


Magnetic Field

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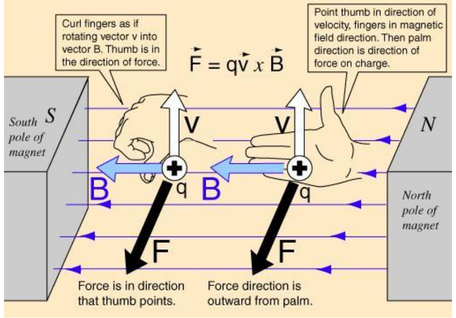
Magnetic Force – Charged Particle

➢ Moving charges create an electric current which generates a magnetic field.

➢The magnetic force due to a moving charged particles in a uniform magnetic field is given as

$$\vec{F} = q\left(\vec{v} \times \vec{B}\right)$$

➢This equation indicates that the direction of magnetic force is always normal to both velocity and magnetic field.



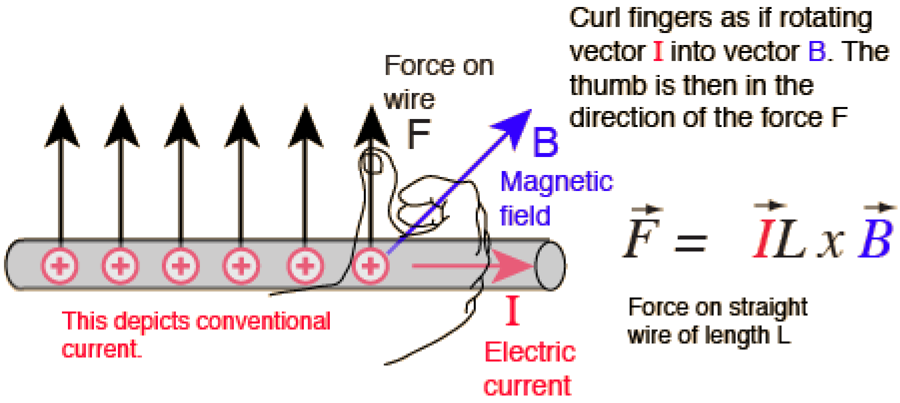
➢The SI unit of magnetic field is Tesla (T) where

$$1 \text{ T} = 1 \text{ N.s/(C.m)} = 1 \text{ N/(A.m)}$$

Magnetic Force – Current

- The magnetic force due to a current passing through a wire of length L is

$$\vec{F} = i\left(\vec{L} \times \vec{B}\right)$$



Charged Particle Circulating in Magnetic Field

- If a charged particle q of mass m and speed v normally enters a uniform magnetic field of B, the path of the particle will be a circle of radius R. The value of the radius is

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

- The frequency of the motion, reciprocal of the period, is

$$f = \frac{qB}{2\pi m} \qquad \rightarrow \qquad \tau = \frac{2\pi m}{qB}$$

- The angular frequency is

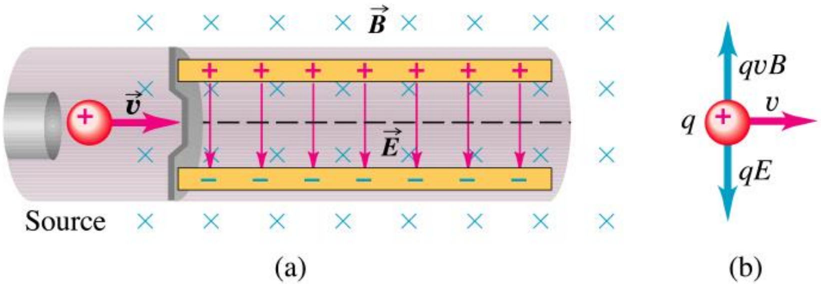
$$\omega = 2\pi f = \frac{qB}{m}$$

Equal Electric and Magnetic Forces

➢If a charged particle enters a region of electric and magnetic forces, the particle will move in a straight line when the net force is zero. That means the electric force equals and opposes the magnetic force. The speed of the particle must be

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

This equation is known as velocity selector.



Magnetic Dipole - Torque

- The magnetic dipole of a wire (coil) of N turns, area A, and current i, is defined as

$$\mu = NiA$$

The SI unit of magnetic dipole is $A.m^2$.

- If one places the above coil in a uniform magnetic field, a torque will be experienced as

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

- The orientation energy (potential energy) of the magnetic dipole is

$$U = -\vec{\mu} \cdot \vec{B}$$

Please revisit chapter 2 and compare these quantities with those of electric field.

Worked Exercises

1. An electron of a speed of 2×10^5 m/s perpendicularly enters a uniform magnetic field of 4 mT. Calculate (i) the magnetic force and (ii) the radius of its path.

Solution

(i) The magnitude of the magnetic force, since the velocity is normal to magnetic field, is

$$F = qvB = 1.6\times10^{-19}\times2\times10^{5}\times4\times10^{-3} = 1.28\times10^{-16}\,N$$

(ii) The radius of its circular path is

$$R = \frac{mv}{qB} = \frac{9.11\times10^{-31}\times2\times10^{5}}{1.6\times10^{-19}\times4\times10^{-3}} = 2.85\times10^{-4}\,m$$

Worked Exercises

2. In a certain electric motor wires that carry a current of 8 A are perpendicular to a magnetic field of 50 mT. Calculate the magnetic force on each centimeter of these wires.

Solution

The magnitude of the magnetic force, since the magnetic field is normal to the wire, is

$$F = iLB = 8 \times 0.01 \times 50 \times 10^{-3} = 0.004N$$

Worked Exercises

3. A proton moving with a speed of 4×10^6 m/s through a magnetic field of 4 T experiences a magnetic force of 12.8×10^{-13} N. Find the angle between the proton's velocity and the magnetic field.

Solution

The magnitude of the magnetic force is defined as

$$F = qvB\sin\theta$$

Hence the angle is

$$\sin\theta = \frac{F}{qvB} = \frac{12.8\times10^{-13}}{1.6\times10^{-19}\times4\times10^{6}\times4} = 0.5 \qquad \rightarrow \qquad \theta = 30^0$$

Worked Exercises

4. A proton moves with a speed of 4×10^6 m/s normally to a magnetic field of 2.4 T. Calculate the acceleration of the proton due to the magnetic force.

Solution

The magnitude of the magnetic force is

$$F = qvB = 1.6\times10^{-19}\times4\times10^{6}\times2.4 = 1.54\times10^{-12}\,N$$

Hence the magnitude of its acceleration (from Newton's second law) is

$$F = ma \qquad \rightarrow \qquad a = \frac{F}{m} = \frac{1.54\times10^{-12}}{1.67\times10^{-27}} = 9.2\times10^{14}\,m/s^2$$

Worked Exercises

5. An electron is in equilibrium under the influence of magnetic and electric forces. If the magnitude of the magnetic field is 1.2 T and its speed is 5×10^4 m/s, calculate the magnitude of the electric field.

Solution

The magnitude of the electric field is

$$v = \frac{E}{B} \quad \rightarrow \quad E = vB = 5\times10^4 \times 1.2 = 6\times10^4 \; V/m$$

Worked Exercises

6. A coil of cross sectional area of 4×10^{-6} m^2 carries a current of 0.2 A. If the magnitude of the magnetic dipole is 12×10^{-5} A.m^2, calculate the number of the coil's turns.

Solution

The magnitude of the magnetic moment is

$$\mu = NiA \qquad \rightarrow \qquad N = \frac{\mu}{iA} = \frac{12\times10^{-5}}{0.2\times4\times10^{-6}} = 150\ turns$$

WORKED EXERCISES

7. A coil of cross-sectional area of 4×10^{-6} m^2 carries a current of 0.2 A. Its magnetic moment is initially aligned with an external magnetic field of 1.2 T. If the work required to rotate the dipole to 90^0 is 6×10^{-3} J, calculate the number of the turns of the coil.

Solution

The magnitude of the magnetic moment is

$$\mu = NiA \qquad \rightarrow \qquad N = \frac{\mu}{iA}$$

But we know that the work is

$$W = -\Delta U = \mu B \qquad \rightarrow \qquad \mu = \frac{W}{B} = \frac{6\times10^{-3}}{1.2} = 0.005\ A.m^2$$

Hence the number of turns is

$$N = \frac{0.005}{0.2\times4\times10^{-6}} = 6250\ turns$$

Worked Exercises

8. A loop of 40 turns of cross-sectional area of 2×10^{-4} m^2 carries a current of 200 mA. The coil is placed in a uniform magnetic field. If the maximum torque exerted on the loop is 4×10^{-4} N.m, calculate the magnitude of the magnetic field.

Solution

The magnitude of the magnetic moment is

$$\mu = NiA = 40\times2\times10^{-4}\times0.2 = 0.0016\ A.m^2$$

But we know that the maximum torque is

$$\tau = \mu B$$

Hence the magnitude of the magnetic field is

$$B = \frac{\tau}{\mu} = \frac{4\times10^{-4}}{0.0016} = 0.25\ T$$