EXAMPLE 21–5 **Pulling a coil from a magnetic field.** A square coil of wire with side $l = 5.00\,\text{cm}$ contains 100 loops and is positioned perpendicular to a uniform 0.600-T magnetic field, as shown in Fig. 21–10. It is quickly pulled from the field at constant speed (moving perpendicular to $\vec{\mathbf{B}}$) to a region where B drops abruptly to zero. At $t = 0$, the right edge of the coil is at the edge of the field. It takes 0.100 s for the whole coil to reach the field-free region. The coil's total resistance is $100\,\Omega$. Find (*a*) the rate of change in flux through the coil, and (*b*) the emf and current induced. (*c*) How much energy is dissipated in the coil? (*d*) What was the average force required?

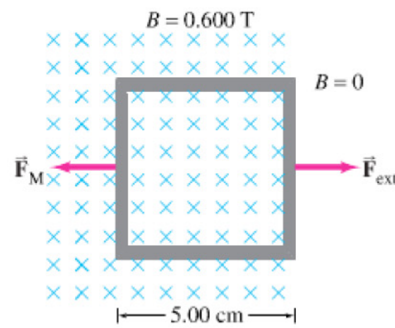

FIGURE 21–10 Example 21–5. The square coil in a magnetic field $B = 0.600\,\text{T}$ is pulled abruptly to the right to a region where $B = 0$.

APPROACH We start by finding how the magnetic flux, $\Phi_B = BA$, changes during the time interval $\Delta t = 0.100\,\text{s}$. Faraday's law then gives the induced emf and Ohm's law gives the current.

SOLUTION (*a*) The area of the coil is $A = l^2 = (5.00 \times 10^{-2}\,\text{m})^2 = 2.50 \times 10^{-3}\,\text{m}^2$. The flux is initially $\Phi_B = BA = (0.600\,\text{T})(2.50 \times 10^{-3}\,\text{m}^2) = 1.50 \times 10^{-3}\,\text{Wb}$. After 0.100 s, the flux is zero. The rate of change in flux is constant (because the coil is square), equal to

$$\frac{\Delta \Phi_B}{\Delta t} = \frac{0 - (1.50 \times 10^{-3}\,\text{Wb})}{0.100\,\text{s}} = -1.50 \times 10^{-2}\,\text{Wb/s}.$$

(*b*) The emf induced (Eq. 21–2) in the 100-loop coil during this 0.100-s interval is

$$\mathscr{E} = -N\frac{\Delta \Phi_B}{\Delta t} = -(100)(-1.50 \times 10^{-2}\,\text{Wb/s}) = 1.50\,\text{V}.$$

The current is found by applying Ohm's law to the $100\text{-}\Omega$ coil:

$$I = \frac{\mathscr{E}}{R} = \frac{1.50\,\text{V}}{100\,\Omega} = 1.50 \times 10^{-2}\,\text{A} = 15.0\,\text{mA}.$$

By Lenz's law, the current must be clockwise to produce more $\vec{\mathbf{B}}$ into the page and thus oppose the decreasing flux into the page.

(*c*) The total energy dissipated in the coil is the product of the power $(= I^2R)$ and the time:

$$E = Pt = I^2Rt = (1.50 \times 10^{-2}\,\text{A})^2(100\,\Omega)(0.100\,\text{s}) = 2.25 \times 10^{-3}\,\text{J}.$$

(*d*) We can use the result of part (*c*) and apply the work-energy principle: the energy dissipated E is equal to the work W needed to pull the coil out of the field (Chapter 6). Because $W = \bar{F}d$ where $d = 5.00\,\text{cm}$, then

$$\bar{F} = \frac{W}{d} = \frac{2.25 \times 10^{-3}\,\text{J}}{5.00 \times 10^{-2}\,\text{m}} = 0.0450\,\text{N}.$$

Alternate Solution (*d*) We can also calculate the force directly using $F = IlB$, Eq. 20–2 for constant $\vec{\mathbf{B}}$. The force the magnetic field exerts on the top and bottom sections of the square coil of Fig. 21–10 are in opposite directions and cancel each other. The magnetic force $\vec{\mathbf{F}}_M$ exerted on the left vertical section of the square coil acts to the left as shown because the current is up (clockwise). The right side of the loop is in the region where $\vec{\mathbf{B}} = 0$. Hence the external force, to the right, needed to just overcome the magnetic force to the left (on $N = 100$ loops) is

$$F_{ext} = NIlB = (100)(0.0150\,\text{A})(0.0500\,\text{m})(0.600\,\text{T}) = 0.0450\,\text{N},$$

which is the same answer, confirming our use of energy conservation above.

EXERCISE B What is the direction of the induced current in the circular loop due to the current shown in each part of Fig. 21–11?

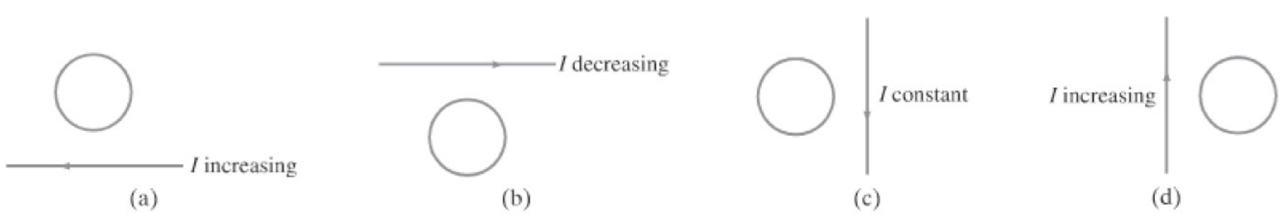

FIGURE 21–11 Exercise B.