Chapter 23 Magnetic Flux and Faraday's Law of induction

Outline

23-3 Faraday's Law of Induction

The induced emf (voltage) is proportional to the rate of the magnetic flux change with the time:

Faraday's Lay of Induction

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} = -N\frac{\Phi_{final} - \Phi_{initial}}{T_{final} - T_{initial}} \qquad (23-3)$$

SI unit: V

Where, N is the number of turns in the loop.

Magnitude of the Induce EMF

$$\varepsilon = \left| N \frac{\Delta\Phi}{\Delta t} \right| = N \left| \frac{\Phi_{final} - \Phi_{initial}}{T_{final} - T_{initial}} \right| \qquad (23-4)$$

SI unit: V

Problem 23-15

The area of a 120-turn coil / loop oriented its plane perpendicular to a 0.20-T magnetic field is 0.050 m^2. Find the average induced emf in this coil, if the magnetic field reverses its direction in 0.34 s.

Solution:

The magnetic flux is changed from BA to –BA.
According to (23-4),

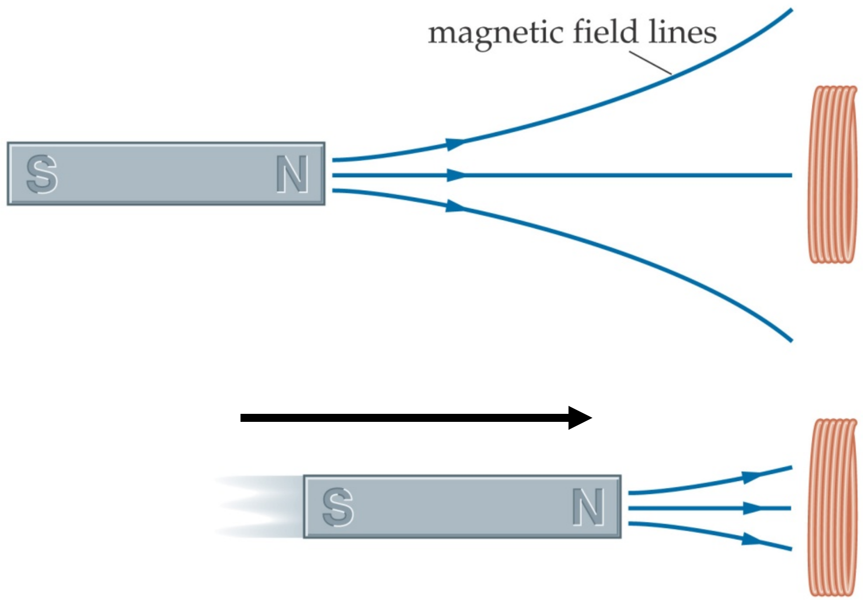
$$|\mathcal{E}| = N\left|\frac{\Delta\Phi}{\Delta t}\right| = N\left|\frac{BA-(-BA)}{\Delta t}\right| = N\left|\frac{2BA}{\Delta t}\right|$$

$$= 120\left|\frac{2(0.20\ \text{T})(0.050\ \text{m}^2)}{0.34\ \text{s}}\right| = \boxed{7.1\ \text{V}}$$

Example 23-2 Bar Magnetic Induction

A bar magnet is moved rapidly toward a 40-turn circular coil of wire. As the magnet moves, the average value of $B\cos\theta$ over the area of the coil increase from 0.0125T to 0.45 T in 0.250 s. If the radius of the coils is 3.05 cm, and the resistance of its wire is 3.55 Ω, find the magnet of **(a)** the induced emf and **(b)** the induced current.

$$\varepsilon = \left| N\frac{\Delta\Phi}{\Delta t} \right| = N\left| \frac{\Phi_{final} - \Phi_{initial}}{T_{final} - T_{initial}} \right|$$



Example 23-2
Bar Magnet Induction

Solution

A 1). The magnetic Flux through the loop,

$$\Phi_i = \left[\ B_i \cos(\theta)\ \right] A$$

$$= (0.0125T)\pi(0.0305m)^2 = 3.65\times10^{-5} T\cdot m^2$$

$$\Phi_f = \left[\ B_f \cos\theta\ \right] A$$

$$= (0.450T)\pi(0.0305m)^2 = 1.32\times10^{-3} T\cdot m^2$$

2) The induced emf,

$$\varepsilon = N\left| \frac{\Phi_{final} - \Phi_{initial}}{T_{final} - T_{initial}} \right|$$

$$= (40)\left|\frac{1.32\times10^{-3} T\cdot m^2 - 3.65\times10^{-5} T\cdot m^2}{0.250s}\right| = 0.205 \quad V$$

B 3) Using Ohm's law to find the current,

$$I = \frac{V}{R} = \frac{0.205V}{3.55\Omega} = 0.0577 \quad A$$

23-4 Lens's Law

Lens's law can be used to explain the minus sign of Faraday's law and determine the direction of the induced current in a circuit/loop.

Lens's Law

An induced current always flows in a direction that opposes the change (of the magnetic flux) that causes it.

Two Cases:

The Force also against the moving!

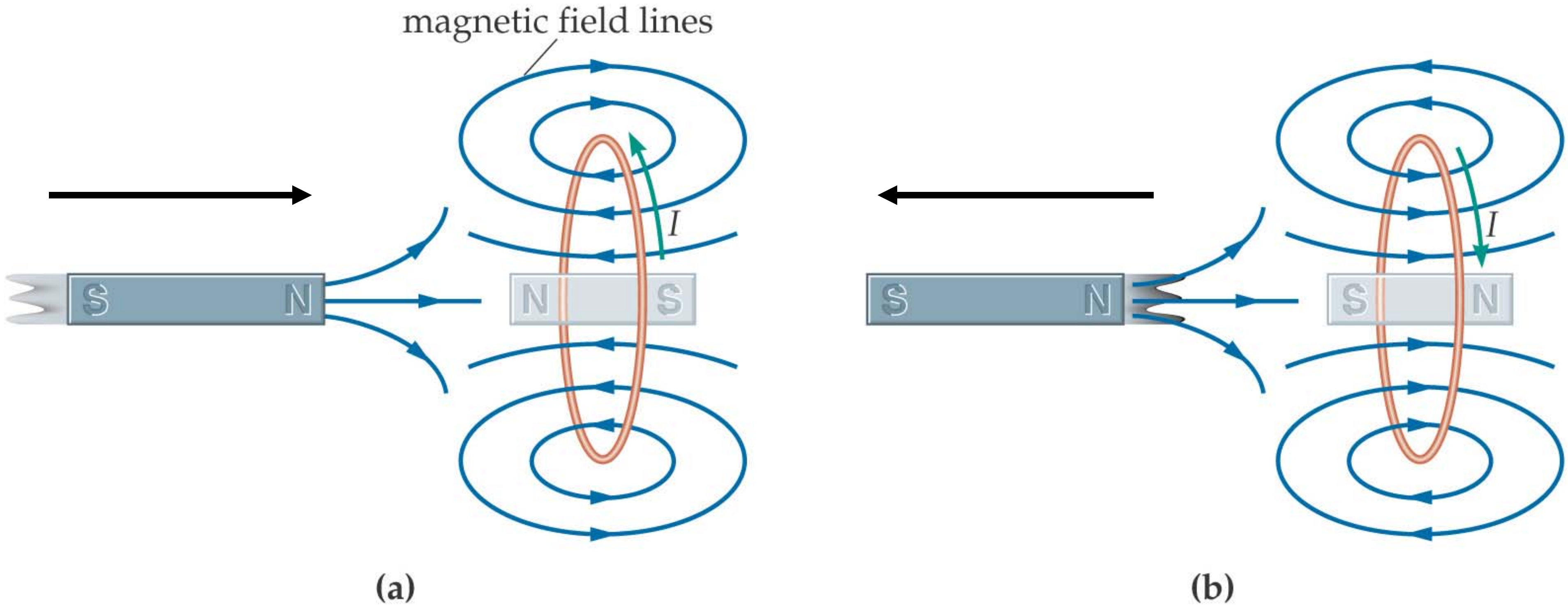
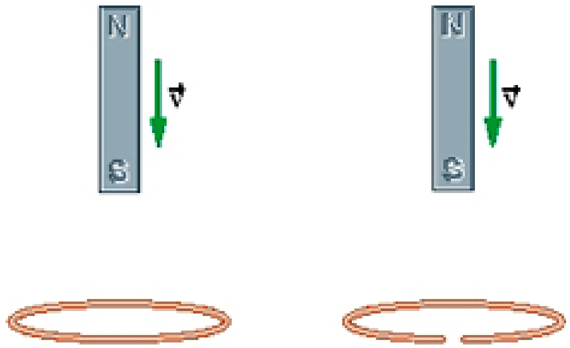
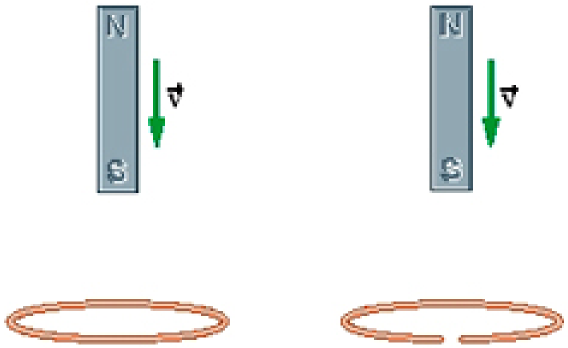


Figure 23-8
Applying Lenz's Law to a Magnet
Moving Toward (a), and Away (b) From a Current Loop



CONCEPTUAL CHECKPOINT 23–2

The magnets shown in the sketch are dropped from rest through the middle of conducting rings. Notice that the ring on the right has a small break in it, whereas the ring on the left forms a closed loop. As the magnets drop toward the rings, does the magnet on the left have an acceleration that is **(a)** more than, **(b)** less than, or **(c)** the same as that of the magnet on the right?



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Reasoning and Discussion

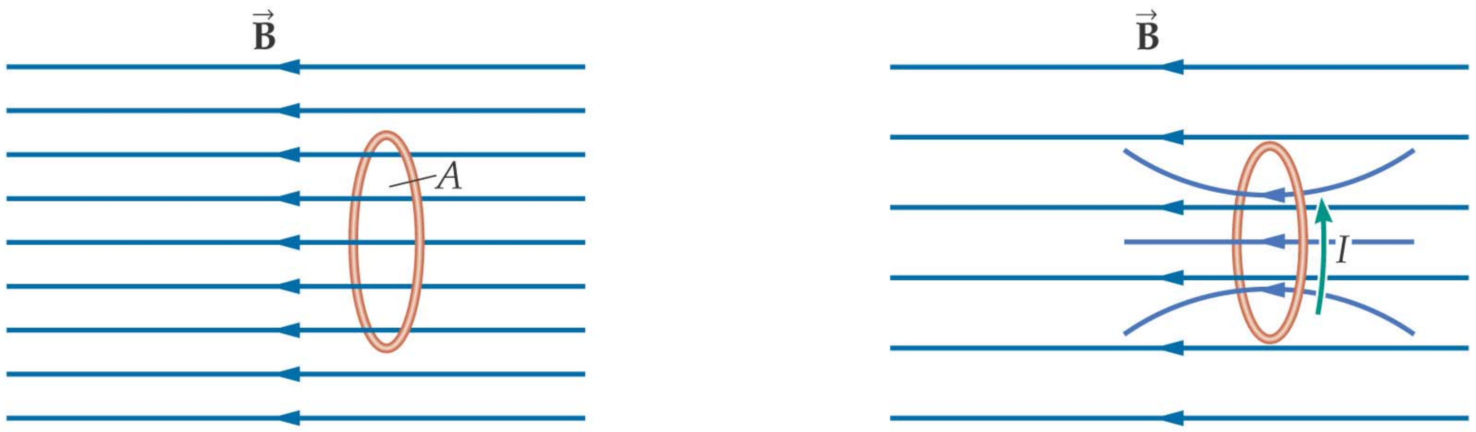
As the magnet on the left approaches the ring it induces a circulating current. According to Lenz's law, this current produces a magnetic field that exerts a repulsive force on the magnet—to oppose its motion. In contrast, the ring on the right has a break, so it cannot have a circulating current. As a result, it exerts no force on its magnet. Therefore, the magnet on the right falls with the acceleration of gravity; the magnet on the left falls with a smaller acceleration.

Answer:

(b) The magnet on the left has the smaller acceleration.

Another Example

Figure 23-9
Lenz's Law Applied to a Decreasing Magnetic Field



Magnetic field decreasing with time

(a) (b)

Motional EMF

A rod is falling down in a uniform B (because of gravity).

Since the change of the magnetic flux in the loop, it creates a current.

How to determine the direction of the current?

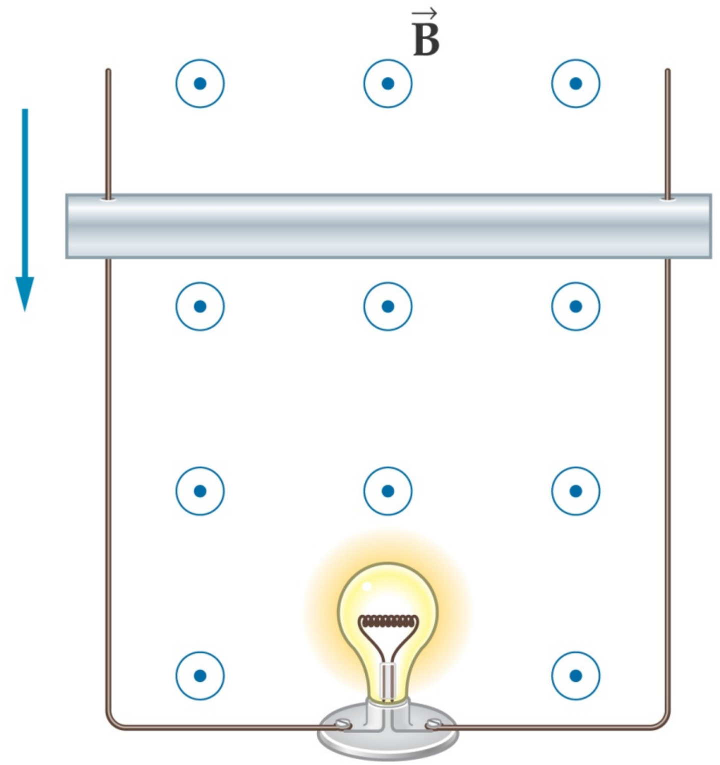


Figure 23-10
Motional emf

Lens’s Law is applied to determined the direction of the current !

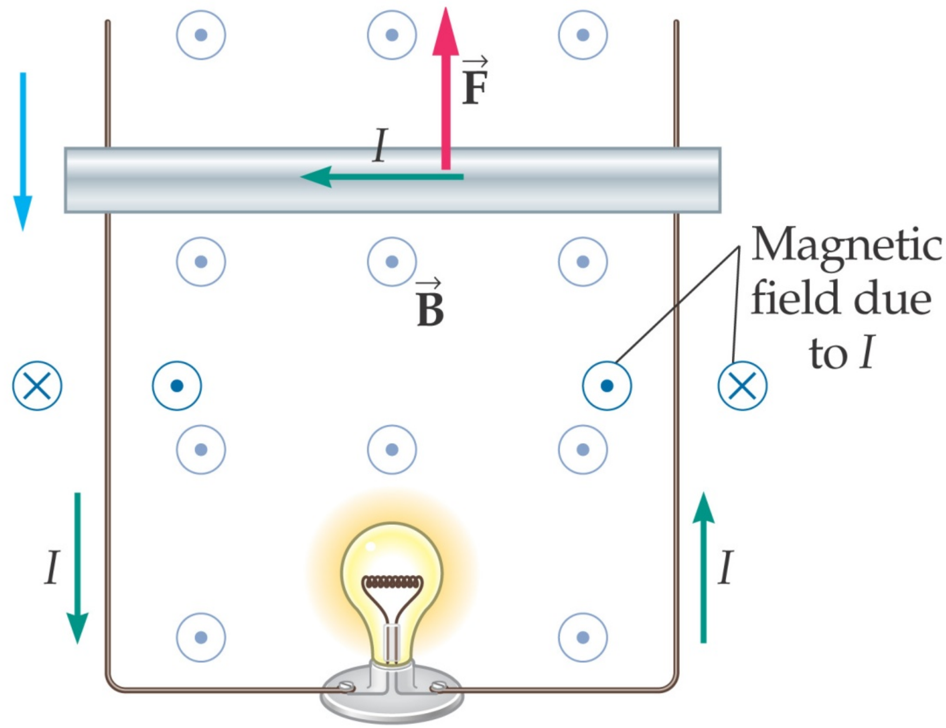
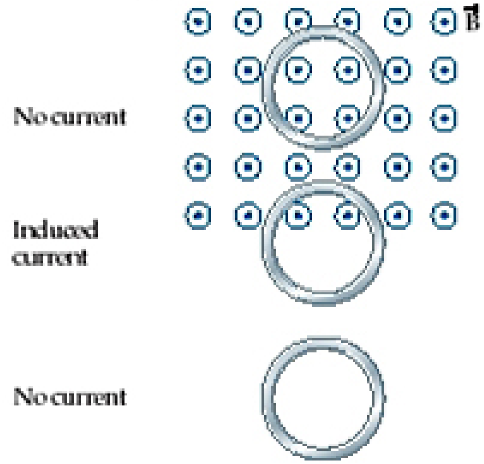


Figure 23-11
Determining the Direction of an Induced Current

CONCEPTUAL CHECKPOINT 23–3

Consider a system in which a metal ring is falling out of a region with a magnetic field and into a field-free region, as shown in our sketch. According to Lenz's law, is the induced current in the ring (a) clockwise or (b) counterclockwise?



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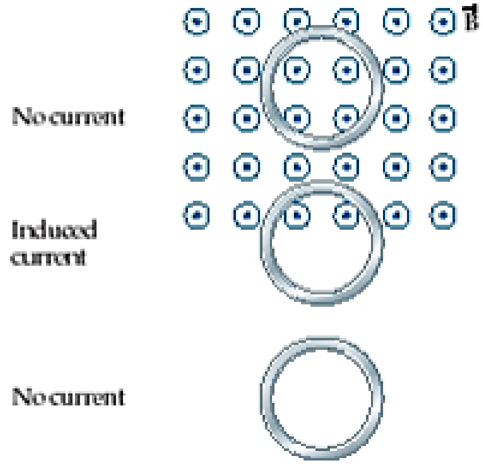
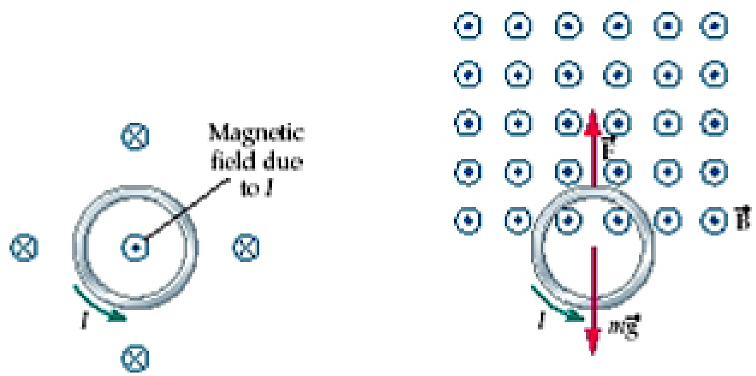


Reasoning and Discussion

The induced current must be in a direction that opposes the change in the system. In this case, the change is that fewer magnetic field lines are piercing the area of the loop and pointing out of the page. The induced current can oppose this change by generating more field lines out of the page within the loop. As shown in the following figure on the left, the induced current must be counterclockwise to accomplish this.



Finally, in the preceding figure on the right, note that the induced current generates an upward magnetic force at the top of the ring, but no magnetic force on the bottom, where the magnetic field is zero. Hence, the motion of the ring is retarded as it drops out of the field.

Answer:

(b) The induced current is counterclockwise.

Summary

Faraday's Lay of Induction

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} = -N\frac{\Phi_{final} - \Phi_{initial}}{T_{final} - T_{initial}} \qquad (23-3)$$

SI unit: V

Lens's Law

An induced current always flows in a direction that opposes the change (of the magnetic field) that causes it.

Exercise 23-1

The induced emf in a single loop of wire has a magnitude of 1.48V when the magnetic flux is changed from 0.850 $T \cdot m^2$ to 0.110 $T \cdot m^2$. How much time is required for this change flux?

Solution

Since

$$\varepsilon = \left| N \frac{\Delta\Phi}{\Delta t} \right| = N \left| \frac{\Phi_{final} - \Phi_{initial}}{T_{final} - T_{initial}} \right| \qquad (23-4)$$

We have

$$\left| T_{final} - T_{initial} \right| = N \left| \frac{\Phi_{final} - \Phi_{initial}}{\varepsilon} \right|$$

$$= (1) \frac{\left| 0.110T \cdot m^2 - 0.850T \cdot m^2 \right|}{1.48V} = 0.500 \quad s$$