If the circuit contains N closely wrapped loops, the emfs induced in each loop add together, so

$$\mathscr{E} = -N\frac{\Delta\Phi_B}{\Delta t}. \qquad [N \text{ loops}] \quad \textbf{(21–2b)}$$

FARADAY'S LAW OF INDUCTION

The minus sign in Eqs. 21–2 is there to remind us in which direction the induced emf acts. Experiments show that

Lenz's law

a current produced by an induced emf moves in a direction so that its magnetic field opposes the original change in flux.

This is known as **Lenz's law**. Be aware that we are now discussing two distinct magnetic fields: (1) the changing magnetic field or flux that induces the current, and (2) the magnetic field produced by the induced current (all currents produce a field). The second field opposes the change in the first.

CAUTION
Distinguish two different magnetic fields

Let us now apply Lenz's law to the relative motion between a magnet and a coil, Fig. 21–2. The changing flux through the coil induces an emf in the coil, producing a current. This induced current produces its own magnetic field. In Fig. 21–2a the distance between the coil and the magnet decreases. The magnet's magnetic field (and number of field lines) through the coil increases, and therefore the flux increases. The magnetic field of the magnet points upward. To oppose the upward increase, the magnetic field inside the coil produced by the induced current needs to point *downward*. Thus, Lenz's law tells us that the current moves as shown (use the right-hand rule). In Fig. 21–2b, the flux *decreases* (because the magnet is moved away and B decreases), so the induced current in the coil produces an *upward* magnetic field through the coil that is "trying" to maintain the status quo. Thus the current in Fig. 21–2b is in the opposite direction from Fig. 21–2a.

It is important to note that an emf is induced whenever there is a change in *flux* through the coil, and we now consider some more possibilities.

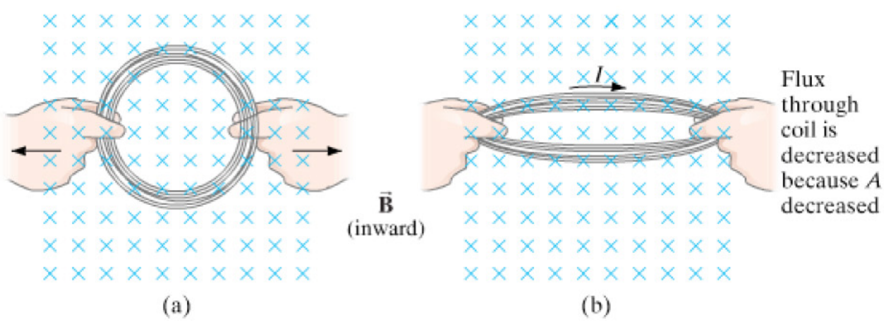

FIGURE 21–6 A current can be induced by changing the area of the coil, even though B doesn't change. In both this case and that of Fig. 21–7, the *flux* through the coil is reduced as we go from (a) to (b). Here the brief induced current acts in the direction shown so as to try to maintain the original flux ($\Phi = BA$) by producing its own magnetic field into the page. That is, as the area A decreases, the current acts to increase B in the original (inward) direction.

Since magnetic flux $\Phi_B = BA\cos\theta$, we see that an emf can be induced in three ways: (1) by a changing magnetic field B; (2) by changing the area A of the loop in the field; or (3) by changing the loop's orientation θ with respect to the field. Figures 21–1 and 21–2 illustrated case 1. Examples of cases 2 and 3 are illustrated in Figs. 21–6 and 21–7, respectively.

Three ways to change the magnetic flux: change B, A, or θ

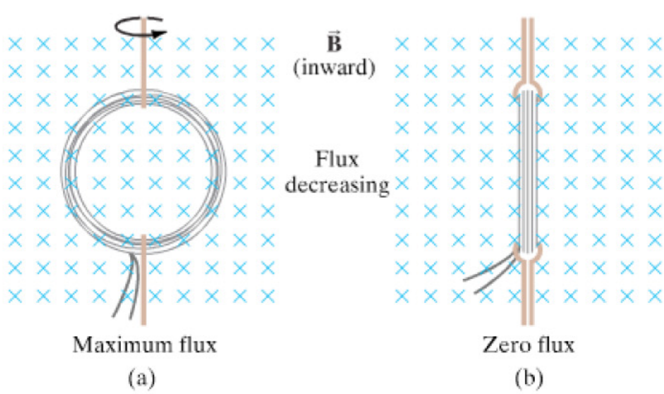

FIGURE 21–7 A current can be induced by rotating a coil in a magnetic field. The flux through the coil changes from (a) to (b) because θ (in Eq. 21–1) went from $0°$ ($\cos\theta = 1$) to $90°$ ($\cos\theta = 0$).