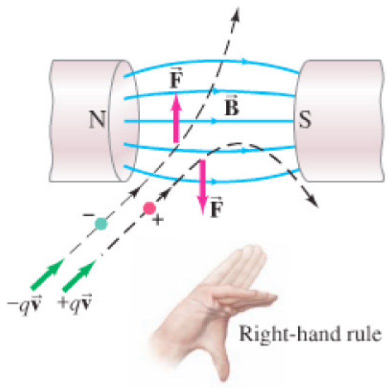


FIGURE 20–14 Force on charged particles due to a magnetic field is perpendicular to the magnetic field direction.

20–4 Force on Electric Charge Moving in a Magnetic Field

We have seen that a current-carrying wire experiences a force when placed in a magnetic field. Since a current in a wire consists of moving electric charges, we might expect that freely moving charged particles (not in a wire) would also experience a force when passing through a magnetic field. Although free electric charges are not as easy to produce in the lab as a current in a wire, it can be done, and experiments do show that moving electric charges experience a force in a magnetic field.

From what we already know we can predict the force on a single electric charge moving in a magnetic field $\vec{\mathbf{B}}$. If N such particles of charge q pass by a given point in time t, they constitute a current $I = Nq/t$. We let t be the time for a charge q to travel a distance l in a magnetic field $\vec{\mathbf{B}}$; then $l = vt$ where v is the magnitude of the velocity $\vec{\mathbf{v}}$ of the particle. Thus, the force on these N particles is, by Eq. 20–1, $F = IlB \sin\theta = (Nq/t)(vt)B\sin\theta = NqvB\sin\theta$. The force on *one* of the N particles is then

Force on moving charge in magnetic field

$$F = qvB\sin\theta. \tag{20–3}$$

This equation gives the magnitude of the force exerted by a magnetic field on a particle of charge q moving with velocity v at a point where the magnetic field has magnitude B. The angle between $\vec{\mathbf{v}}$ and $\vec{\mathbf{B}}$ is θ. The force is greatest when the particle moves perpendicular to $\vec{\mathbf{B}}$ ($\theta = 90°$):

$$F_{\text{max}} = qvB. \qquad [\vec{\mathbf{v}} \perp \vec{\mathbf{B}}] \tag{20–4}$$

The force is *zero* if the particle moves *parallel* to the field lines ($\theta = 0°$). The *direction* of the force is perpendicular to the magnetic field $\vec{\mathbf{B}}$ and to the velocity $\vec{\mathbf{v}}$ of the particle. It is again given by a **right-hand rule**: you orient your right hand so that your outstretched fingers point along the direction of the particle's velocity ($\vec{\mathbf{v}}$), and when you bend your fingers they must point along the direction of $\vec{\mathbf{B}}$. Then your thumb will point in the direction of the force. This is true only for *positively* charged particles, and will be "down" for the situation shown in Fig. 20–14. For negatively charged particles, the force is in exactly the opposite direction, "up" in Fig. 20–14.

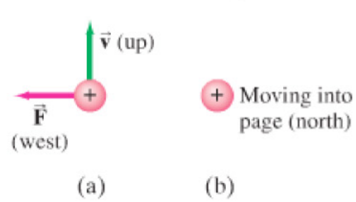
Right-hand-rule-3: force on moving charge exerted by $\vec{\mathbf{B}}$

CONCEPTUAL EXAMPLE 20–3 **Negative charge near a magnet.** A negative charge $-Q$ is placed at rest near a magnet. Will the charge begin to move? Will it feel a force? What if the charge were positive, $+Q$?

RESPONSE No to all questions. A charge at rest has velocity equal to zero. Magnetic fields exert a force only on moving electric charges (Eq. 20–3).

EXAMPLE 20–4 **Magnetic force on a proton.** A proton having a speed of 5.0×10^6 m/s in a magnetic field feels a force of 8.0×10^{-14} N toward the west when it moves vertically upward (Fig. 20–15a). When moving horizontally in a northerly direction, it feels zero force (Fig. 20–15b). Determine the magnitude and direction of the magnetic field in this region. (The charge on a proton is $q = +e = 1.6 \times 10^{-19}$ C.)

FIGURE 20–15 Example 20–4.



APPROACH Since the proton feels no force when moving north, the field must be in a north–south direction. In order to produce a force to the west when the proton moves upward, the right-hand rule tells us that $\vec{\mathbf{B}}$ must point toward the north. (Your thumb points west and the outstretched fingers of your right hand point upward only when your bent fingers point north.) The magnitude of $\vec{\mathbf{B}}$ is found using Eq. 20–3.

SOLUTION Equation 20–3 with $\theta = 90°$ gives

$$B = \frac{F}{qv} = \frac{8.0 \times 10^{-14}\,\text{N}}{(1.6 \times 10^{-19}\,\text{C})(5.0 \times 10^6\,\text{m/s})} = 0.10\,\text{T}.$$

EXERCISE D Determine the force on the proton of Example 20–4 if it heads horizontally south.