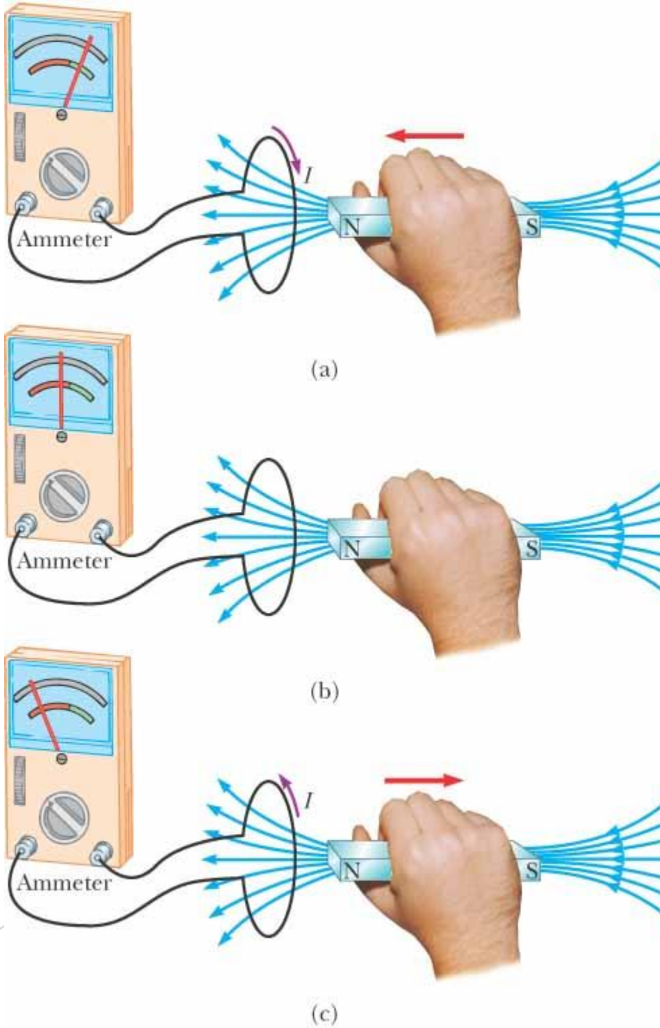
Chapter 31

Faraday's Law

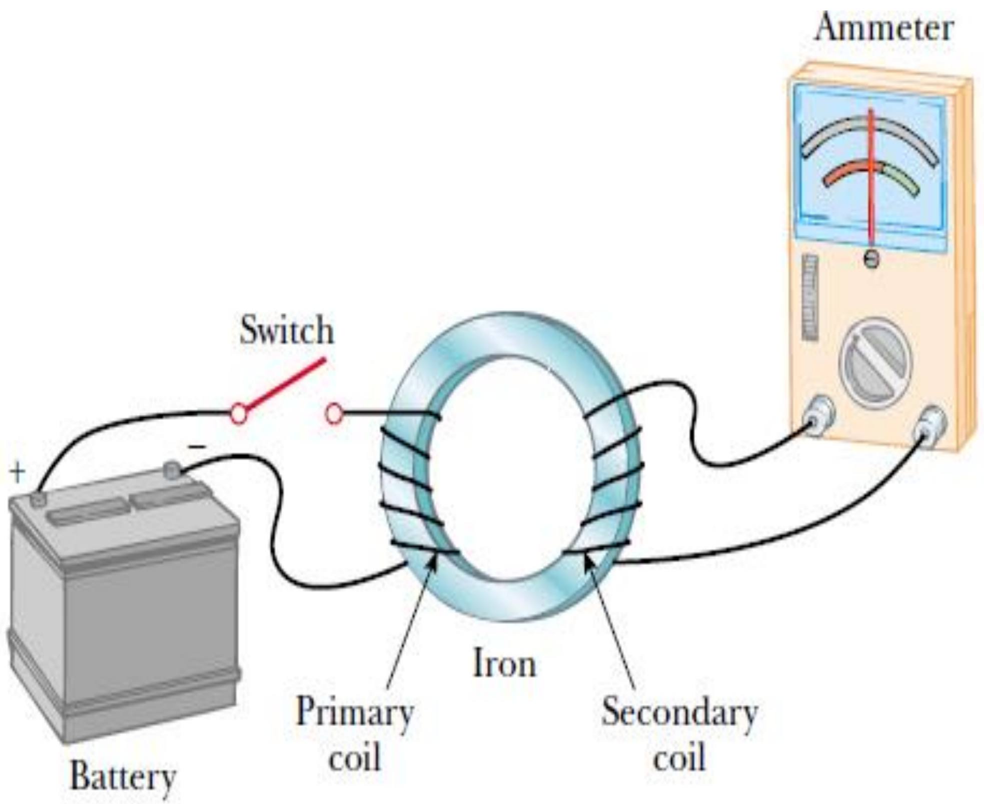
31.1 Faraday's Law of Induction

How an emf can be induced by a changing magnetic field?

(a) When a magnet is moved toward a loop of wire connected to a sensitive ammeter, the ammeter deflects as shown, indicating that a current is induced in the loop. (b) When the magnet is held stationary, there is no induced current in the loop, even when the magnet is inside the loop. (c) When the magnet is moved away from the loop, the ammeter deflects in the opposite direction, indicating that the induced current is opposite that shown in part (a). Changing the direction of the magnet's motion changes the direction of the current induced by that motion.



31.1 Faraday's Experiment



An electric current can be induced in a circuit (the secondary circuit in our setup) by a changing magnetic field.

Faraday’s Law of Induction

The EMF induced in a circuit is directly proportional to the time rate of change of magnetic flux through

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

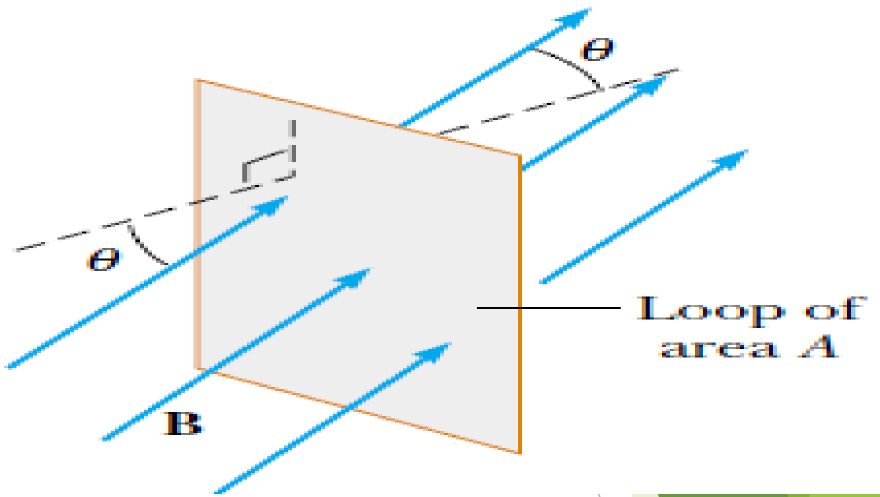
If the circuit is a coil consisting of N loops all of the same area and if Φ_B *is* the magnetic flux through one loop, an emf is induced in every loop

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t} = -N\frac{\Delta(BA\cos\theta)}{\Delta t}$$

$N = \#$ turns of wire

- Suppose the magnetic field is uniform over a loop of area A lying in a plane as shown in the figure below.
- The flux through the loop is equal to B·A·cos θ; and the induced EMF is:

$$\varepsilon = \frac{-d(B \cdot A \cdot \cos\theta)}{dt}$$



An emf can be induced in the circuit in several ways:

• The magnitude of B can change with time.

• The area enclosed by the loop can change with time.

• The angle between B and the normal to the loop can change with time.

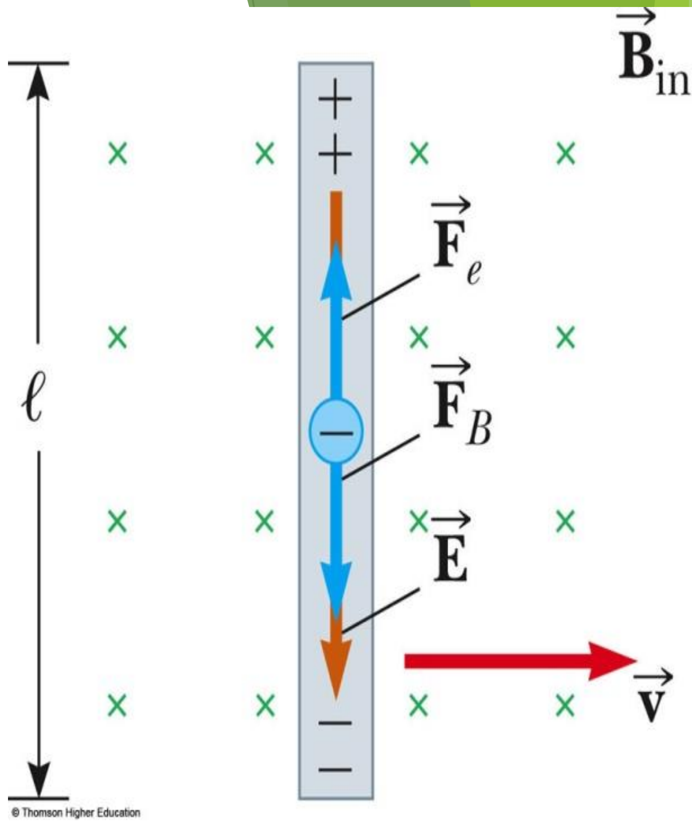
Example

A coil consists of 200 turns of wire. Each turn is a square of side 18cm, and a uniform magnetic field directed perpendicular to the plane of the coil is turned on. If the field changes linearly from 0 to 0.50T in 0.80s, what is the magnitude of the induced emf in the coil while the field is changing

31.2 Motional emf

- A **motional emf** is the emf induced in a conductor moving through a constant magnetic field
- The electrons in the conductor experience a force, that is directed along ℓ

$$\vec{\mathbf{F}} = q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$



- Under the influence of the force, the electrons move to the lower end of the conductor and accumulate there
- As a result of the charge separation, an electric field is produced inside the conductor
- The charges accumulate at both ends of the conductor until they are in equilibrium with regard to the electric and magnetic forces

$$F_B = F_E$$

$$qvB = qE$$

The electric field is related to the potential difference across the ends of the conductor:

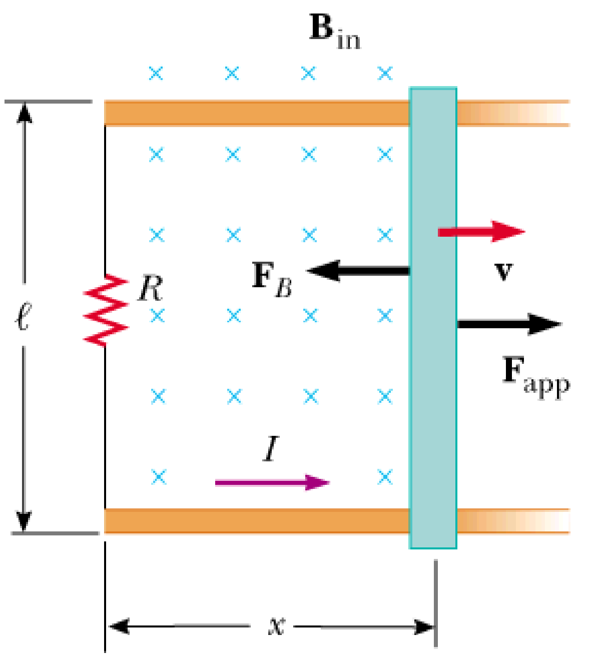
$$\Delta V = El = Blv$$

A potential difference is maintained between the ends of the conductor as long as the conductor continues to move through the uniform magnetic field

- A bar moving through a uniform field and the equivalent circuit diagram
- Assume the bar has zero resistance
- The stationary part of the circuit has a resistance *R* The induced emf is

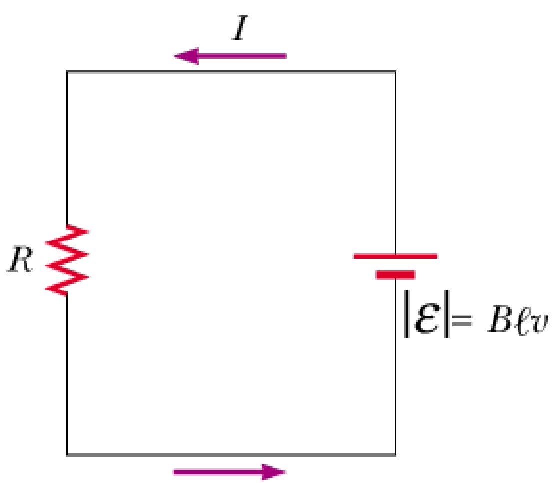
$$\Phi_B = BA = Blx$$

$$\varepsilon = -\frac{d\Phi_B}{dt} = -B\ell\frac{dx}{dt} = -B\ell v$$



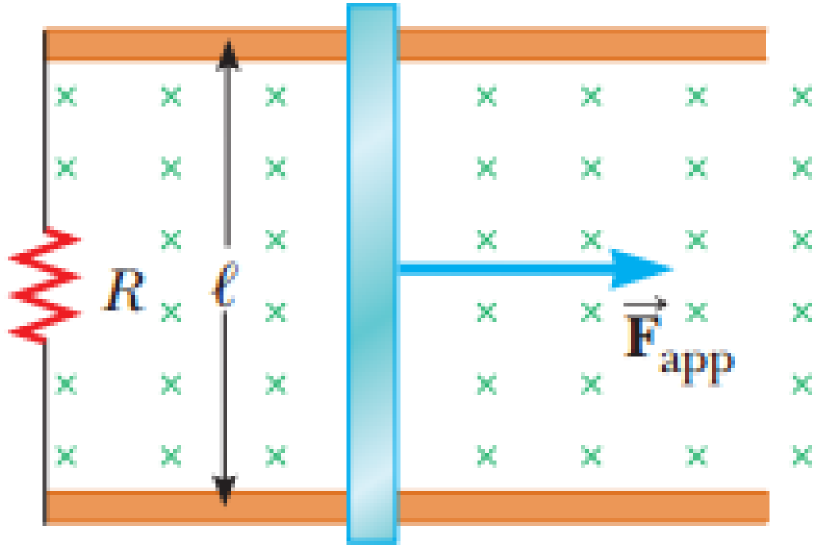
- Since the resistance in the circuit is *R*, the current is

$$I = \frac{|\varepsilon|}{R} = \frac{B\ell v}{R}$$



Example

Consider the arrangement shown in Figure P20.24. Assume $R = 6.00\ \Omega$, $\ell = 1.20$ m, and a uniform 2.50-T magnetic field is directed *into* the page. At what speed should the bar be moved to produce a current of 0.500 A in the resistor?



Example

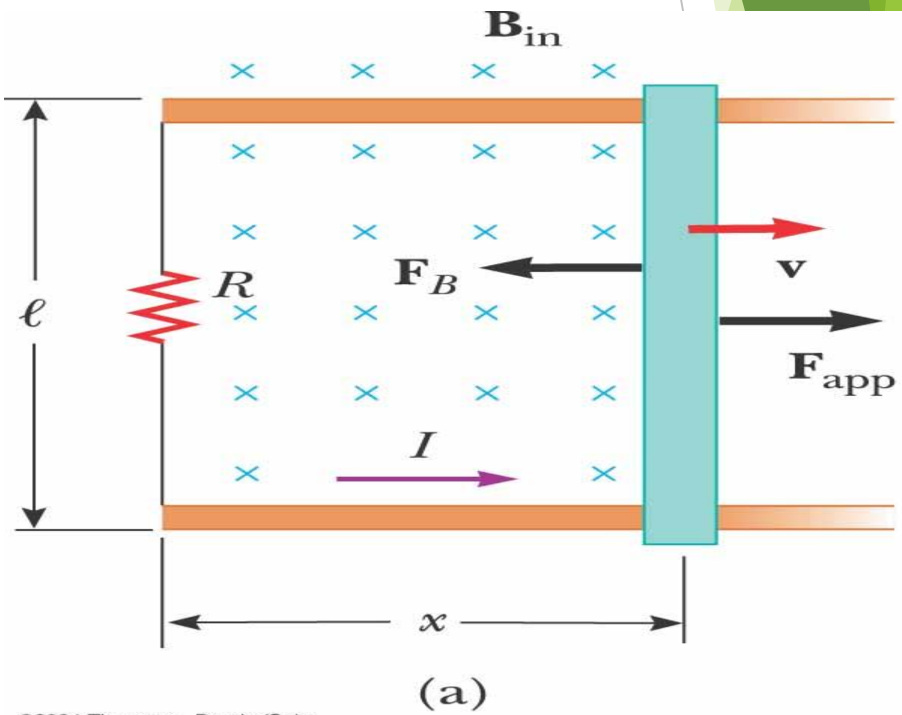
In the given figure, if I = 2 A, R= 3 Ω , *L* = 1.2 m, and B = 2.5 T, the applied force F_{app} required to move the bar to the right with constant speed of 2 m/s equals:

A. 2 N

B. 3 N

C. 6 N

D. 8 N



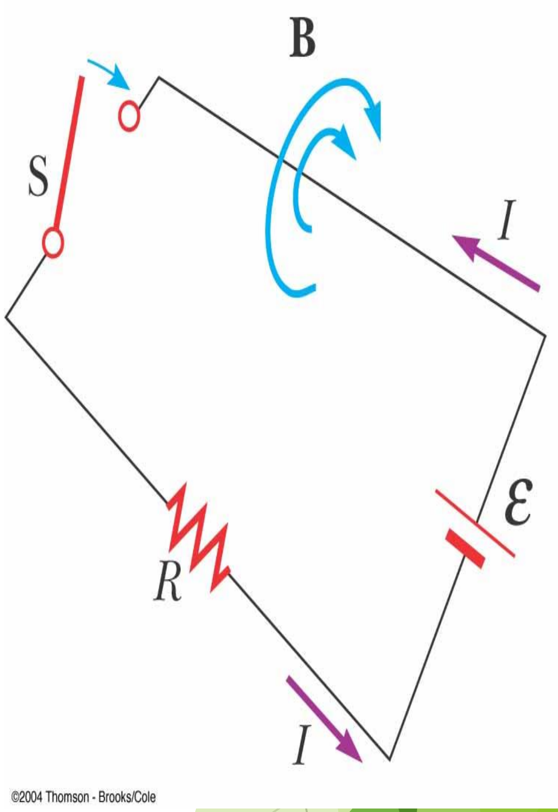
Example

Chapter 32

<u>Inductance</u>

32.1 Self-Inductance

- When the switch is closed, the current does not immediately reach its maximum value
- Faraday's law can be used to describe the effect
- As the source current increases with time, the magnetic flux through the circuit loop due to this current also increases with time. This increasing flux ***creates an induced emf*** in the circuit.
- The direction of the induced emf is such that it would cause an induced current in the loop (if a current were not already flowing in the loop), which would establish a magnetic field that would oppose the change in the source magnetic field.

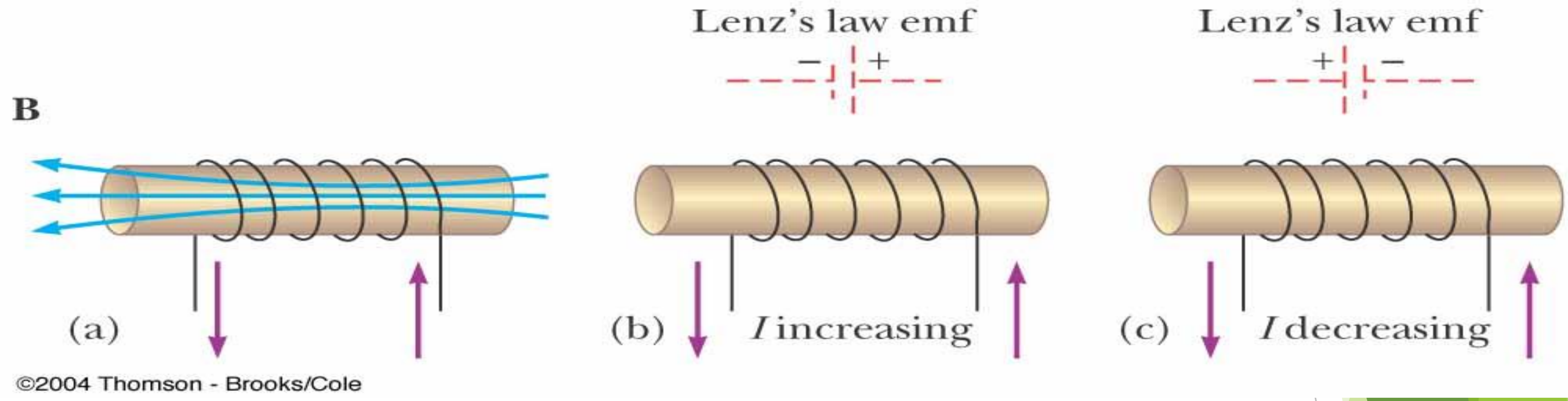


32.1 Self-Inductance

- **After the switch is closed, the current produces a magnetic flux through the area enclosed by the loop.**
- **As the current increases toward its equilibrium value, this magnetic flux changes in time and induces an emf in the loop (back emf).**

The emf set up in this case is called a
self-induced emf.

32.1 Self-Inductance



- A current in the coil produces a magnetic field directed toward the left (a)
- If the current increases, the increasing flux creates an induced emf of the polarity shown (b)
- The polarity of the induced emf reverses if the current decreases (c)

32.1 Self-Inductance

$$\varepsilon = -N\frac{d\Phi_B}{dt} = -N\frac{d(\mu_o nIA)}{dt} = -N\mu_o nA\frac{dI}{dt} = -\frac{NBA}{I}\frac{dI}{dt}$$

$$\varepsilon = -\frac{N\Phi_B}{I}\frac{dI}{dt} = -L\frac{dI}{dt}$$

$$L = \frac{N\Phi_B}{I}$$

$$L = \left[\frac{V}{A/s}\right] = [\Omega - s] = [\text{Henry}] = [H]$$

Example: Inductance of a Solenoid

(a) Calculate the inductance of a solenoid containing 300 turns if the length of the solenoid is 25.0 cm and its cross-sectional area is 4.00 $\times 10^{4}$ m^2

(b) Calculate the self-induced emf in the solenoid described in part (a) if the current in the solenoid decreases at the rate of 50.0 A/s.

32.3 Energy in Magnetic Field

Energy stored in a capacitor:

$$U = \frac{1}{2} C V^2$$

Energy stored in an inductor:

$$U = \frac{1}{2} L I^2$$

Energy Density in a coil

$$u_B = \frac{U}{A\ell} = \frac{B^2}{2\mu_0}$$