Forces on Currents in a Magnetic Field

In the previous lesson, we saw that an electric current exerts a force on a magnet, such as a compass needle. Newton's third law tells us that if one object exerts a force on a second object, then the second object must exert an equal and opposite force on the first. Thus, we should expect that a magnet exerts a force on a current-carrying wire. In this lesson, we will learn how to determine the magnitude and direction of this force.

Definition of Magnetic Field

The **magnetic field** is the region surrounding a magnet or a current-carrying wire where another magnet or current-carrying wire will experience a magnetic force.

The **strength of a magnetic field** (B) is defined as the magnetic force acting on a unit current element. This is calculated by dividing the magnetic force (F_B) acting on a current-carrying wire by the product of the current in the wire (I) and the length of the wire (L).

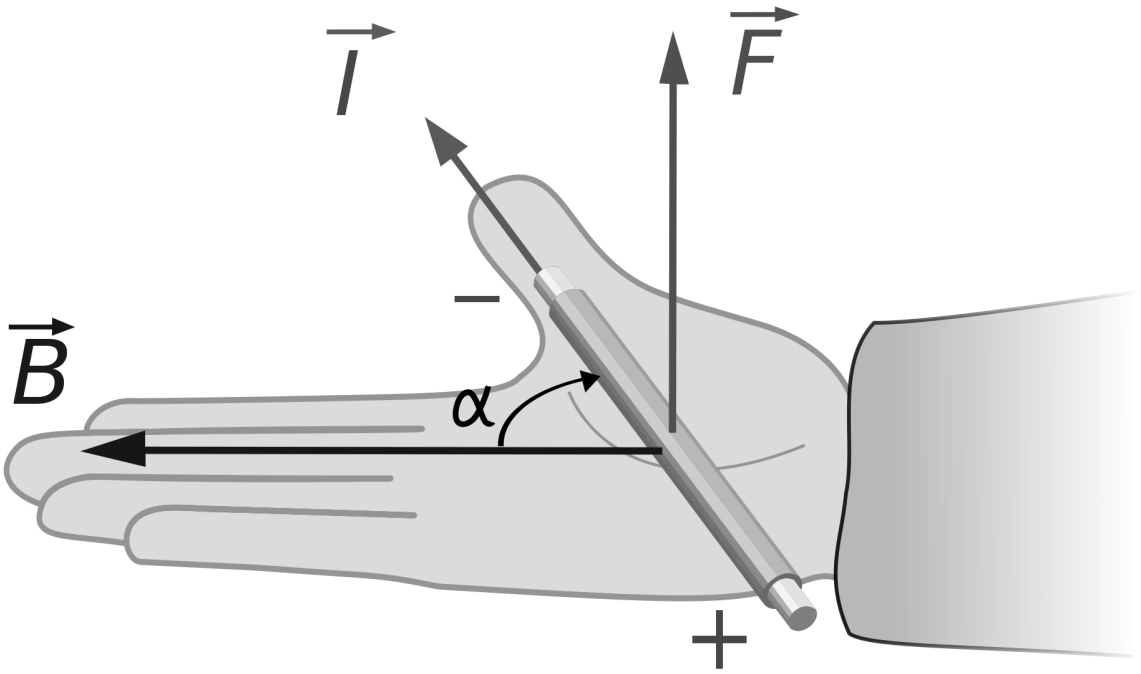
$$B = \frac{F_B}{IL}$$

The unit of magnetic field strength is the tesla (T).

Example 1
A wire of length $1.55\ m$ experiences a magnetic force of $0.375\ N$ when a current of $5.00\ A$ flows through the wire. What is the magnetic field strength at the location of the wire?

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, as shown below. 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 2
Suppose that a current flows to your right, while in a magnetic field that points away from you. Determine the direction of the magnetic force this current would experience.

Example 3
What is the direction of a current that would experience a magnetic force to the east in a magnetic field that points down?

The magnitude of the force acting on a current-carrying wire in a magnetic field can be calculated using the formula for the strength of a magnetic field strength:

$$F_B = BIL$$

Example 4
A straight wire of length $1.25\ m$ carries a current of $3.25\ A$ flowing north. The wire is immersed in a magnetic field of $0.465\ T$ pointing upwards. What is the magnitude and direction of the magnetic force acting on this wire?

It is important to understand that, for this equation ($F_B = BIL$) to work, the current-carrying wire must be perpendicular to the magnetic field. If the wire and the magnetic field are not perpendicular, then we must use a slightly different formula:

$$F_B = BIL\sin\theta$$

where θ represents the angle between the magnetic field lines and the wire. This formula implies a couple of important points:

1. If the wire is perpendicular to the field, $\theta = 90°$, and the formula becomes $F_B = BIL$.

2. If the wire is parallel to the field, $\theta = 0$ or $\theta = 180°$, and $F_B = 0$.

To determine the direction of the force in situations where the wire and the field are not perpendicular, you must point your fingers in the direction of the **component of the field that is perpendicular to the wire**, and your thumb in the direction of the current. Your palm will then "push" in the direction of the force acting on the wire.

Example 5
If a current of $10.0\ A$ flows north through a $2.00\ m$ length of wire in a magnetic field of $6.00\ T$ that points at an angle of $30.0°$ west of north, what is the force on the wire?

Electromagnetism Worksheet

1. A wire in the armature of an electric motor is 25 *cm* long and remains in, and perpendicular to, a uniform magnetic field of 0.20 *T*. What force is exerted on the wire when it carries a current of 15 *A*? (0.75 *N*)

2. What length of conductor, running at right angles to a 0.033 *T* magnetic field and carrying a current of 20 *A*, experiences a force of 0.10 *N*? (0.15 *m*)

3. A wire connecting a taillight to a motorcycle battery is 1.0 *m* long, and is lying perpendicular to Earth's magnetic field. If it experiences a force of $6.0 \times 10^{-5}\ N$ when carrying a current of 1.5 *A*, what is the magnitude of Earth's magnetic field at that location? ($4.0 \times 10^{-5}\ T$)

4. Two electrical line poles are situated 50 *m* apart, one directly north of the other, and the horizontal wire running between them carries a DC current of 200 *A*. If Earth's magnetic field, in the vicinity, has a magnitude of $5.0 \times 10^{-5}\ T$ and the magnetic inclination is $45°$, what is the magnetic force on the wire? **Hint**: The magnetic inclination will be equal tot the angle between the wire and the magnetic field. (0.35 *N*)

5. A 15 *cm* length of wire carrying a current of 20 *A* is situated at right angles to a uniform magnetic field. If it experiences a magnetic force of 0.40 *N*, what is the magnetic field intensity? (0.13 *T*)

6. What is the magnetic force on a wire 0.25 *m* long, carrying a current of 4.0 *A*, when placed in a uniform magnetic field of 0.50 *T*, at an angle of $45°$ to the wire? (0.35 *N*)

7. A conductor 40 *cm* long has a mass of 15 *g* and lies in a horizontal position, at a $90°$ angle to the field lines of a uniform horizontal magnetic field of 0.20 *T*. What must the current in the conductor be, so that the magnetic force on it will support its own weight? (1.8 *A*)

8. A wire 0.50 *m* long carrying a current of 8.0 *A* is at right angles to a 0.40 *T* magnetic field. How strong a force acts on the wire? (1.6 *N*)

9. A wire 75 *cm* long carrying a current of 6.0 *A* is at right angles to a uniform magnetic field. The magnitude of the force acting on the wire is 0.60 *N*. What is the strength of the magnetic field? (0.13 *T*)

10. A copper wire 40 *cm* long carries a current of 6.0 *A* and weighs 0.35 *N*. A certain magnetic field is strong enough to balance the force of gravity on the wire. What is the strength of the magnetic field? (0.1 *T*)

11. 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?

12. 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?