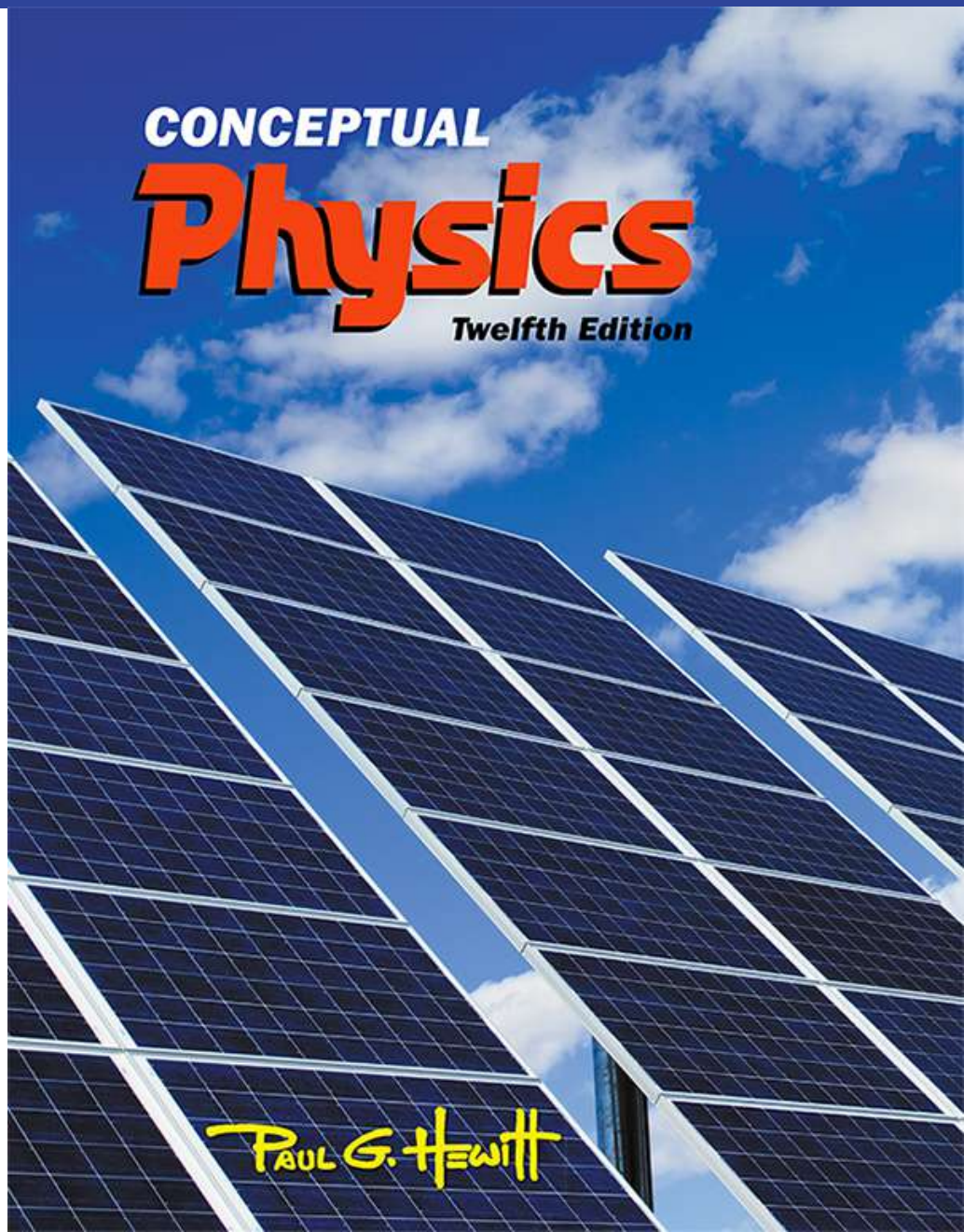
Lecture Outline

Chapter 25: Electromagnetic Induction

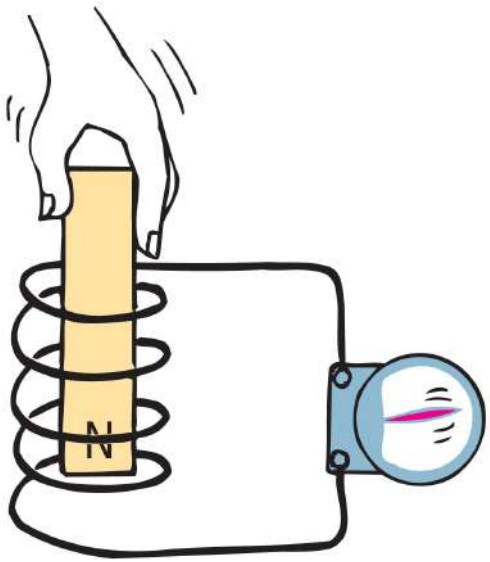


This lecture will help you understand:

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

Electromagnetic Induction

- Electromagnetic induction

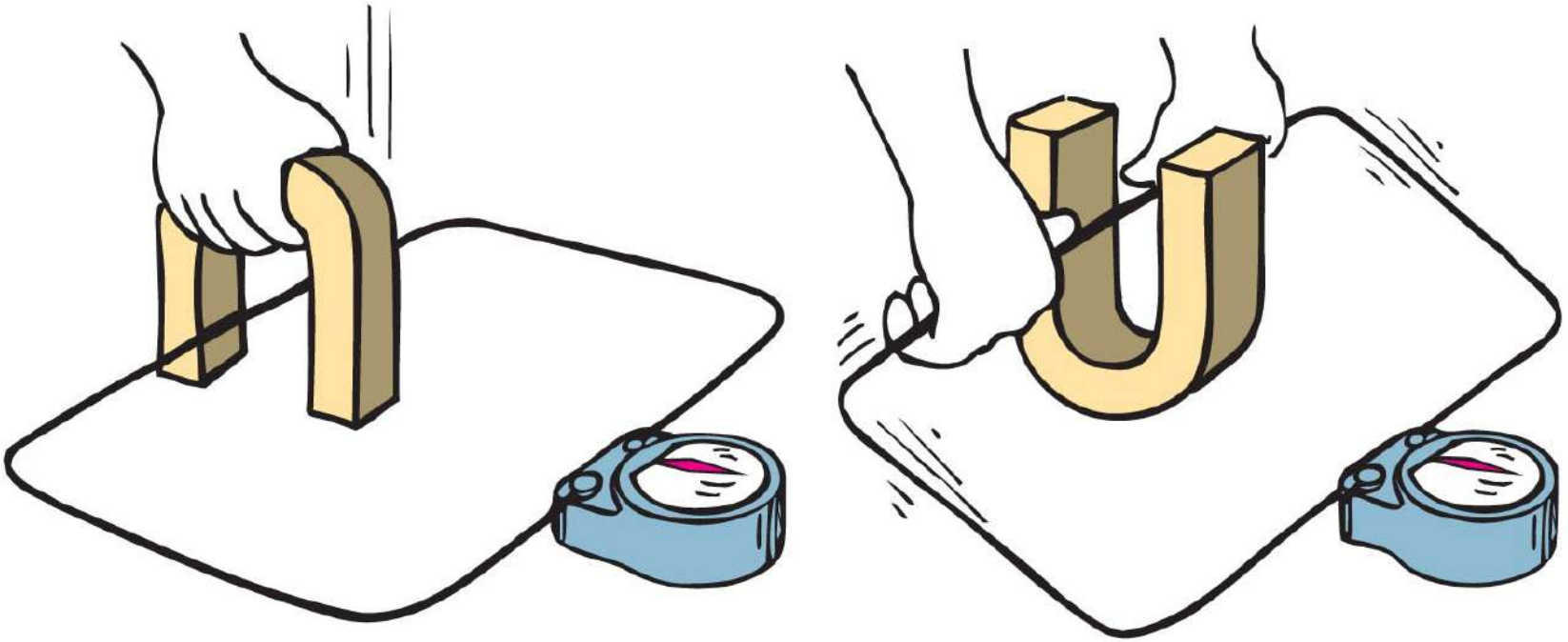


- Discovered by Faraday and Henry
- Induces voltage by changing the magnetic field strength in a coil of wire

Electromagnetic Induction, Continued

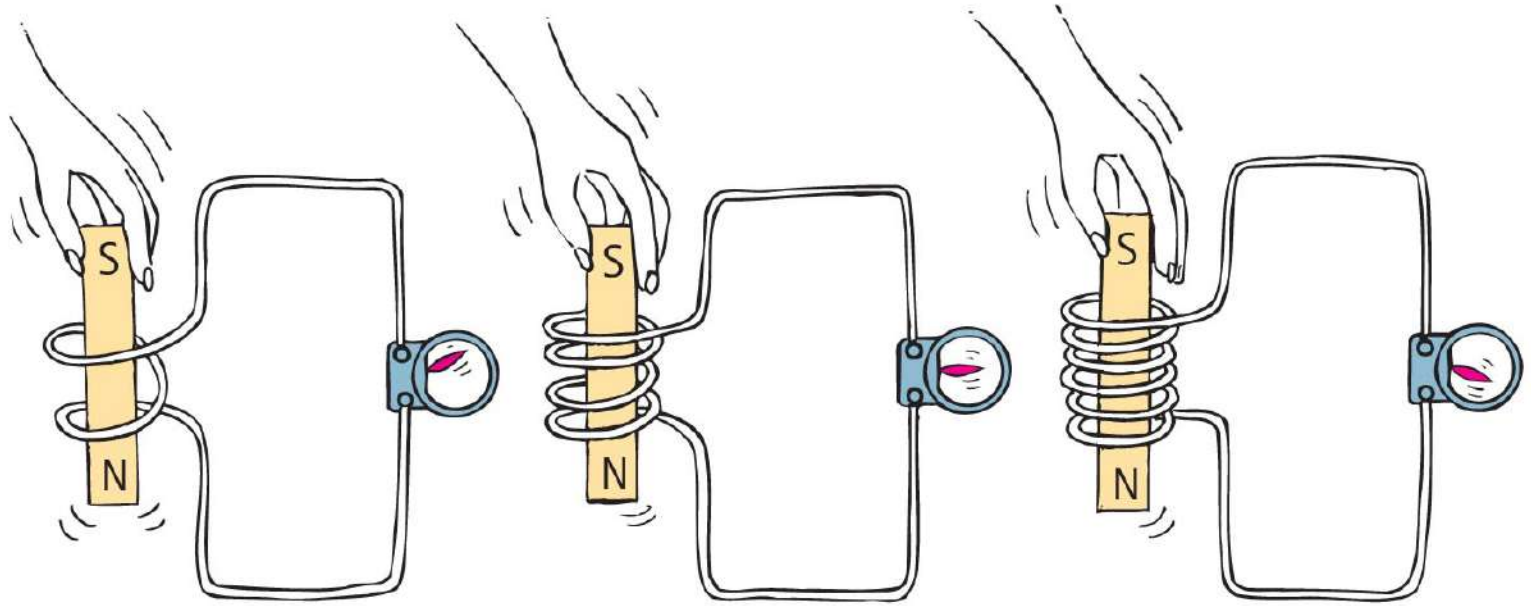
- Electromagnetic induction (continued)
  - Induced voltage can be increased by
    - increasing the number of loops of wire in a coil.
    - increasing the speed of the magnet entering and leaving the coil.
      - Slow motion produces hardly any voltage.
      - Rapid motion produces greater voltage.

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.

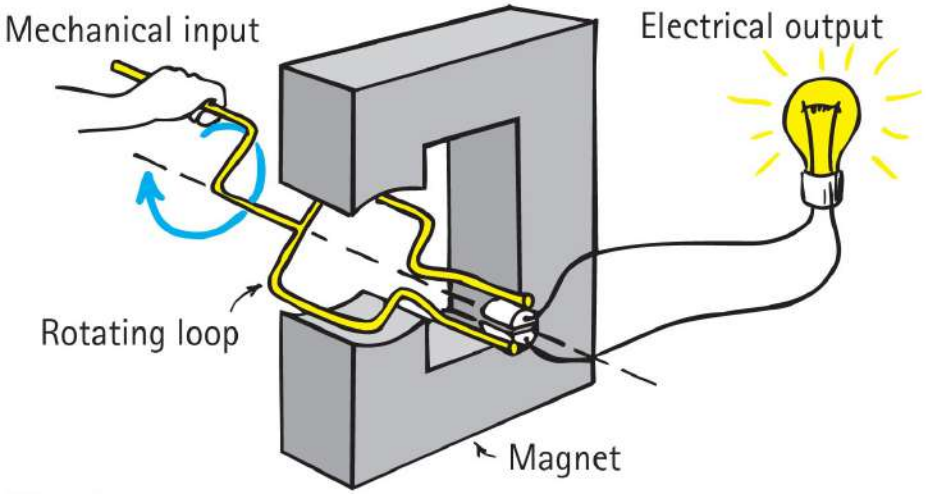
A. current

Comment:

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

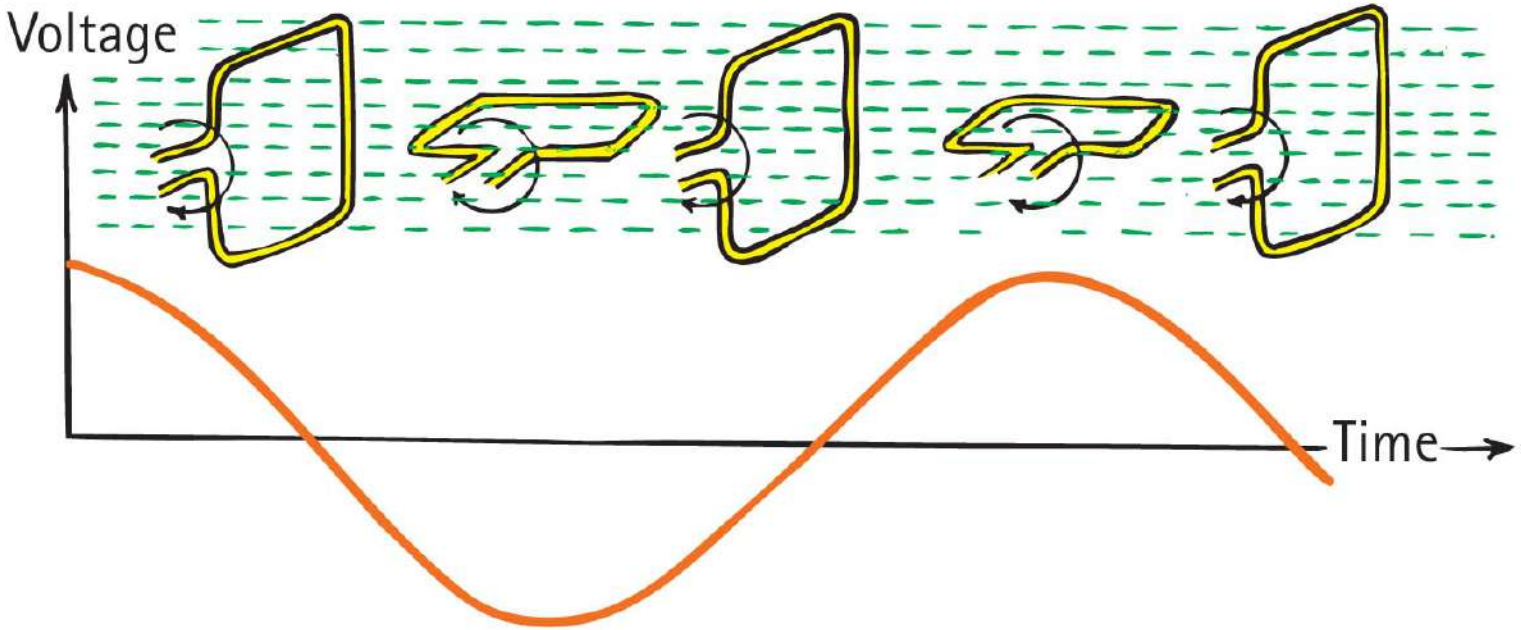
Generators and Alternating Current

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



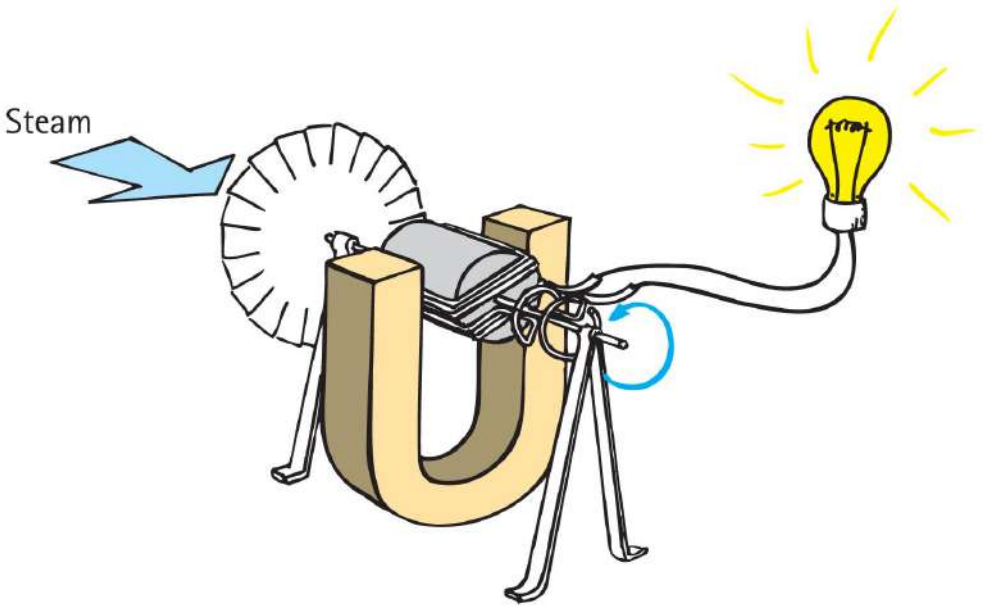
Generators and Alternating Current, Continued

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



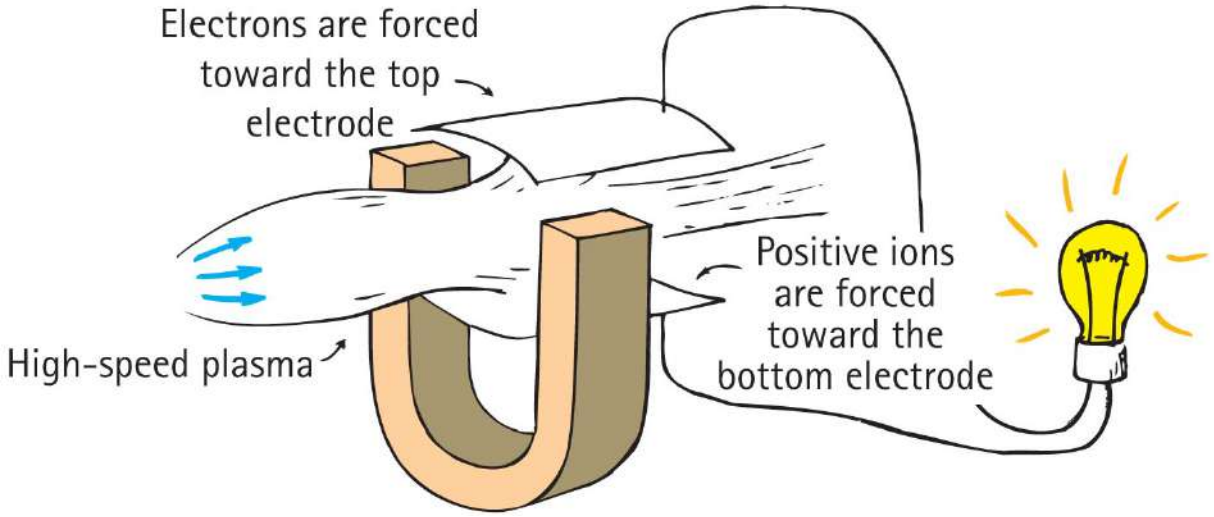
Power Production

- 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.



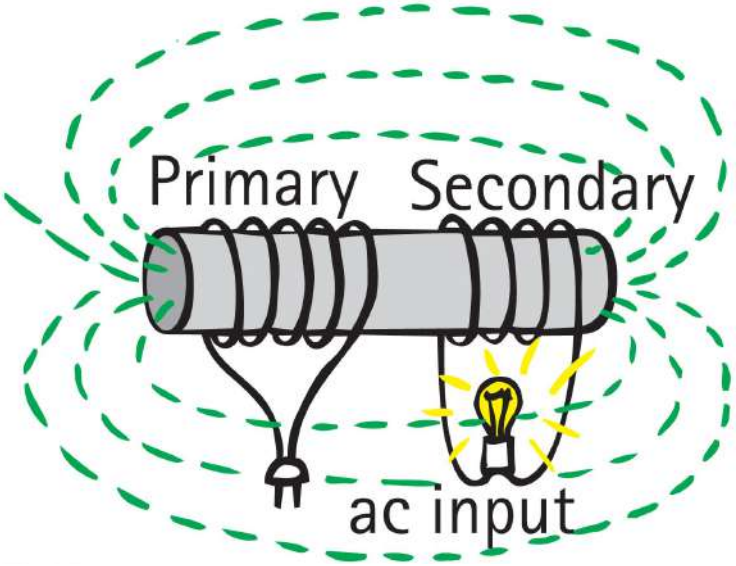
Power Production, Continued

- 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

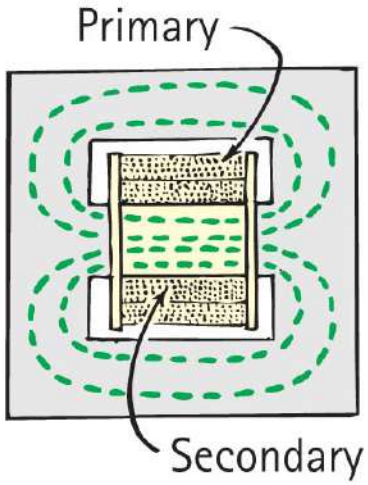
- Transformer



  - 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

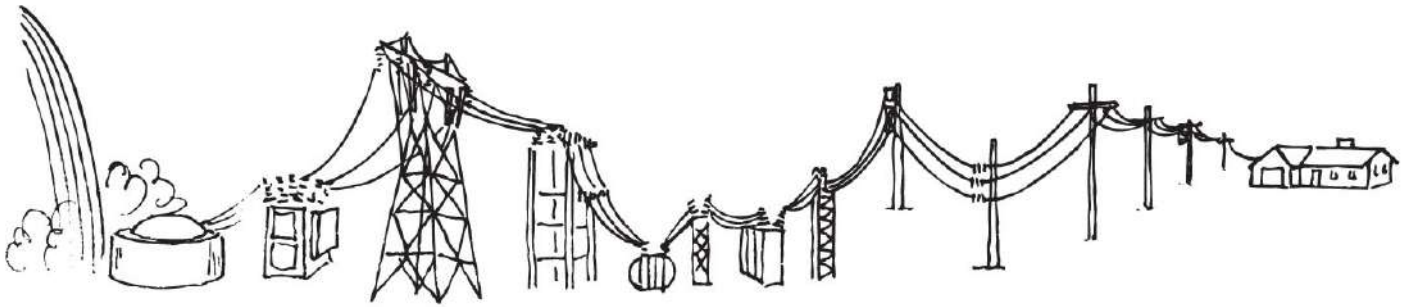
A. current.

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!