Conductor in a Magnetic Field

It has been observed that a current carrying wire in a magnetic field will experience a force. The magnitude of this force is given by

$$F_B = BIL\sin\theta$$

Where,

F is the force on the wire

B is the magnetic field intensity in Teslas (T)

I is the current in the wire in amperes (A)

L is the length of wire

θ is the angle between B and I

The force is at its maximum when the wire is perpendicular to the magnetic field and is zero when the wire is parallel to the magnetic field.

The direction of the force acting on a current-carrying wire in a magnetic field is determined using the **third right hand rule**.

Right Hand Rule #3
Hold your hand with your fingers straight and your thumb extended perpendicular to your fingers (like a karate-chop). Your thumb represents the direction of the current in the wire. Your fingers represent the direction of the magnetic field. Your palm "pushes" in the direction of the magnetic force acting on the wire.

Example 1
A straight conductor carries a current of $15\ A$ through a magnetic field a distance of $10\ cm$, when the magnetic field intensity is $0.6\ T$. Calculate the magnitude of the force on the conductor, when the angle between it and the magnetic field is:

a) 90° b) 45° c) 0°

Force on a Charge Moving in a Magnetic Field

The force a conductor experiences in a magnetic field is due to the motion of the charged particles moving through it. It stands to reason, then, that a freely moving charged particle would experience a similar force.

Consider a particle of charge q, moving with a velocity v, at an angle θ to a magnetic field B. If n such particles pass a given point in a time t, they constitute an electric current given by

$$I = \frac{nq}{t}$$

Also, if L is the distance traveled through the magnetic field by each of the charges in the time t,

$$L = v \cdot t$$

Thus, using the equation for the force on a conductor, the magnitude of the total force acting on the n charged particles is

$$\begin{aligned} F_B &= BIL\sin\theta \\ &= B\left(\frac{nq}{t}\right)(v \cdot t)\sin\theta \\ &= nqvB\sin\theta \end{aligned}$$

Therefore, the magnitude of the force on each charged particle is:

$$\boxed{F_B = qvB\sin\theta}$$

Where,

- F is the force on the moving charge
- q is the value of the moving charge
- v is the velocity of the moving charge
- B is the magnetic field intensity
- θ is the angle between v and B

- The force is **greatest** when the particle moves perpendicular to the magnetic field
- The force is **zero** if the particle moves parallel to the field lines.

The direction of the force acting on the charged particle is perpendicular to both v and B, and is given by the **fourth right-hand rule**:

Right Hand Rule #4
Hold your hand with your fingers straight and your thumb extended perpendicular to your fingers (like a karate-chop). Your thumb represents the direction of the velocity of the particle. Your fingers represent the direction of the magnetic field. Your palm "pushes" in the direction of the magnetic force acting on the particle.

Note: This is true only for positively charged particles. For negatively charged particles, the force will be in exactly the opposite direction as indicated by RH Rule #4.

Example 2
A proton having a speed of $5\times10^{6}\ m/s$ in a magnetic field feels a force of $8\times10^{-14}\ N$ toward the west when it moves vertically upward. When moving horizontally in a northerly direction, it feels zero force. What is the magnitude and direction of the magnetic field in this region.

Since the force on a charged particle in a magnetic field is perpendicular to the velocity, the path of a charged particle moving in a plane perpendicular to a uniform magnetic field will be a **circle** (or the **arc** of a circle if the particle leaves the magnetic field region).

The force moving the particle in a circular path can therefore also be described as the centripetal force.

$$F_c = F_B$$

$$\frac{mv^2}{r} = qvB$$

$$\boxed{r = \frac{mv}{qB}}$$

Where m is the mass of the particle, and r is the radius of its circular path.

Example 3

An electron with a mass of $9.1 \times 10^{-31}\ kg$ and charge of $1.6 \times 10^{-19}\ C$, is accelerated to a velocity of $4 \times 10^{6}\ m/s$, then enters a uniform magnetic field of $5 \times 10^{-3}\ T$ at an angle of $90°$ to the field.

a) What is the radius of the circular path it follows?

b) Through what potential difference was the electron accelerated?

Example 4
An electron travels at $2 \times 10^7\ m/s$ in a plane perpendicular to a $0.1\ T$ magnetic field. Calculate the radius of the circular path the particle travels.

Homework
Force on a Conductor Worksheet
Charges in a Magnetic Field Worksheet

Force on a Conductor Worksheet

1. What force is experienced by a 30 *cm* wire carrying a 12 *A* current perpendicular to a uniform magnetic field of strength 0.25 *T*? (0.9 *N*)

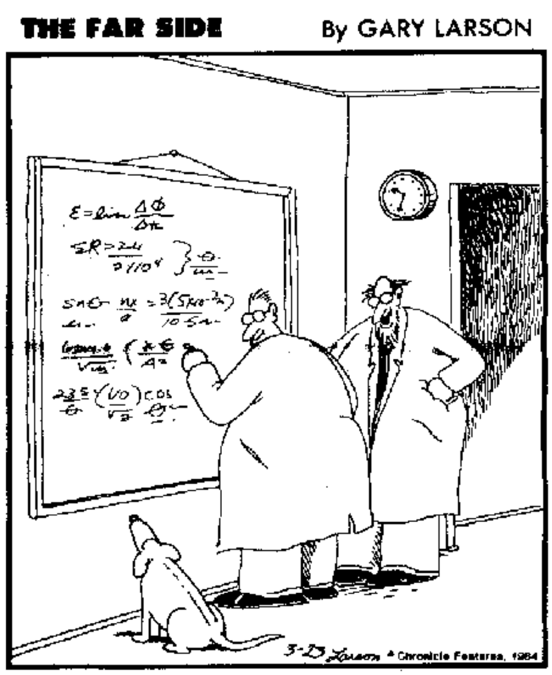
2. A 2.5 *N* magnetic force acts on a 475 *m* wire that is perpendicular to a 0.50 *T* magnetic field. What is the current in the wire? (0.011 *A*)

3. A thin 1.00 *m* long copper rod has a mass of 50.0 *g*. What is the minimum current needed in the rod to cause it to float in a magnetic field of 2.00 *T*? (0.245 *A*)

4. In what direction in relation to a magnetic field would you run a current-carrying wire so that the force on it resulting from the field is minimized or even made to be zero?

5. A power line carries a 225 *A* current from east to west parallel to the surface of Earth (**Note**: The intensity of Earth's magnetic field is $5.0\times10^{-5}\ T$ and it is directed from south to north parallel to Earth's surface).

   a) What is the magnitude of the force acting on each meter of wire? (0.011 *N/m*)
   b) What is the direction of the force?
   c) In your judgment, would this force be important in designing towers to hold these power lines?



"Ohhhhhhh . . . Look at that, Schuster . . . Dogs are so cute when they try to comprehend quantum mechanics."

Charges in a Magnetic Field Worksheet

1. Determine the magnitude and direction of the magnetic force on a proton moving horizontally to the north at $8.6 \times 10^4\ m/s$, as it enters a magnetic field of 1.2 *T*, pointing vertically upward. ($1.7 \times 10^{-14}\ N$ [E])

2. What is the magnitude and direction of the magnetic force on a proton moving vertically upward at $4.3 \times 10^4\ m/s$ in a 1.5 *T* magnetic field pointing horizontally to the west? ($1.0 \times 10^{-14}\ N$ [south])

3. What is the magnitude and direction of a magnetic field if an electron moving through it at $2.0 \times 10^6\ m/s$ experiences a maximum magnetic force of $5.1 \times 10^{-14}\ N$ [left] when moving vertically straight up? (0.16 *T* [horizontal, towards observer])

4. A proton traveling to the right along the *x*-axis enters a region where there is a magnetic field of magnitude 2.5 *T* directed upward along the *y*-axis. If the proton experiences a force of $3.2 \times 10^{-12}\ N$, find the speed of the proton. ($8.0 \times 10^6\ m/s$)

5. Calculate the radius of the path taken by an alpha particle (He^{+2} ion, of charge $3.2 \times 10^{-19}\ C$ and mass $6.7 \times 10^{-27}\ kg$) injected at a speed of $1.5 \times 10^7\ m/s$ into a uniform magnetic field of 2.4 *T*, at right angles to the field. (0.13 *m*)

6. Calculate the velocity of a proton, moving in a circular path of radius 8.0 *cm*, in a plane perpendicular to a 1.5 *T* magnetic field. What voltage would be required to accelerate the proton from rest in a vacuum? ($1.1 \times 10^7\ m/s$, $6.9 \times 10^5\ V$)

7. An airplane flying through the earth's magnetic field at a speed of 200 *m/s* acquires a charge of 100 *C*. What is the maximum magnetic force on it in a region where the magnitude of the earth's magnetic field is $5.0 \times 10^{-5}\ T$? (1.0 *N*)

8. An electron is injected into a magnetic field of strength 0.02 *T* at a speed of $1.5 \times 10^7\ m/s$ in a direction perpendicular to the field. What is the radius of the circle traversed by this electron? ($4.3 \times 10^{-3}\ m$)

9. A singly charged positive ion with a mass of $6.68 \times 10^{-27}\ kg$ moves clockwise with a speed of $1.00 \times 10^4\ m/s$ in a circular path with radius 3.00 *cm*. Find the direction and strength of the magnetic field. ($1.39 \times 10^{-2}\ T$ [toward the observer])

10. What speed would a proton need to achieve in order to circle Earth 1000 *km* above the magnetic equator, where Earth's magnetic field is directed over a line between magnetic north and south and has an intensity $4.0 \times 10^{-8}\ T$? ($2.82 \times 10^7\ m/s$)