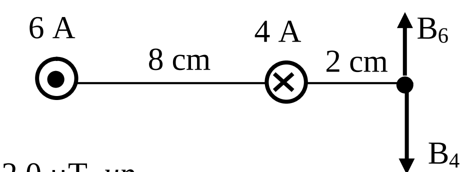
*29-37. What is the resultant magnetic field at point B located 2 cm to the right of the 4-A wire?

Find the fields due to each wire, and then add them as vectors at the point 2 cm to the right.



$$B_6 = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(6 \text{ A})}{2\pi(0.10 \text{ m})} = 12.0 \ \mu\text{T}, \textit{ up}$$

$$B_4 = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(4 \text{ A})}{2\pi(0.04 \text{ m})} = 40.0 \ \mu\text{T}, \textit{ down}$$

$$B_R = 12 \ \mu\text{T} - 40 \ \mu\text{T}; \quad \boxed{B_R = 28 \ \mu\text{T}, \textit{ downward}}$$

*****29-38. Two parallel wires carrying currents I_1 and I_2 are separated by a distance d. Show that the force per unit length F/l each wire exerts on the other is given by

$$\frac{F}{\ell} = \frac{\mu I_1 I_2}{2\pi d}$$

Wire 1 finds itself in a magnetic field created by the current in wire 2. Thus, the force on wire 1 due to its own current can be calculated:

$$F_1 = I_1 B_2 l_1 \text{ and } B_2 = \frac{\mu I_2}{2\pi d}; \quad F_1 = I_1\left(\frac{\mu I_2}{2\pi d}\right) l_1 \quad \textit{(Force on wire 1 due to } B_2\textit{)}$$

Same result would be obtained by considering force on wire 2 due to B_1, Thus,

$$\boxed{\frac{F}{l} = \frac{\mu I_1 I_2}{2\pi d}}$$

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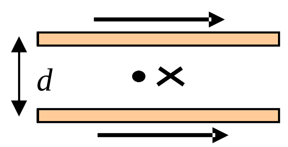
*29-39. Two wires lying in a horizontal plane carry parallel currents of 15 A each and are 200 mm apart in air. If both currents are directed to the right, what are the magnitude and direction of the flux density at a point midway between the wires?



The magnitudes of the B fields at the midpoint are the same, but B_{upper} is inward and B_{lower} is outward, so that $B_{net} = 0$.

$$\boxed{B_{midpoint} = 0}$$

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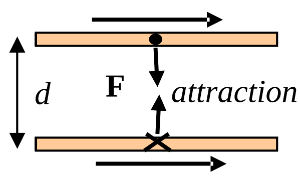
*29-40. What is the force per unit length that teach wire in Problem 29-39 exerts on the other? Is it attraction or repulsion?



$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi \times 10^{-7}\,\text{T}\cdot\text{m/A})(15\text{ A})(15\text{ A})}{2\pi(0.200\text{ m})}$$

$$\boxed{\frac{F}{l} = 2.25 \times 10^{-4}\ \text{N/m}, \textit{ attraction}}$$

The force on upper wire due to B_{lower} is downward; The force on lower wire is upward.

*29-41. A solenoid of length 20 cm and 220 turns carries a coil current of 5 A. What should be the relative permeability of the core to produce a magnetic induction of 0.2 T at the center of the coil?

$$B = \frac{\mu NI}{L}; \quad \mu = \frac{BL}{NI} = \frac{(0.2\text{ T})(0.20\text{ m})}{(220)(5\text{ A})}; \quad \mu = 3.64 \times 10^{-5}\text{ T}\cdot\text{m/A}$$

$$\mu_r = \frac{\mu}{\mu_0} = \frac{3.64 \times 10^{-5}\text{T}\cdot\text{m/A}}{4\pi \times 10^{-7}\text{T}\cdot\text{m/A}}; \quad \boxed{\mu_r = 28.9}$$

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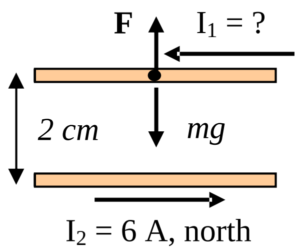
*29-42. A one meter segment of wire is fixed so that it cannot move, and it carries a current of 6 A directed north. Another 1-m wire segment is located 2 cm above the fixed wire. If the upper wire has a mass of 0.40 g, what must be the magnitude and direction of the current in the upper wire if its weight is to be balanced by the magnetic force due to the field of the fixed wire?



$$F = mg = (0.04\text{ kg})(9.8\text{ m/s}^2) = 0.00392\text{ N}; \quad \frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

$$I_1 = \frac{2\pi dF}{\mu_o I_2 l} = \frac{2\pi(0.02\text{ m})(0.00392\text{ N})}{(4\pi \times 10^{-7}\text{T}\cdot\text{m/A})(6\text{ A})(1\text{ m})}; \quad I_1 = 65.3\text{ A}$$

The direction of I_1 must be south (left) in order to produce an upward force.

$$\boxed{I_1 = 65.3\text{ A, south}}$$

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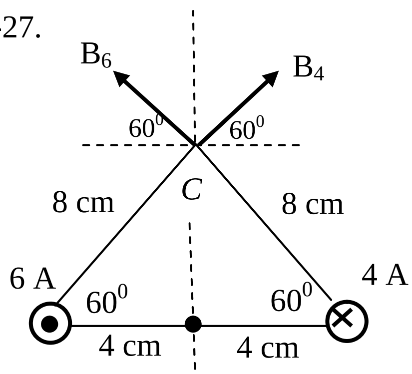
*29-43. What is the resultant magnetic field at point C in Fig. 29-27.

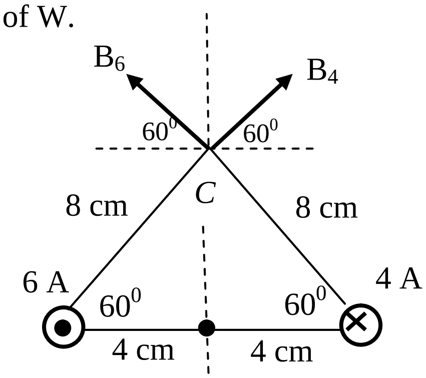


$$B_4 = \frac{\mu_0 I_4}{2\pi d} = \frac{(4\pi \times 10^{-7}\text{T}\cdot\text{m/A})(4\text{ A})}{2\pi(0.08\text{ m})} = 10.0\ \mu\text{T}$$

$$B_6 = \frac{\mu_0 I_4}{2\pi d} = \frac{(4\pi \times 10^{-7}\text{T}\cdot\text{m/A})(6\text{ A})}{2\pi(0.08\text{ m})} = 15.0\ \mu\text{T}$$

Right hand rules, give directions of B_4 and B_6 as shown.

*29-43. (Cont.); B_4 = 15 μT, 60^0 N of E; B_6 = 10 μT, 60^0 N of W.



$B_x = (10\ \mu T) \cos 60^0 - (15\ \mu T) \cos 60^0 = -2.50\ \mu T$

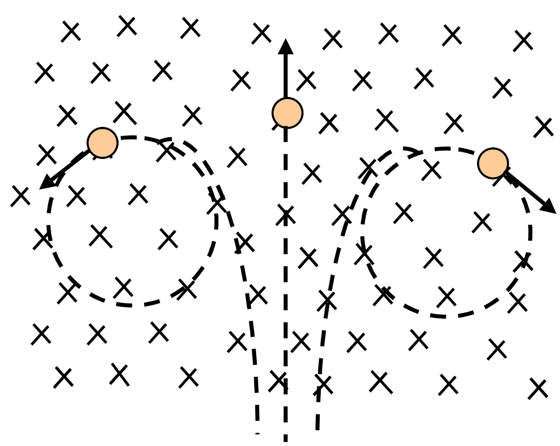
$B_y = (10\ \mu T) \sin 60^0 + (15\ \mu T) \sin 60^0 = 21.65\ \mu T$

$$B = \sqrt{(-2.5)^2 + (21.65)^2} \qquad \boxed{B = 21.8\ \mu T}$$

$$\tan\theta = \frac{21.65\ \mu T}{-2.5\ \mu T}; \qquad \boxed{\theta = 96.6^0}$$

Critical Thinking Problems

*29-44. A magnetic filed of 0.4 T is directed into the paper. Three particles are injected into the field in an upward direction, each with a velocity of 5 x 10^5 m/s. Particle 1 is observed to move in a clockwise circle of radius 30 cm; particle 2 continues to travel in a straight line; and particle 3 is observed to move counterclockwise in a circle of radius 40 cm. What are the magnitude and sign of the charge per unit mass *(q/m)* for each of the particles? (*Apply right-hand rule to each.)*



Particle 1 has a rightward force on entering. It's charge is therefore negative; Particle 3 has a leftward force and is therefore positive. Particle 3 has zero charge (undeviated.)

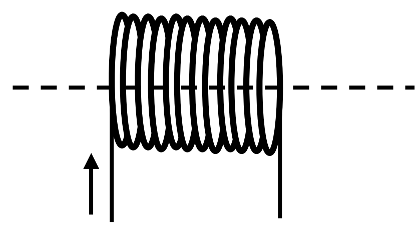
$$\frac{mv^2}{R} = qvB; \qquad \frac{q}{m} = \frac{v}{RB} \quad \textit{in each instance.}$$

Particle 1: $\frac{q}{m} = \frac{v}{RB} = \frac{5 \times 10^5 \text{m/s}}{(0.30 \text{ m})(0.4 \text{ T})}$; $\boxed{\frac{q}{m} = -4.17 \times 10^6 \text{C/kg}}$

Particle 3: $\frac{q}{m} = \frac{v}{RB} = \frac{5 \times 10^5 \text{m/s}}{(0.40 \text{ m})(0.4 \text{ T})}$; $\boxed{\frac{q}{m} = +3.12 \times 10^6 \text{C/kg}}$

Particle 2 has zero charge and zero q/m. (No deviation.)

*29-45. A 4.0 A current flows through the circular coils of a solenoid in a counterclockwise direction as viewed along the positive x axis which is aligned with the air core of the solenoid. What is the direction of the B field along the central axis? How many turns per meter of length is required to produce a B field of 0.28 T? If the air core is replaced by a material whose relative permeability is 150, what current would be needed to produce the same 0.28-T field as before?



Grasping the coil from the near side with the the thumb pointing upward, shows the field at the center to be directed to the left (negative).

$$B = \frac{\mu NI}{L} = \mu nI, \quad where \quad n = \frac{I}{L}; \qquad n = \frac{B}{\mu L} = \frac{0.28 \text{ T}}{(4\pi \text{ x } 10^{-7} \text{T} \cdot \text{m/A})(4 \text{ A})}$$

n = 55,000 turns/m

$$\mu = \mu_r \mu_o = 150(4\pi \text{x } 10^{-7} \text{ T m/A}) = 1.88 \text{ x } 10^{-4} \text{ T m/A}$$

$$I = \frac{B}{\mu n} = \frac{0.28 \text{ T}}{(1.88 \text{ x } 10^{-4} \text{T} \cdot \text{m/A})(55{,}000 \text{ turns/m})};$$

I = 27.0 mA

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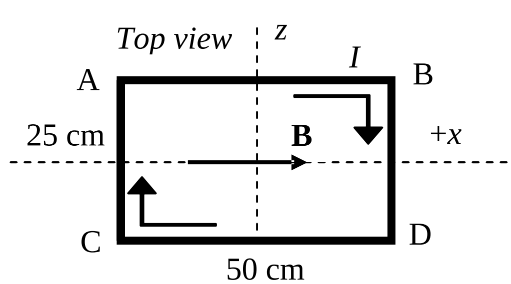
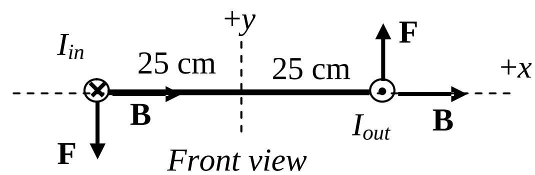
*29-46. The plane of a current loop 50 cm long and 25 cm wide is parallel to a 0.3 T **B** field directed along the positive x axis. The 50 cm segments are parallel with the field and the 25 cm segments are perpendicular to the field. When looking down from the top, the 6-A current is clockwise around the loop. Draw a sketch to show the directions of the **B** field and the directions of the currents in each wire segment. (a) What are the magnitude and direction of the magnetic force acting on each wire segment? (b) What is the resultant torque on the current loop?



The top view is shown to the right:

Forces on segments AB and CD are each equal to <u>zero</u>, since I is parallel to **B**.

*29-46. (Cont.) *Forces on AC and BD are equal and opposite, as shown in front view, but form a torque couple. Resultant is sum of each.*



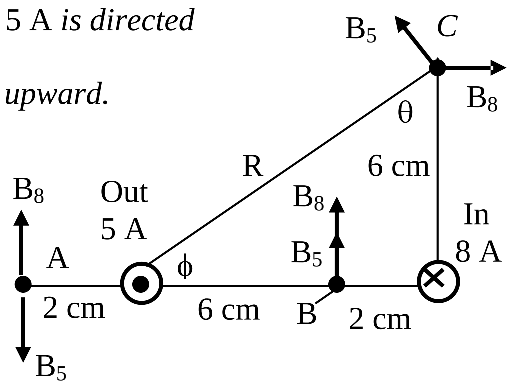
$F_{AC} = Bil_{AC}$ = (0.3 T)(6 A)(0.25 m) = 0.450 N

F_{AC} = 0.450 N, down; F_{BD} = 0.450 N, up

$$\tau_R = F_{AC}\frac{l_{CD}}{2} + F_{BD}\frac{l_{CD}}{2} = (0.450 \text{ N})(0.25 \text{ m}) + (0.450 \text{ N})(0.25 \text{ m})$$

τ_R = 0.225 N·m, *counterclockwise about z axis.*

*****29-47. Consider the two wires in Fig. 29-29 where the dot indicates current out of the page and the cross indicates current into the page. What is the resultant flux density at points A, B, and C? *First consider point A. The field due to* 5 A *is directed downward at A, and the field due to* 8 A *is directed upward.*



$$B_5 = \frac{-(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(5 \text{ A})}{2\pi(0.02 \text{ m})} = -50\ \mu\text{T}$$

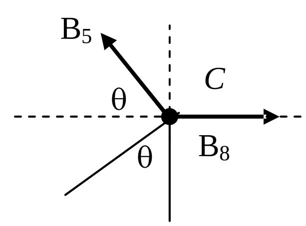
$$B_8 = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(8 \text{ A})}{2\pi(0.10 \text{ m})} = +16\ \mu\text{T}$$

B_A = -50 μT + 16 μT; B_A = -34 μT, *downward*

Next consider field at point B:

$$B_B = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(5 \text{ A})}{2\pi(0.06 \text{ m})} + \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(8 \text{ A})}{2\pi(0.02 \text{ m})};$$

B_B = +96.7 μT, *upward*



$$\tan\theta = \frac{6 \text{ cm}}{8 \text{ cm}}; \quad \theta = 36.9^0; \quad R = \sqrt{(8 \text{ cm})^2 + (6 \text{ cm})^2} = 10 \text{ cm}$$

At C: $B_x = B_5 \cos\theta + B_8$ *and* $B_y = +B_5 \sin\theta$

$$B_x = \frac{-(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(5 \text{ A})}{2\pi(0.10 \text{ m})}\cos 36.9^0 + \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(8 \text{ A})}{2\pi(0.06 \text{ m})};$$

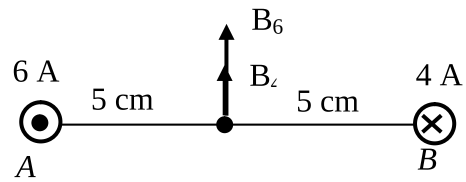
B_x = 20.7 μT

$$B_x = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(5 \text{ A})}{2\pi(0.10 \text{ m})}\sin 36.9^0 = 8.00\ \mu\text{T};$$

B_R = 22.2 μT, 21.2^0

*29-48. Two long, fixed, parallel wires A and B are 10 cm apart in air and carry currents of 6 A and 4 A, respectively, in opposite directions. (a) Determine the net flux density at a point midway between the wires. (b) What is the magnetic force per unit length on a third wire placed midway between A and B and carrying a current of 2 A in the same direction as A?

Applying right thumb rule, both fields are UP.



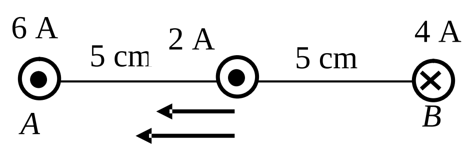
$$B_6 = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(6 \text{ A})}{2\pi(0.05 \text{ m})} = 24.0\ \mu\text{T}, \textit{ up}$$

$$B_4 = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(4 \text{ A})}{2\pi(0.05 \text{ m})} = 16.0\ \mu\text{T}, \textit{ up};$$

B_R = 24 μT + 16 μT; **B_R = 40 μT, *up***

Currents in same direction attract each other; Currents in opposite directions repel:

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(6 \text{ A})(2 \text{ A})}{2\pi(0.05 \text{ m})}$$



$$\frac{F_{AC}}{l} = 48\ \mu\text{N/m, } \textit{toward A}$$

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{(4\pi \text{ x } 10^{-7}\text{T}\cdot\text{m/A})(4 \text{ A})(2 \text{ A})}{2\pi(0.05 \text{ m})}$$

$$\frac{F_{BC}}{l} = 32\ \mu\text{N/m, } \textit{toward A}$$

Therefore, the resultant force per unit length on the 2 A wire is: 48 μN/m + 32μN/m

Resultant *F/l* = 80 μN/m, *toward A*