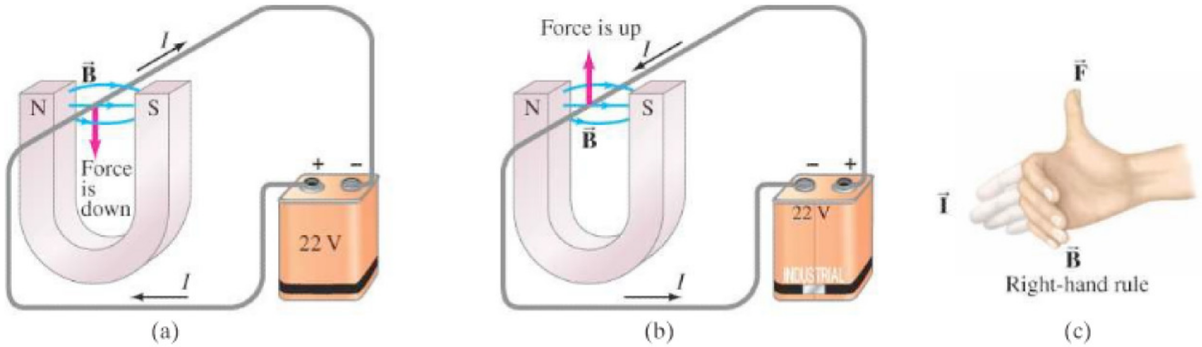

FIGURE 20–11 (a) Force on a current-carrying wire placed in a magnetic field $\vec{\mathbf{B}}$; (b) same, but current reversed; (c) right-hand rule for setup in (b).

20–3 Force on an Electric Current in a Magnetic Field; Definition of $\vec{\mathbf{B}}$

Magnet exerts a force on an electric current

In Section 20–2 we saw that an electric current exerts a force on a magnet, such as a compass needle. By Newton's third law, we might expect the reverse to be true as well: we should expect that *a magnet exerts a force on a current-carrying wire.* Experiments indeed confirm this effect, and it too was first observed by Oersted.

Suppose a straight wire is placed in the magnetic field between the poles of a horseshoe magnet as shown in Fig. 20–11. When a current flows in the wire, experiment shows that a force is exerted on the wire. But this force is *not* toward one or the other pole of the magnet. Instead, the force is directed at right angles to the magnetic field direction, downward in Fig. 20–11a. If the current is reversed in direction, the force is in the opposite direction, upward as shown in Fig. 20–11b. Experiments show that *the direction of the force is always perpendicular to the direction of the current and also perpendicular to the direction of the magnetic field*, $\vec{\mathbf{B}}$.

Right-hand-rule-2: force on current exerted by $\vec{\mathbf{B}}$

The direction of the force is given by another **right-hand rule**, as illustrated in Fig. 20–11c. Orient your right hand until your outstretched fingers can point in the direction of the conventional current I, and when you bend your fingers they point in the direction of the magnetic field lines, $\vec{\mathbf{B}}$. Then your outstretched thumb will point in the direction of the force $\vec{\mathbf{F}}$ on the wire.

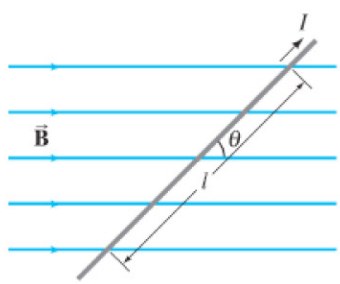

FIGURE 20–12 Current-carrying wire in a magnetic field. Force on the wire is directed into the page.

This right-hand rule describes the direction of the force. What about the magnitude of the force on the wire? It is found experimentally that the magnitude of the force is directly proportional to the current I in the wire, and to the length l of wire exposed to the magnetic field (assumed uniform). Furthermore, if the magnetic field B is made stronger, the force is found to be proportionally greater. The force also depends on the angle θ between the current direction and the magnetic field (Fig. 20–12), being proportional to $\sin\theta$. Thus, the force on a wire carrying a current I with length l in a uniform magnetic field B is given by

$$F \propto IlB\sin\theta.$$

When the current is perpendicular to the field lines ($\theta = 90°$), the force is strongest. When the wire is parallel to the magnetic field lines ($\theta = 0°$), there is no force at all.

Up to now we have not defined the magnetic field strength precisely. In fact, the magnetic field B can be conveniently defined in terms of the above proportion so that the proportionality constant is precisely 1. Thus we have

Force on electric current in a uniform magnetic field

$$F = IlB\sin\theta. \tag{20–1}$$

If the direction of the current is perpendicular to the field $\vec{\mathbf{B}}$ ($\theta = 90°$), then the force is

$$F_{max} = IlB. \qquad [\text{current} \perp \vec{\mathbf{B}}] \tag{20–2}$$

Definition of magnetic field

If the current is parallel to the field ($\theta = 0°$), the force is zero. The magnitude of $\vec{\mathbf{B}}$ can be defined using Eq. 20–2 as $B = F_{max}/Il$, where F_{max} is the magnitude of the force on a straight length l of wire carrying a current I when the wire is perpendicular to $\vec{\mathbf{B}}$.†

†In our discussion, we have assumed that the magnetic field is uniform. If it is not, then B in Eqs. 20–1 and 20–2 is the average field over the length l of the wire.