

or

$$I = \frac{mg}{B\ell} = \frac{\lambda g}{B} \quad (8.9.8)$$

8.9.3 Charged Particles in Magnetic Field

Particle A with charge q and mass m_A and particle B with charge $2q$ and mass m_B , are accelerated from rest by a potential difference ΔV , and subsequently deflected by a uniform magnetic field into semicircular paths. The radii of the trajectories by particle A and B are R and $2R$, respectively. The direction of the magnetic field is perpendicular to the velocity of the particle. What is their mass ratio?

Solution:

The kinetic energy gained by the charges is equal to

$$\frac{1}{2}mv^2 = q\Delta V \quad (8.9.9)$$

which yields

$$v = \sqrt{\frac{2q\Delta V}{m}} \quad (8.9.10)$$

The charges move in semicircles, since the magnetic force points radially inward and provides the source of the centripetal force:

$$\frac{mv^2}{r} = qvB \quad (8.9.11)$$

The radius of the circle can be readily obtained as:

$$r = \frac{mv}{qB} = \frac{m}{qB} \sqrt{\frac{2q\Delta V}{m}} = \frac{1}{B} \sqrt{\frac{2m\Delta V}{q}} \quad (8.9.12)$$

which shows that r is proportional to $(m/q)^{1/2}$. The mass ratio can then be obtained from

$$\frac{r_A}{r_B} = \frac{(m_A/q_A)^{1/2}}{(m_B/q_B)^{1/2}} \Rightarrow \frac{R}{2R} = \frac{(m_A/q)^{1/2}}{(m_B/2q)^{1/2}} \quad (8.9.13)$$

which gives

$$\frac{m_A}{m_B} = \frac{1}{8} \quad (8.9.14)$$

8.10 Conceptual Questions

1. Can a charged particle move through a uniform magnetic field without experiencing any force? Explain.
2. If no work can be done on a charged particle by the magnetic field, how can the motion of the particle be influenced by the presence of a field?
3. Suppose a charged particle is moving under the influence of both electric and magnetic fields. How can the effect of the two fields on the motion of the particle be distinguished?
4. What type of magnetic field can exert a force on a magnetic dipole? Is the force repulsive or attractive?
5. If a compass needle is placed in a uniform magnetic field, is there a net magnetic force acting on the needle? Is there a net torque?

8.11 Additional Problems

8.11.1 Force Exerted by a Magnetic Field

The electrons in the beam of television tube have an energy of 12 keV ($1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$). The tube is oriented so that the electrons move horizontally from south to north. At MIT, the Earth's magnetic field points roughly vertically down (i.e. neglect the component that is directed toward magnetic north) and has magnitude $B \sim 5 \times 10^{-5} \text{ T}$.

- (a) In what direction will the beam deflect?
- (b) What is the acceleration of a given electron associated with this deflection? [Ans. $\sim 10^{-15} \text{ m/s}^2$.]
- (c) How far will the beam deflect in moving 0.20 m through the television tube?

8.11.2 Magnetic Force on a Current Carrying Wire

A square loop of wire, of length $\ell = 0.1 \text{ m}$ on each side, has a mass of 50 g and pivots about an axis AA' that corresponds to a horizontal side of the square, as shown in Figure 8.11.1. A magnetic field of 500 G, directed vertically downward, uniformly fills the region in the vicinity of the loop. The loop carries a current I so that it is in equilibrium at $\theta = 20^\circ$.

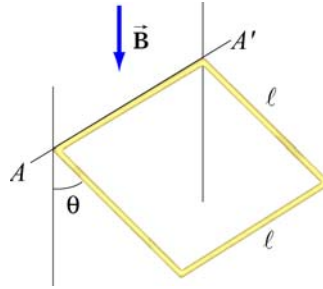


Figure 8.11.1 Magnetic force on a current-carrying square loop.

- Consider the force on each segment separately and find the direction of the current that flows in the loop to maintain the 20° angle.
- Calculate the torque about the axis due to these forces.
- Find the current in the loop by requiring the sum of all torques (about the axis) to be zero. (Hint: Consider the effect of gravity on each of the 4 segments of the wire separately.) [Ans. $I \sim 20$ A.]
- Determine the magnitude and direction of the force exerted on the axis by the pivots.
- Repeat part (b) by now using the definition of a magnetic dipole to calculate the torque exerted on such a loop due to the presence of a magnetic field.

8.11.3 Sliding Bar

A conducting bar of length ℓ is placed on a frictionless inclined plane which is tilted at an angle θ from the horizontal, as shown in Figure 8.11.2.

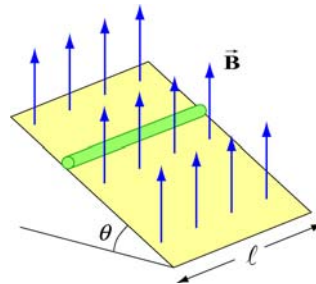


Figure 8.11.2 Magnetic force on a conducting bar

A uniform magnetic field is applied in the vertical direction. To prevent the bar from sliding down, a voltage source is connected to the ends of the bar with current flowing through. Determine the magnitude and the direction of the current such that the bar will remain stationary.

8.11.4 Particle Trajectory

A particle of charge $-q$ is moving with a velocity \vec{v} . It then enters midway between two plates where there exists a uniform magnetic field pointing into the page, as shown in Figure 8.11.3.

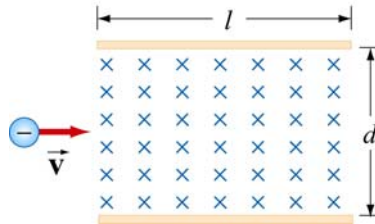


Figure 8.11.3 Charged particle moving under the influence of a magnetic field

- Is the trajectory of the particle deflected upward or downward?
- Compute the distance between the left end of the plate and where the particle strikes.

8.11.5 Particle Orbits in a Magnetic Field

Suppose the entire x - y plane to the right of the origin O is filled with a uniform magnetic field \vec{B} pointing out of the page, as shown in Figure 8.11.4.

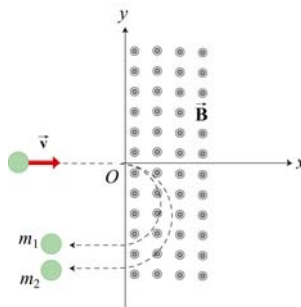


Figure 8.11.4

Two charged particles travel along the negative x axis in the positive x direction, each with speed v , and enter the magnetic field at the origin O . The two particles have the same charge q , but have different masses, m_1 and m_2 . When in the magnetic field, their trajectories both curve in the same direction, but describe semi-circles with different radii. The radius of the semi-circle traced out by particle 2 is exactly *twice* as big as the radius of the semi-circle traced out by particle 1.

- Is the charge q of these particles such that $q > 0$, or is $q < 0$?

(b) *Derive* (do not simply state) an expression for the radius R_1 of the semi-circle traced out by particle 1, in terms of q , v , B , and m_1 .

(c) What is the ratio m_2 / m_1 ?

(d) Is it possible to apply an electric field \vec{E} in the region $x > 0$ only which will cause both particles to continue to move in a straight line after they enter the region $x > 0$? If so, indicate the magnitude and direction of that electric field, in terms of the quantities given. If not, why not?

8.11.6 Force and Torque on a Current Loop

A current loop consists of a semicircle of radius R and two straight segments of length ℓ with an angle θ between them. The loop is then placed in a uniform magnetic field pointing to the right, as shown in Figure 8.11.5.

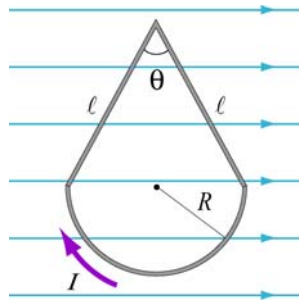


Figure 8.11.5 Current loop placed in a uniform magnetic field

(a) Find the net force on the current loop.

(b) Find the net torque on the current loop.

8.11.7 Force on a Wire

A straight wire of length 0.2 m carries a 7.0 A current. It is immersed in a uniform magnetic field of 0.1 T whose direction lies 20 degrees from the direction of the current.

(a) What is the direction of the force on the wire? Make a sketch to show your answer.

(b) What is the magnitude of the force? [Ans. ~ 0.05 N]

(c) How could you maximize the force without changing the field or current?