21–3 EMF Induced in a Moving Conductor

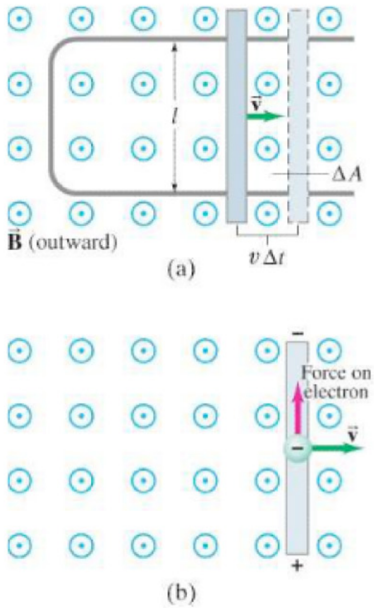


FIGURE 21–12 (a) A conducting rod is moved to the right on a U-shaped conductor in a uniform magnetic field $\vec{\mathbf{B}}$ that points out of the paper. (b) Upward force on an electron in the metal rod (moving to the right) due to $\vec{\mathbf{B}}$ pointing out of page.

Another way to induce an emf is shown in Fig. 21–12a, and this situation helps illuminate the nature of the induced emf. Assume that a uniform magnetic field $\vec{\mathbf{B}}$ is perpendicular to the area bounded by the U-shaped conductor and the movable rod resting on it. If the rod is made to move at a speed v, it travels a distance $\Delta x = v\,\Delta t$ in a time Δt. Therefore, the area of the loop increases by an amount $\Delta A = l\,\Delta x = lv\,\Delta t$ in a time Δt. By Faraday's law there is an induced emf $\mathscr{E}$ whose magnitude is given by

$$\mathscr{E} = \frac{\Delta\Phi_B}{\Delta t} = \frac{B\,\Delta A}{\Delta t} = \frac{Blv\,\Delta t}{\Delta t} = Blv. \qquad \textbf{(21–3)}$$

Equation 21–3 is valid as long as B, l, and v are mutually perpendicular. (If they are not, we use only the components of each that are mutually perpendicular.) An emf induced on a conductor moving in a magnetic field is sometimes called *motional emf.*

We can also obtain Eq. 21–3 without using Faraday's law. We saw in Chapter 20 that a charged particle moving perpendicular to a magnetic field B with speed v experiences a force $F = qvB$ (Eq. 20–4). When the rod of Fig. 21–12a moves to the right with speed v, the electrons in the rod also move with this speed. Therefore, since $\vec{\mathbf{v}} \perp \vec{\mathbf{B}}$, each electron feels a force $F = qvB$, which acts up the page as shown in Fig. 21–12b. If the rod was not in contact with the U-shaped conductor, electrons would collect at the upper end of the rod, leaving the lower end positive (see signs in Fig. 21–12b). There must thus be an induced emf. If the rod does slide on the U-shaped conductor (Fig. 21–12a), the electrons will flow into the U. There will then be a clockwise (conventional) current in the loop. To calculate the emf, we determine the work W needed to move a charge q from one end of the rod to the other against this potential difference: $W = \text{force} \times \text{distance} = (qvB)(l)$. The emf equals the work done per unit charge, so $\mathscr{E} = W/q = qvBl/q = Blv$, the same result as from Faraday's law above, Eq. 21–3.

EXERCISE C In what direction will the electrons flow in Fig. 21–12 if the rod moves to the left, decreasing the area of the current loop?

FIGURE 21–13 Example 21–6.

EXAMPLE 21–6 **Does a moving airplane develop a large emf?** An airplane travels 1000 km/h in a region where the Earth's magnetic field is 5.0×10^{-5} T and is nearly vertical (Fig. 21–13). What is the potential difference induced between the wing tips that are 70 m apart?

APPROACH We consider the wings to be a 70-m-long conductor moving through the Earth's magnetic field. We use Eq. 21–3 to get the emf.

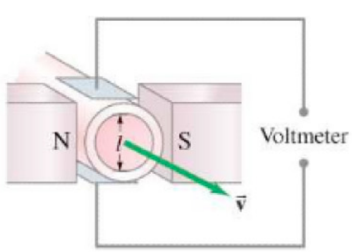
SOLUTION Since $v = 1000\text{ km/h} = 280\text{ m/s}$, and $\vec{\mathbf{v}} \perp \vec{\mathbf{B}}$, we have

$$\mathscr{E} = Blv = (5.0 \times 10^{-5}\,\text{T})(70\,\text{m})(280\,\text{m/s}) = 1.0\,\text{V}.$$

NOTE Not much to worry about.

PHYSICS APPLIED
Blood flow measurement

FIGURE 21–14 Measurement of blood velocity from the induced emf. Example 21–7.



EXAMPLE 21–7 **Electromagnetic blood-flow measurement.** The rate of blood flow in our body's vessels can be measured using the apparatus shown in Fig. 21–14, since blood contains charged ions. Suppose that the blood vessel is 2.0 mm in diameter, the magnetic field is 0.080 T, and the measured emf is 0.10 mV. What is the flow velocity of the blood?

APPROACH The magnetic field $\vec{\mathbf{B}}$ points horizontally from left to right (N pole toward S pole). The induced emf acts over the width $l = 2.0$ mm of the blood vessel (Fig. 21–14), perpendicular to $\vec{\mathbf{B}}$ and $\vec{\mathbf{v}}$, just as in Fig. 21–12. We can then use Eq. 21–3 to get v.

SOLUTION We solve for v in Eq. 21–3:

$$v = \frac{\mathscr{E}}{Bl} = \frac{(1.0 \times 10^{-4}\,\text{V})}{(0.080\,\text{T})(2.0 \times 10^{-3}\,\text{m})} = 0.63\,\text{m/s}.$$

NOTE In actual practice, an alternating current is used to produce an alternating magnetic field. The induced emf is then alternating.