

# Lecture Outline

## Chapter 25: Electromagnetic Induction

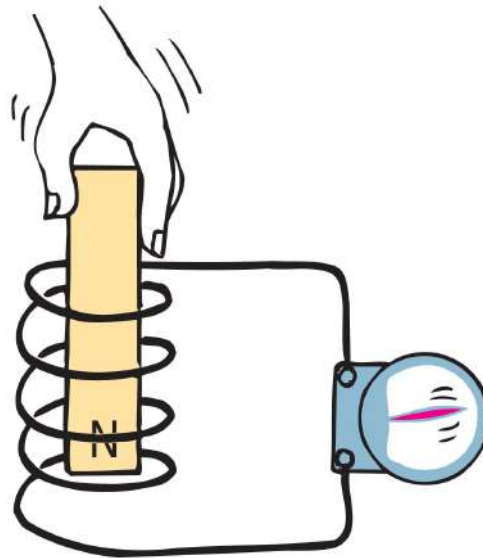


# This lecture will help you understand:

- Electromagnetic Induction
- Faraday's Law
- Generators and Alternating Current
- Power Production
- Self-Induction
- Power Transmission
- Field Induction

# Electromagnetic Induction

- Electromagnetic induction

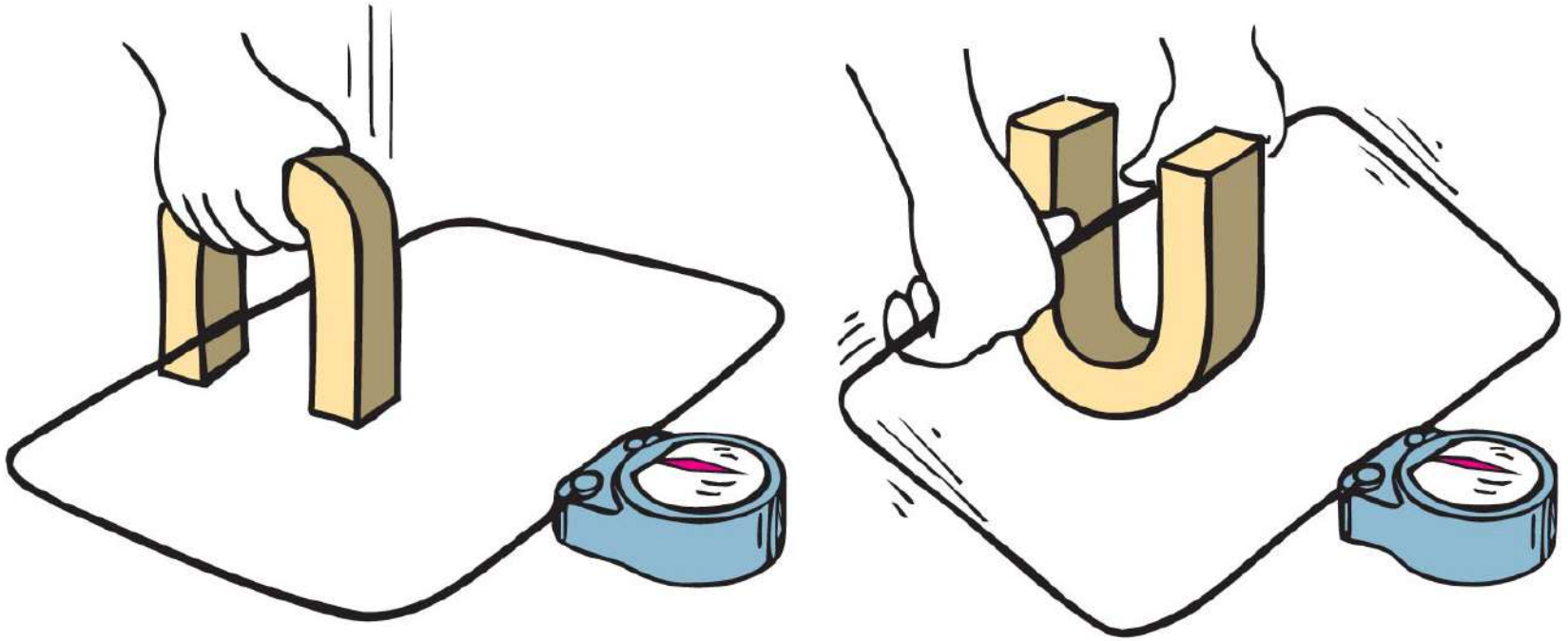


- Discovered by Faraday and Henry
- Induces voltage by changing the magnetic field strength in a coil of wire

# Electromagnetic Induction, Continued

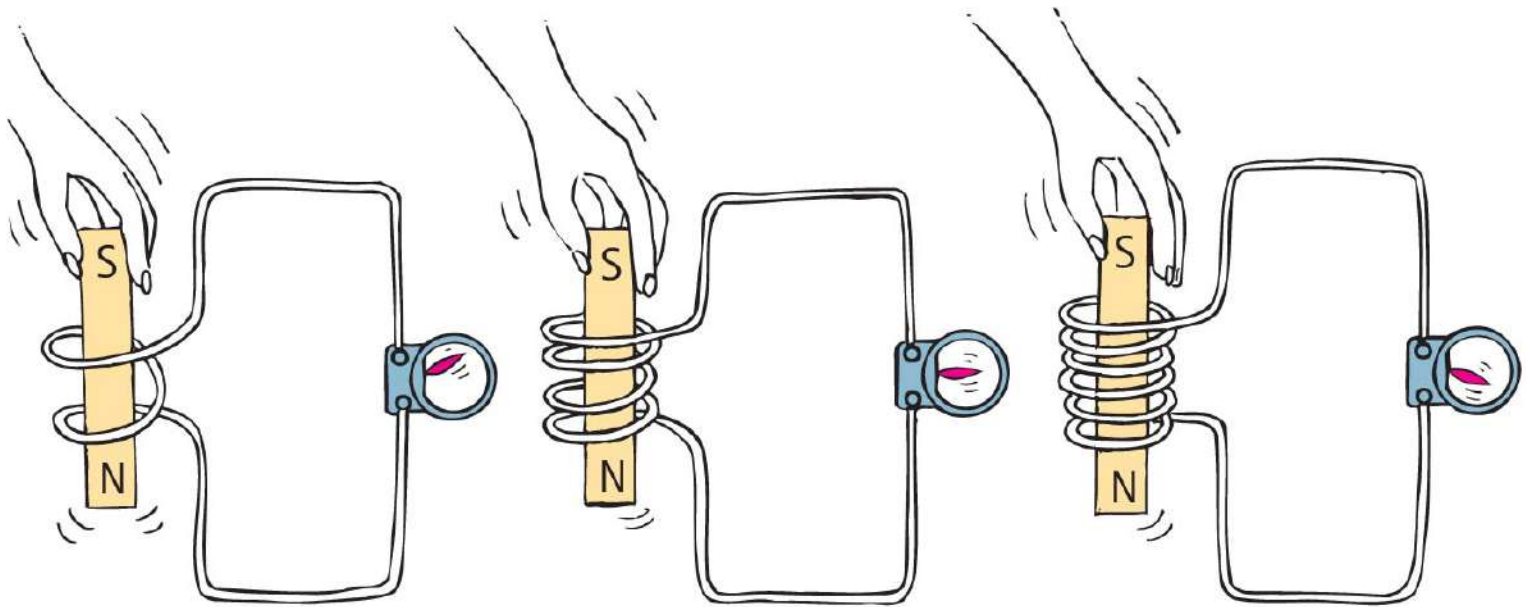
- Electromagnetic induction (continued)
  - Induced voltage can be increased by
    - increasing the number of loops of wire in a coil.
    - increasing the speed of the magnet entering and leaving the coil.
      - Slow motion produces hardly any voltage.
      - Rapid motion produces greater voltage.

# Electromagnetic Induction, Continued-1



- Voltage is induced in the wire loop whether the magnetic field moves past the wire or the wire moves through the magnetic field.

# Electromagnetic Induction, Continued-2



- When a magnet is plunged into a coil with twice as many loops as another, twice as much voltage is induced. If the magnet is plunged into a coil with 3 times as many loops, 3 times as much voltage is induced.

# Faraday's Law

- Faraday's law
  - States that the induced voltage in a coil is proportional to the number of loops, multiplied by the rate at which the magnetic field changes within those loops.
  - Amount of current produced by electromagnetic induction is dependent on
    - resistance of the coil,
    - circuit that it connects,
    - induced voltage.



# Faraday's Law, Continued

- It is more difficult to push the magnet into a coil with many loops because the magnetic field of each current loop resists the motion of the magnet.





# Faraday's Law

## CHECK YOUR NEIGHBOR

The resistance you feel when pushing a piece of iron into a coil involves

- A. repulsion by the magnetic field you produce.
- B. energy transfer between the iron and coil.
- C. Newton's third law.
- D. resistance to domain alignment in the iron.

# Faraday's Law

## CHECK YOUR ANSWER

The resistance you feel when pushing a piece of iron into a coil involves

**A. repulsion by the magnetic field you produce.**

# Faraday's Law, Continued-1

- Voltage induced in a wire requires changing magnetic field in the loop by
  - moving the loop near a magnet,
  - moving a magnet near a loop,
  - changing the current in a nearby loop.

# Faraday's Law, Continued-2

- Application of Faraday's law
  - Activation of traffic lights by a car moving over underground coils of wire
  - Triggering security system at the airport by altering magnetic field in the coils as one walks through
  - Scanning magnetic strips on back of credit cards
  - Recording of sound on tape
  - Electronic devices in computer hard drives, iPods

# Faraday's Law

## CHECK YOUR NEIGHBOR, Continued

More voltage is induced when a magnet is thrust into a coil

- A. more quickly.
- B. more slowly.
- C. Both A and B.
- D. Neither A nor B.

# Faraday's Law

## CHECK YOUR ANSWER, Continued

More voltage is induced when a magnet is thrust into a coil

**A. more quickly.**

# Faraday's Law

## CHECK YOUR NEIGHBOR, Continued-1

Not only is voltage induced when a magnet is thrust into a coil of wire but \_\_\_\_\_ is also induced.

- A. current
- B. energy
- C. power
- D. None of the above.



# Faraday's Law

## CHECK YOUR ANSWER, Continued-1

Not only is voltage induced when a magnet is thrust into a coil of wire but \_\_\_\_\_ is also induced.

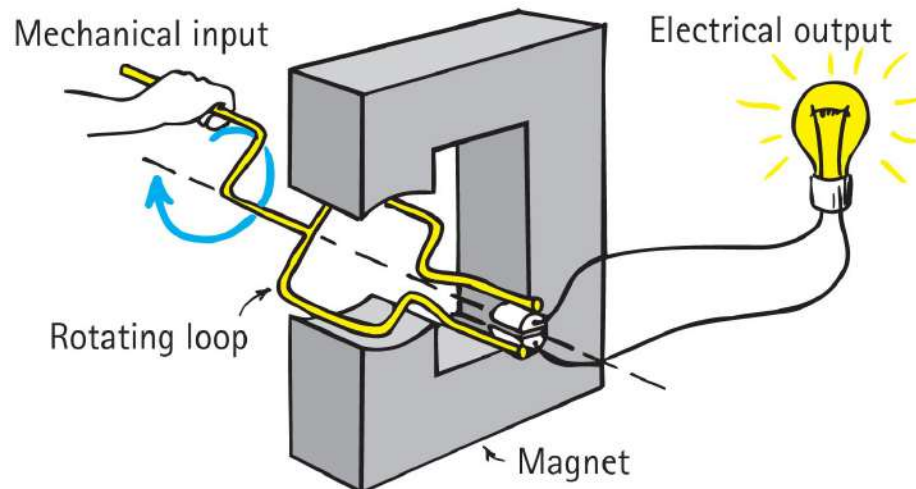
**A. current**

### **Comment:**

Don't say *energy* or *power*, which are conservation-of-energy no-no's! Energy can be transferred but not created by induction.

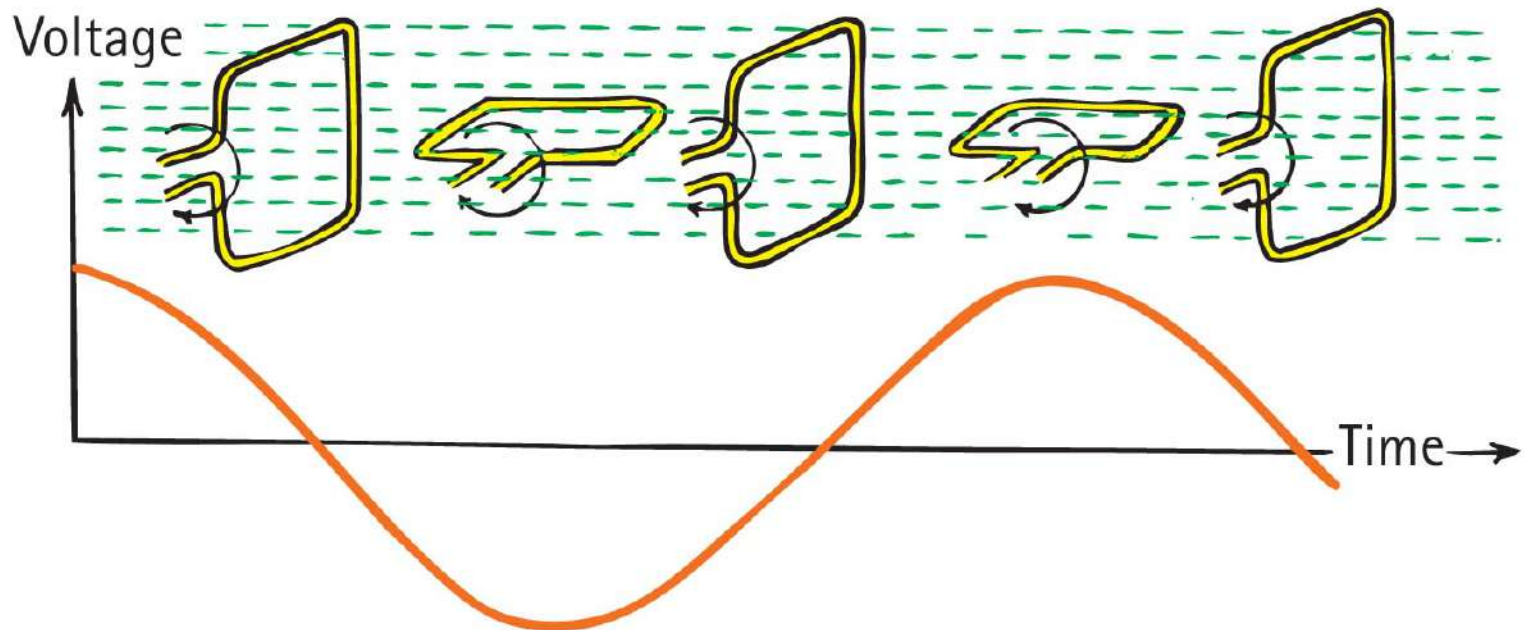
# Generators and Alternating Current

- Generator
  - Opposite of a motor
  - Converts mechanical energy into electrical energy via coil motion
  - Produces alternating voltage and current



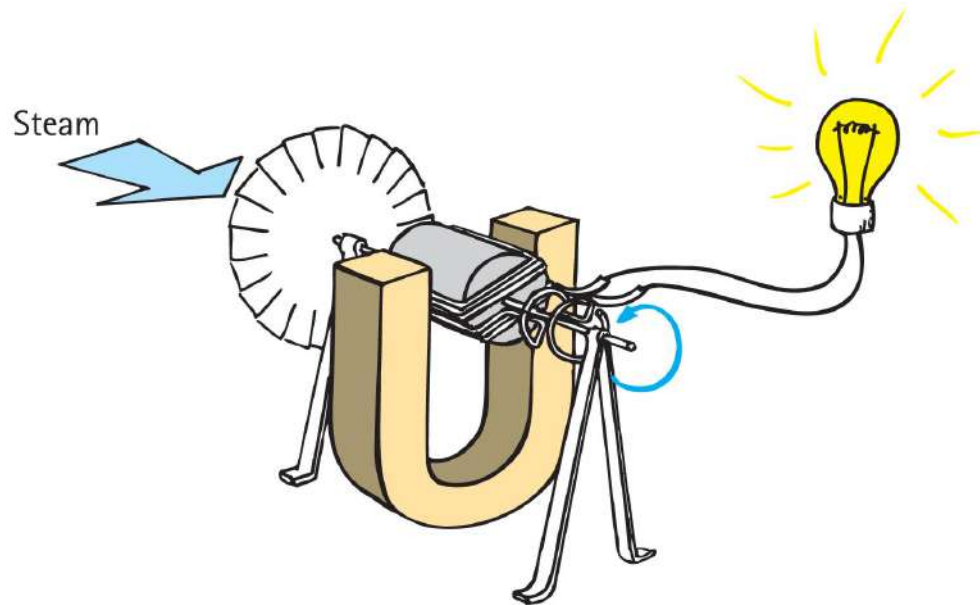
# Generators and Alternating Current, Continued

- The frequency of alternating voltage induced in a loop is equal to the frequency of the changing magnetic field within the loop.



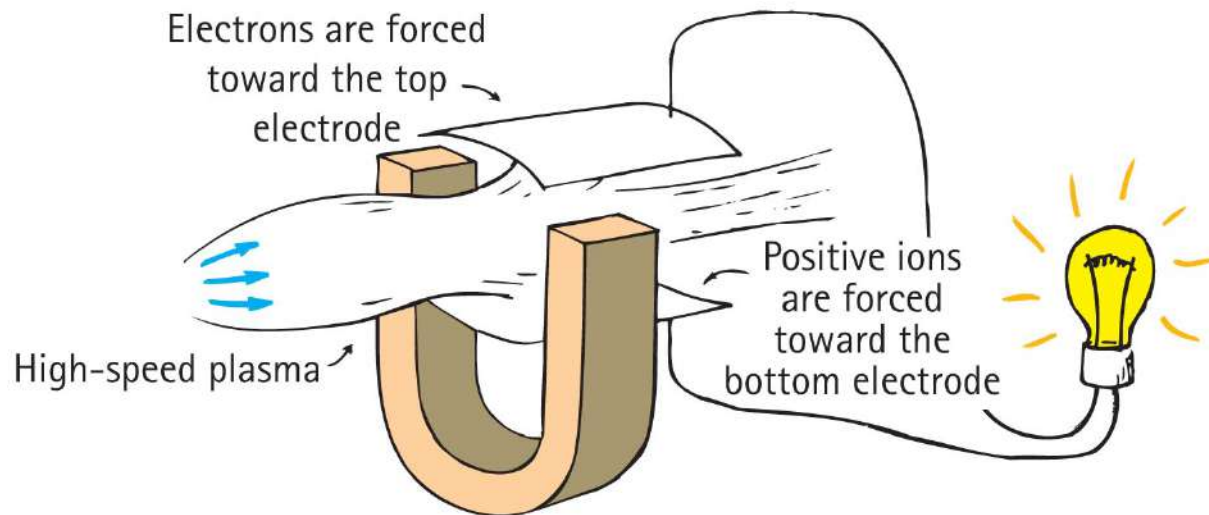
# Power Production

- Using Faraday and Henry's discovery of electromagnetic induction, Nikola Tesla and George Westinghouse showed that electricity could be generated in sufficient quantities to light cities.



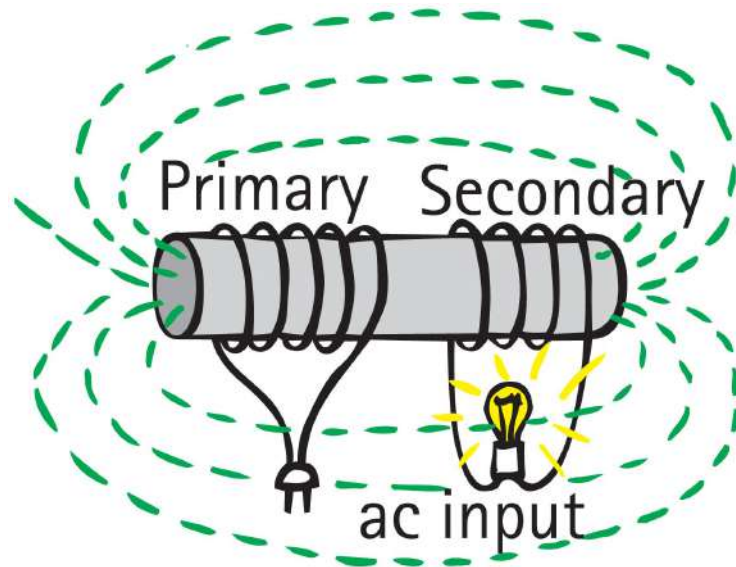
# Power Production, Continued

- MHD (MagnetoHydroDynamic) generator
  - Eliminates the turbine and spinning armature altogether.
  - A plasma of electrons and positive ions expands through a nozzle and moves at supersonic speed through a magnetic field.
  - The motion of charges through a magnetic field gives rise to a voltage and flow of current as per Faraday's law.



# Power Production, Continued-1

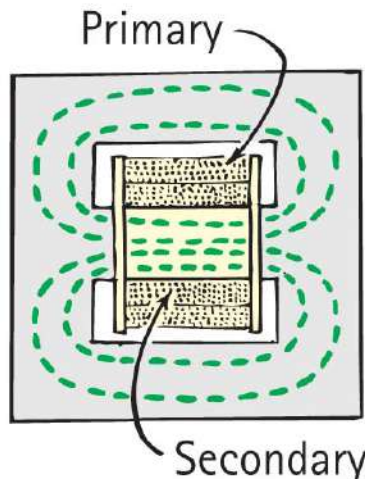
- Transformer



- Input coil of wire—the primary powered by ac voltage source
- Output coil of wire—the secondary connected to an external circuit

# Power Production, Continued-2

- Transformer (continued)
  - Both wound on a common iron core so that the magnetic field of the primary passes through the secondary
  - Uses an alternating current and voltage in one coil to induce an alternating current and voltage in a second coil





# Power Production, Continued-3

- Transformers can be step-up or step-down voltage.
  - Step-up transformer
    - produces a greater voltage in the secondary than supplied by the primary
    - secondary has more turns in coil than the primary
  - Step-down transformer
    - produces a smaller voltage in the secondary than supplied by the primary
    - secondary has less turns in coil than the primary

# Power Production, Continued-4

- Transformer relationship:

$$\frac{\text{Primary voltage}}{\text{Number of primary turns}} = \frac{\text{secondary voltage}}{\text{number of secondary turns}}$$

# Power Production, Continued-5

- Transformer transfers energy from one coil to another.
  - Rate of energy transfer is power.
  - Power into primary = power into secondary or
  - $(\text{Voltage} \times \text{current})_{\text{primary}} = (\text{voltage} \times \text{current})_{\text{secondary}}$

# Power Production, Continued-6

- Transformer transfers energy from one coil to another.  
(continued)
- Example:
  - voltage stepped up before leaving power station
  - voltage stepped down for distribution near cities by cables that feed power to the grid
  - voltage stepped down again before being supplied to businesses and consumers through substations



# Power Production

## CHECK YOUR NEIGHBOR

A step-up transformer in an electrical circuit can step up

- A. voltage.
- B. energy.
- C. Both A and B.
- D. Neither A nor B.

# Power Production

## CHECK YOUR ANSWER

A step-up transformer in an electrical circuit can step up

**A. voltage.**

**Explanation:**

Stepping up energy is a conservation of energy no-no!

# Power Production

## CHECK YOUR NEIGHBOR, Continued

An efficient transformer in an ac electric circuit can change

- A. current.
- B. energy.
- C. power.
- D. All of the above.



# Power Production

## CHECK YOUR ANSWER, Continued

An efficient transformer in an ac electric circuit can change

**A. current.**

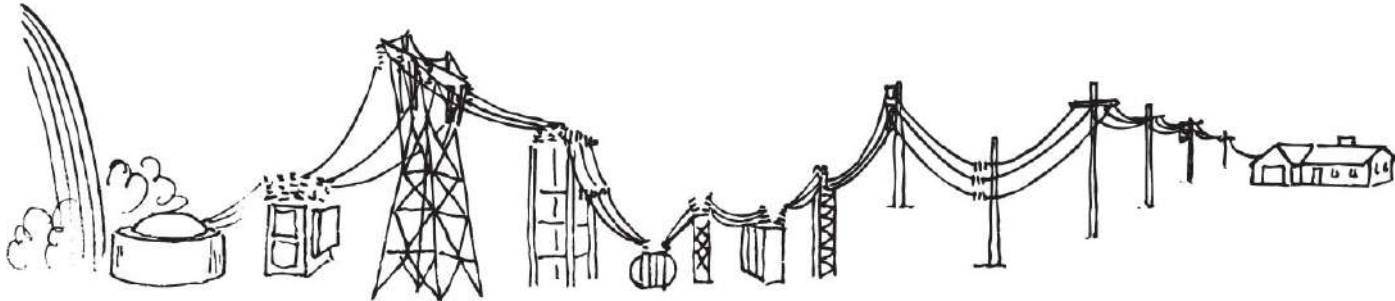
# Self-Induction

- Current-carrying loops in a coil interact not only with loops of other coils but also with loops of the same coil.
- Each loop in a coil interacts with the magnetic field around the current in other loops of the same coil. This is *self-induction*.
- When the switch is opened, the magnetic field of the coil collapses. This sudden change in the field can induce a huge voltage.



# Power Transmission

- Almost all electric energy sold today is in the form of ac because of the ease with which it can be transformed from one voltage to another.
- Large currents in wires produce heat and energy losses, so power is transmitted great distances at high voltages and low currents.
- Power is generated at 25,000 V or less and is stepped up near the power station to as much as 750,000 V for long-distance transmission.
- It is then stepped down in stages at substations and distribution points to voltages needed in industrial applications (often 440 V or more) and for the home (240 and 120 V).



# Field Induction

- Electromagnetic induction is a "two-way street."
  - Faraday's law
    - States that an electric field is induced in any region of space in which a magnetic field is changing with time
  - Maxwell's counterpart to Faraday's law
    - States that a magnetic field is induced in any region of space in which an electric field is changing with time

# Field Induction

## CHECK YOUR NEIGHBOR

The mutual induction of electric and magnetic fields can produce

- A. light.
- B. energy.
- C. sound.
- D. None of the above.

# Field Induction

## CHECK YOUR ANSWER

The mutual induction of electric and magnetic fields can produce

**A. light.**

# Field Induction, Continued

- Light is produced by the mutual induction of electric and magnetic fields.
- Speed of light is the speed of emanation of these fields.
  - Too slow, the regenerating fields die out.
  - Too fast, fields build up in a crescendo of ever-increasing energy.
  - At speed  $c$ , just right! And, there is light!