Summary

A magnet has two **poles**, north and south. The north pole is that end which points toward geographic north when the magnet is freely suspended. Like poles of two magnets repel each other, whereas unlike poles attract.

We can picture that a **magnetic field** surrounds every magnet. The SI unit for magnetic field is the **tesla** (T).

Electric currents produce magnetic fields. For example, the lines of magnetic field due to a current in a straight wire form circles around the wire, and the field exerts a force on magnets (or currents) near it.

A magnetic field exerts a force on an electric current. For a straight wire of length ℓ carrying a current I, the force has magnitude

$$F = I\ell B \sin\theta, \tag{20–1}$$

where θ is the angle between the magnetic field $\vec{\mathbf{B}}$ and the current direction. The direction of the force is perpendicular to the current-carrying wire and to the magnetic field, and is given by a right-hand rule. Equation 20–1 serves as the definition of magnetic field $\vec{\mathbf{B}}$.

Similarly, a magnetic field exerts a force on a charge q moving with velocity v of magnitude

$$F = qvB \sin\theta, \tag{20–3}$$

where θ is the angle between $\vec{\mathbf{v}}$ and $\vec{\mathbf{B}}$. The direction of $\vec{\mathbf{F}}$ is perpendicular to $\vec{\mathbf{v}}$ and to $\vec{\mathbf{B}}$ (again a right-hand rule). The path of a charged particle moving perpendicular to a uniform magnetic field is a circle.

The magnitude of the magnetic field produced by a current I in a long straight wire, at a distance r from the wire, is

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}. \tag{20–6}$$

Two currents exert a force on each other via the magnetic field each produces. Parallel currents in the same direction attract each other; currents in opposite directions repel.

The magnetic field inside a long tightly wound solenoid is

$$B = \mu_0 NI/\ell, \tag{20–8}$$

where N is the number of loops in a length ℓ of coil, and I is the current in each loop.

Ampère's law states that around any chosen closed loop path, the sum of each path segment $\Delta\ell$ times the component of $\vec{\mathbf{B}}$ parallel to the segment equals μ_0 times the current I enclosed by the closed path:

$$\Sigma B_{\parallel}\,\Delta\ell = \mu_0 I_{\text{encl}}. \tag{20–9}$$

The torque τ on N loops of current I in a magnetic field $\vec{\mathbf{B}}$ is

$$\tau = NIAB \sin\theta. \tag{20–10}$$

The force or torque exerted on a current-carrying wire by a magnetic field is the basis for operation of many devices, such as **motors**, **loudspeakers**, and **galvanometers** used in analog electric meters.

[*A **mass spectrometer** uses electric and magnetic fields to determine the mass of ions.]

[*Iron and a few other materials that are **ferromagnetic** can be made into strong permanent magnets. Ferromagnetic materials are made up of tiny **domains**—each a tiny magnet—which are preferentially aligned in a permanent magnet. When iron or another ferromagnetic material is placed in a magnetic field B_0 due to a current, the iron becomes magnetized. When the current is turned off, the material remains magnetized; when the current is increased in the opposite direction, a graph of the total field B versus B_0 is a **hysteresis loop**, and the fact that the curve does not retrace itself is called **hysteresis**.]

Questions

1. A compass needle is not always balanced parallel to the Earth's surface, but one end may dip downward. Explain.
2. Explain why the Earth's "north pole" is really a magnetic south pole. Indicate how north and south magnetic poles were defined and how we can tell experimentally that the north pole is really a south magnetic pole.
3. In what direction are the magnetic field lines surrounding a straight wire carrying a current that is moving directly away from you? Explain.
4. A horseshoe magnet is held vertically with the north pole on the left and south pole on the right. A wire passing between the poles, equidistant from them, carries a current directly away from you. In what direction is the force on the wire? Explain.
5. Will a magnet attract any metallic object, such as those made of aluminum or copper? (Try it and see.) Why is this so?
6. Two iron bars attract each other no matter which ends are placed close together. Are both magnets? Explain.
7. The magnetic field due to current in wires in your home can affect a compass. Discuss the effect in terms of currents, including if they are ac or dc.
8. If a negatively charged particle enters a region of uniform magnetic field which is perpendicular to the particle's velocity, will the kinetic energy of the particle increase, decrease, or stay the same? Explain your answer. (Neglect gravity and assume there is no electric field.)
9. In Fig. 20–47, charged particles move in the vicinity of a current-carrying wire. For each charged particle, the arrow indicates the initial direction of motion of the particle, and the + or − indicates the sign of the charge. For each of the particles, indicate the direction of the magnetic force due to the magnetic field produced by the wire. Explain.

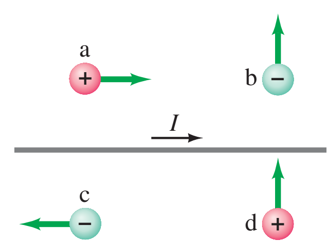

FIGURE 20–47 Question 9.

10. Three particles, a, b, and c, enter a magnetic field and follow paths as shown in Fig. 20–48. What can you say about the charge on each particle? Explain.

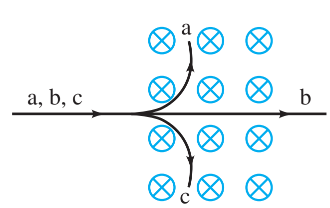

FIGURE 20–48 Question 10.

11. Can an iron rod attract a magnet? Can a magnet attract an iron rod? What must you consider to answer these questions?