

# Lecture PowerPoint

## Chapter 21

### *Physics: Principles with Applications, 6<sup>th</sup> edition*

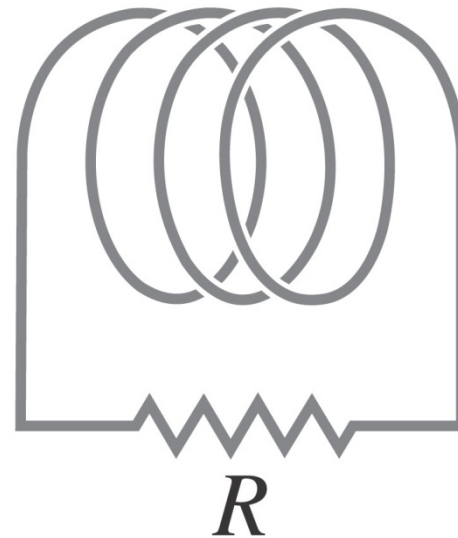
Giancoli

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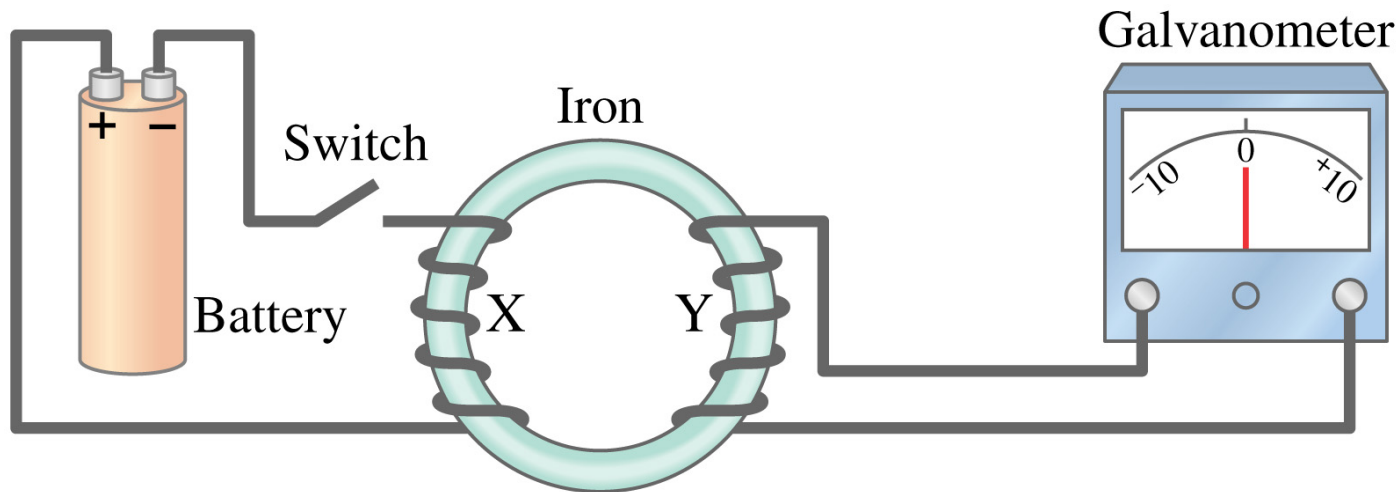
# Chapter 21

## Electromagnetic Induction and Faraday's Law



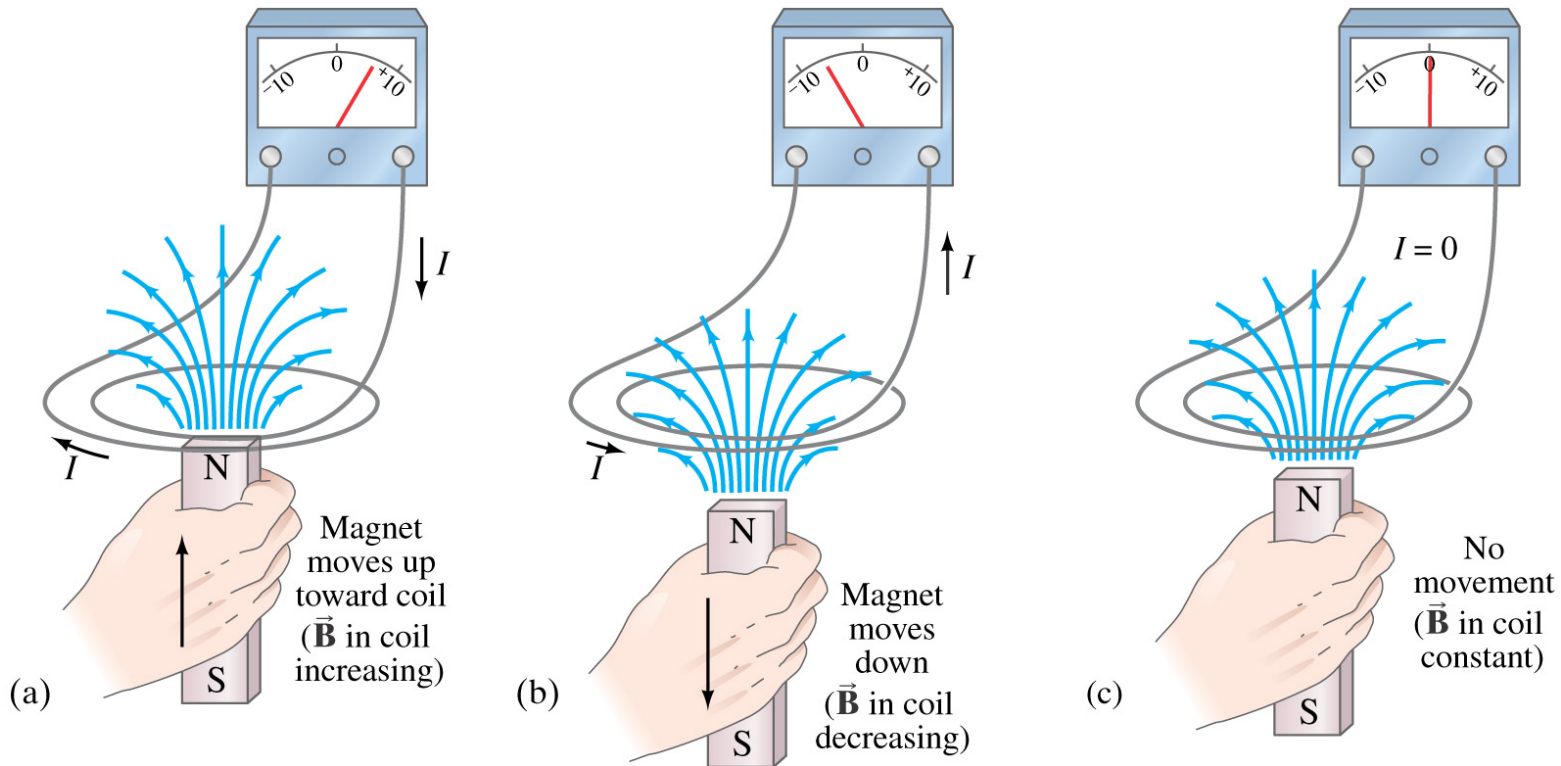
# 21.1 Induced EMF

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

**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.

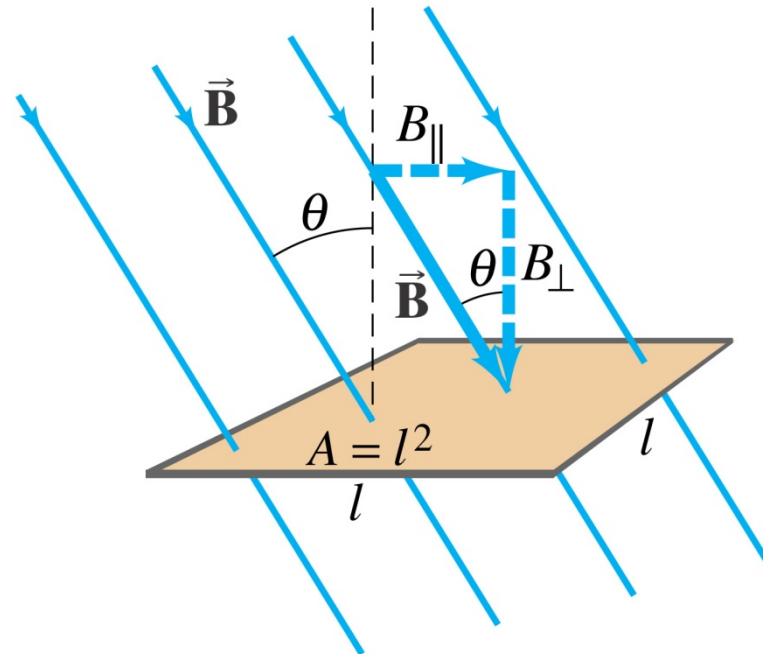
Magnetic flux:  $\Phi_B = B_{\perp} A = BA \cos \theta$  (21-1)

Unit of magnetic flux: weber, Wb.

$1 \text{ Wb} = 1 \text{ T}\cdot\text{m}^2$

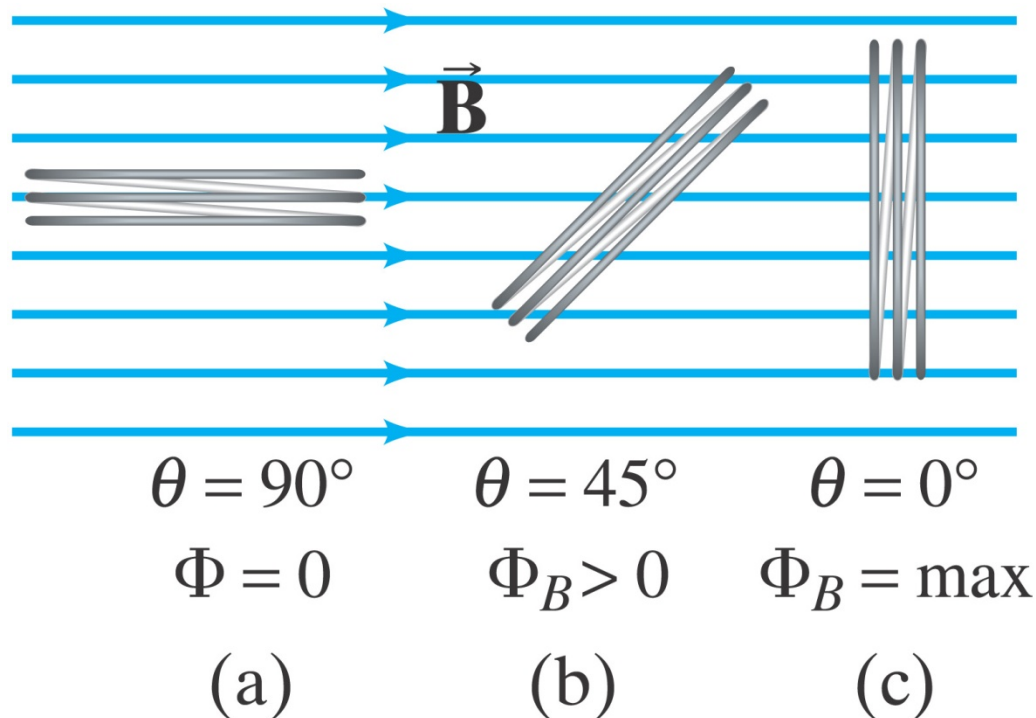
# 21.2 Faraday's Law of Induction; Lenz's Law

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.**

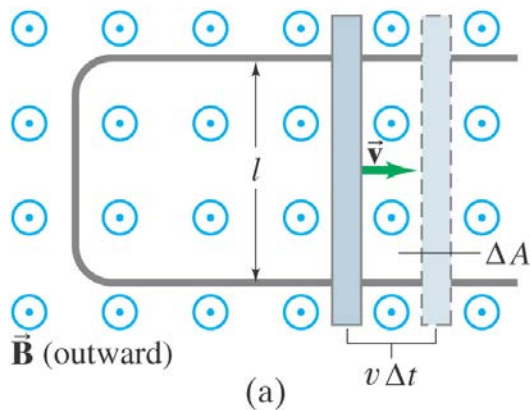
# 21.2 Faraday's Law of Induction; Lenz's Law

## Problem Solving: Lenz's Law

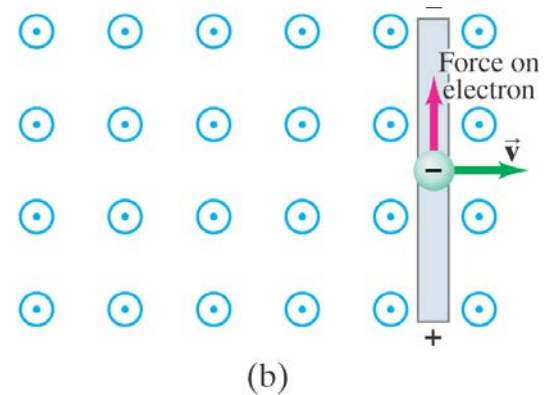
1. Determine whether the magnetic flux is increasing, decreasing, or unchanged.
2. The magnetic field due to the induced current points in the opposite direction to the original field if the flux is increasing; in the same direction if it is decreasing; and is zero if the flux is not changing.
3. Use 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 (a) shows another way the magnetic flux can change



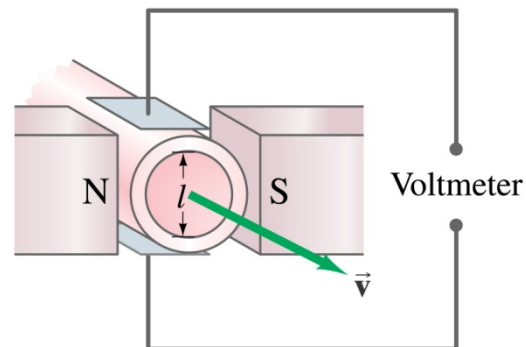
The induced current is in a direction that tends to slow the moving bar – it will take an external force to keep it moving.



The induced emf has magnitude

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

Measurement of blood velocity from induced emf



## 21.4 Changing Magnetic Flux Produces an Electric Field

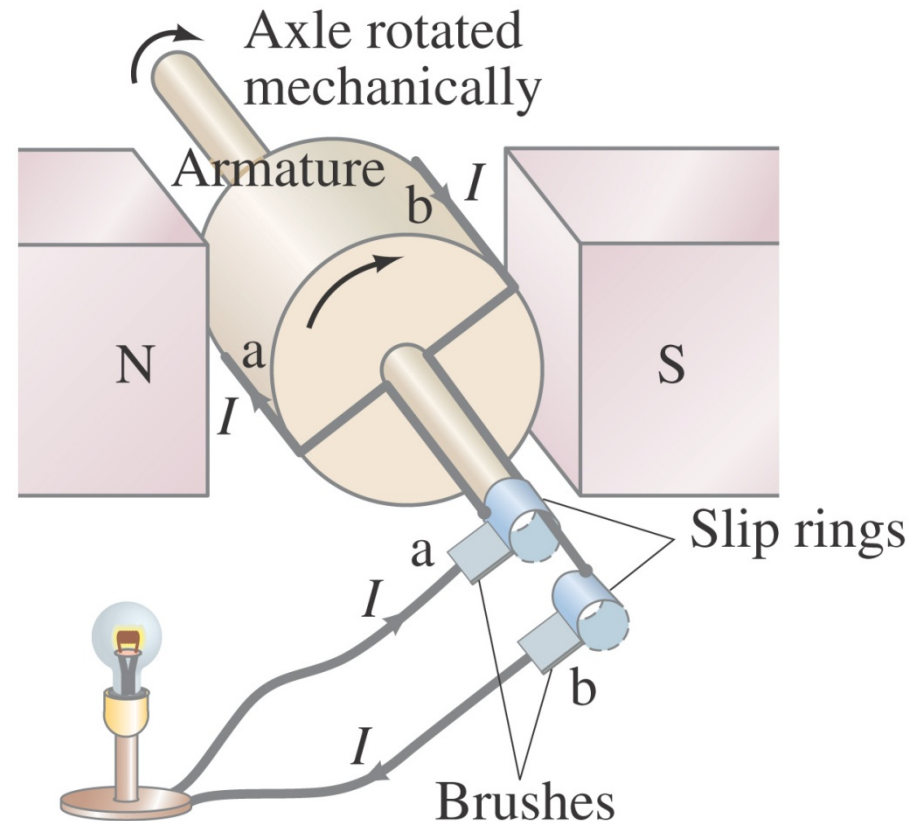
A changing magnetic flux induces an electric field; this is a generalization of Faraday's law. The electric field will exist regardless of whether there are any conductors around.

$$E = F/q = qvB/q \rightarrow E = vB \rightarrow v = E/B$$

# 21.5 Electric Generators

A generator is the opposite of a motor – it transforms mechanical energy into electrical energy. This is an ac generator:

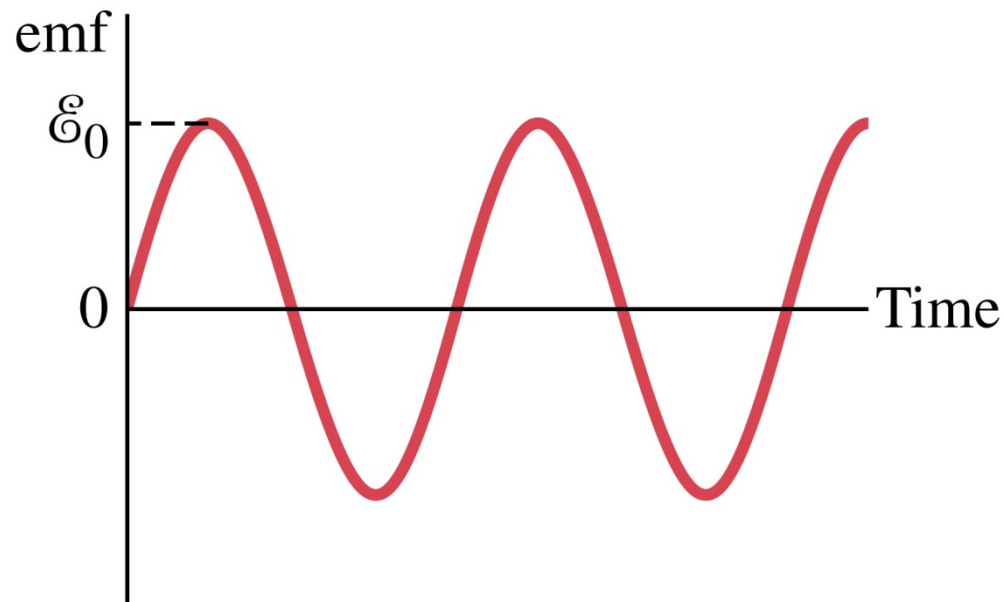
The axle is rotated by an external force such as falling water or steam. The brushes are in constant electrical contact with the slip rings.



## 21.5 Electric Generators

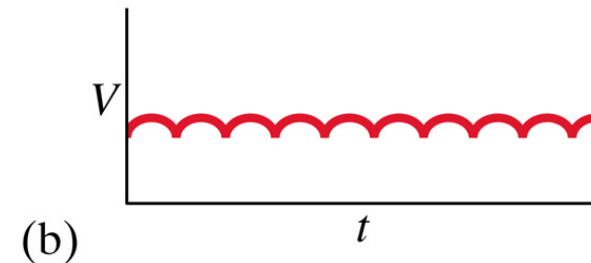
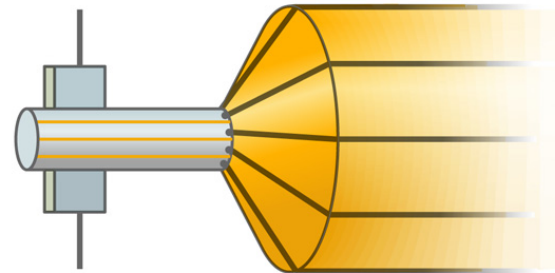
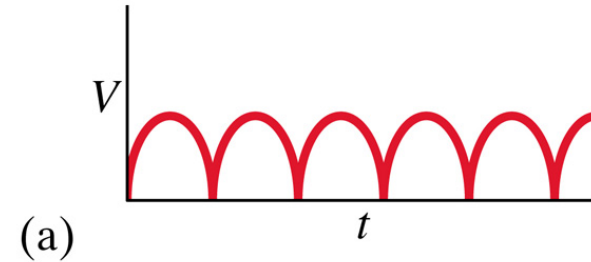
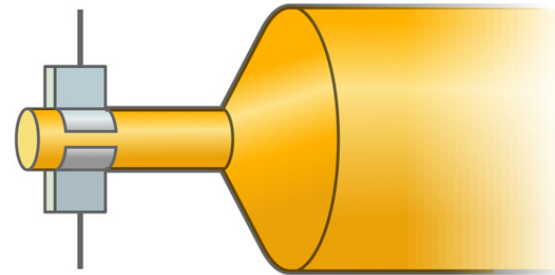
A sinusoidal emf is induced in the rotating loop ( $N$  is the number of turns, and  $A$  the area of the loop):

$$\mathcal{E} = NB\omega A \sin \omega t \quad (21-5)$$



# 21.5 Electric Generators

A dc generator is similar, except that it has a split-ring commutator instead of slip rings.



# 21.7 Transformers and Transmission of Power

- A transformer consists of two coils, either interwoven or linked by an iron core. A changing emf in one induces an emf in the other.

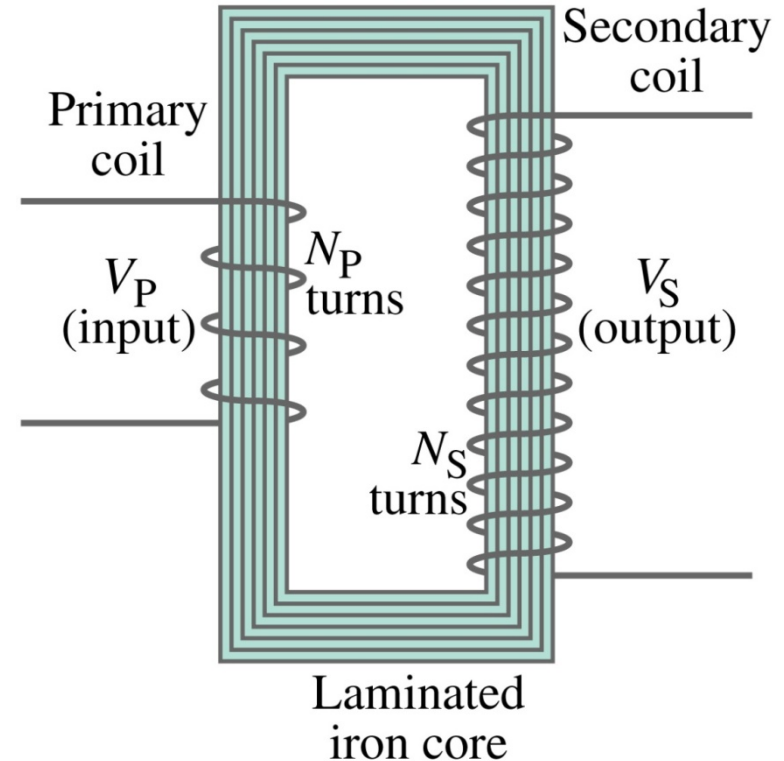
The ratio of the emfs is equal to the ratio of the number of turns in each coil:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} \quad (21-6)$$

If  $N_s > N_p$ ,  $V_s > V_p \rightarrow$  Step up transformer

If  $N_s < N_p$ ,  $V_s < V_p \rightarrow$  Step down transformer

In the figure show, it is a step-up transformer – the emf in the secondary coil is larger than the emf in the primary.



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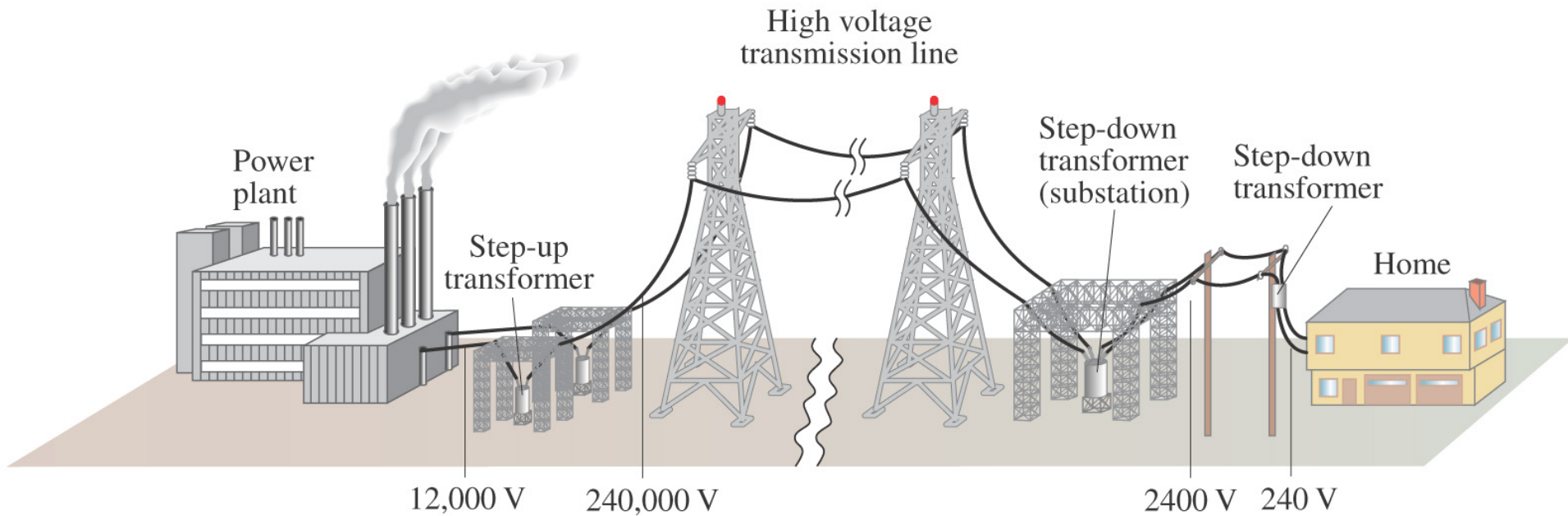
## 21.7 Transformers and Transmission of Power

Energy must be conserved; therefore, in the absence of losses, the ratio of the currents must be the inverse of the ratio of turns:

$$\frac{I_S}{I_P} = \frac{N_P}{N_S} \quad (21-6)$$

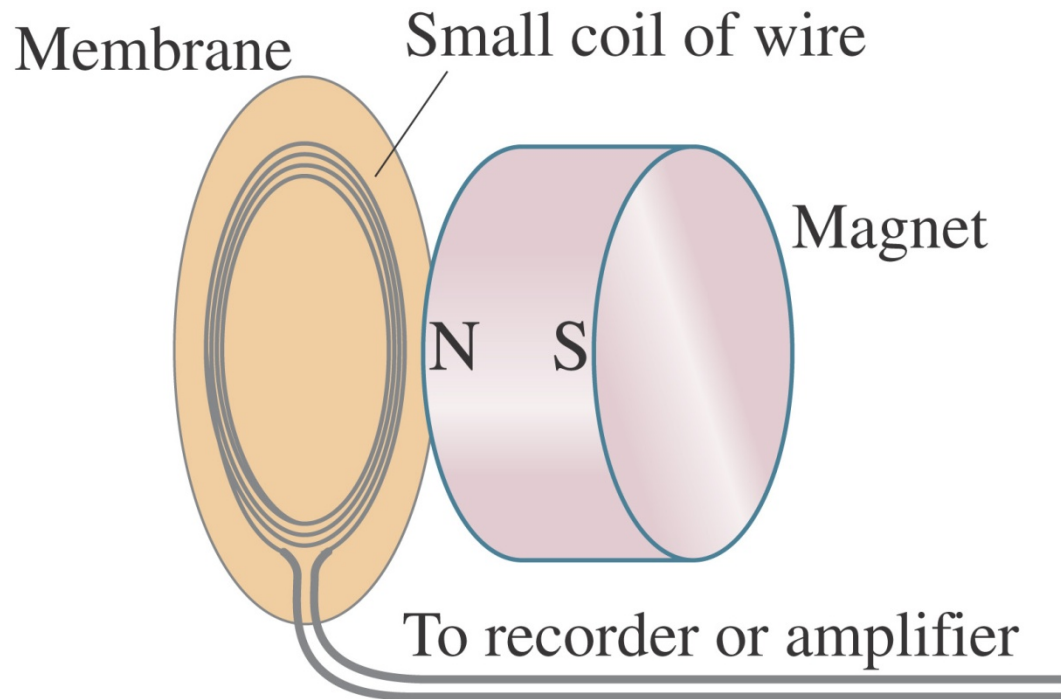
# 21.7 Transformers and Transmission of Power

Transformers work only if the current is changing; this is one reason why electricity is transmitted as ac.



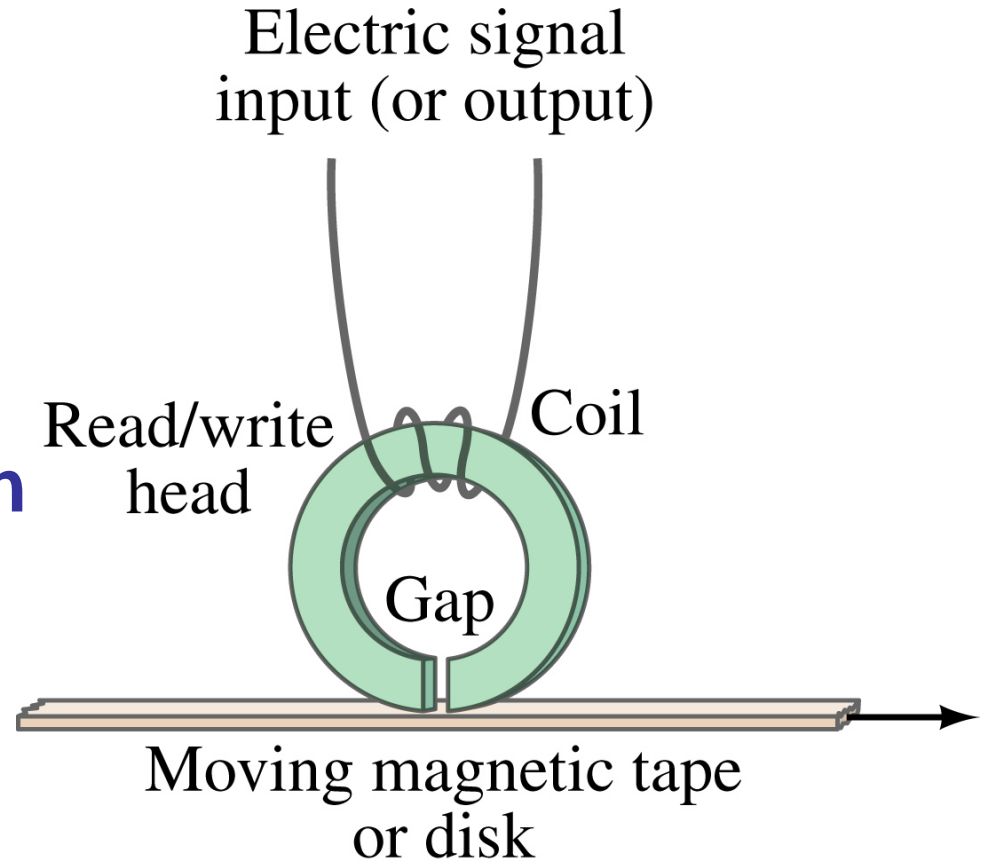
# 21.8 Applications of Induction: Sound Systems, Computer Memory, Seismograph, GFCI

This microphone works by induction; the vibrating membrane induces an emf in the coil



# 21.8 Applications of Induction: Sound Systems, Computer Memory, Seismograph, GFCI

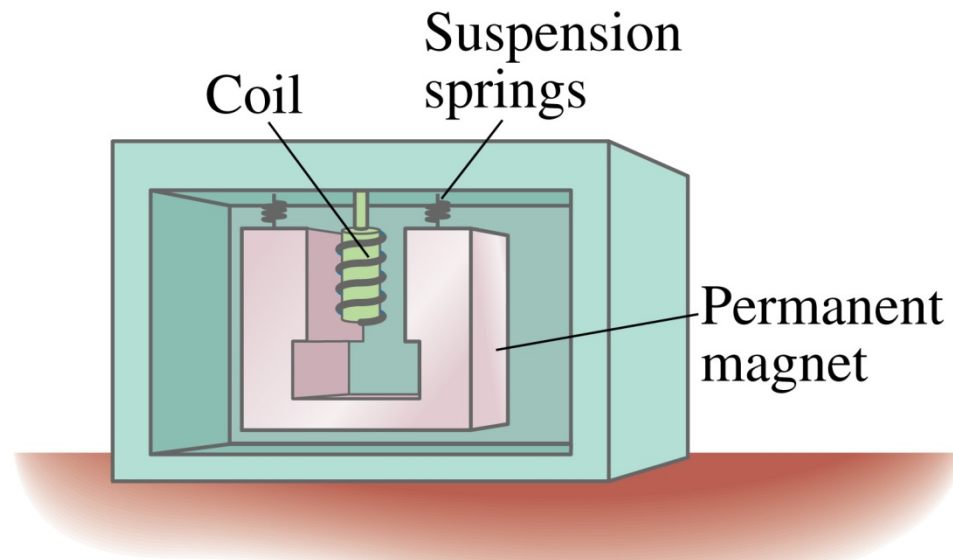
Differently magnetized areas on an audio tape or disk induce signals in the read/write heads.



(a)

# 21.8 Applications of Induction: Sound Systems, Computer Memory, Seismograph, GFCI

A seismograph has a fixed coil and a magnet hung on a spring (or vice versa), and records the current induced when the earth shakes.

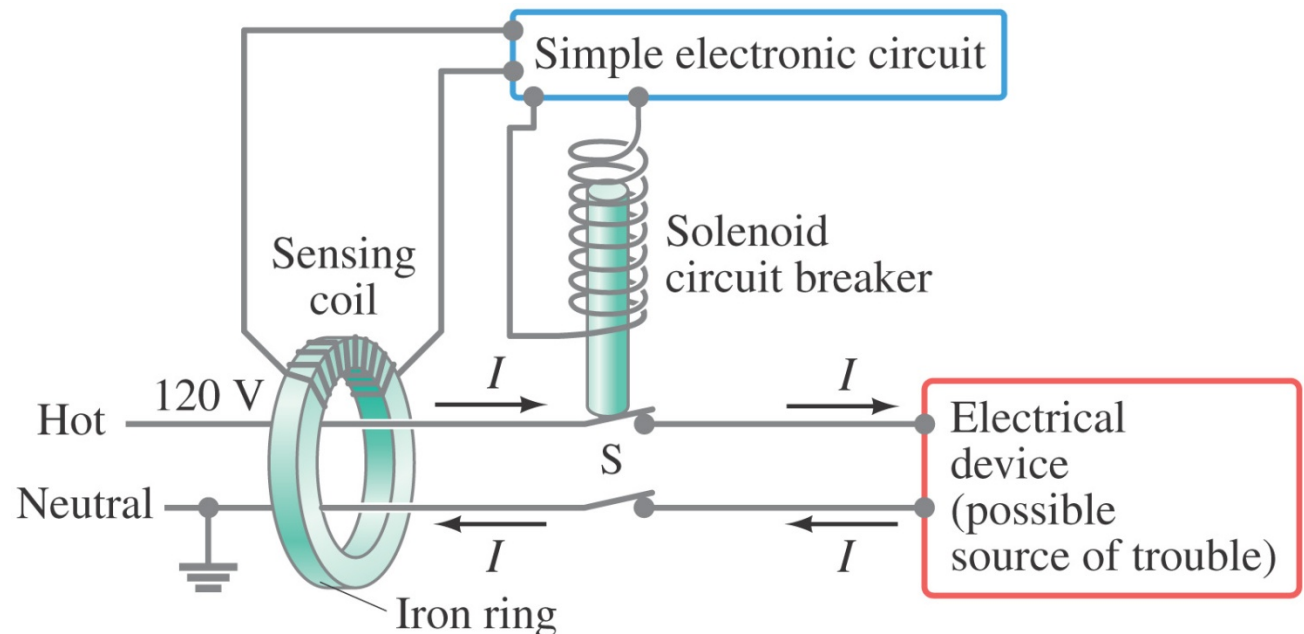


# Applications of Induction: GFCI

- A ground fault circuit interrupter (GFCI) will interrupt the current to a circuit that has shorted out in a very short time, before a dangerous current flows, preventing electrocution.
- Relies on the the hot and neutral wires carry exactly equal but opposite currents when a device is plugged into the outlet and switched on.
- Anti-parallel currents produce opposite magnetic fields, so a short distance away from the wires, there is NO NET Magnetic Field.
- If even a tiny current leaks out of the device (say to your wet finger as you reach for a hair dryer), the incoming and outgoing currents become imbalanced.
- Unbalanced currents means a net magnetic field appears, causing an induced EMF - Current flows in the sensing coil, and a second coil opens a switch.

**A GFCI will save your life, possibly without you even noticing!**

**Note: a fuse won't blow until your body gets shocked with 15 Amps -enough to injure or kill**



# Summary of Chapter 21

- **Magnetic flux:**

$$\Phi_B = B_{\perp} A = BA \cos \theta$$

- **Changing magnetic flux induces emf:**

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

- **Induced emf produces current that opposes original flux change**

# Summary of Chapter 21

- **Changing magnetic field produces an electric field**
- **Electric generator changes mechanical energy to electrical energy; electric motor does the opposite**
- **Transformer uses induction to change voltage:**

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$