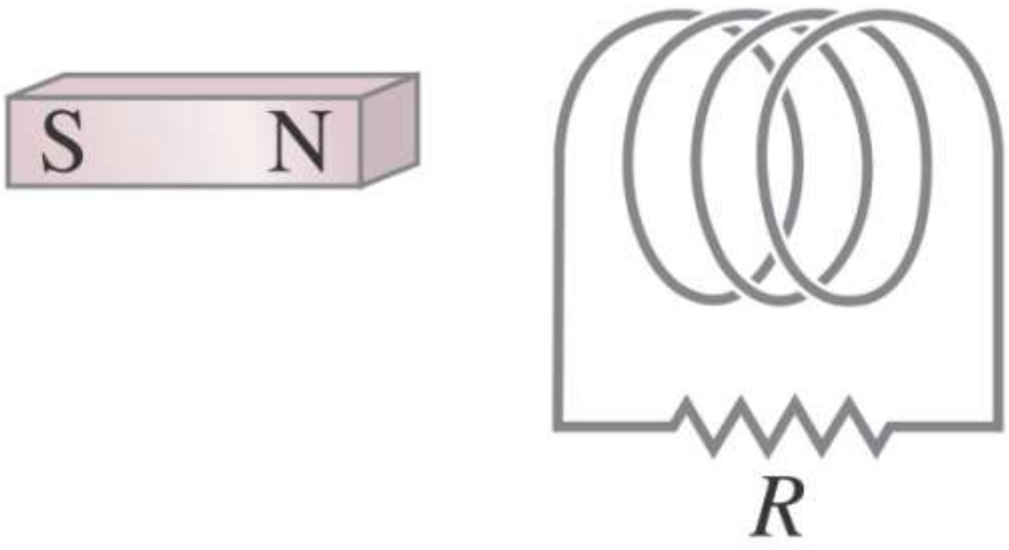
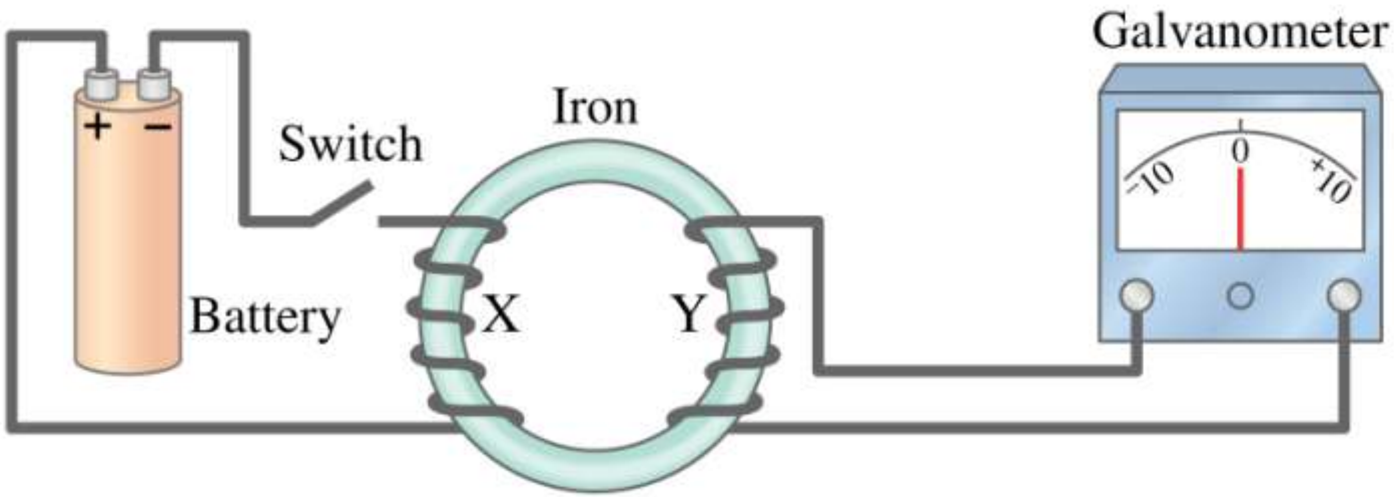
Chapter 21

Electromagnetic Induction and Faraday's Law



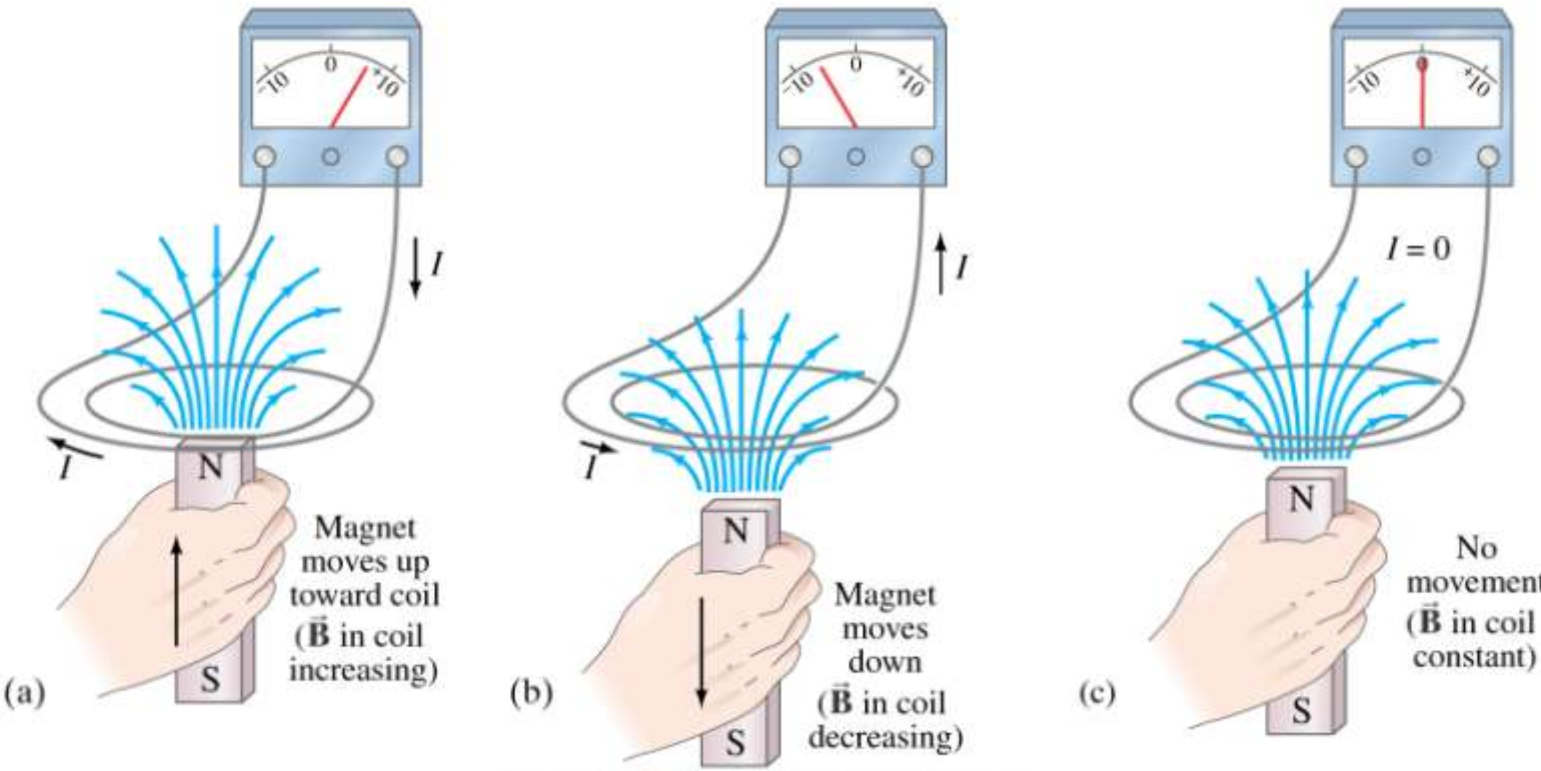
21.1 Induced EMF

Almost 200 years ago, Faraday looked for evidence that a magnetic field would induce an electric current with this apparatus:



21.1 Induced EMF

He found no evidence when the current was steady, but did see a current induced when the switch was turned on or off.



21.1 Induced EMF

Time for a Gizmo!

21.1 Induced EMF

Therefore, a changing magnetic field induces an emf.

Faraday’s experiment used a magnetic field that was changing because the current producing it was changing; the previous graphic shows a magnetic field that is changing because the magnet is moving.

21.2 Faraday's Law of Induction; Lenz's Law

The induced emf in a wire loop is proportional to the rate of change of magnetic flux through the loop.

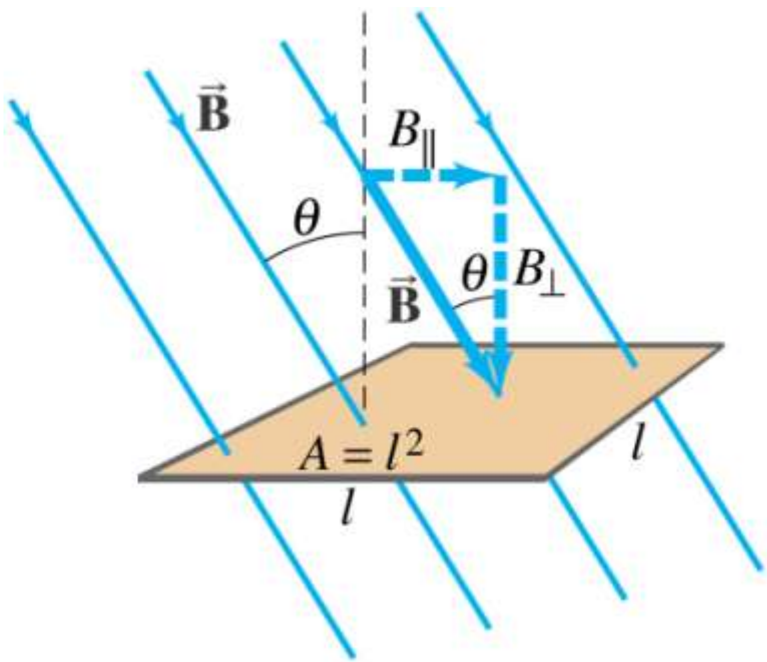
Magnetic flux: $$\Phi_B = B_\perp A = BA\cos\theta \qquad (21\text{-}1)$$

Unit of magnetic flux: weber, Wb.

1 Wb = 1 $T \cdot m^2$

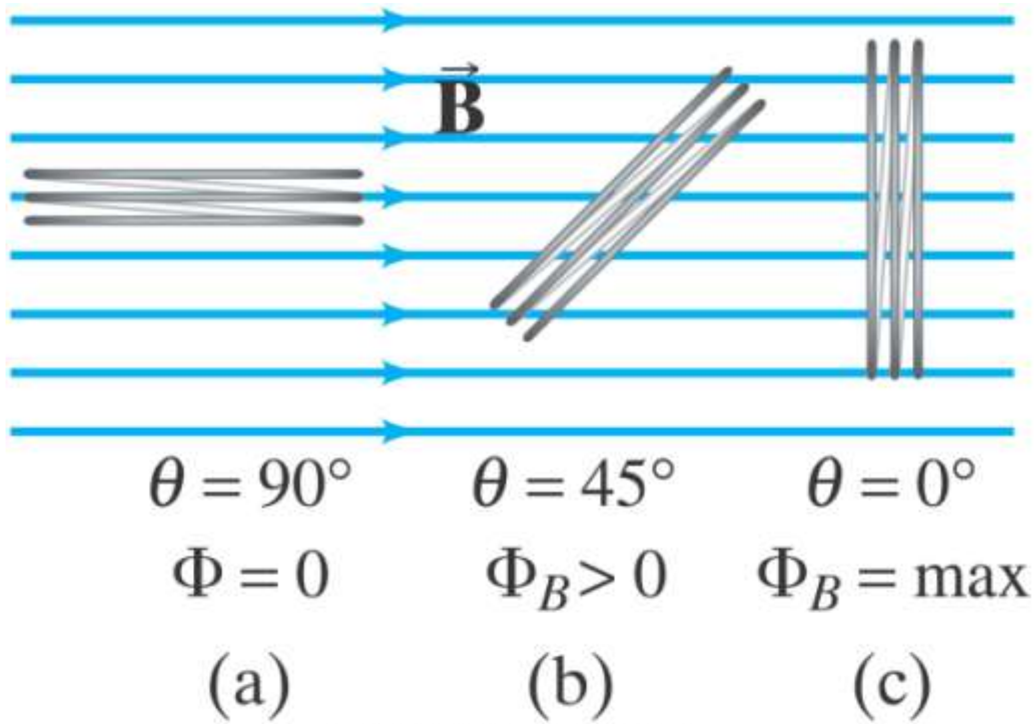
21.2 Faraday's Law of Induction; Lenz's Law

This drawing shows the variables in the flux equation:



21.2 Faraday's Law of Induction; Lenz's Law

The magnetic flux is analogous to the electric flux – it is proportional to the total number of lines passing through the loop.



21.2 Faraday's Law of Induction; Lenz's Law

Faraday's law of induction:

$$\mathcal{E} = -\frac{\Delta\Phi_B}{\Delta t}$$

[1 loop] (21-2a)

$$\mathcal{E} = -N\frac{\Delta\Phi_B}{\Delta t}$$

[N loops] (21-2b)

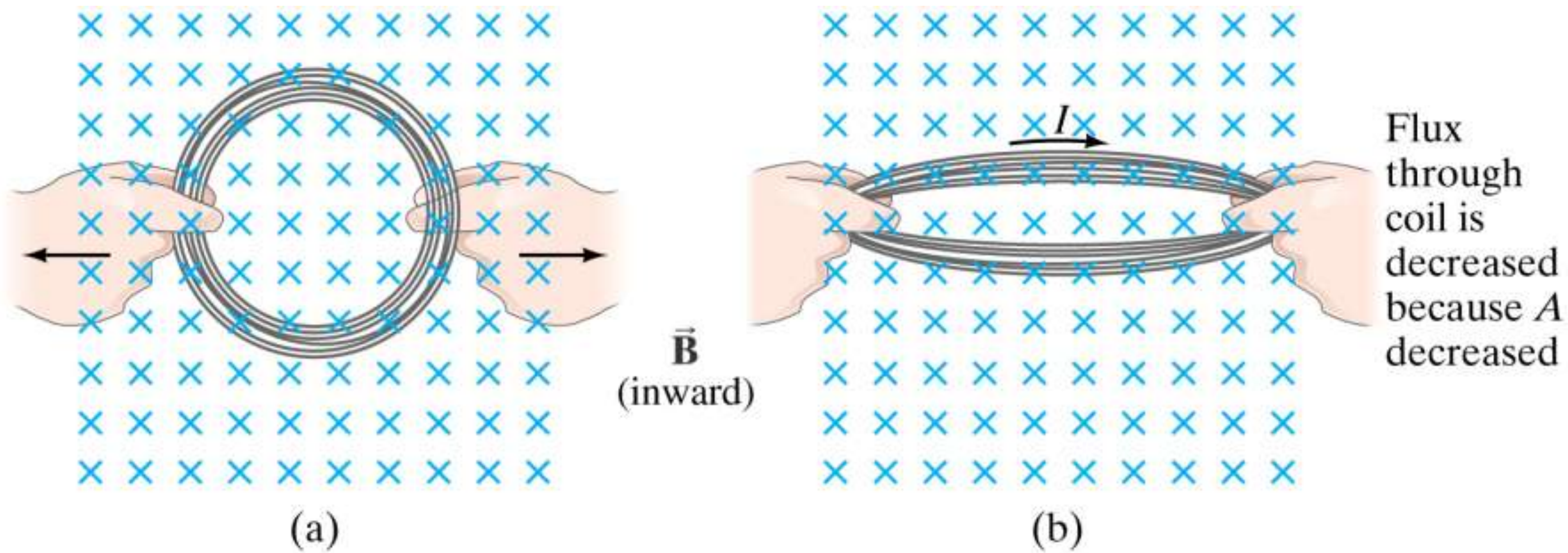
21.2 Faraday's Law of Induction; Lenz's Law

The minus sign gives the direction of the induced emf:

A current produced by an induced emf moves in a direction so that the magnetic field it produces tends to restore the changed field.

21.2 Faraday's Law of Induction; Lenz's Law

Magnetic flux will change if the area of the loop changes:

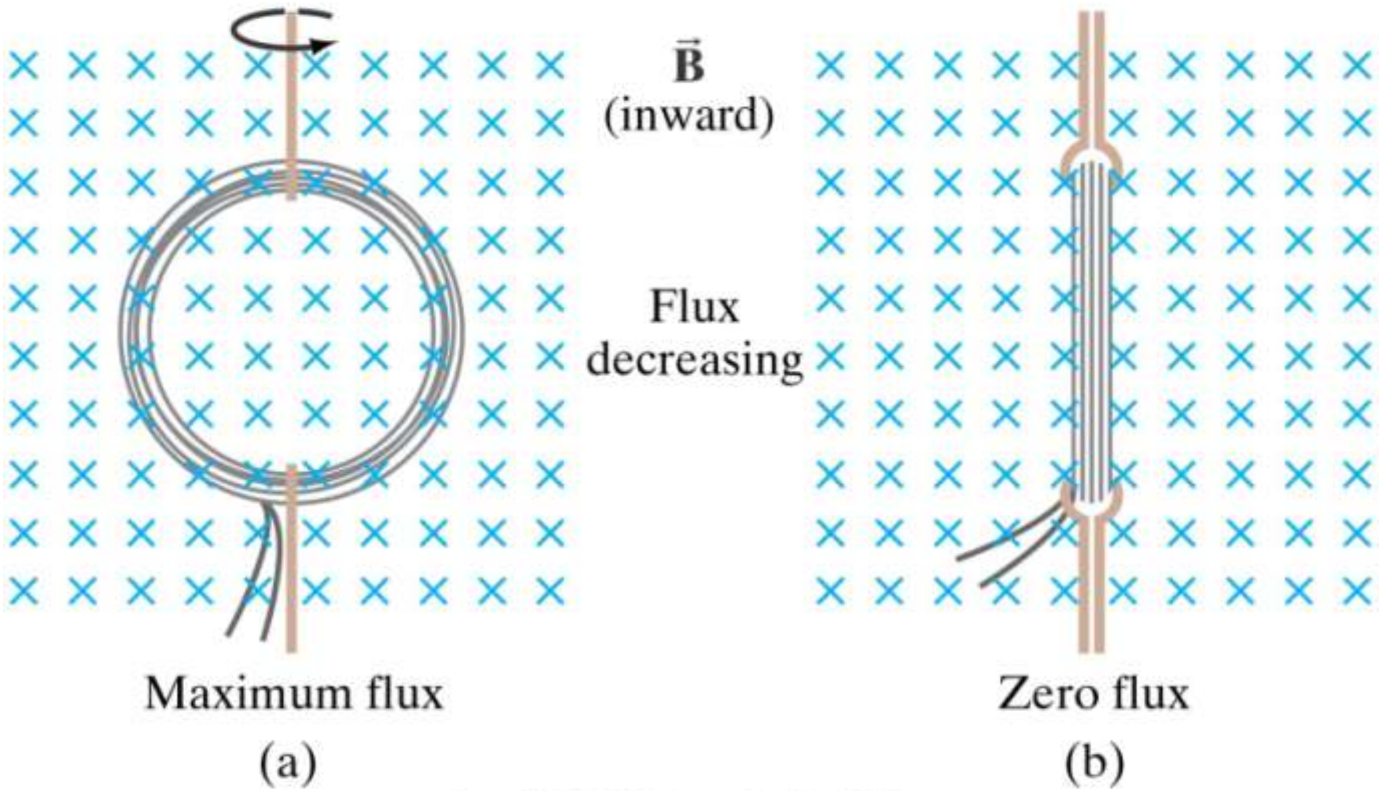


21.1 Induced EMF

Time for a Gizmo!

21.2 Faraday's Law of Induction; Lenz's Law

Magnetic flux will change if the angle between the loop and the field changes:



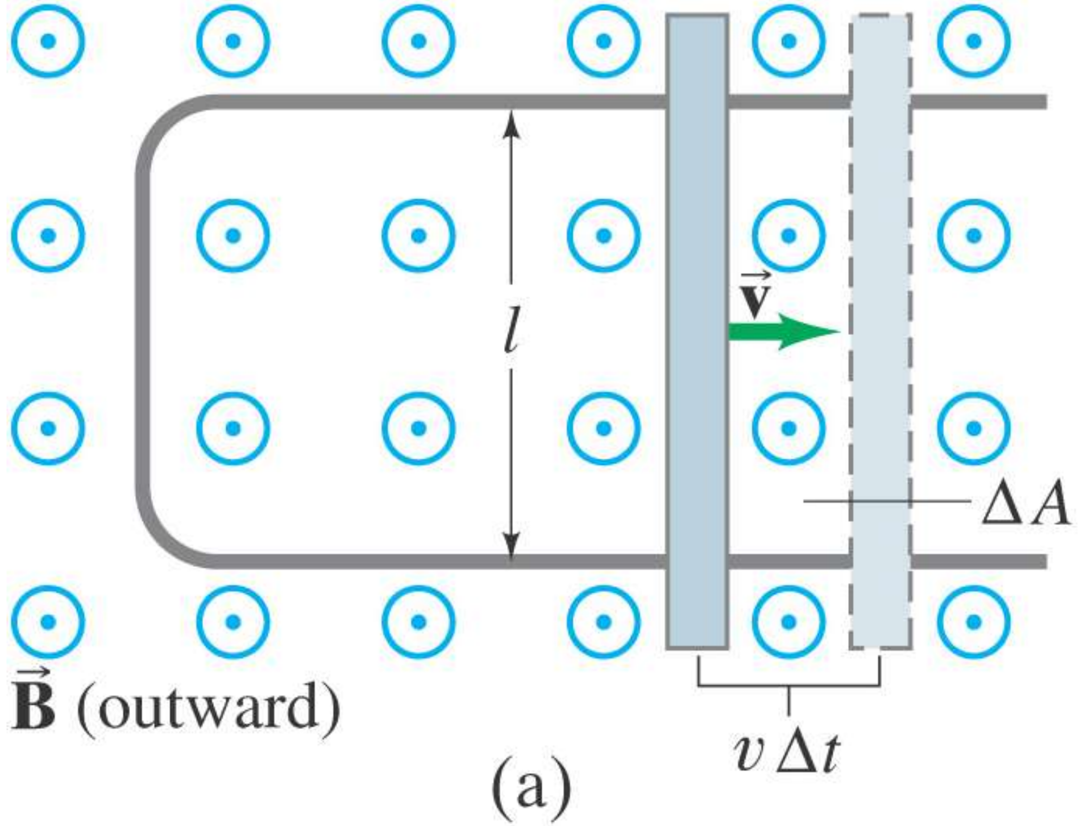
21.2 Faraday's Law of Induction; Lenz's Law

Problem Solving: Lenz's Law

1. Determine whether the magnetic flux is increasing, decreasing, or unchanged.
2. The magnetic field due to the induced current points in the opposite direction to the original field if the flux is increasing; in the same direction if it is decreasing; and is zero if the flux is not changing.
3. Use the right-hand rule to determine the direction of the current.
4. Remember that the external field and the field due to the induced current are different.

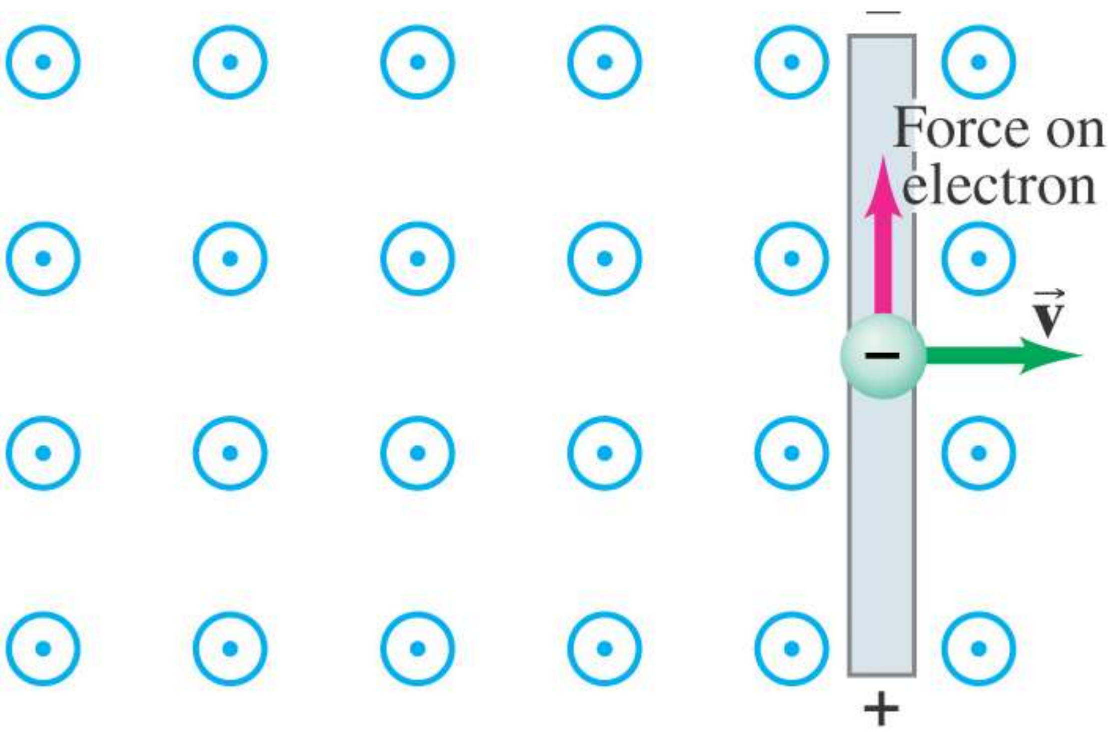
21.3 EMF Induced in a Moving Conductor

This image shows another way the magnetic flux can change:



21.3 EMF Induced in a Moving Conductor

The induced current is in a direction that tends to slow the moving bar – it will take an external force to keep it moving.

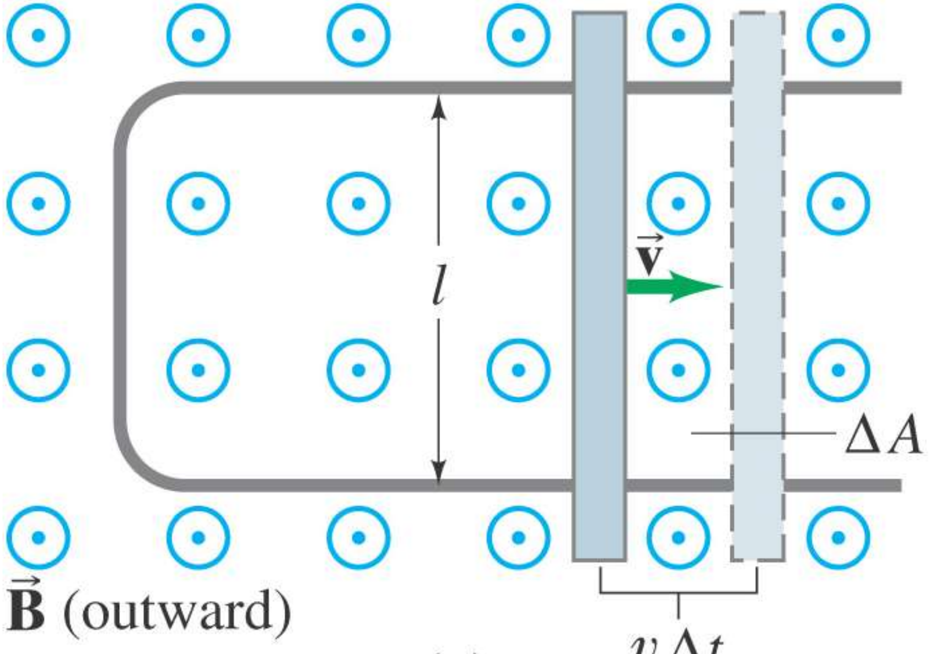


(b)

21.3 EMF Induced in a Moving Conductor

The induced emf has magnitude

$$\mathcal{E} = \frac{\Delta\Phi_B}{\Delta t} = \frac{B\,\Delta A}{\Delta t} = \frac{Blv\,\Delta t}{\Delta t} = Blv \qquad \textbf{(21-3)}$$



(a)

21.4 Changing Magnetic Flux Produces an Electric Field

A changing magnetic flux induces an electric field; this is a generalization of Faraday's law. The electric field will exist regardless of whether there are any conductors around.