10.5: Magnetic Field Strength- Force on a Moving Charge in a Magnetic Field

Learning Objectives

- Describe the effects of magnetic fields on moving charges.
- Use the right hand rule 1 to determine the velocity of a charge, the direction of the magnetic field, and the direction of the magnetic force on a moving charge.
- Calculate the magnetic force on a moving charge.

What is the mechanism by which one magnet exerts a force on another? The answer is related to the fact that all magnetism is caused by current, the flow of charge. *Magnetic fields exert forces on moving charges*, and so they exert forces on other magnets, all of which have moving charges.

Magnetic Force on a Moving Charge

The magnetic force on a moving charge is one of the most fundamental known. Magnetic force is as important as the electrostatic or Coulomb force. Yet the magnetic force is more complex, in both the number of factors that affects it and in its direction, than the relatively simple Coulomb force.

The magnitude of the magnetic force F on a charge depends on: the quantity of charge q, its speed v, the strength of magnetic field B, and **the direction of motion relative to the magnetic field's direction**. Motion, and its direction, are critical.

The **maximum** force occurs when the direction of motion and the magnetic field's direction are *perpendicular* to one another (i.e. ninety degree angle between directions).

$$\mathbf{v} \perp \mathbf{B}$$

In that situation, the magnitude of the magnetic force is

$$F = qvB$$

The **minimum** force occurs when the direction of motion and the magnetic field's direction are *parallel* to one another (i.e. zero or 180 degree angle between directions).

$$\mathbf{v} \| \mathbf{B}$$

In that situation, the magnitude of the magnetic force is

$$F = 0$$

We define the magnetic field strength B in terms of the force on a charged particle moving in a magnetic field. The SI unit for magnetic field strength B is called the **tesla** (T) after the eccentric but brilliant inventor Nikola Tesla (1856–1943). To determine how the tesla relates to other SI units, we solve for the magnetic field strength.

$$B = \frac{F}{qv}$$

So, the tesla is

$$1\ \mathrm{T} = \frac{1\ \mathrm{N}}{\mathrm{C} \cdot \mathrm{m/s}} = \frac{1\ \mathrm{N}}{\mathrm{A} \cdot \mathrm{m}}$$

(note that C/s = A).

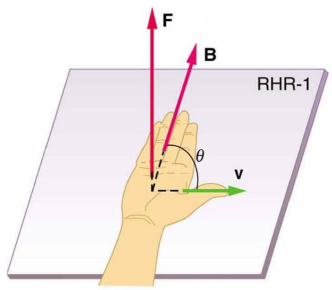
Another smaller unit, called the **gauss** (G), where $1\ \mathrm{G} = 10^{-4}\ \mathrm{T}$, is sometimes used. The strongest permanent magnets have fields near 2 T; superconducting electromagnets may attain 10 T or more. The Earth's magnetic field on its surface is only about $5 \times 10^{-5}\ \mathrm{T}$, or 0.5 G.

MAKING CONNECTIONS: CHARGES AND MAGNETS

There is no magnetic force on static charges. However, there is a magnetic force on moving charges. When charges are stationary, their electric fields do not affect magnets. But, when charges move, they produce magnetic fields that exert forces on other magnets. When there is relative motion, a connection between electric and magnetic fields emerges—each affects the other.

Direction of Force: Right Hand Rule 1

The *direction* of the magnetic force $\mathbf{F}$ is perpendicular to the plane formed by $\mathbf{v}$ and $\mathbf{B}$, as determined by the **right hand rule 1** (or RHR-1), which is illustrated in Figure 10.5.1. RHR-1 states that, to determine the direction of the magnetic force on a positive moving charge, you point the thumb of the right hand in the direction of $\mathbf{v}$, the fingers in the direction of $\mathbf{B}$, and a perpendicular to the palm points in the direction of $\mathbf{F}$. One way to remember this is that there is one velocity, and so the thumb represents it. There are many field lines, and so the fingers represent them. The force is in the direction you would push with your palm. The force on a negative charge is in exactly the opposite direction to that on a positive charge.



F ⊥ plane of **v** and **B**

Figure 10.5.1: Magnetic fields exert forces on moving charges. This force is one of the most basic known. The direction of the magnetic force on a moving charge is perpendicular to the plane formed by $\mathbf{v}$ and B and follows right hand rule–1 (RHR-1) as shown. The magnitude of the force is proportional to q, v, B, and depends on the angle between $\mathbf{v}$ and B.

Section Summary

- The maximum force a magnetic field can exert on a moving charge is

$$F = qvB$$

- The SI unit for magnetic field strength B is the tesla (T), which is related to other units by

$$1\ \mathrm{T} = \frac{1\ \mathrm{N}}{\mathrm{C} \cdot \mathrm{m/s}} = \frac{1\ \mathrm{N}}{\mathrm{A} \cdot \mathrm{m}}.$$

- The *direction* of the force on a moving charge is given by right hand rule 1 (RHR-1): Point the thumb of the right hand in the direction of v, the fingers in the direction of B, and a perpendicular to the palm points in the direction of F.
- The force is perpendicular to the plane formed by $\mathbf{V}$ and B. Since the force is zero if $\mathbf{V}$ is parallel to B, charged particles often follow magnetic field lines rather than cross them.

Glossary

right hand rule 1 (RHR-1)

the rule to determine the direction of the magnetic force on a positive moving charge: when the thumb of the right hand points in the direction of the charge's velocity $\mathbf{v}$ and the fingers point in the direction of the magnetic field $\mathbf{B}$, then the force on the charge is perpendicular and away from the palm; the force on a negative charge is perpendicular and into the palm

tesla

T, the SI unit of the magnetic field strength; $1\ \mathrm{T} = \frac{1\ \mathrm{N}}{\mathrm{A \cdot m}}$

magnetic force

the force on a charge produced by its motion through a magnetic field

gauss

G, the unit of the magnetic field strength; $1\,\mathrm{G} = 10^{-4}\ \mathrm{T}$