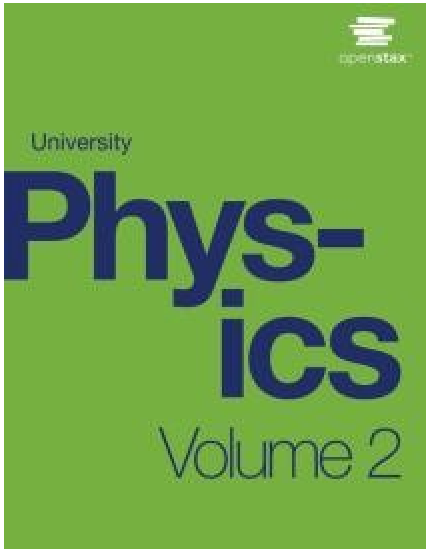
UNIVERSITY PHYSICS

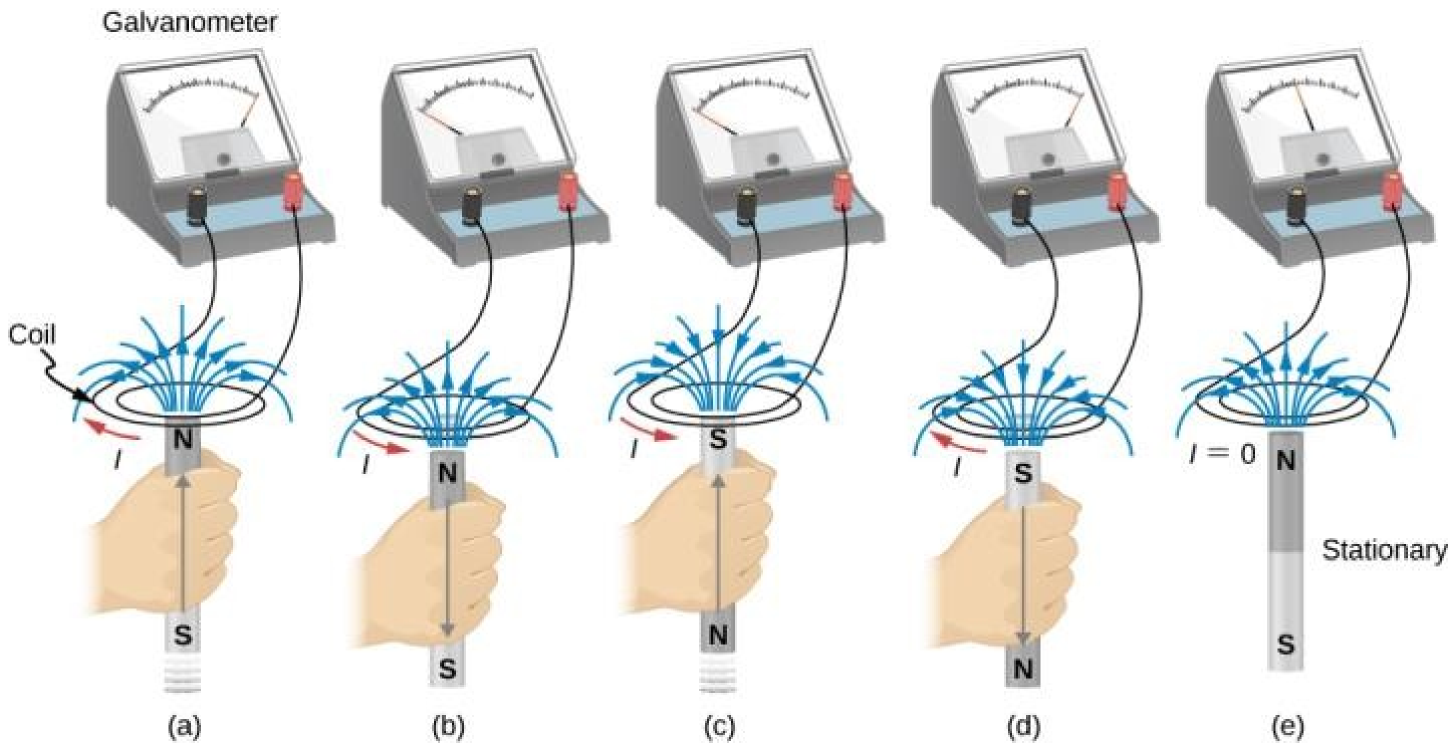
Chapter 13 ELECTROMAGNETIC INDUCTION

PowerPoint Image Slideshow



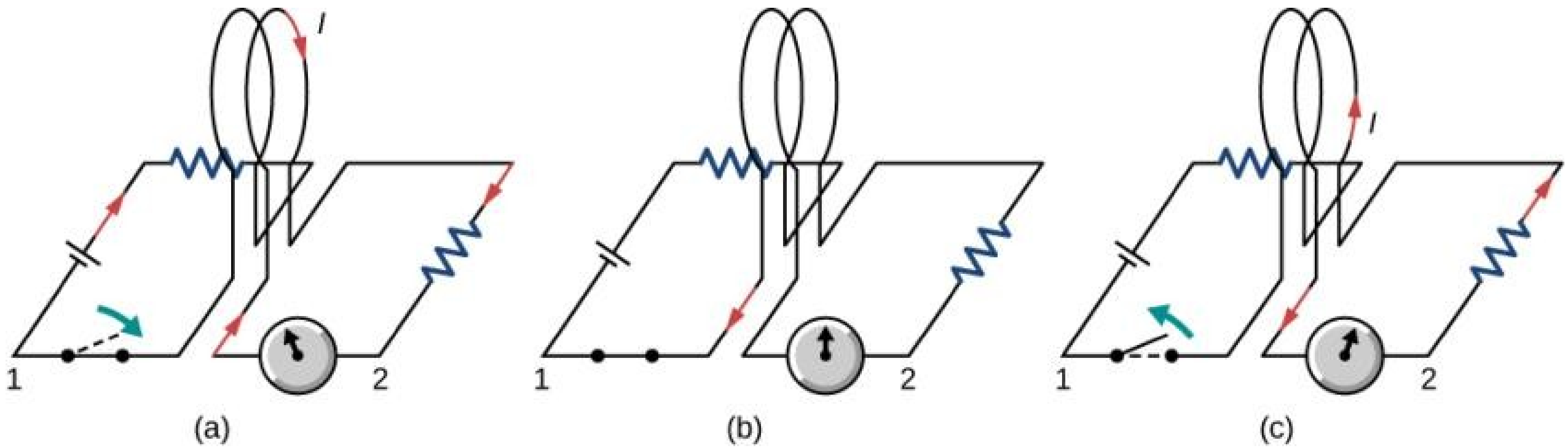
Induction

FIGURE 13.2



Movement of a magnet relative to a coil produces emfs as shown (a–d). The same emfs are produced if the coil is moved relative to the magnet. This short-lived emf is only present during the motion. The greater the speed, the greater the magnitude of the emf, and the emf is zero when there is no motion, as shown in (e).

FIGURE 13.3



(a) Closing the switch of circuit 1 produces a short-lived current surge in circuit 2.

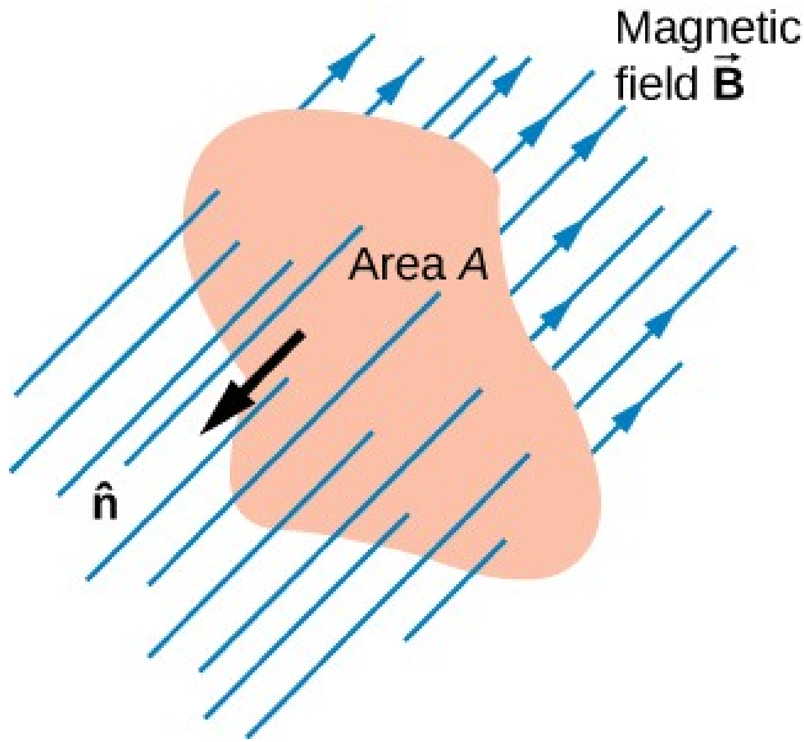
(b) If the switch remains closed, no current is observed in circuit 2.

(c) Opening the switch again produces a short-lived current in circuit 2 but in the opposite direction from before.

Magnetic flux

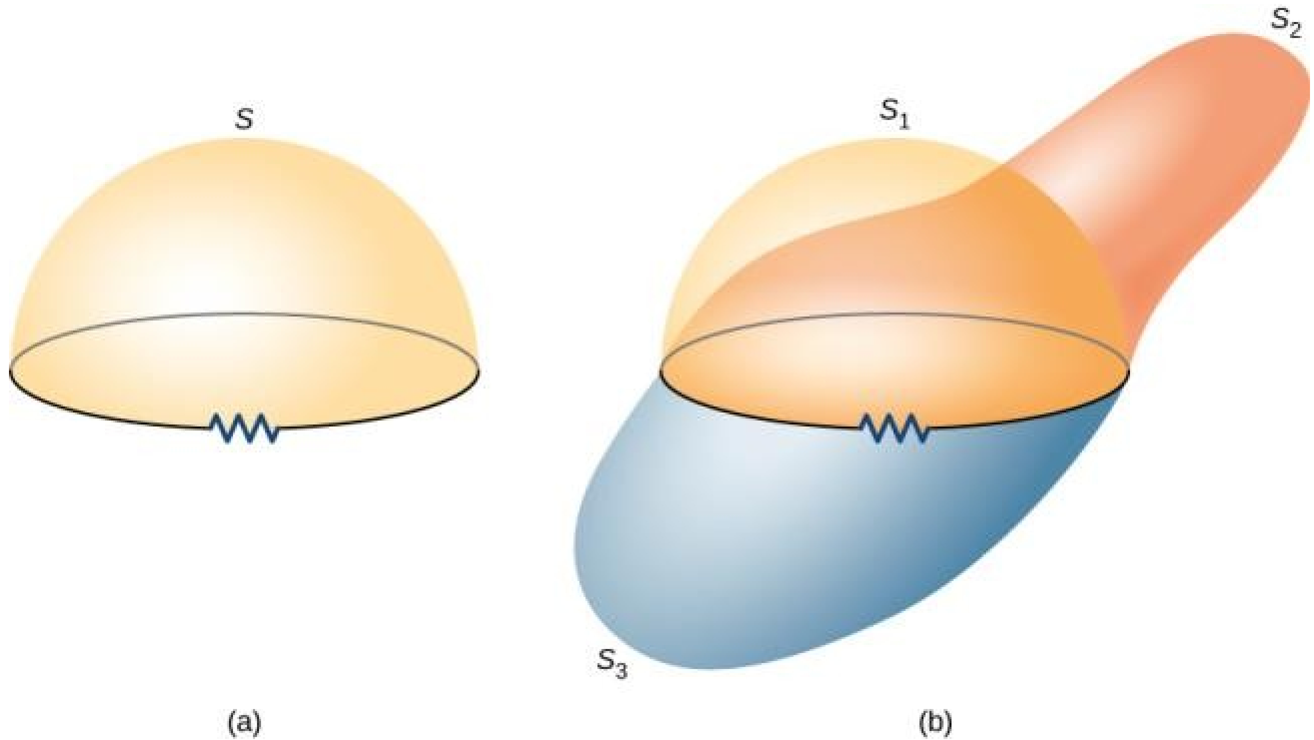
$$\Phi = \int \vec{B} \cdot d\vec{A}$$

FIGURE 13.4



The magnetic flux is the amount of magnetic field lines cutting through a surface area *A* defined by the unit area vector . If the angle between the unit area and magnetic field vector are parallel or antiparallel, as shown in the diagram, the magnetic flux is the highest possible value given the values of area and magnetic field.

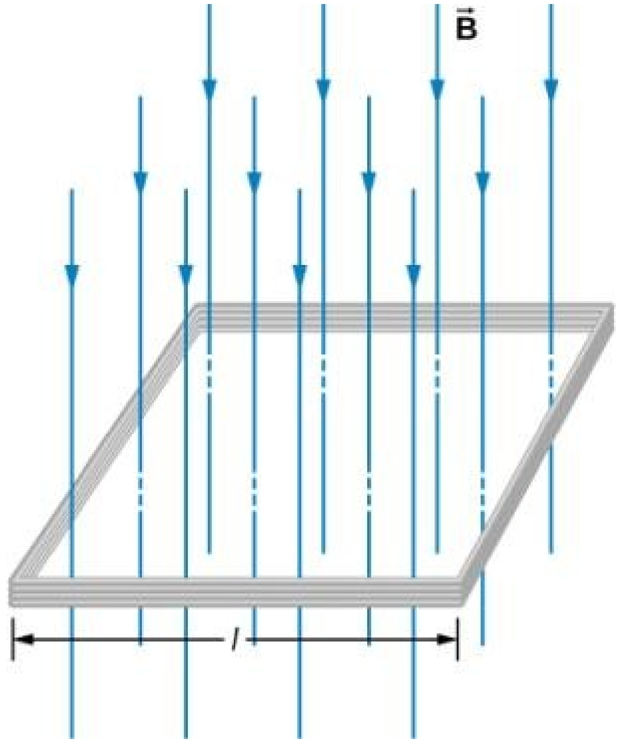
FIGURE 13.5



(a) A circuit bounding an arbitrary open surface *S*. The planar area bounded by the circuit is not part of *S*.

(b) Three arbitrary open surfaces bounded by the same circuit. The value of Φ_m is the same for all these surfaces.

FIGURE 13.6

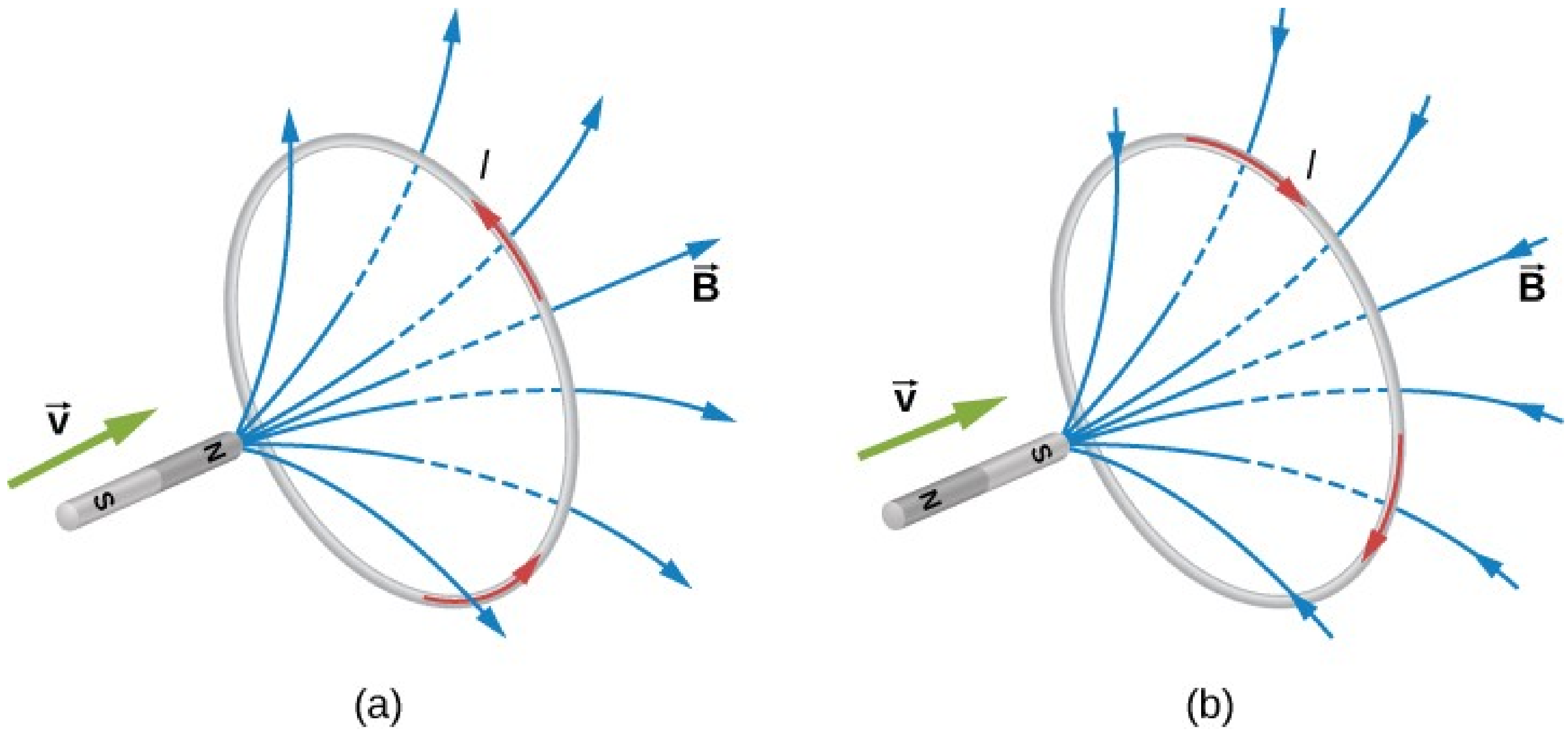


A square coil with N turns of wire with uniform magnetic field directed in the downward direction, perpendicular to the coil.

Induction

$$\epsilon = \frac{-d\Phi}{dt}$$

FIGURE 13.7

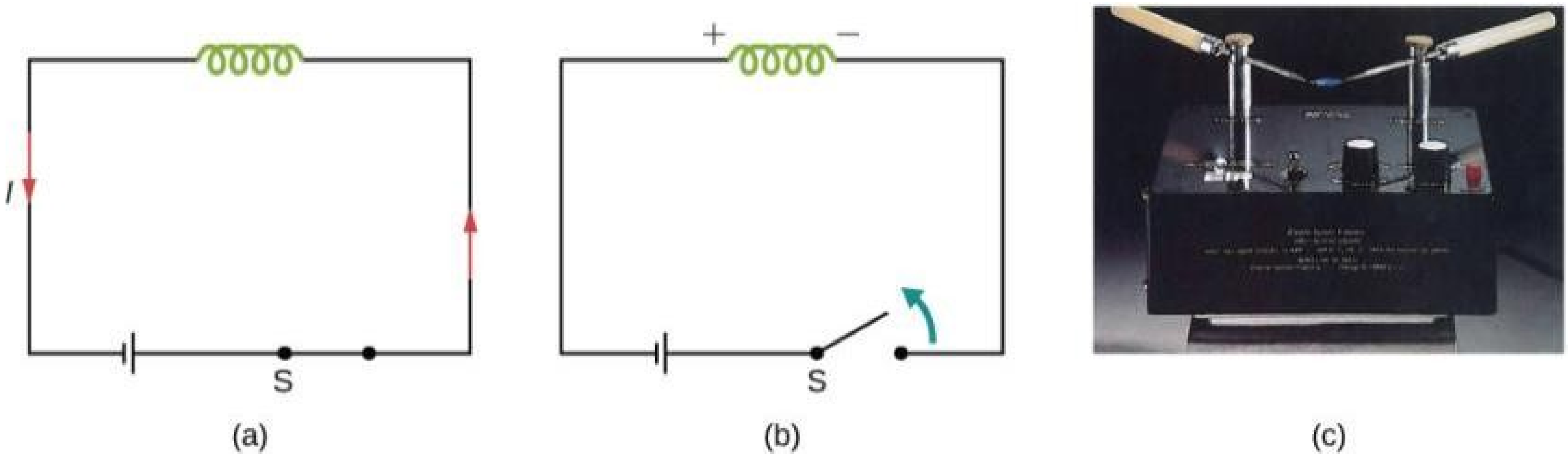


The change in magnetic flux caused by the approaching magnet induces a current in the loop.

(a) An approaching north pole induces a counterclockwise current with respect to the bar magnet.

(b) An approaching south pole induces a clockwise current with respect to the bar magnet.

FIGURE 13.8

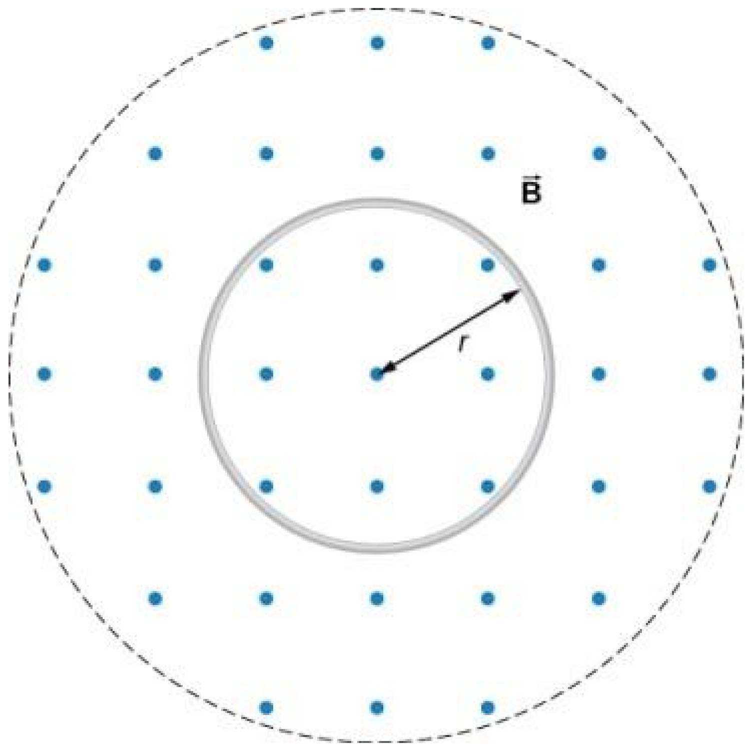


(a) A solenoid connected to a source of emf.

(b) Opening switch S terminates the current, which in turn induces an emf in the solenoid.

(c) Potential difference between the ends of the sharply pointed rods is produced by inducing an emf in a coil. This potential difference is large enough to produce an arc between the sharp points.

FIGURE 13.9

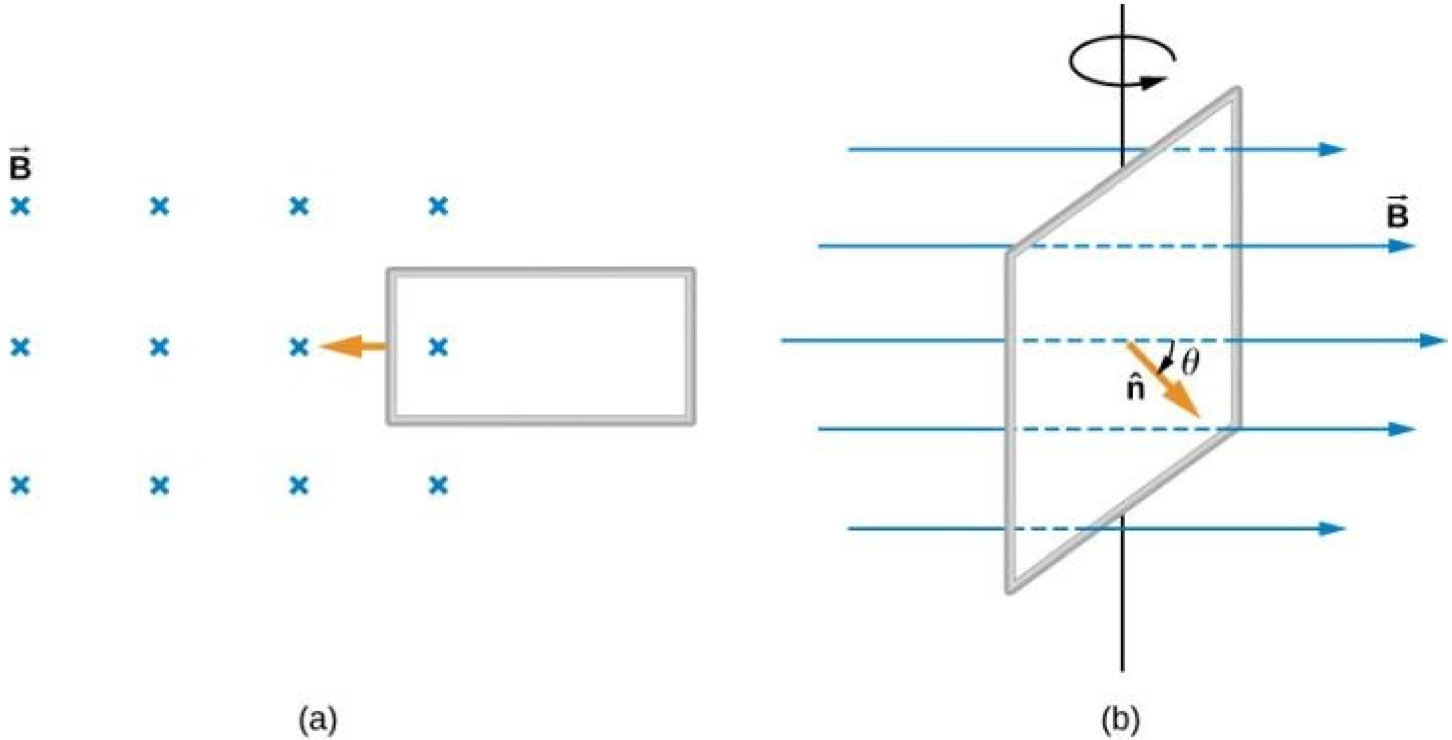


A circular coil in a decreasing magnetic field.

FIGURE 13.10

The jumping ring. When a current is turned on in the vertical solenoid, a current is induced in the metal ring. The stray field produced by the solenoid causes the ring to jump off the solenoid.

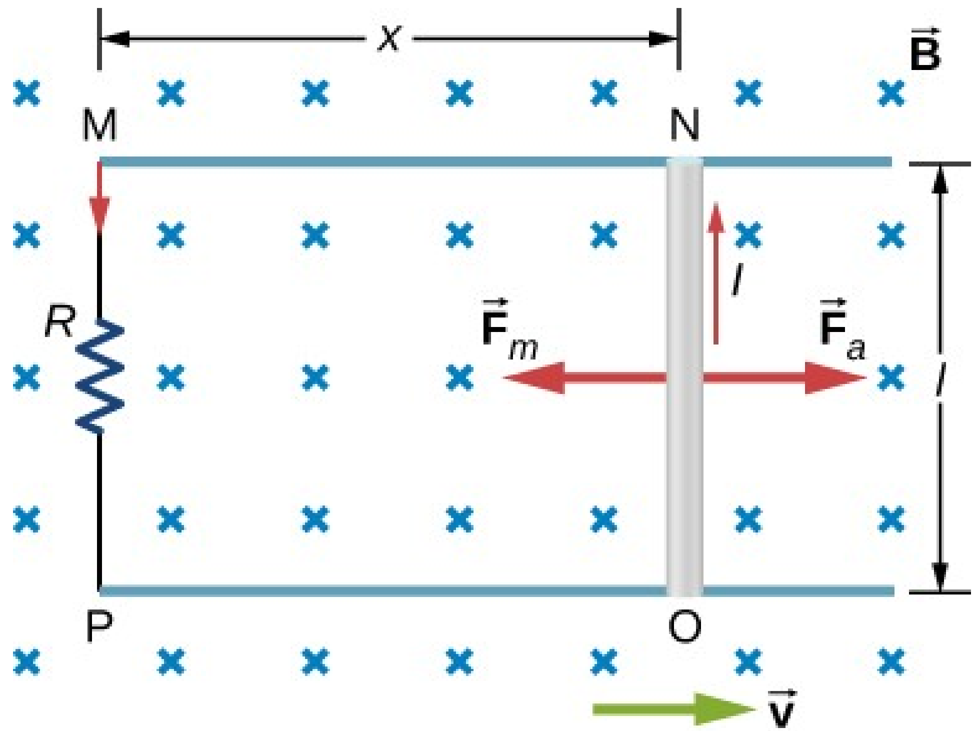
FIGURE 13.11



(a) Magnetic flux changes as a loop moves into a magnetic field;

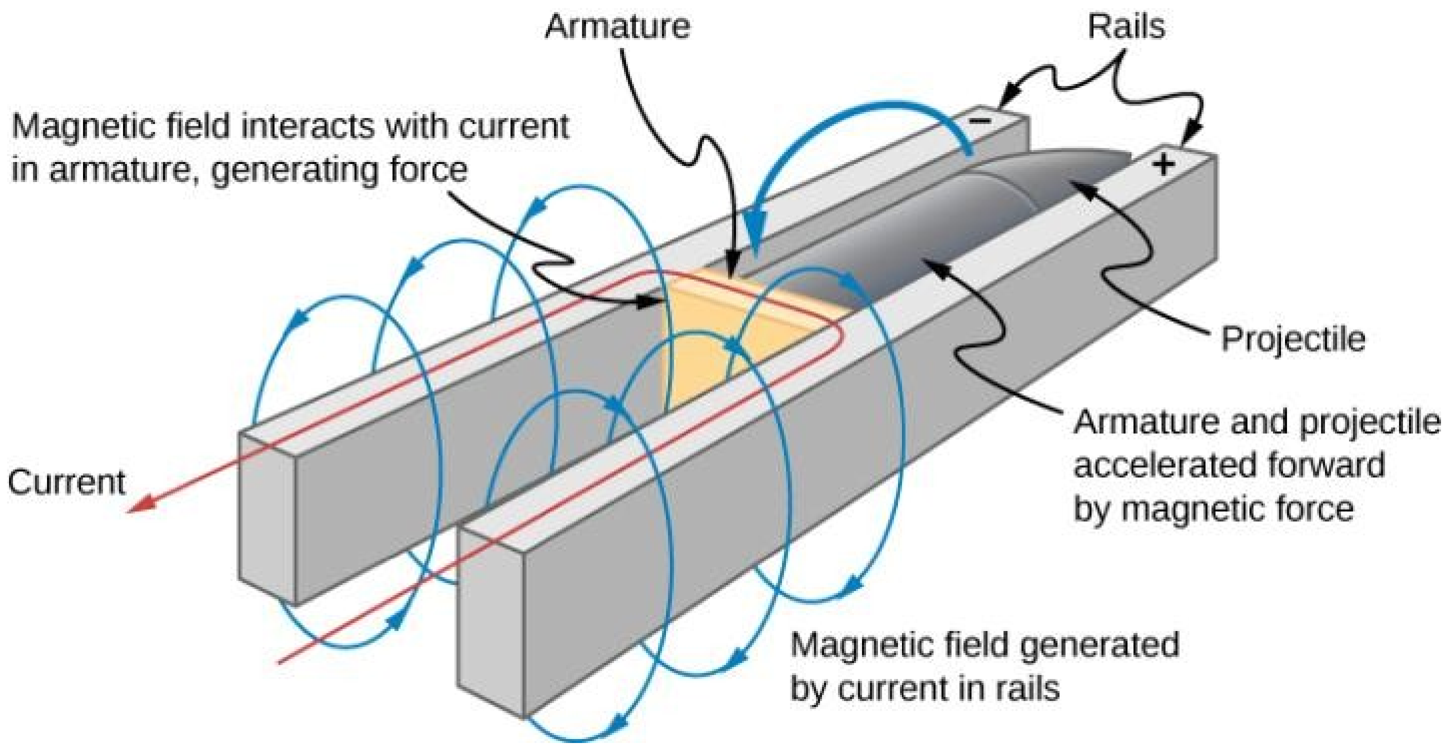
(b) magnetic flux changes as a loop rotates in a magnetic field.

FIGURE 13.12



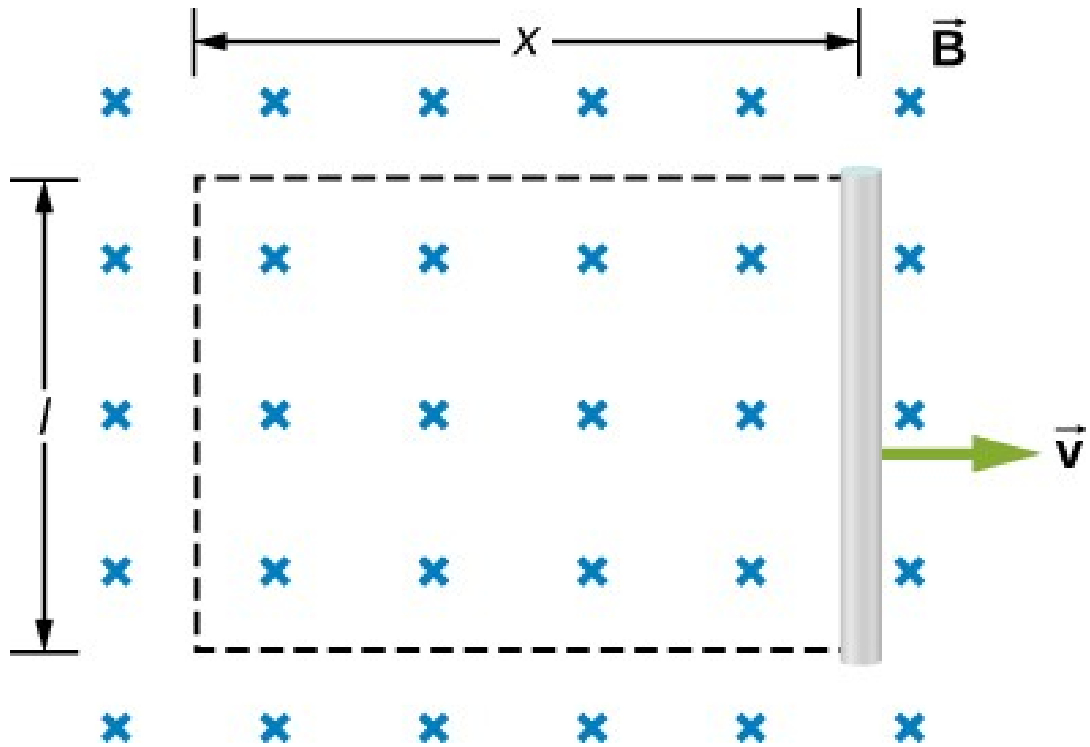
A conducting rod is pushed to the right at constant velocity. The resulting change in the magnetic flux induces a current in the circuit.

FIGURE 13.13



Current through two rails drives a conductive projectile forward by the magnetic force created.

FIGURE 13.14



With the imaginary rectangle shown, we can use Faraday's law to calculate the induced emf in the moving rod.

FIGURE 13.15

Motional emf as electrical power conversion for the space shuttle was the motivation for the tethered satellite experiment. A 5-kV emf was predicted to be induced in the 20-km tether while moving at orbital speed in Earth's magnetic field. The circuit is completed by a return path through the stationary ionosphere.

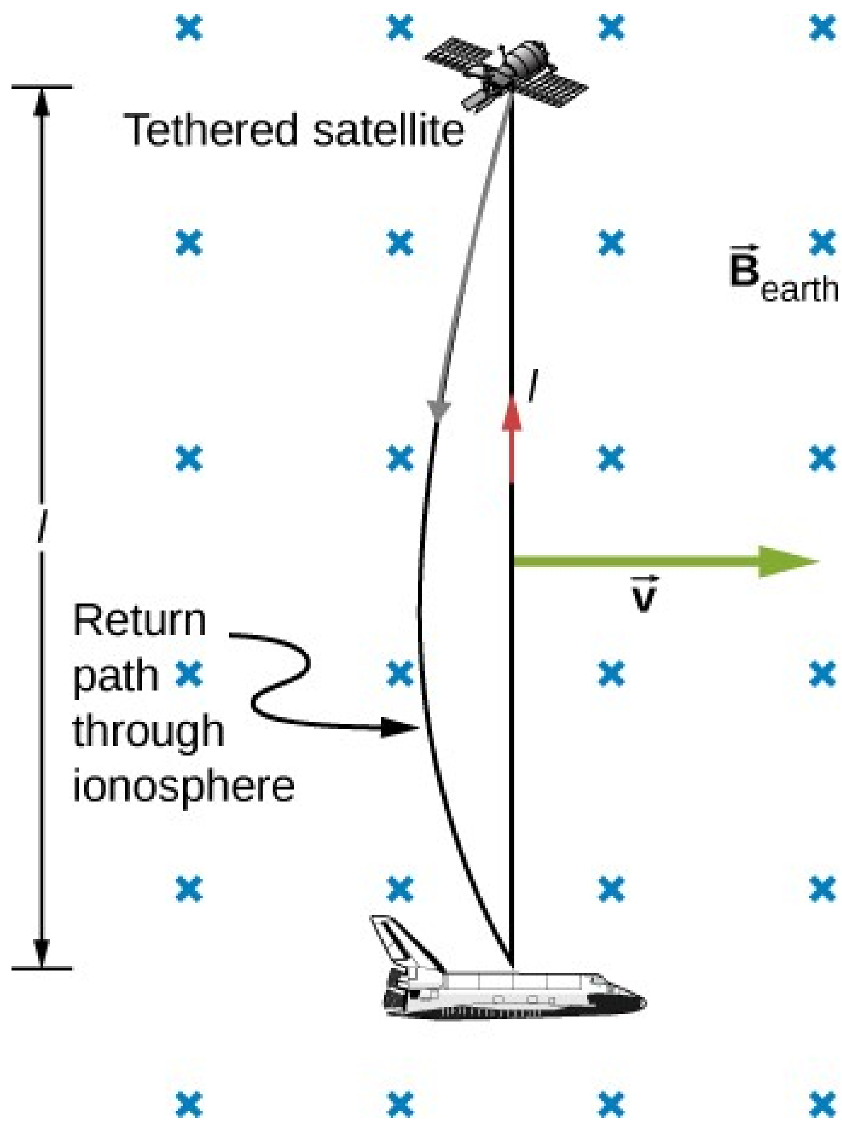
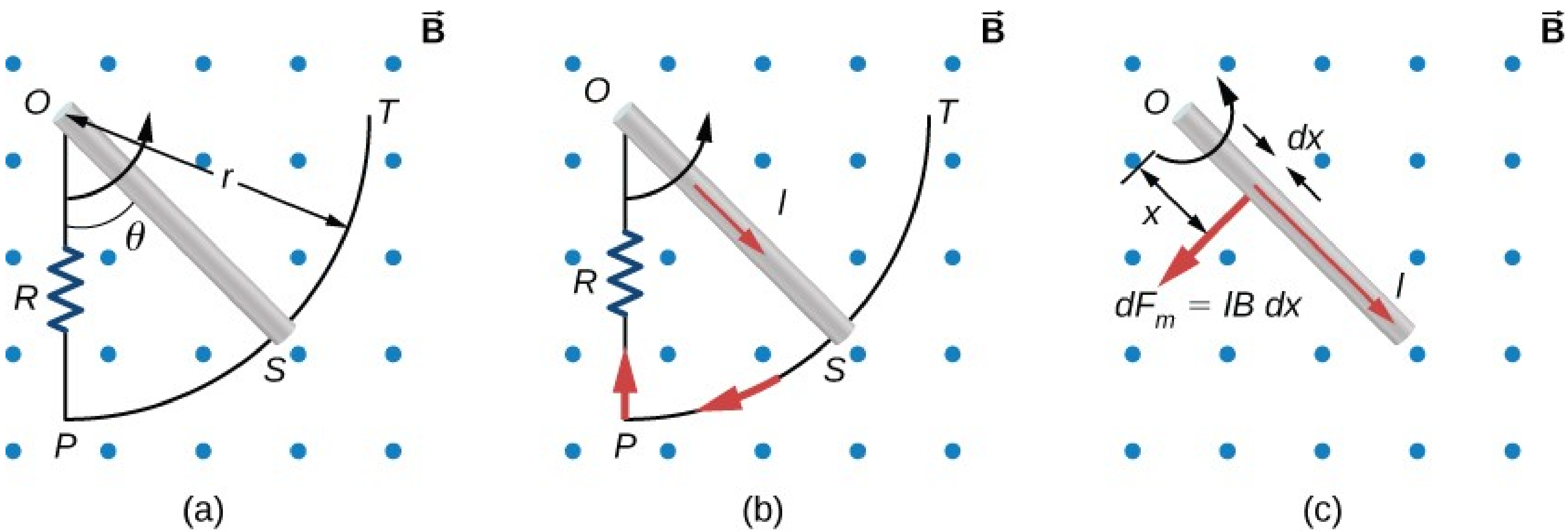


FIGURE 13.16

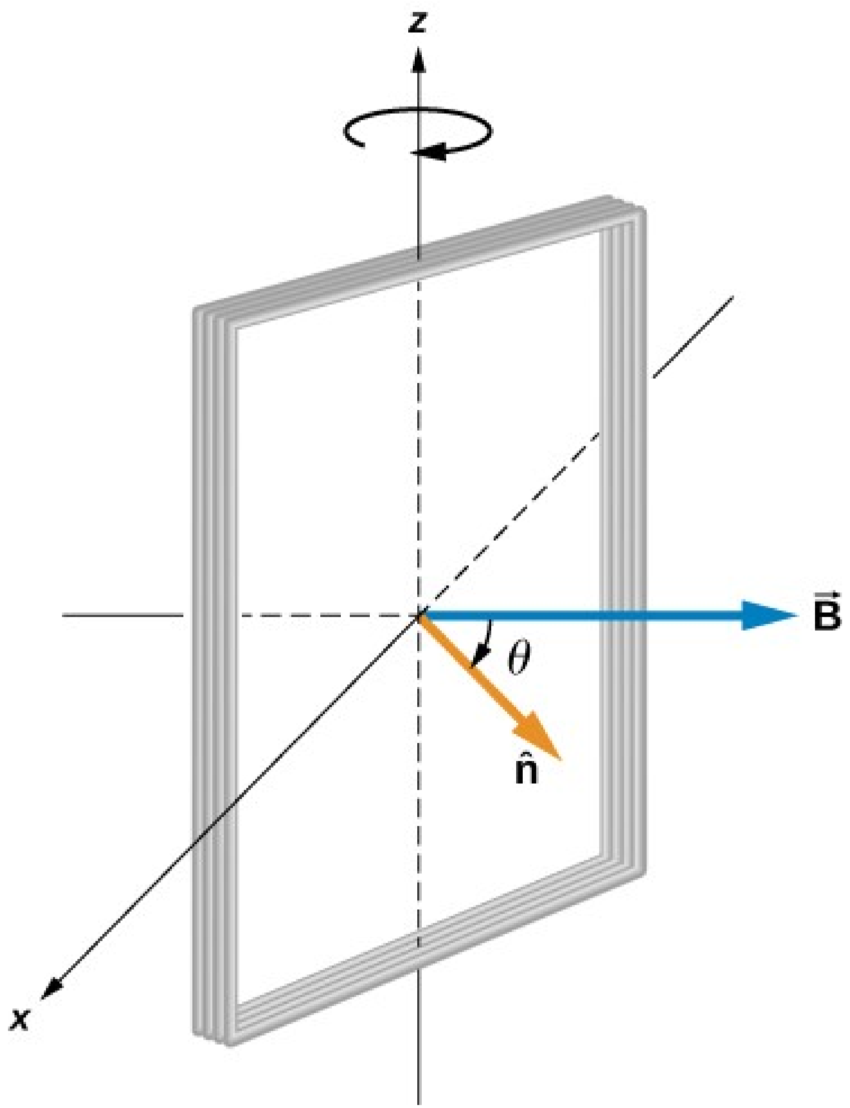


(a) The end of a rotating metal rod slides along a circular wire in a horizontal plane.

(b) The induced current in the rod.

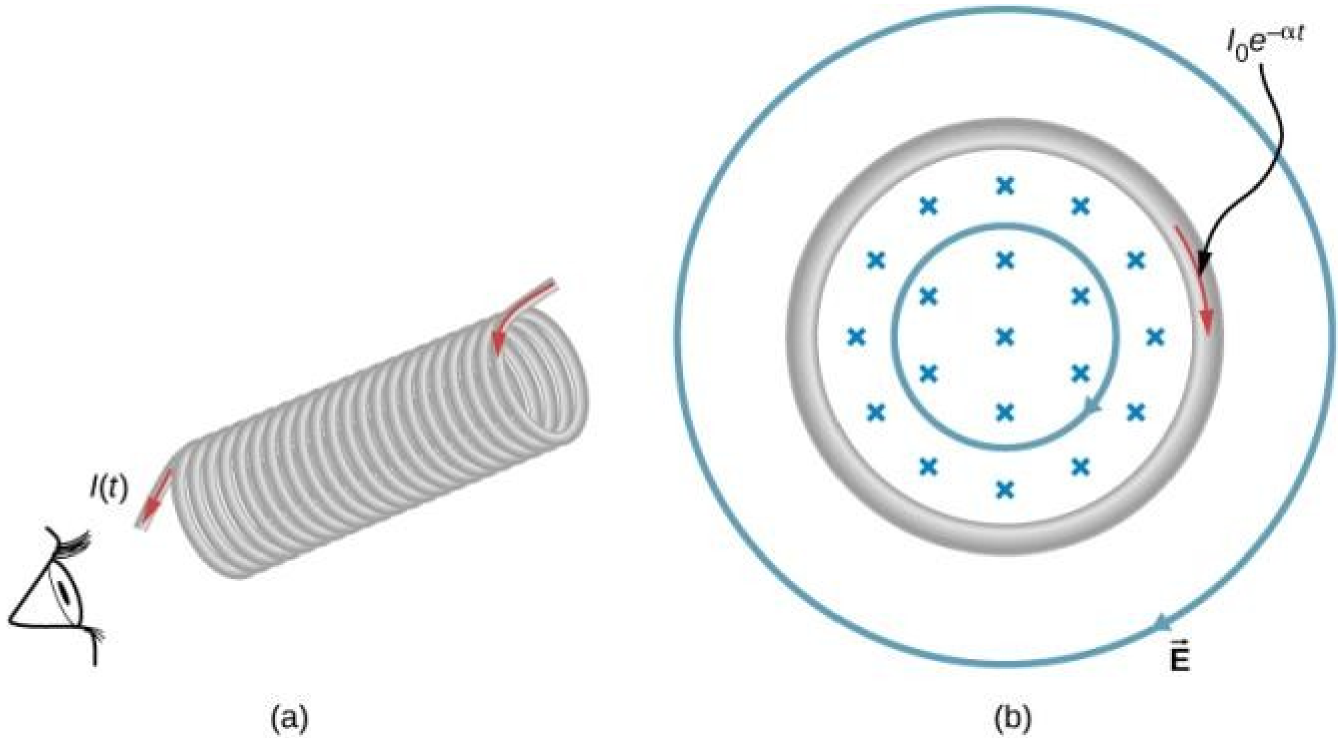
(c) The magnetic force on an infinitesimal current segment.

FIGURE 13.17



A rectangular coil rotating in a uniform magnetic field.

FIGURE 13.18

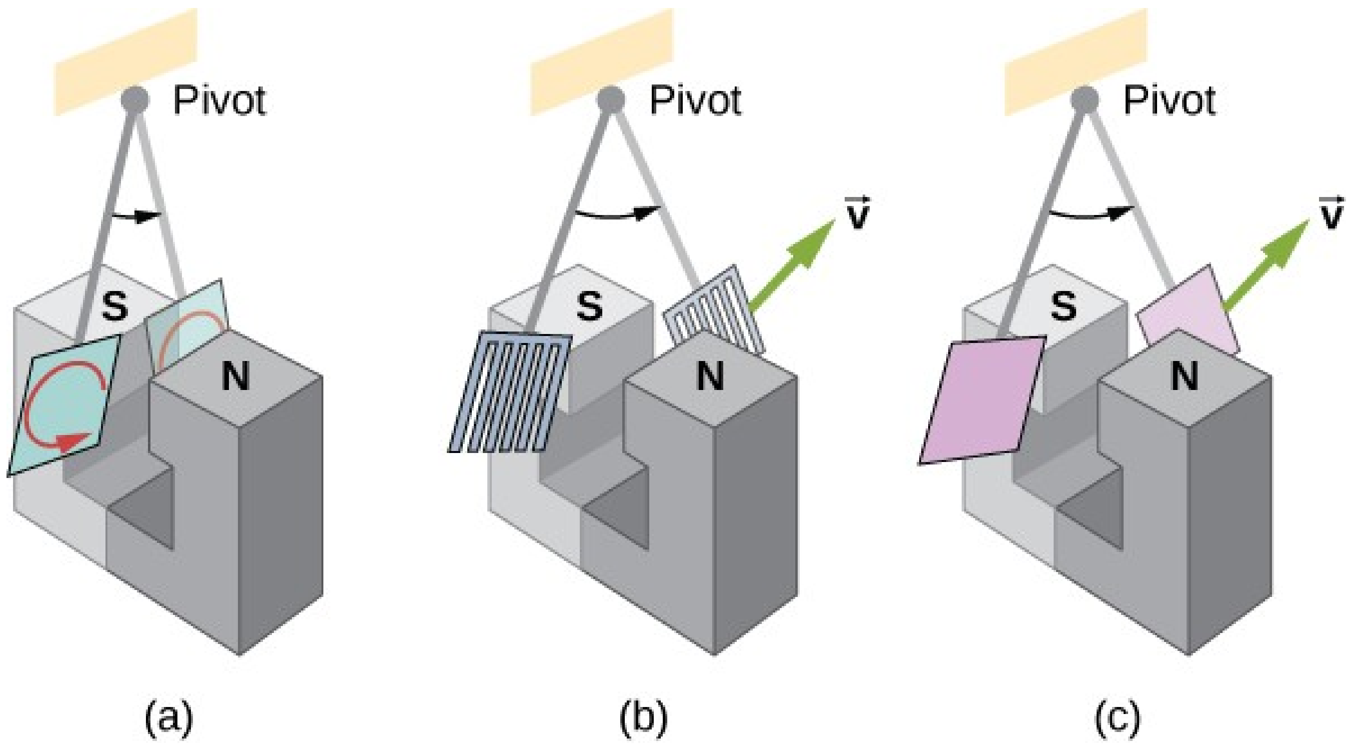


(a) The current in a long solenoid is decreasing exponentially.

(b) A cross-sectional view of the solenoid from its left end. The cross-section shown is near the middle of the solenoid. An electric field is induced both inside and outside the solenoid.

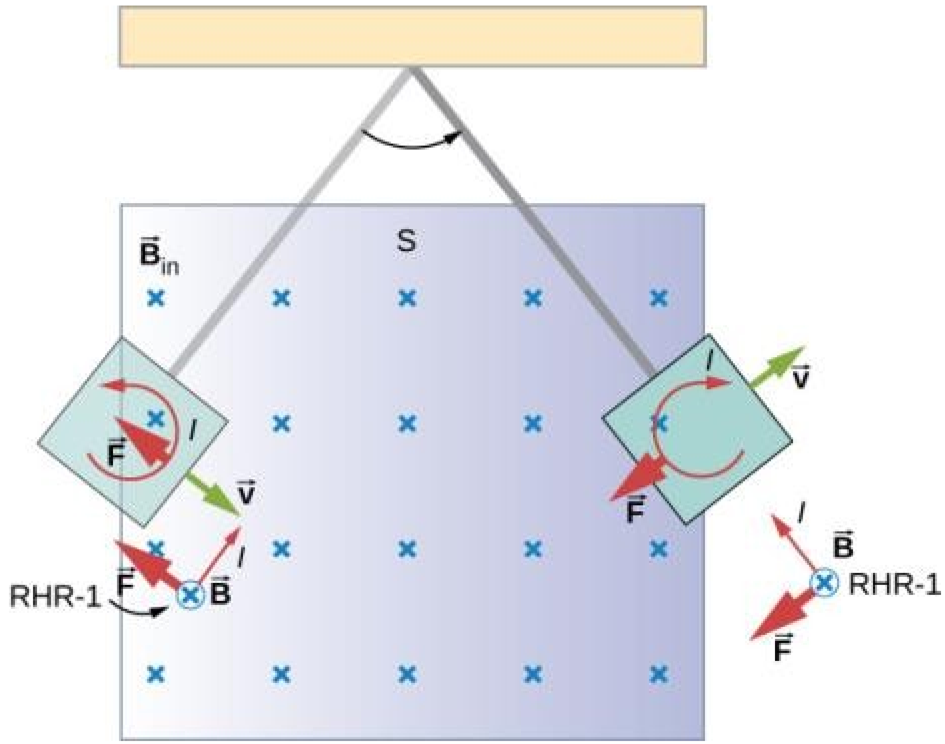
Eddy currents

FIGURE 13.20



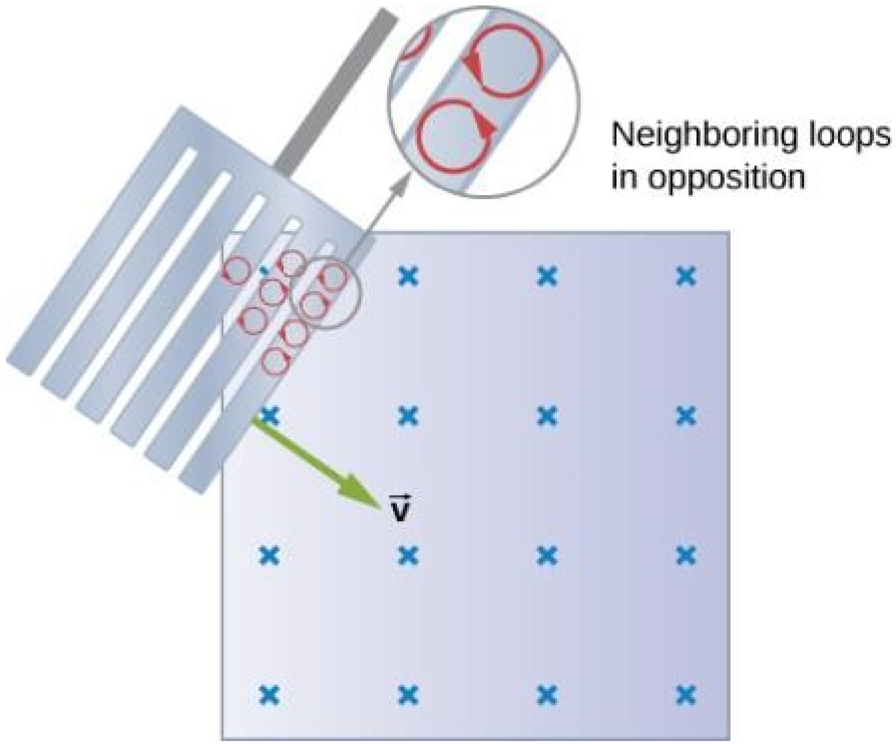
A common physics demonstration device for exploring eddy currents and magnetic damping. (a) The motion of a metal pendulum bob swinging between the poles of a magnet is quickly damped by the action of eddy currents. (b) There is little effect on the motion of a slotted metal bob, implying that eddy currents are made less effective. (c) There is also no magnetic damping on a nonconducting bob, since the eddy currents are extremely small.

FIGURE 13.21



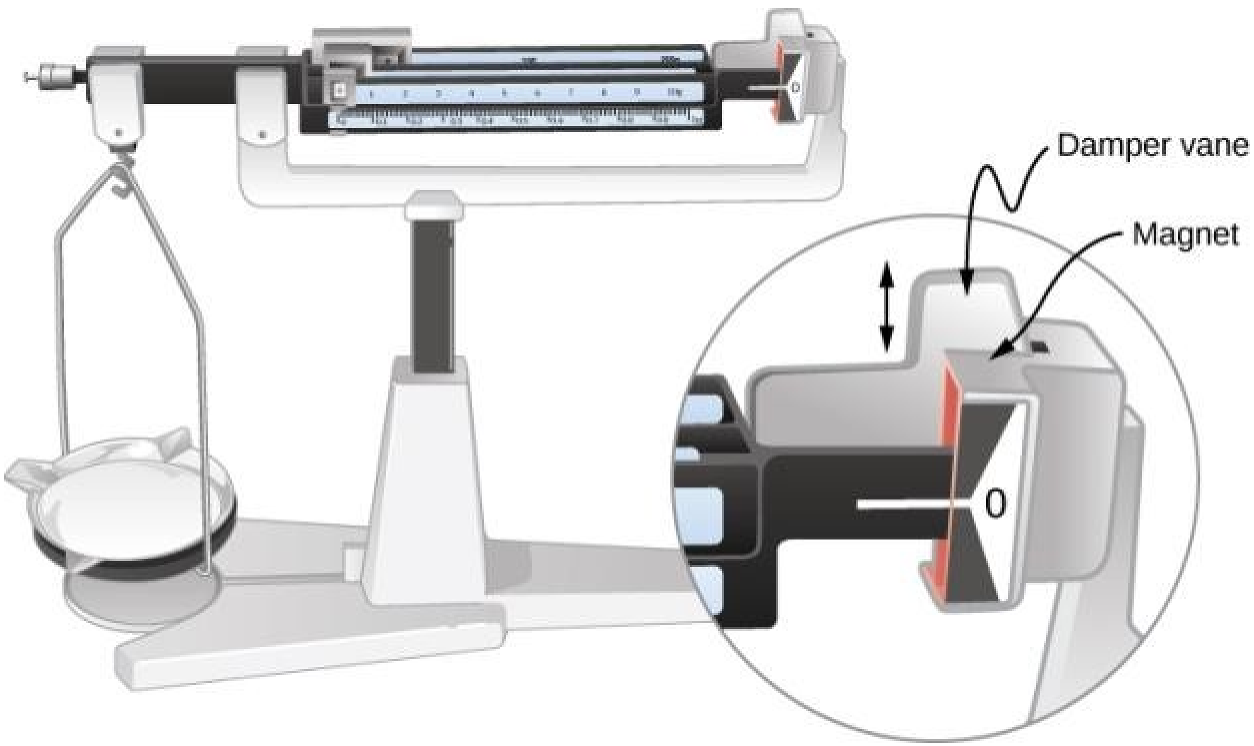
A more detailed look at the conducting plate passing between the poles of a magnet. As it enters and leaves the field, the change in flux produces an eddy current. Magnetic force on the current loop opposes the motion. There is no current and no magnetic drag when the plate is completely inside the uniform field.

FIGURE 13.22



Eddy currents induced in a slotted metal plate entering a magnetic field form small loops, and the forces on them tend to cancel, thereby making magnetic drag almost zero.

FIGURE 13.23



Magnetic damping of this sensitive balance slows its oscillations. Since Faraday's law of induction gives the greatest effect for the most rapid change, damping is greatest for large oscillations and goes to zero as the motion stops.

Generators

FIGURE 13.27

Example 13.9: When this generator coil is rotated through one-fourth of a revolution, the magnetic flux Φ_m changes from its maximum to zero, inducing an emf.

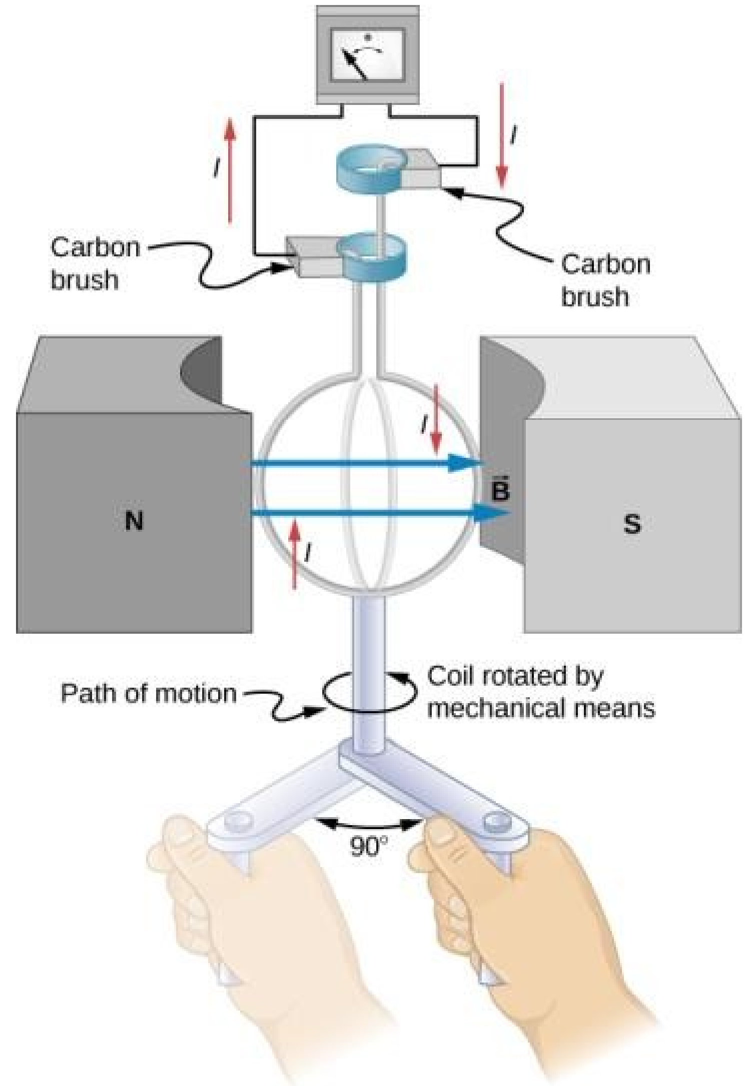
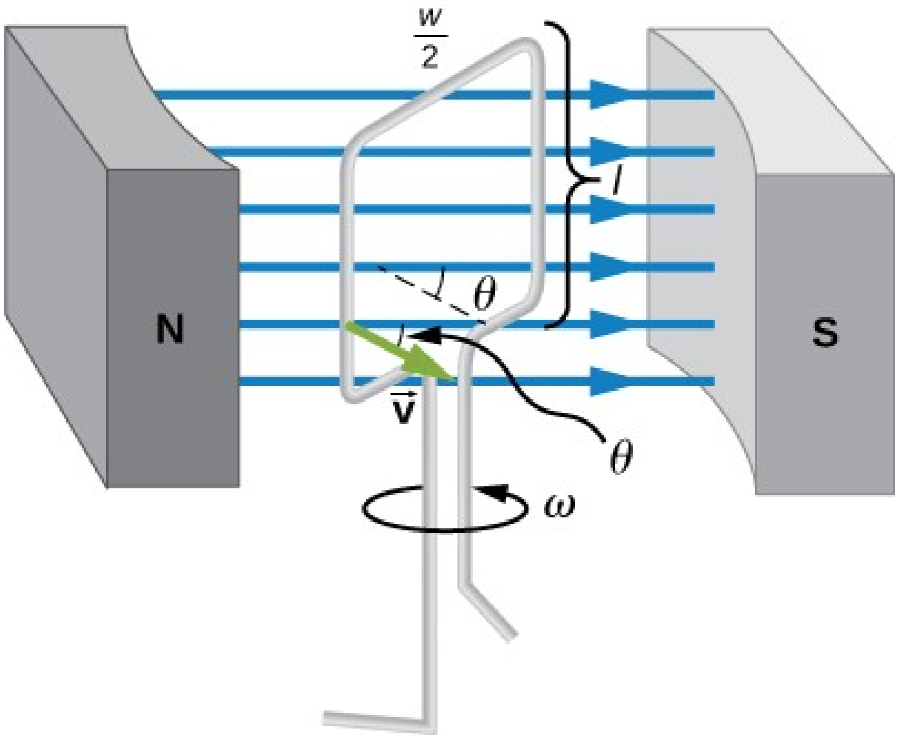
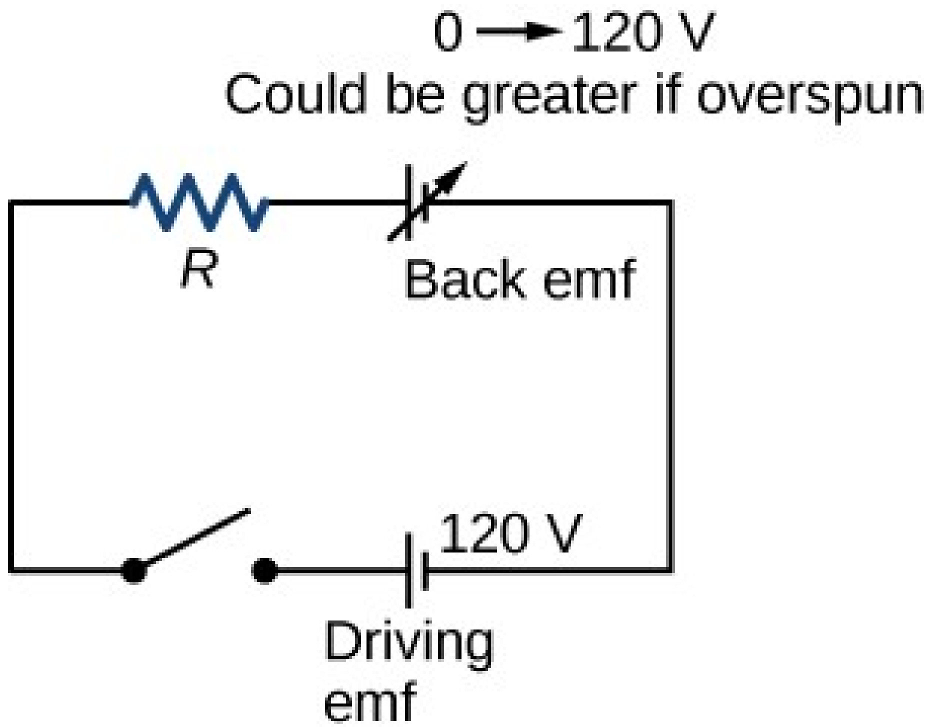


FIGURE 13.28



A generator with a single rectangular coil rotated at constant angular velocity in a uniform magnetic field produces an emf that varies sinusoidally in time. Note the generator is similar to a motor, except the shaft is rotated to produce a current rather than the other way around.

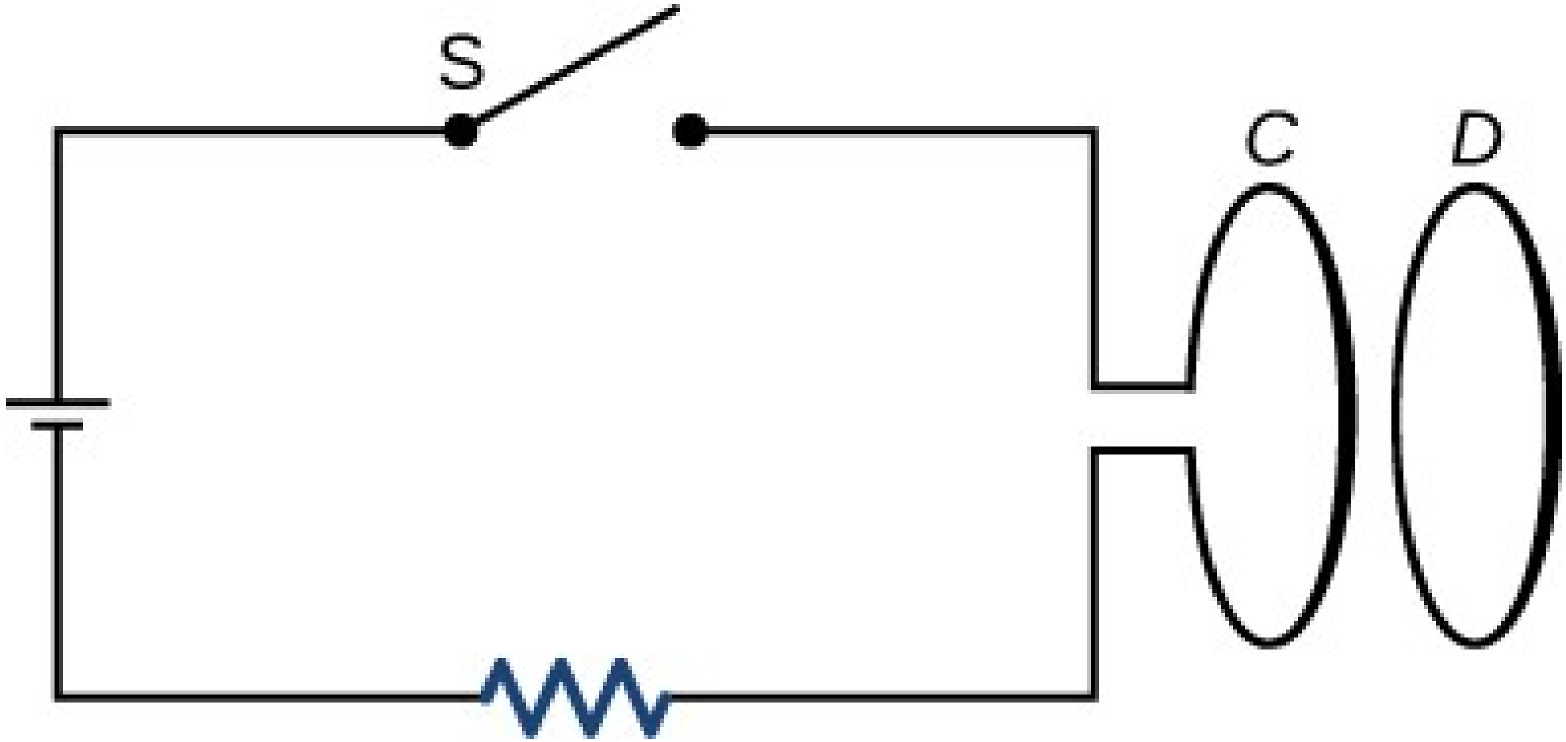
FIGURE 13.32



The coil of a dc motor is represented as a resistor in this schematic. The back emf is represented as a variable emf that opposes the emf driving the motor. Back emf is zero when the motor is not turning and increases proportionally to the motor's angular velocity.

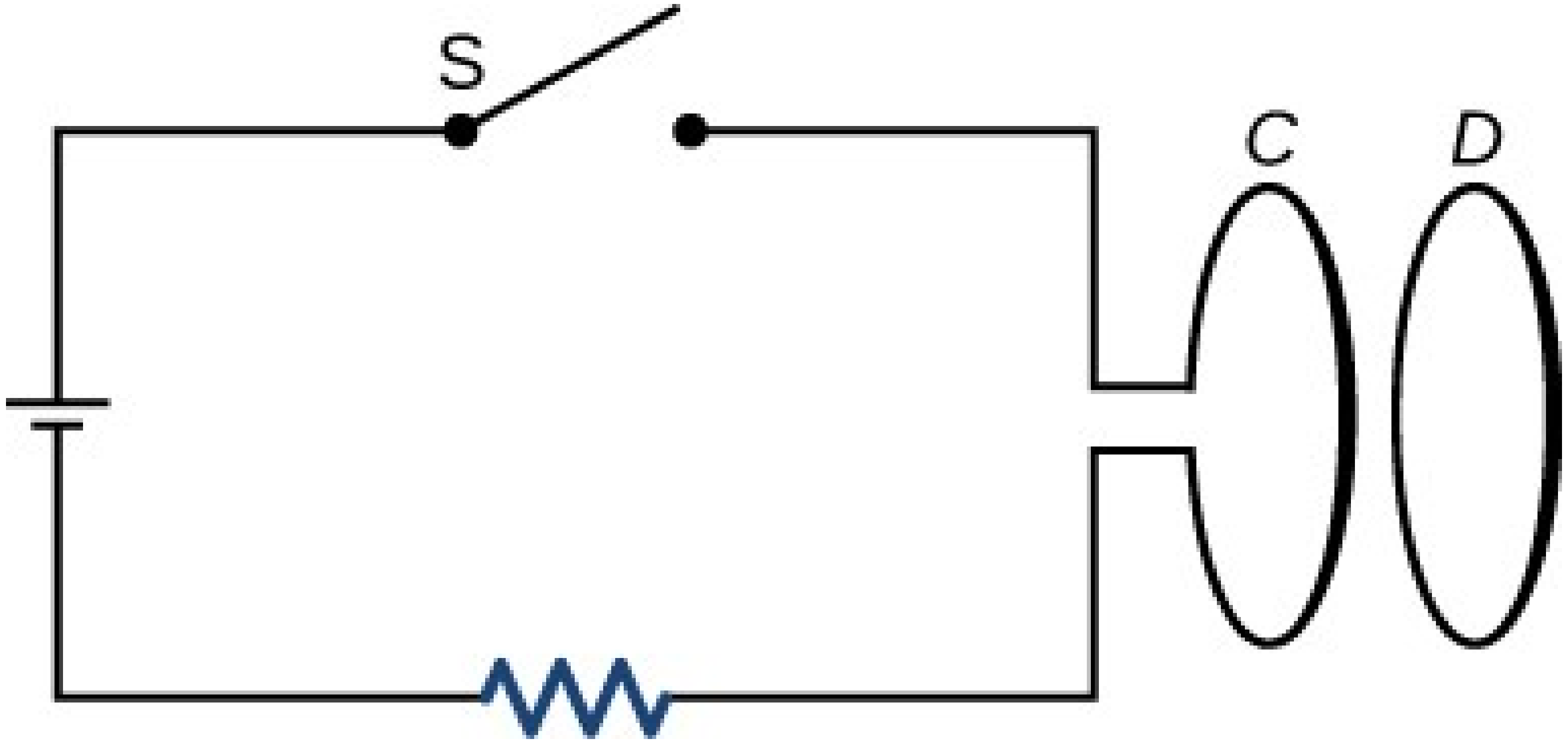
Examples

EXERCISE 6



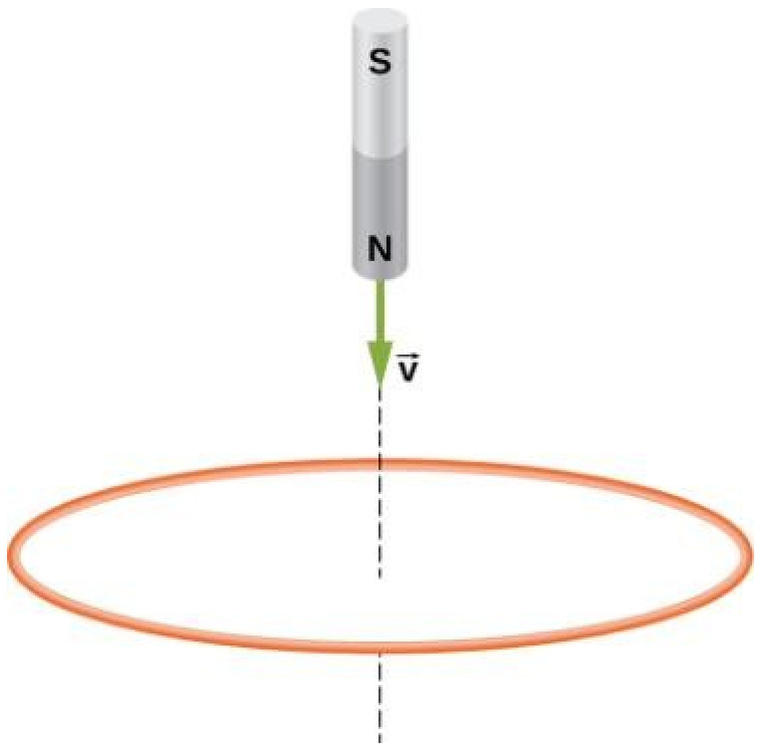
How would changing the radius of loop *D* shown below affect its emf, assuming *C* and *D* are much closer together compared to their radii?

EXERCISE 11



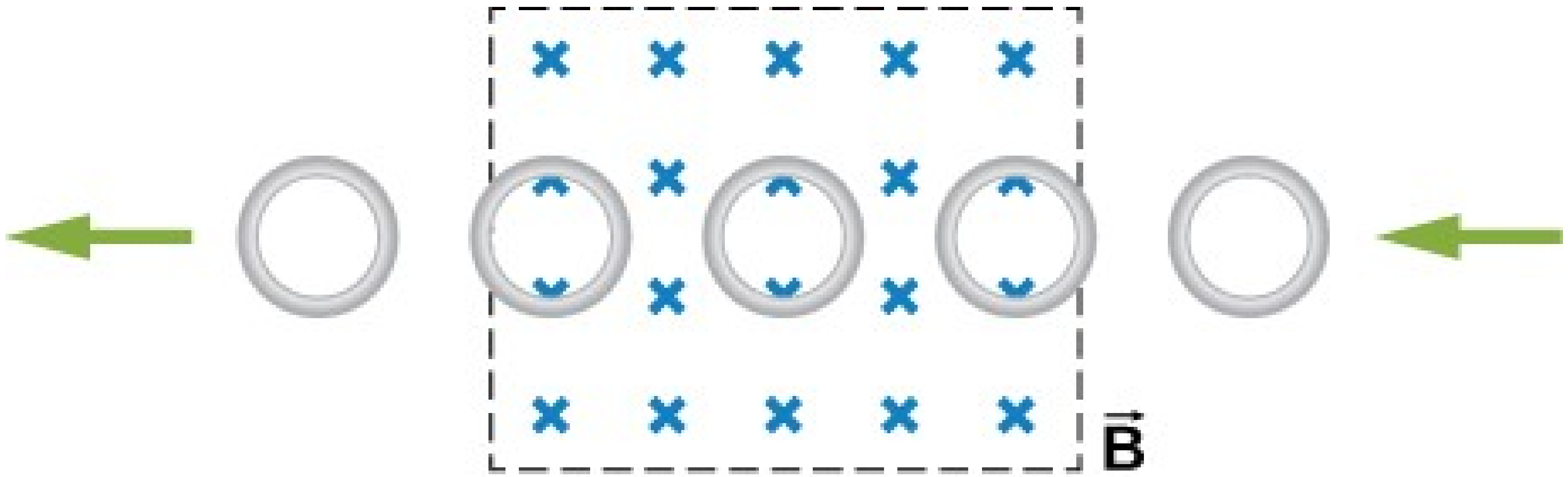
The circular conducting loops shown in the accompanying figure are parallel, perpendicular to the plane of the page, and coaxial. (a) When the switch S is closed, what is the direction of the current induced in *D*? (b) When the switch is opened, what is the direction of the current induced in loop *D*?

EXERCISE 12



The north pole of a magnet is moved toward a copper loop, as shown below. If you are looking at the loop from above the magnet, will you say the induced current is circulating clockwise or counterclockwise?

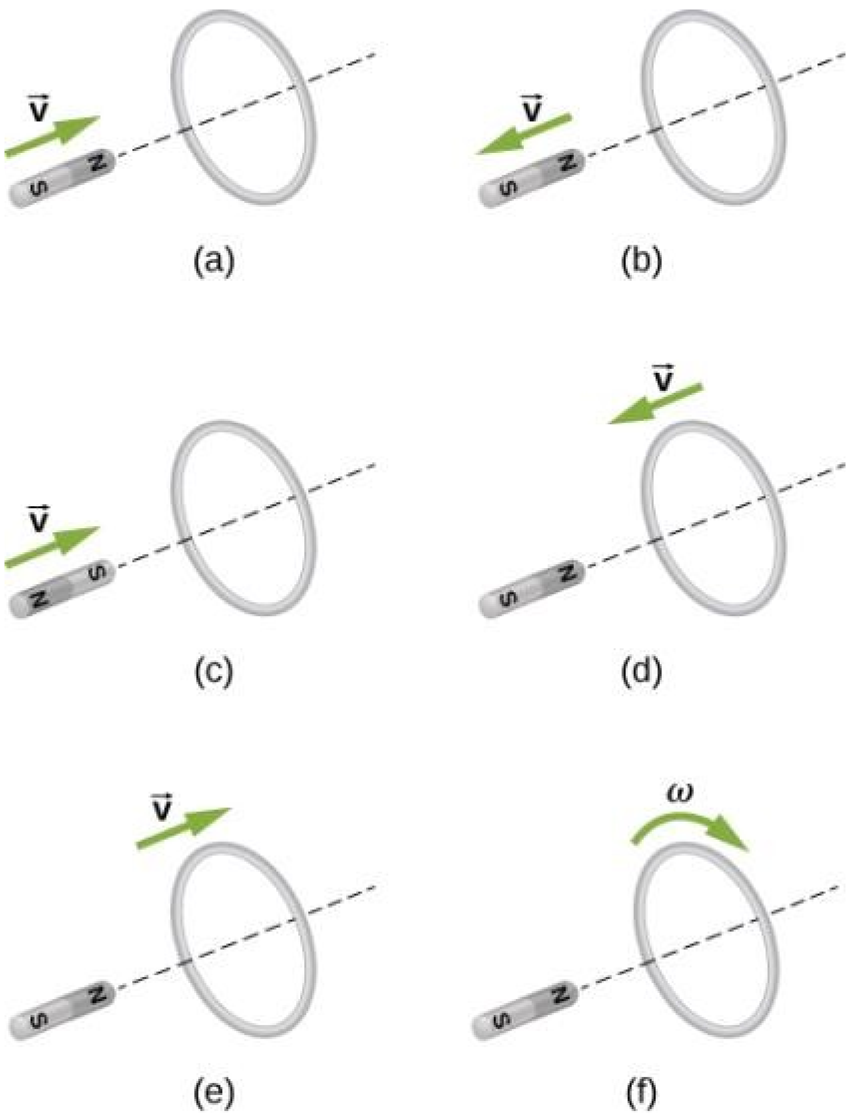
EXERCISE 13



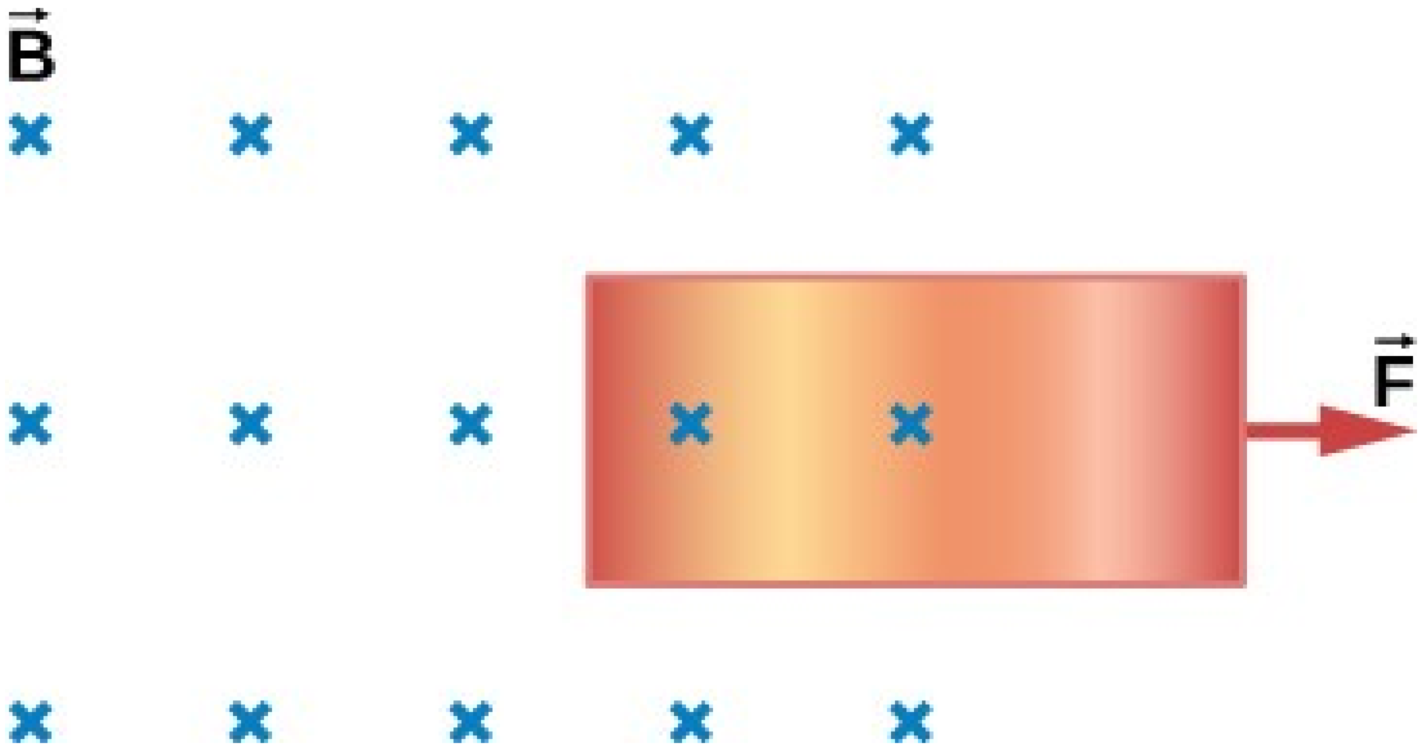
The accompanying figure shows a conducting ring at various positions as it moves through a magnetic field. What is the sense of the induced emf for each of those positions?

EXERCISE 15

State the direction of the induced current for each case shown below, observing from the side of the magnet.

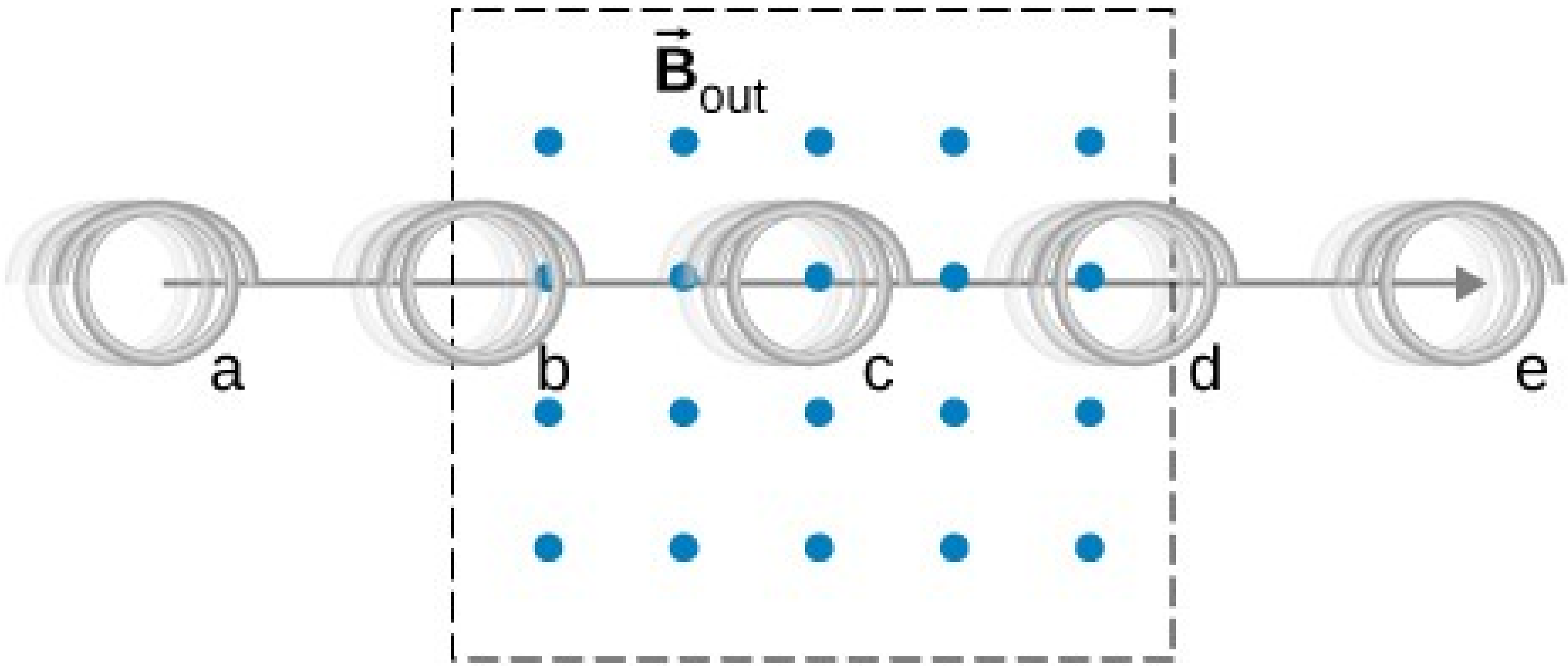


EXERCISE 20



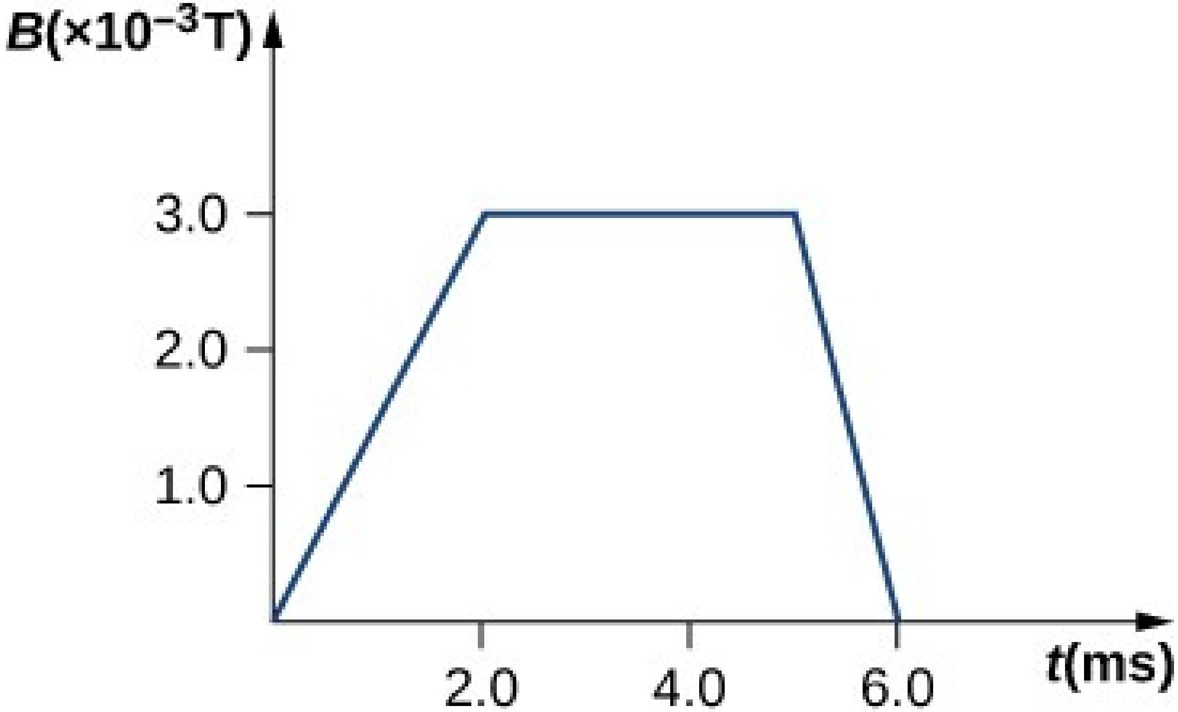
The copper sheet shown below is partially in a magnetic field. When it is pulled to the right, a resisting force pulls it to the left. Explain. What happen if the sheet is pushed to the left?

EXERCISE 23



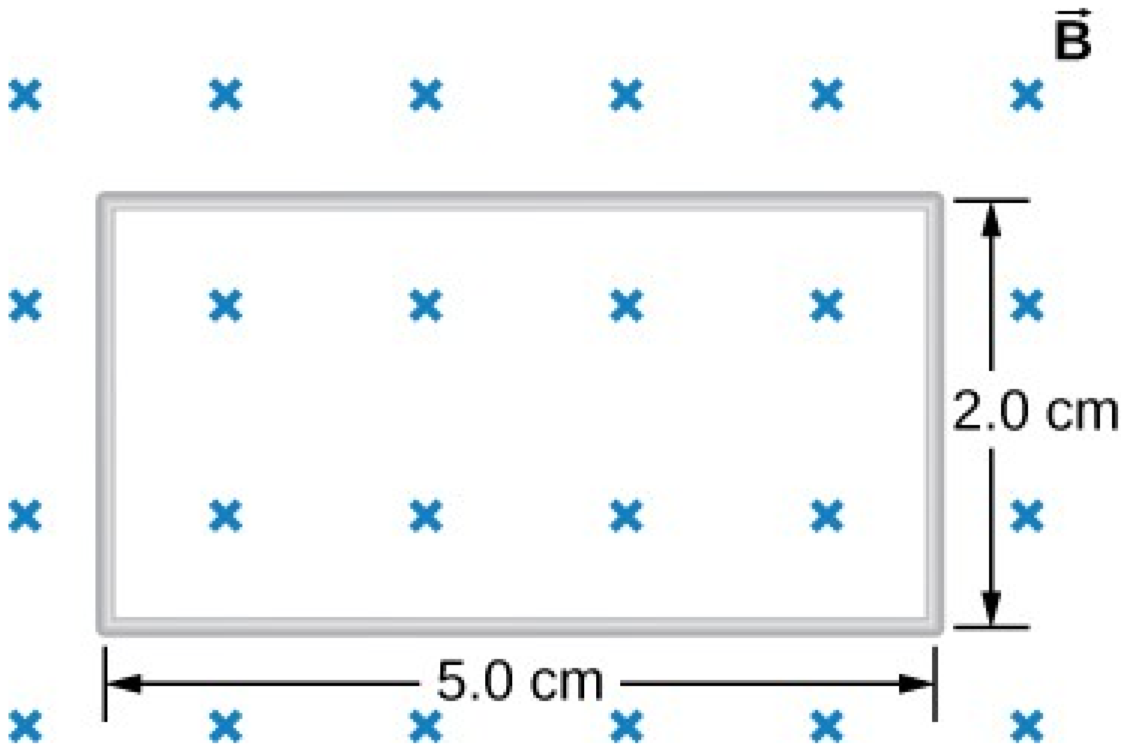
A coil is moved through a magnetic field as shown below. The field is uniform inside the rectangle and zero outside. What is the direction of the induced current and what is the direction of the magnetic force on the coil at each position shown?

EXERCISE 27



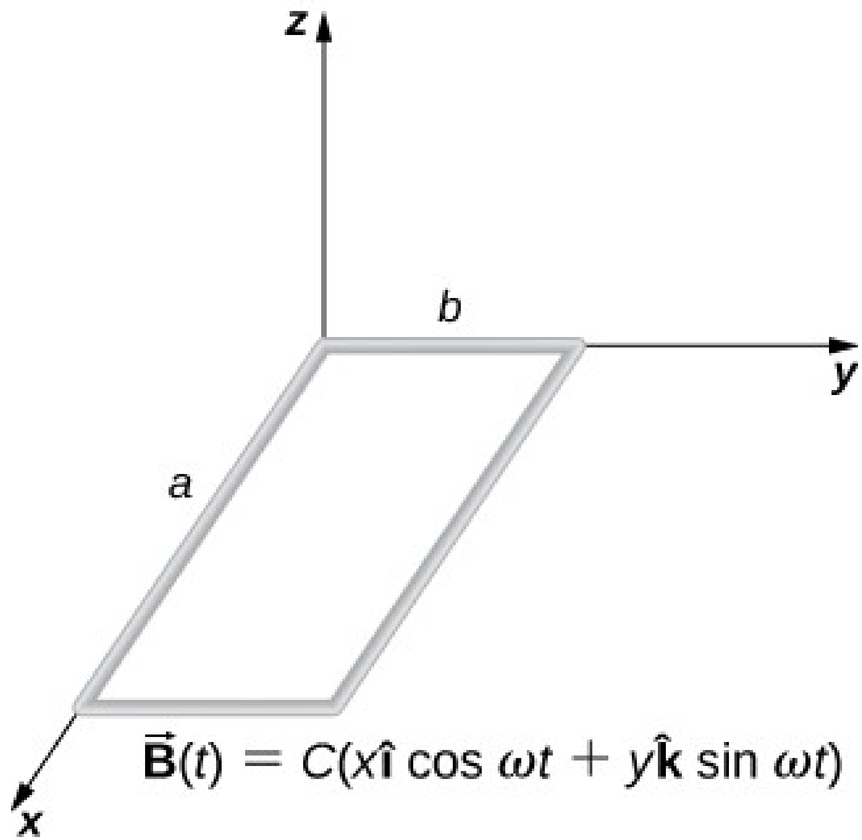
The magnetic field through a circular loop of radius 10.0 cm varies with time as shown below. The field is perpendicular to the loop. Plot the magnitude of the induced emf in the loop as a function of time.

EXERCISE 28



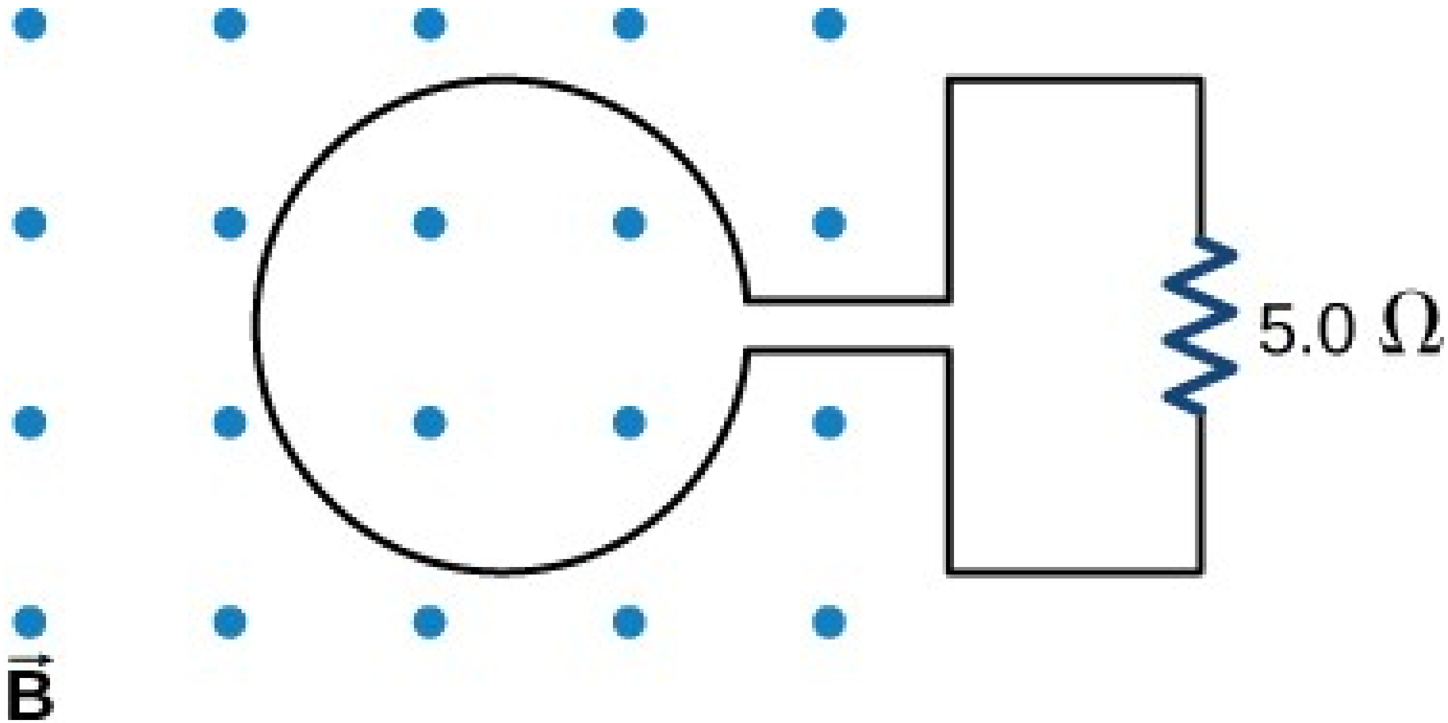
The accompanying figure shows a single-turn rectangular coil that has a resistance of $2.0\ \Omega$. The magnetic field at all points inside the coil varies according to $B = B_0 e^{-\alpha t}$, where $B_0 = 0.25\ \text{T}$ and $\alpha = 200\ \text{Hz}$. What is the current induced in the coil at (a) $t = 0.001\ \text{s}$, (b) 0.002 s, (c) 2.0 s?

EXERCISE 31



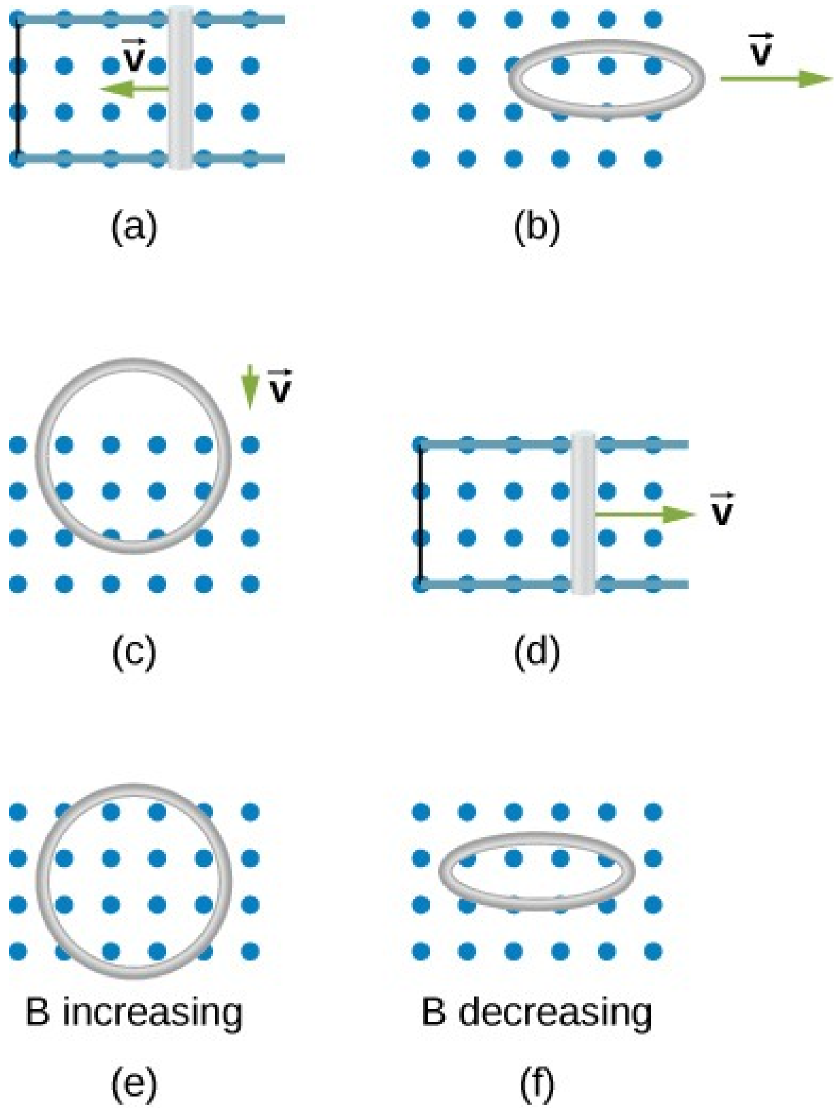
A rectangular wire loop with length *a* and width *b* lies in the *xy*-plane, as shown below. Within the loop there is a time-dependent magnetic field given by $\vec{B}(t) = C\left((x\cos\omega t)\hat{i} + (y\sin\omega t)\hat{k}\right)$, with $\vec{B}(t)$ in tesla. Determine the emf induced in the loop as a function of time.

EXERCISE 35



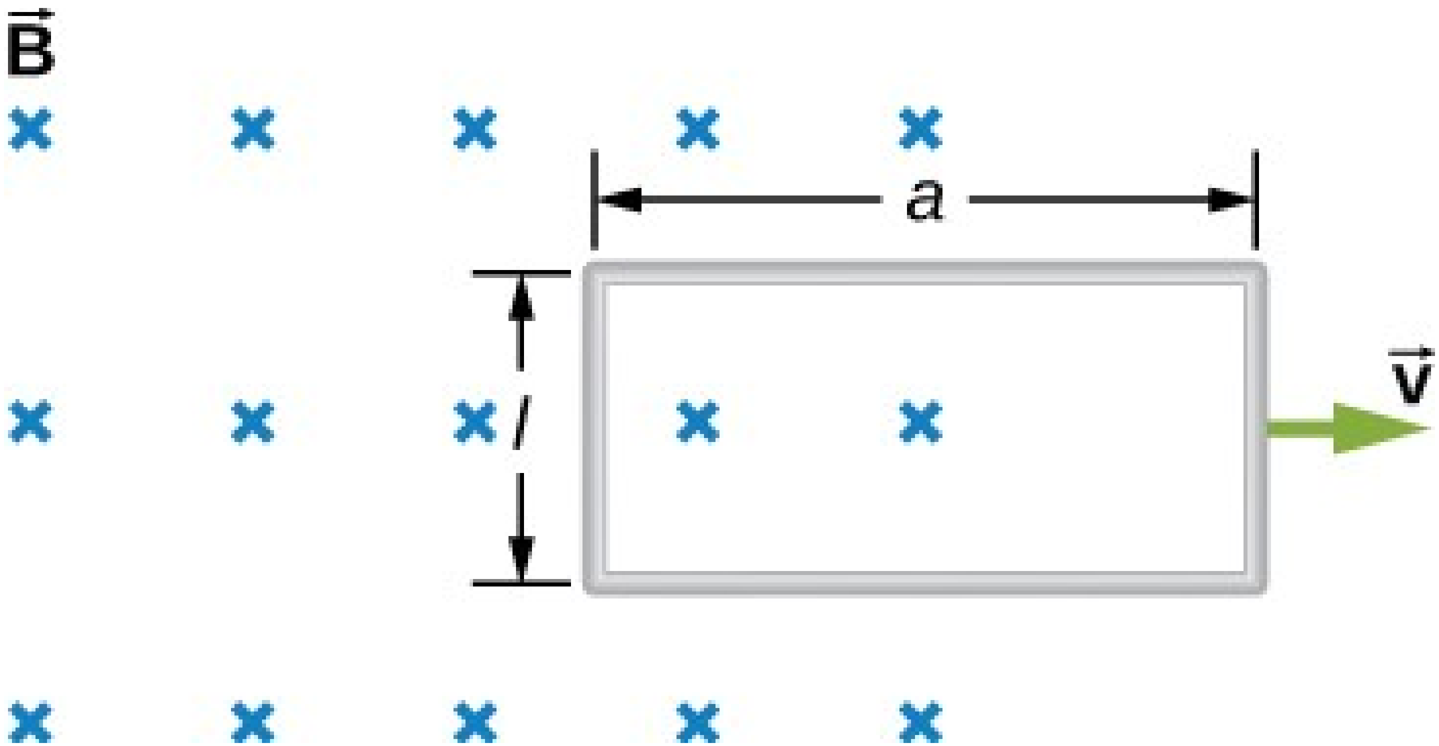
The magnetic flux through the loop shown in the accompanying figure varies with time according to $\Phi_m = 2.00e^{-3t}\sin(120\pi t)$, where Φ_m is in webers. What are the direction and magnitude of the current through the $5.00\text{-}\Omega$ resistor at (a) $t = 0$; (b) $t = 2.17 \times 10^{-2}\,\text{s}$, and (c) $t = 3.00\,\text{s}$?

EXERCISE 36



Use Lenz's law to determine the direction of induced current in each case.

EXERCISE 38



The rectangular loop of N turns shown below moves to the right with a constant velocity while leaving the poles of a large electromagnet. (a) Assuming that the magnetic field is uniform between the pole faces and negligible elsewhere, determine the induced emf in the loop. (b) What is the source of work that produces this emf?