12.3: Magnetic Fields

Electromagnet lifting scrap metal

Figure 18.2.1

Powerful electromagnets are commonly used for industrial lifting. Here, a magnet is lifting scrap iron and loading it onto a railroad car for transporting to a scrap iron recovery plant. Other uses for lifting magnets include moving cars in a junk yard, lifting rolls of steel sheeting, and lifting large steel parts for various machines. Electromagnets are usually used for these jobs because they are magnets only when the electric current is on. The magnet will hold the iron object when the current is on and release it when the current is off.

Electric Currents and Magnetic Fields

Electricity and magnetism are inextricably linked. Under certain conditions, electric current causes a magnetic field. Under other conditions, a magnetic field can cause an electric current. A moving charged particle creates a magnetic field around it. Additionally, when a moving charged particle moves through a different magnetic field, the two magnetic fields will interact. The result is a force exerted on the moving charged particle.

Magnetic Field Around a Current Carrying Wire

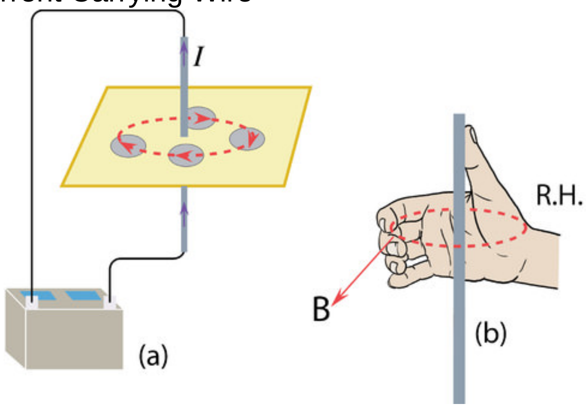

Figure 18.2.2

In sketch (a) above, a current is being pushed through a straight wire. Small compasses placed around the wire point in a circle, instead of all towards the north pole. This demonstrates the presence of a magnetic field around the wire. If the current is turned off, the compass points return to pointing north.

The current moving in a straight wire produces a circular magnetic field around the wire. When using conventional current, the direction of the magnetic field is determined by using the **right hand rule**. The rule says to curl your right hand around the wire such that your thumb points in the direction of the conventional current. Having done this, your fingers will curl around the wire in the direction of the magnetic field. Note that the right hand rule is for conventional current. If you are dealing with an electron flow current, the charges are flowing in the opposite direction, so you must use your left hand. That is, curl your left hand around the wire with your thumb pointing in the direction of the electron flow and your fingers will point in the direction of the magnetic field.

Charged Particles Moving Through a Magnetic Field

When a charged particle moves through a magnetic field at right angles to the field, the field exerts a force on the charged particle in a different direction.

Illustration of an electron moving through a magnetic field

Figure 18.2.3

In the case sketched above, an electron is moving downward through a magnetic field. The motion of the electron is perpendicular to the magnetic field. The force (F) exerted on the electron can be calculated by the equation,

$$F=Bqv$$

where v is the velocity of the particle in meters per second and q is the charge on the particle in coulombs. The term B represents the strength of the magnetic field in teslas. A tesla is equal to 1NewtonAmpere·meter and is a unit named after the Serbian physicist Nikolai Tesla. An ampere is equivalent to 1coulombsecond and you can see in the equations below that the units on the side of the equation cancel out to leave us with newtons, the unit of force.

$$F=Bqv$$

$$F=(\text{Newton}/\text{Amp}\cdot\text{meter})\times\text{coulomb}\times(\text{meter}/\text{second})$$

Replacing amperes with its unit definition:

$$F=(\text{Newton}\cdot\text{second}/\text{coulomb}\cdot\text{meter})\times\text{coulomb}\times(\text{meter}/\text{second})$$

Cancelling units:

$$F=(\text{Newton}\cdot\cancel{\text{second}}/\text{coulomb}\cdot\cancel{\text{meter}})\times\text{coulomb}\times(\cancel{\text{meter}}/\cancel{\text{second}})$$

$$F=\text{Newtons}$$

Again, we can determine the direction of the force acting upon the electron using a hand rule. Since the electron has a negative charge, the **left hand rule** is used. The fingers of the left hand are pointed in the direction of the magnetic field and the thumb points in the direction of the initial electron movement. The direction of the force acting on the electron is the direction the palm of the left hand faces. The direction of the magnetic field, the direction of the moving charge, and the direction of the force on the particle are all perpendicular to each other.

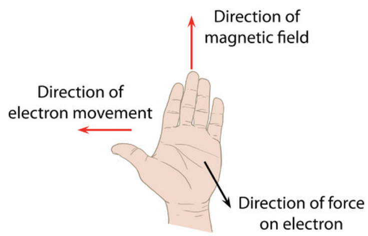

Figure 18.2.4

In most situations, a positive test charged is used, instead of an electron. In these circumstances, the **right hand rule** is used. The right hand rule is the same as the left hand rule; the thumb is the direction of initial charge movement, the fingers are the direction of the field, and the palm is the direction of the acting force.

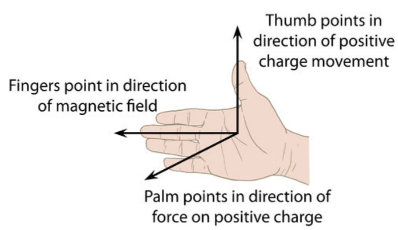

Figure 18.2.5

In dealing with the relationships that exist between magnetic fields and electric charges, there are both left hand and right hand rules that we use to indicate various directions – directions of fields, directions of currents, directions of motion. To avoid errors, it is absolutely vital to know and express whether the system we are observing is using conventional current or electron current. This allows us to use the appropriate rule.

✔ Example 18.2.1

An electron traveling at 3.0×106 m/s passes through a 0.0400 N/amp·m uniform magnetic field. The electron is moving at right angles to the magnetic field. What force acts on the electron?

Solution

$$F=Bqv=(0.0400\ \text{N/amp}\cdot\text{m})(1.6\times10^{-19}\ \text{C})(3.0\times10^{6}\ \text{m/s})$$

$$=1.9\times10^{-14}\ \text{N}$$

When the current is traveling through a magnetic field while inside a wire, the magnetic force is still exerted but now it is calculated as the force on the wire rather than on the individual charges in the current.

The equation for the force on the wire is given as F=BIL, where *B* is the strength of the magnetic field, *I* is the current in amps and *L* is the length of the wire in and perpendicular to the field.

Example 18.2.2

A wire 0.10 m long carries a current of 5.0 A. The wire is at right angles to a uniform magnetic field. The force the field exerts on the wire is 0.20 N. What is the magnitude of the magnetic field?

Solution

$$B=F/IL=0.20\text{ N}/(5.0\text{ A})(0.10\text{ m})=0.40\text{ N/A}\cdot\text{m}$$

In a particle accelerator, a strong magnetic field is used to exert a force on moving particles in a direction perpendicular to their motion. As a result, the particles begin to travel in a circle. Scientists can measure the radius of these circles and use them to distinguish the type of particle (electron, proton, neutrino, muon, etc). Different particles will have different masses and charges, and so will interact with the magnetic field in different ways. Use the Particle Tracks simulation below to learn more:

Summary

- A moving charged particle creates a magnetic field around it.
- Charge through a wire creates a magnetic field around it, the properties of which can be determined using a right hand rule.
- When a moving charged particle moves through another magnetic field, that field will exert a force on the moving charged particle that can be expressed using F=Bqv.
- The relationships between the moving charged particle, magnetic field, and the force exerted can be determined using the right hand rule if the particle is positive, or the left hand rule if it is negative.
- When the current is traveling through a magnetic field while inside a wire, the magnetic force is still exerted but now it is calculated as the force on the wire rather than on the individual charges in the current, calculated using F=BIL.

Review

1. Find the force on a 115 m long wire at right angles to a 5.0×10^{-5} N/A·m magnetic field, if the current through the wire is 400. A.
2. Find the force on an electron passing through a 0.50 T magnetic field if the velocity of the electron is 4.0×10^{6} m/s.
3. A stream of doubly ionized particles (charge=2+) moves at a velocity of 3.0×10^{4} m/s perpendicularly to a magnetic field of 0.0900 T. What is the magnitude of the force on the particles?
4. A wire 0.50 m long carrying a current of 8.0 A is at right angles to a 1.0 T magnetic field. What force acts on the wire?
5. Suppose a magnetic field exists with the north pole at the top of the computer monitor and the south pole at the bottom of the monitor screen. If a positively charged particle entered the field moving from your face to the other side of the monitor screen, which way would the path of the particle bend?
    1. left
    2. right
    3. up
    4. down
    5. none of these
6. Suppose the surface of your dining room table is a magnetic field with the north pole at the north edge and the south pole at the south edge. If an electron passes through this field from ceiling to floor, which way will the path of the electron bend?
    1. west
    2. east
    3. north
    4. south
    5. toward the ceiling

Explore More

Use this resource to answer the questions that follow.

1. What happens to the wire when the current begins to flow?
2. What difference would it make if the magnetic field were stronger?
3. What difference would it make if the battery were 3.0 V instead of 1.5 V?

Additional Resources

Study Guide: Magnetism Study Guide

Real World Application: Solar Attack

Videos: