Conceptual Physics Fundamentals

Paul G. Hewitt

Chapter 11:

MAGNETISM AND ELECTROMAGNET INDUCTION

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This lecture will help you understand:

- Magnetic Poles
- Magnetic Fields
- Magnetic Domains
- Electric Currents and Magnetic Fields
- Magnetic Forces on Moving Charges
- Electromagnetic Induction
- Generators and Alternating Current
- Power Production
- The Transformer—Boosting or Lowering Voltage
- Field Induction

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Magnetism and Electromagnetic Induction

Magnetism

- term from Magnesia, an ancient city in Asia Minor, where more than 2000 years ago, Greeks found unusual lodestones that attracted pieces of iron

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Magnetism and Electromagnetic Induction

Magnet facts

- rubbing iron against a lodestone produces a magnet
- in 1750, John Michell found that magnetic poles obey the inverse-square law
- Hans Christian Oersted—magnetism related to electricity
- Andre Marie Ampere—electric currents are source of all magnetic phenomena

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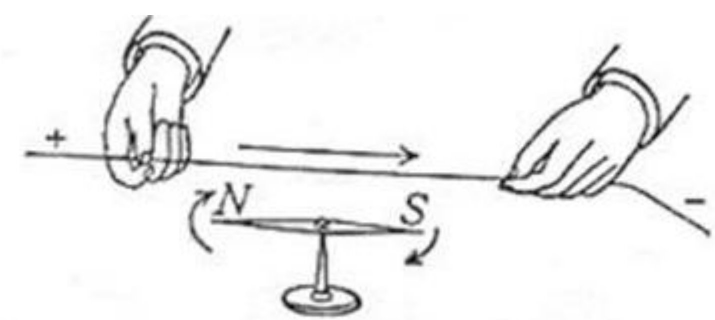
Magnetism and Electromagnetic Induction

Magnet facts

- 800 BC, rubbing iron against a lodestone produces a magnet
- 1750, John Michell found that magnetic poles obey the inverse-square law
- 1820, Hans Christian Oersted—magnetism related to electricity



- 1820, Andre Marie Ampere—electric currents are source of all magnetic phenomena

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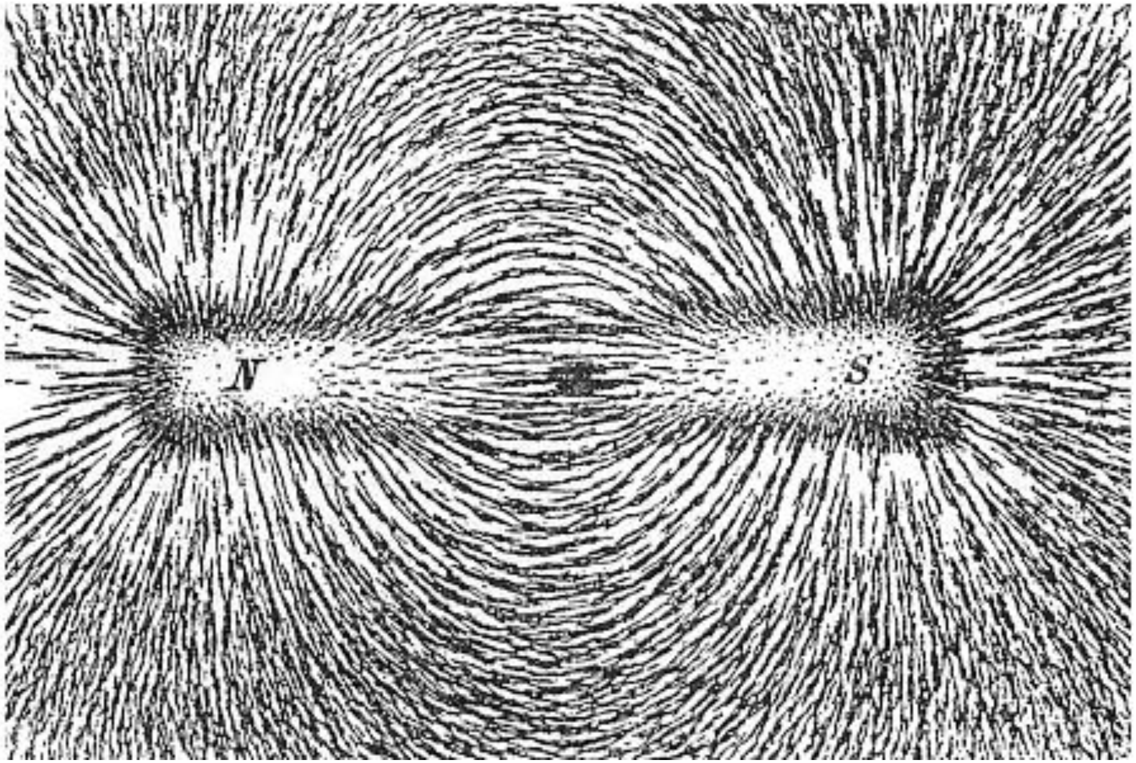
Magnetic Poles



Magnetic force

- behavior similar to electrical forces
- strength of interaction depends on the distance between the two magnets

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Magnetic Poles

Magnetic poles

- give rise to magnetic force
- two types interacting with each other
  - north pole (north-seeking pole)
  - south pole (south-seeking pole)

Rule for magnetic forces between magnetic poles

- Like poles repel; opposite poles attract

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Magnetic Poles

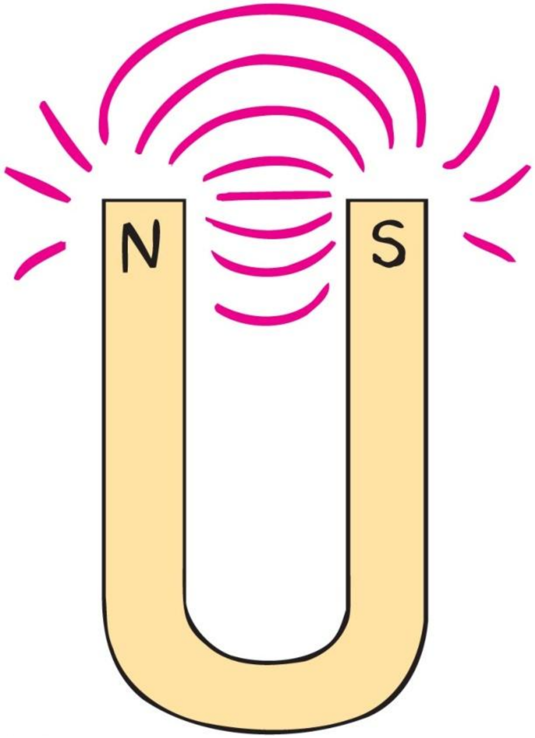
Magnetic poles (continued)

- in all magnets—can't have one pole without the other
- no single pole known to exist

  example:

  – simple bar magnet—poles at the two ends

  – horseshoe magnet: bent U shape—poles at ends



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Magnetic Poles
CHECK YOUR NEIGHBOR

A weak and strong magnet repel each other. The greater repelling force is by the

A. stronger magnet.
B. weaker magnet.
C. both the same
D. none of the above

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Magnetic Poles
CHECK YOUR ANSWER

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Explanation:
Remember Newton's third law!

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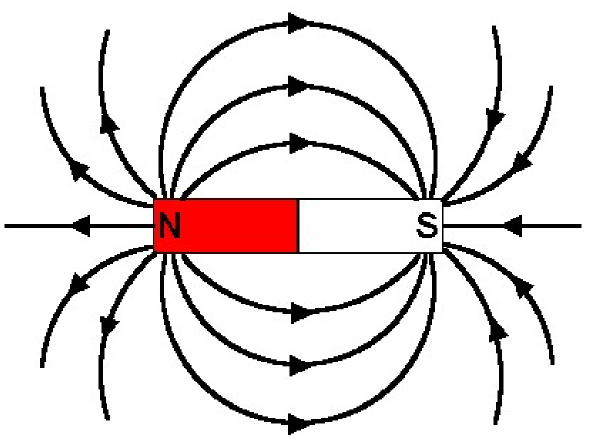
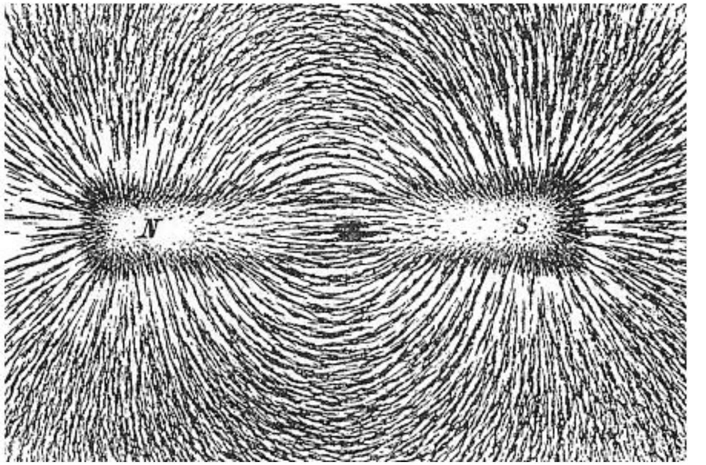
Magnetic Fields

Magnetic fields

- region of magnetic influence surrounding magnetic poles
- shape revealed by lines that spread from one pole to the other
- by convention, direction is from the north pole to the south pole, produced by motions of electric charge in atoms





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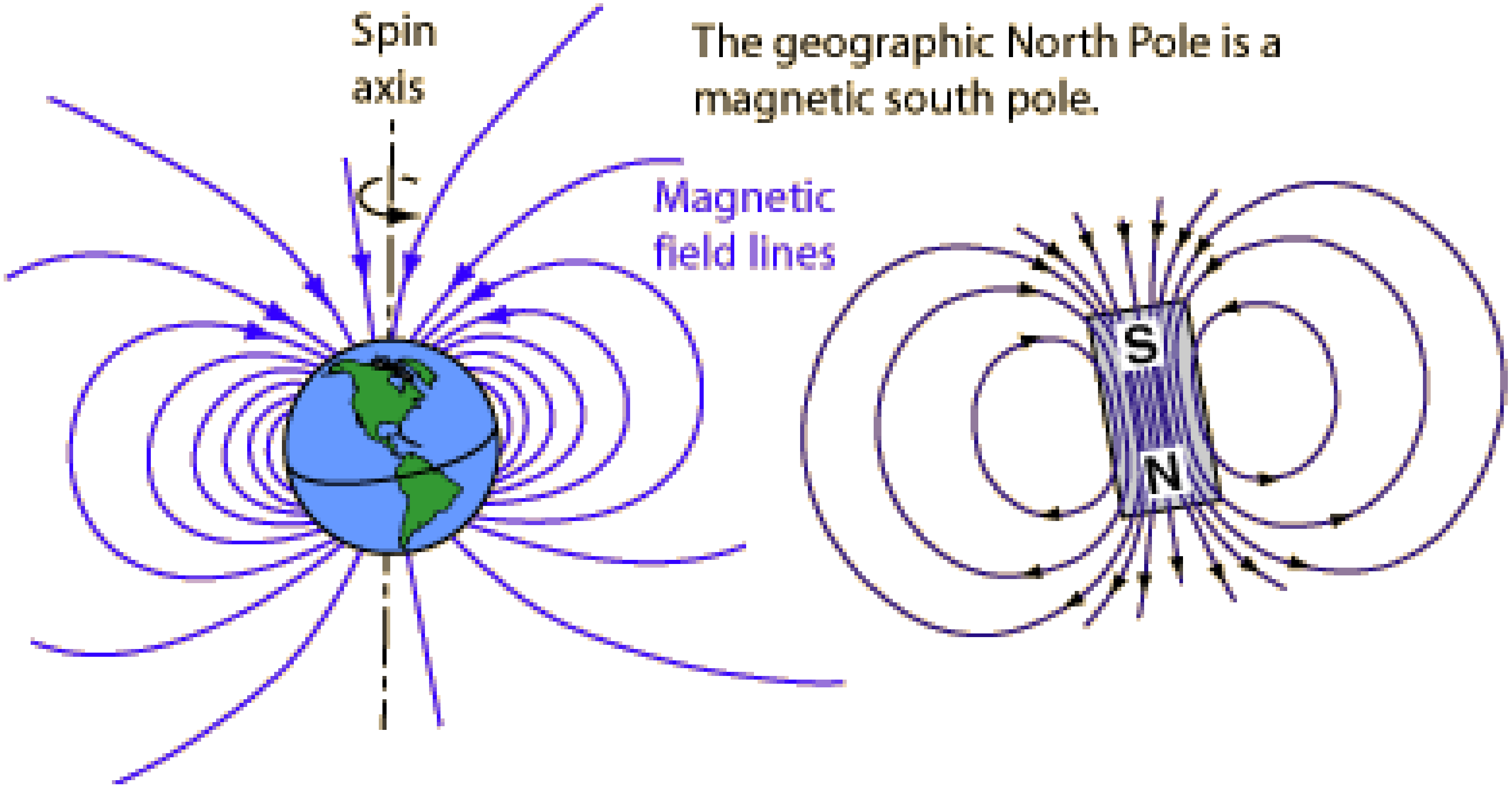
Earth’s Magnetic Field



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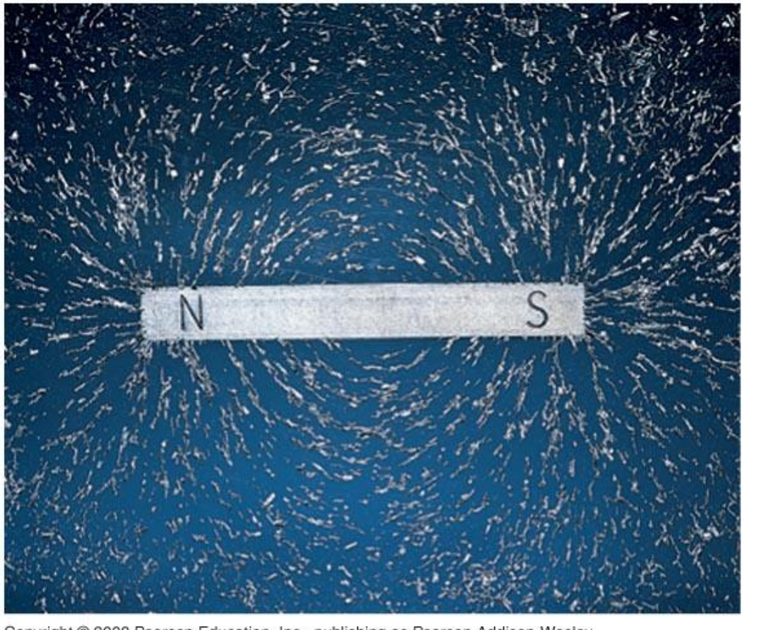
Magnetic Fields

Magnetic fields (continued)

- strength indicated by closeness of the lines
  - lines close together; strong magnetic field
  - lines farther apart; weak magnetic field



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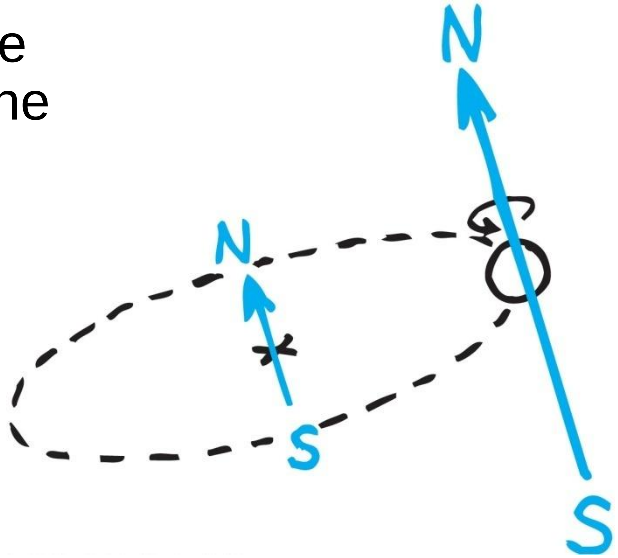
Magnetic Fields

Magnetic fields (continued)

- produced by two kinds of electron motion
  - electron spin
    - main contributor to magnetism
    - pair of electrons spinning in same direction creates a stronger magnet
    - pair of electrons spinning in opposite direction cancels magnetic field of the other
  - electron revolution



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Magnetic Fields
CHECK YOUR NEIGHBOR

The source of all magnetism is

A. electrons rotating around an atomic nucleus.
B. electrons spinning around internal axes.
C. both A and B
D. tiny bits of iron.

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Magnetic Fields
CHECK YOUR NEIGHBOR

Where magnetic field lines are more dense, the field there is

A. weaker.
B. stronger.
C. both A and B
D. neither A nor B

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Magnetic Domains

Magnetic domains

- magnetized clusters of aligned magnetic atoms

Permanent magnets made by

- placing pieces of iron or similar magnetic materials in a strong magnetic field
- stroke material with a magnet to align the domains

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Magnetic Domains

Difference between permanent magnet and temporary magnet

- permanent magnet
  - alignment of domains remains once external magnetic field is removed
- temporary magnet
  - alignment of domains returns to random arrangement once external magnetic field is removed

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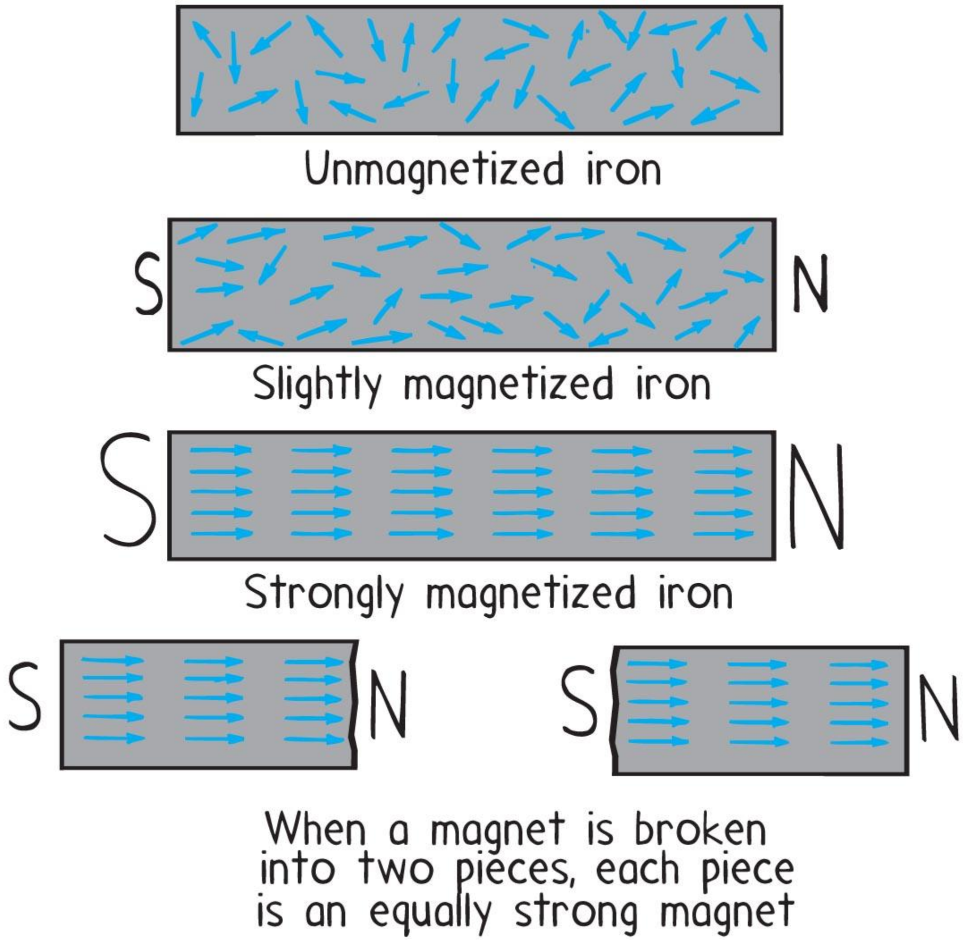
Magnetic Domains



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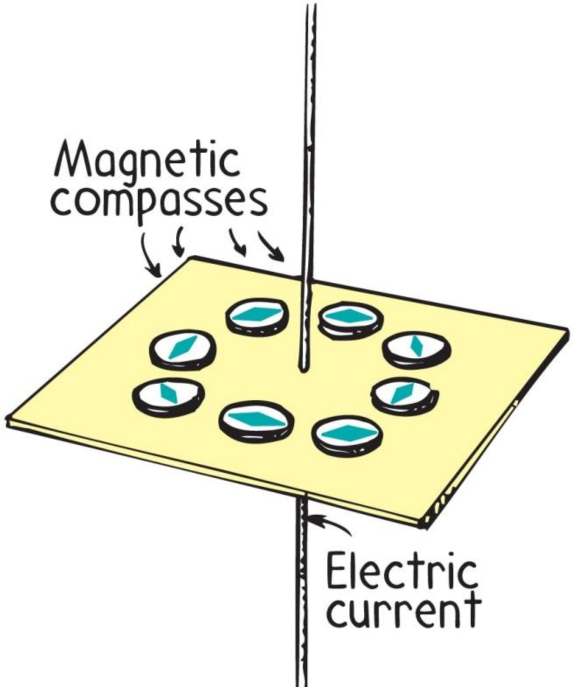
Electric Currents and Magnetic Fields

Connection between electricity and magnetism

- magnetic field forms a pattern of concentric circles around a current-carrying wire
- when current reverses direction, the direction of the field lines reverse



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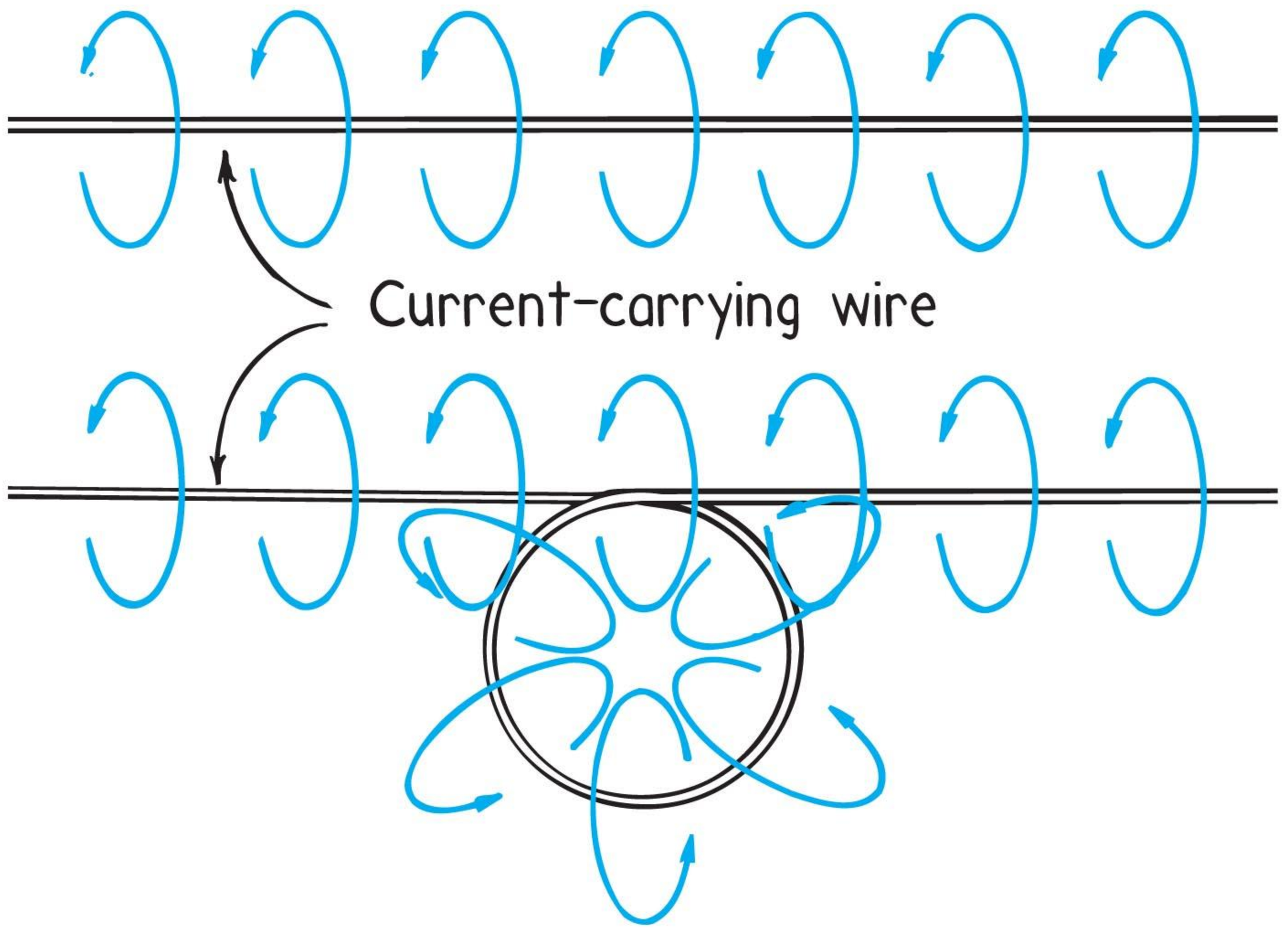
Electric Currents and Magnetic Fields



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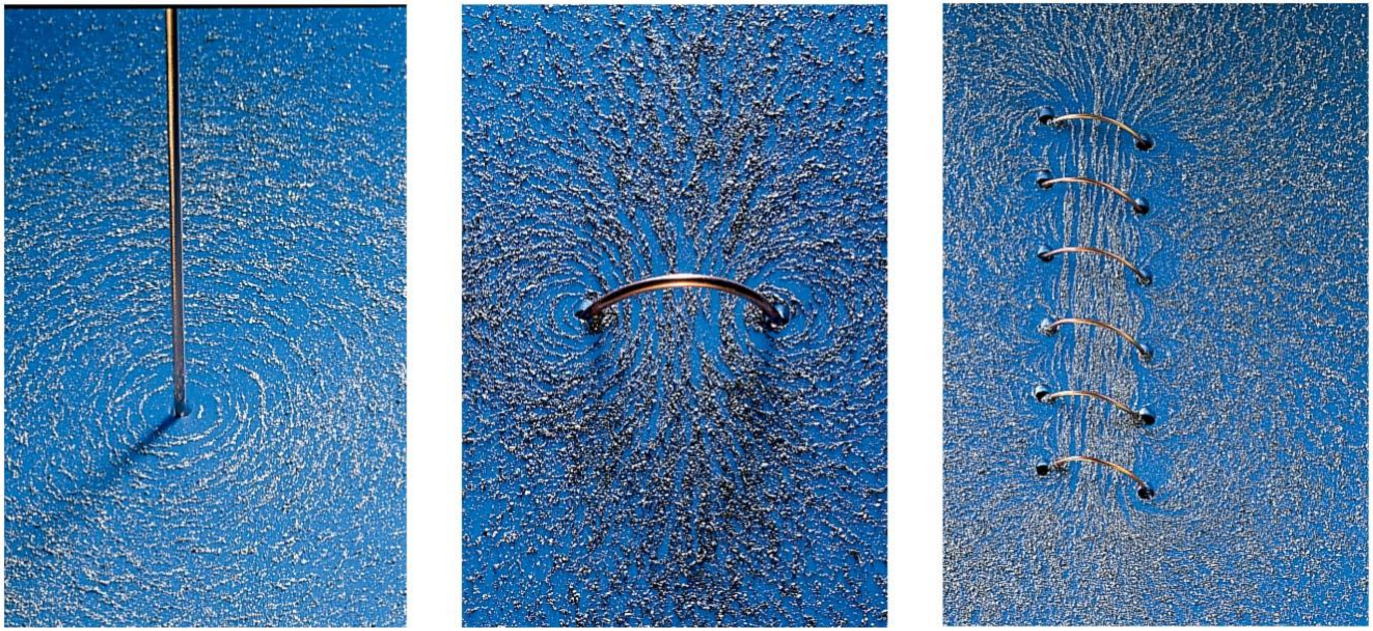
Electric Currents and Magnetic Fields

Magnetic field intensity

- increases as the number of loops increase in a current-carrying coil temporary magnet



(a) (b) (c)

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Electric Currents and Magnetic Fields

Electromagnet

- iron bar placed in a current-carrying coil
- most powerful—employs superconducting coils that eliminate the core
- applications
  - control charged-particle beams in high-energy accelerators
  - lift automobiles and other iron objects
  - levitate and propel high-speed trains

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Electric Currents and Magnetic Fields
CHECK YOUR NEIGHBOR

An electromagnet can be made stronger by

A. increasing the number of turns of wire.
B. increasing the current in the coil.
C. both A and B
D. none of the above

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Electric Currents and Magnetic Fields
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Magnetic Forces on Moving Charges

Moving charges in a magnetic field experience a deflecting force

- greatest force
  - particle movement in direction perpendicular to the magnetic field lines
- least force
  - particle movement other than perpendicular to the magnetic field lines
- no force
  - particle movement parallel to the magnetic field lines

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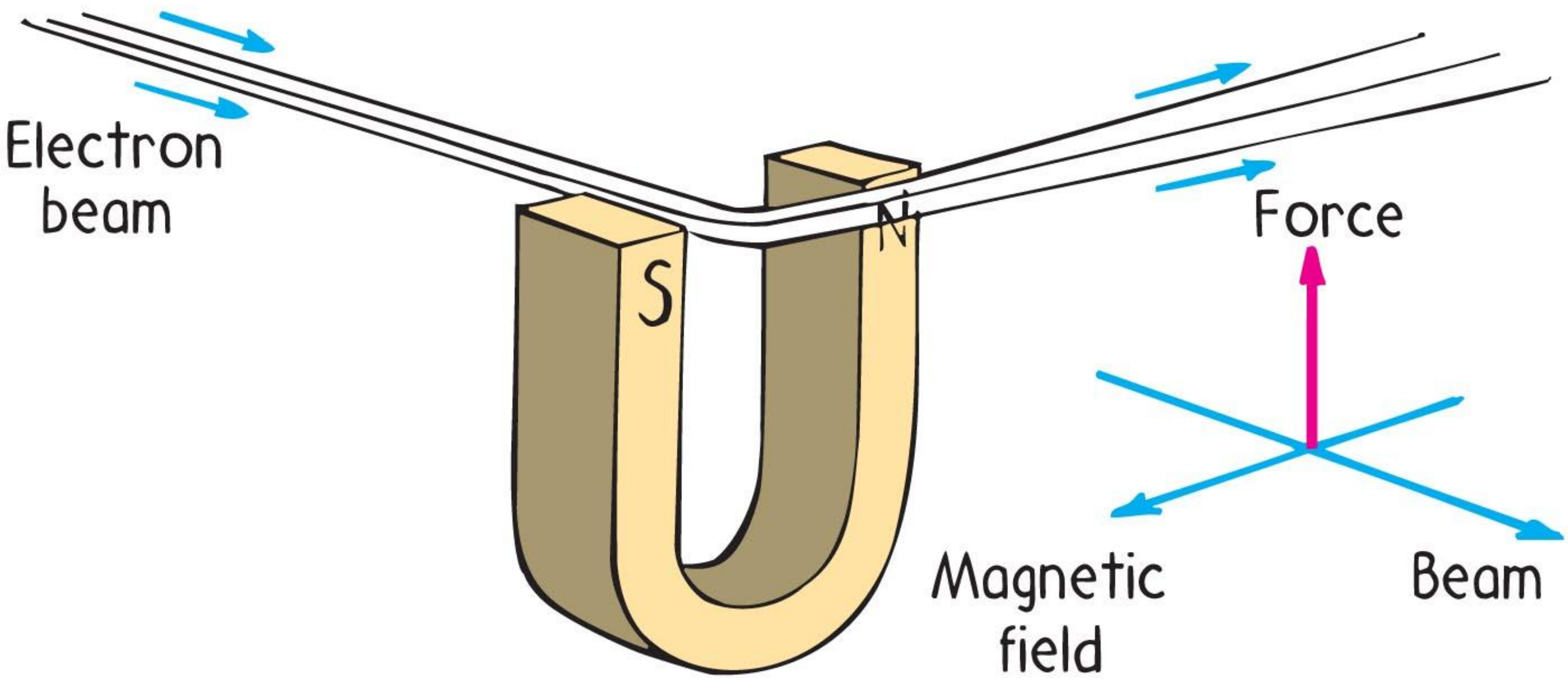
Magnetic Forces on Moving Charges

Moving charges in a magnetic field experience a deflecting force (continued)



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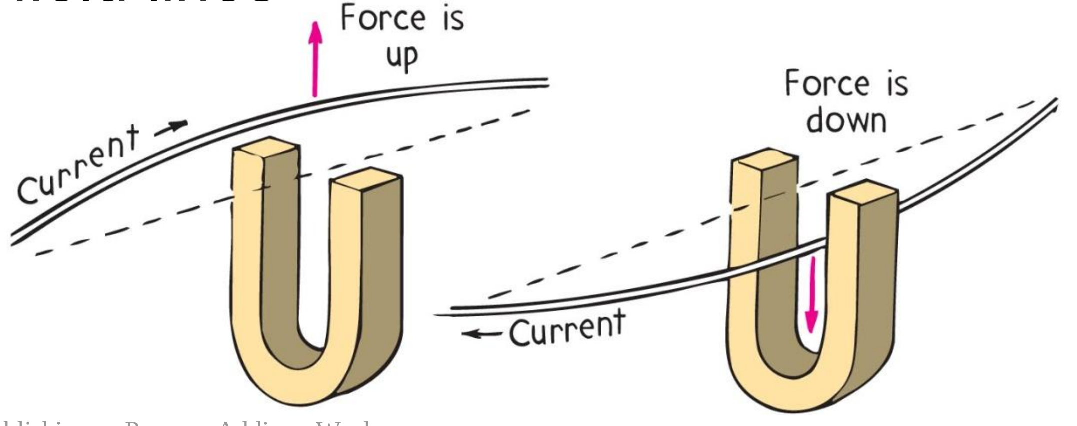
Magnetic Force on Moving Charges

Magnetic force on current-carrying wires

- current of charged particles moving through a magnetic field experiences a deflecting force
  - direction is perpendicular to both magnetic field lines and current (perpendicular to wire)
  - strongest when current is perpendicular to the magnetic field lines



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Magnetic Force on Moving Charges
CHECK YOUR NEIGHBOR

The reason that an electron moving in a magnetic field doesn’t pick up speed is

A. magnets only divert them.
B. only electric fields can change the speed of a charged particle.
C. the magnetic force is always perpendicular to its motion.
D. all of the above

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Magnetic Force on Moving Charges
CHECK YOUR ANSWER

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A. magnets only divert them.

B. only electric fields can change the speed of a charged particle.

C. the magnetic force is always perpendicular to its motion.

D. all of the above

Explanation:

Although all statements are true, the reason is given only by C. With no component of force in the direction of motion, speed doesn’t change.

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Magnetic Force on Moving Charges
CHECK YOUR NEIGHBOR

The magnetic force on a moving charged particle can change the particle's

A. speed.
B. direction.
C. both A and B
D. neither A nor B

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Magnetic Force on Moving Charges
CHECK YOUR ANSWER

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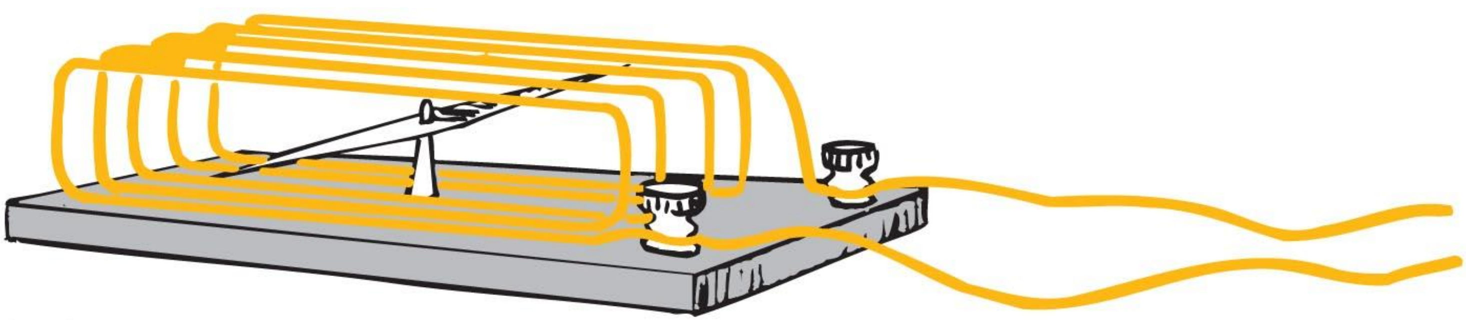
Magnetic Force on Moving Charges

Electric meters

- detect electric current

  example:

  - magnetic compass
  - compass in a coil of wires



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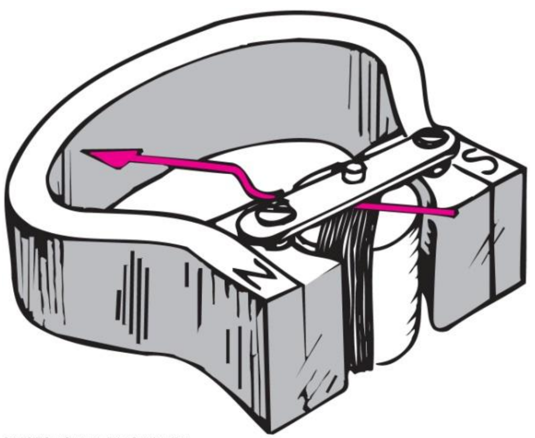
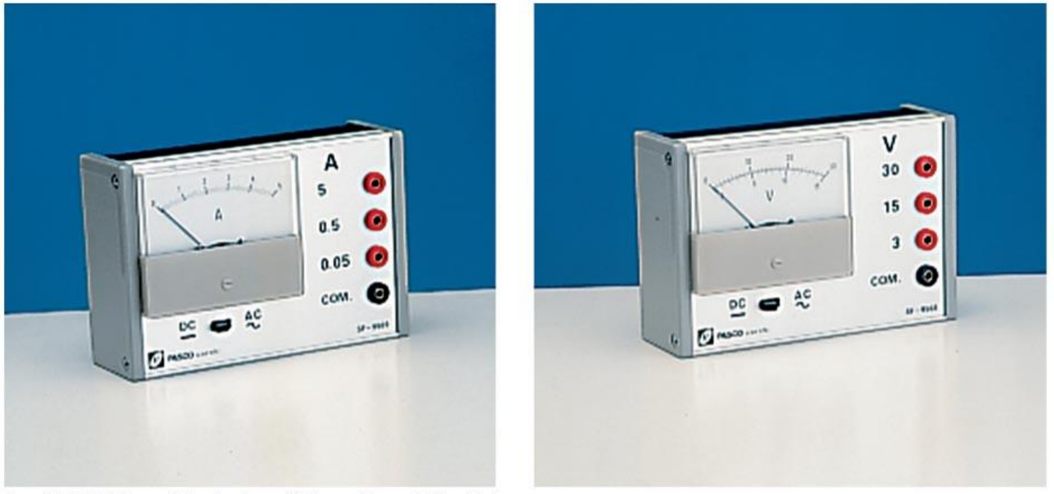
Magnetic Force on Moving Charges

Galvanometer

- current-indicating device named after Luigi Galvani
- called ammeter when calibrated to measure current (amperes)
- called voltmeter when calibrated to measure electric potential (volts)





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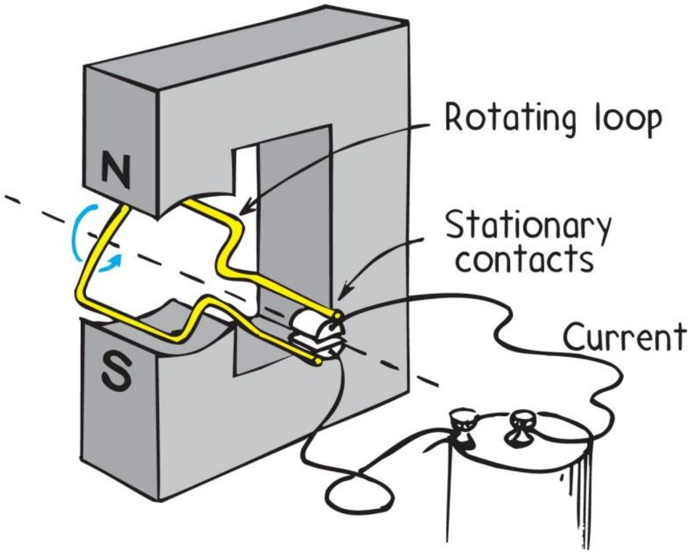
Magnetic Force on Moving Charges

Electric motor

- different from galvanometer in that each time the coil makes a half rotation, the direction of the current changes in cyclic fashion to produce continuous rotation



http://www.youtube.com/watch?v=Ue6S8L4On-Y&feature=related

http://www.youtube.com/watch?NR=1&v=Xi7o8cMPI0E&feature=fvwp

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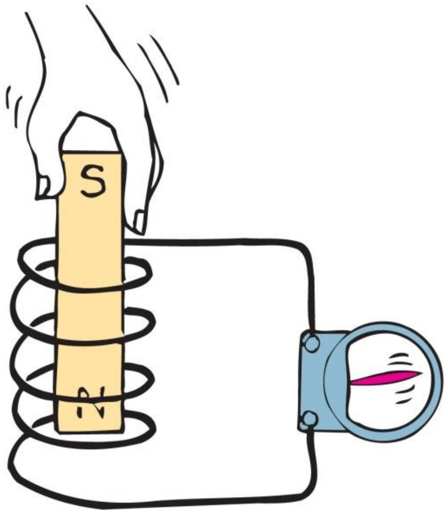
Electromagnetic Induction

Electromagnetic induction



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

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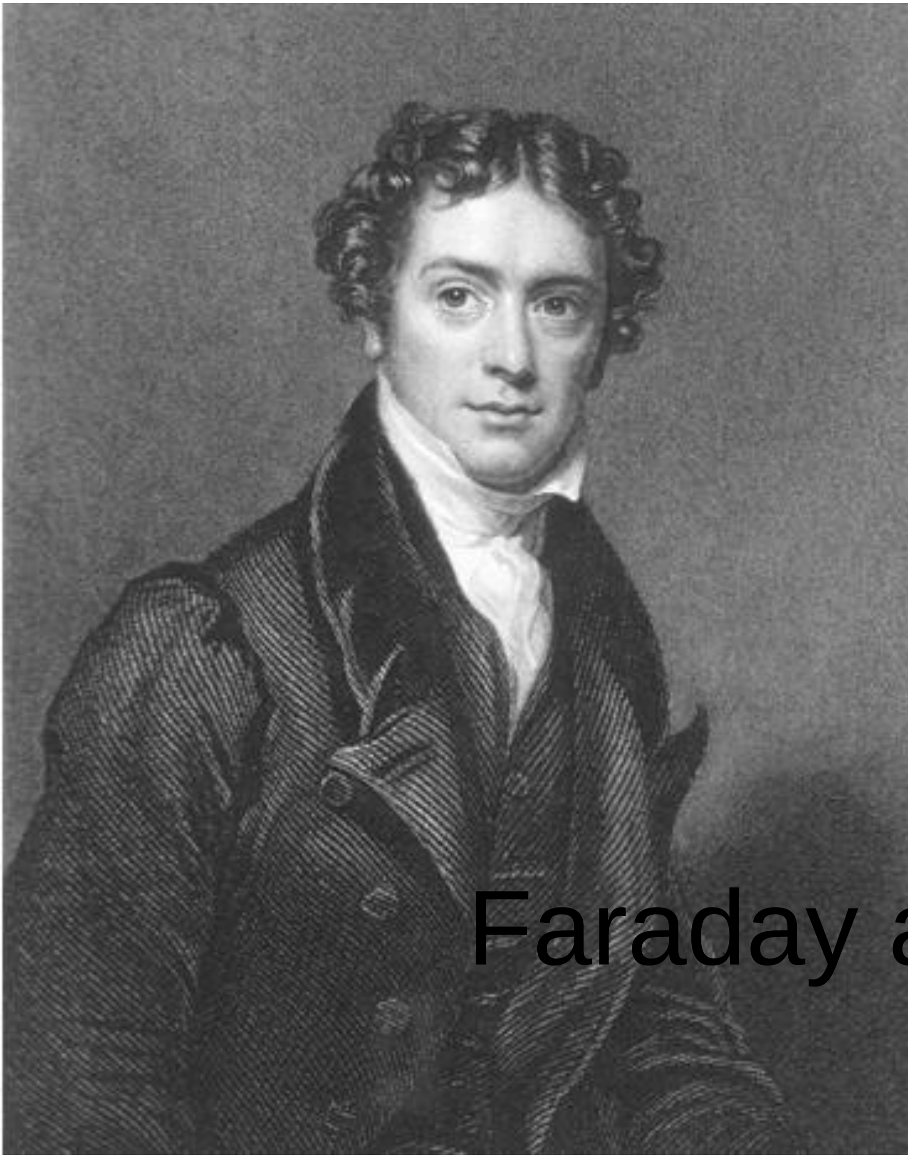
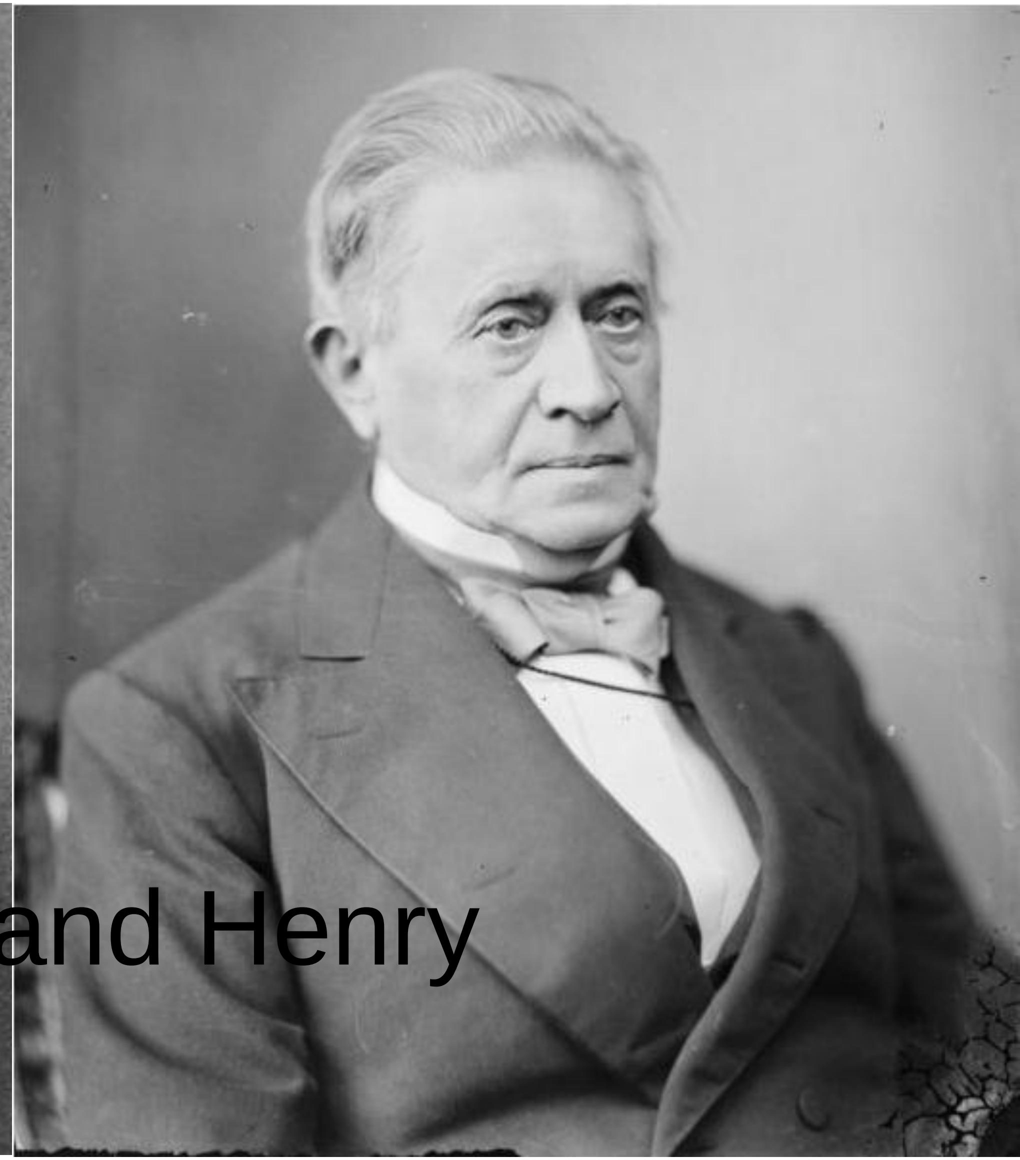
Electromagnetic Induction





Faraday and Henry

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Electromagnetic Induction

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

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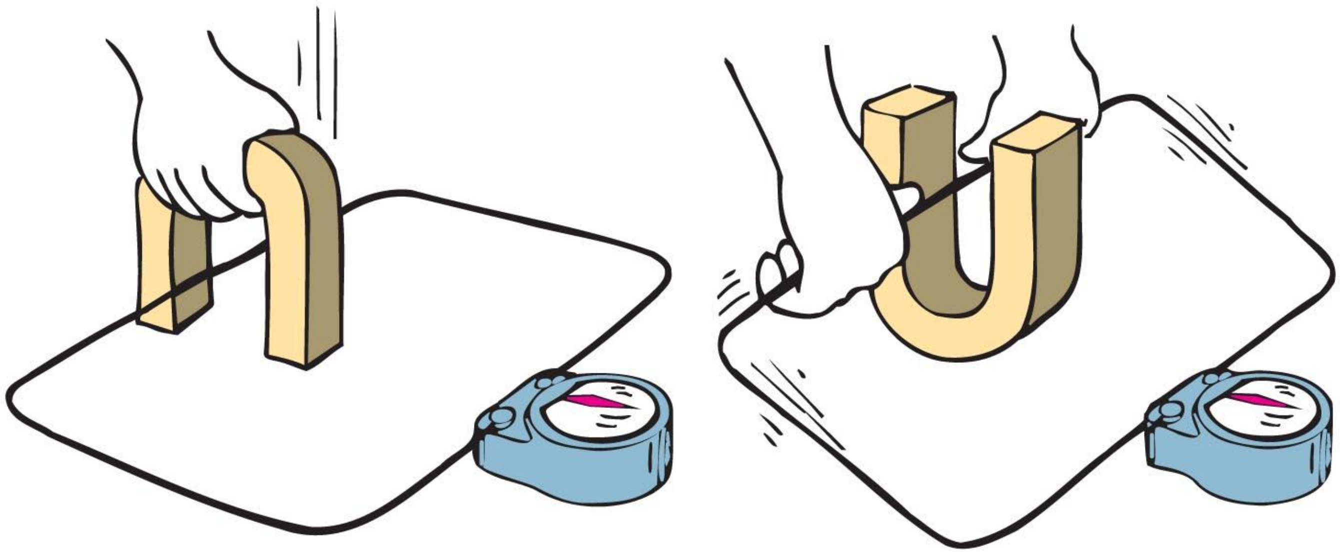
Electromagnetic Induction



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

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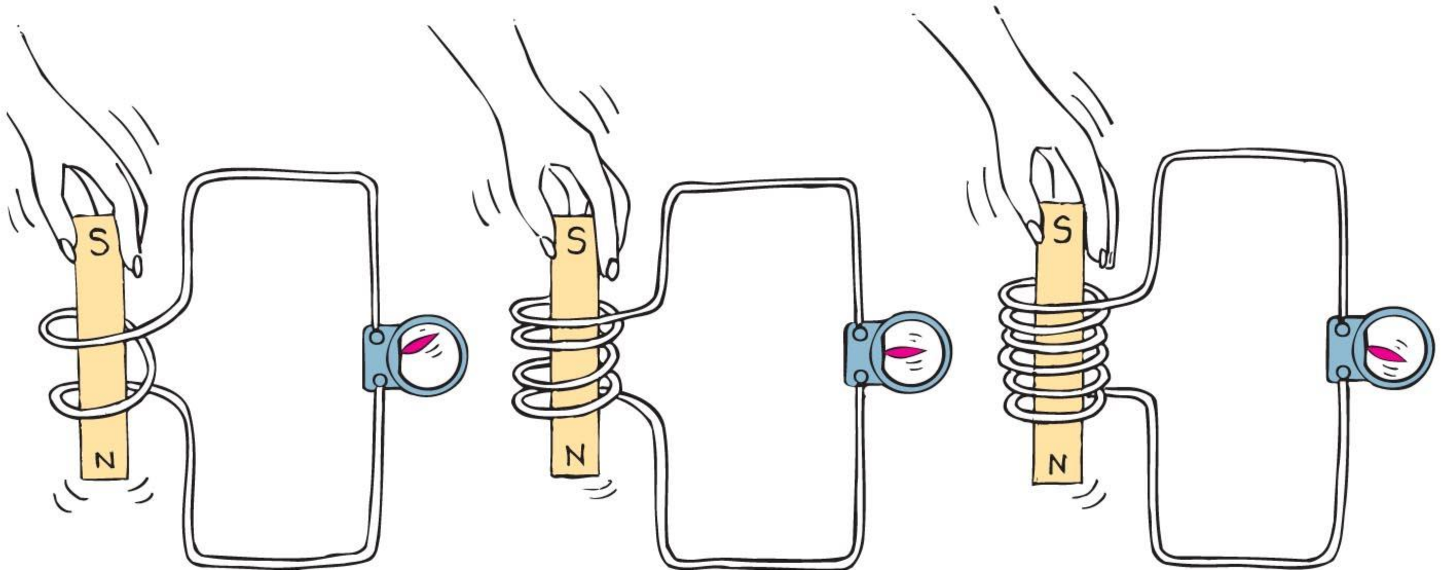
Electromagnetic Induction



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 three times as many loops, three times as much voltage is induced.

http://www.youtube.com/watch?v=gfJG4M4wi1o

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Electromagnetic Induction

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

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Electromagnetic Induction

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.

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Electromagnetic Induction

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

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Electromagnetic Induction

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

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Electromagnetic Induction
CHECK YOUR NEIGHBOR

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

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CHECK YOUR ANSWER

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

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CHECK YOUR NEIGHBOR

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

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CHECK YOUR ANSWER

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

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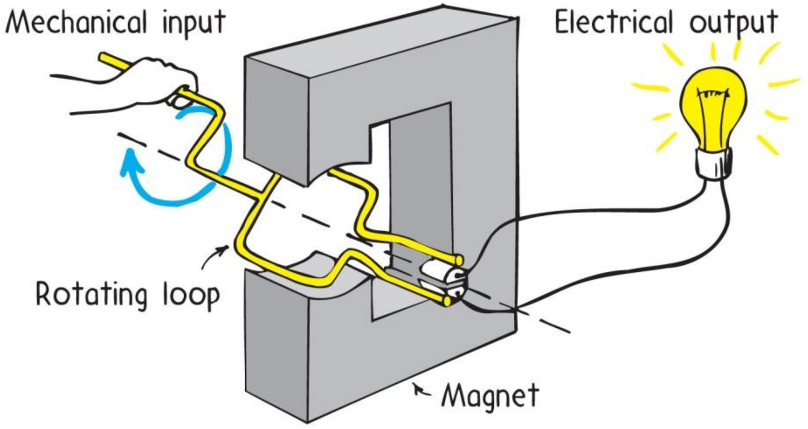
Generators and Alternating Current

Generator

- opposite of a motor
- converts mechanical energy into electrical energy via coil motion
- produces alternating voltage and current



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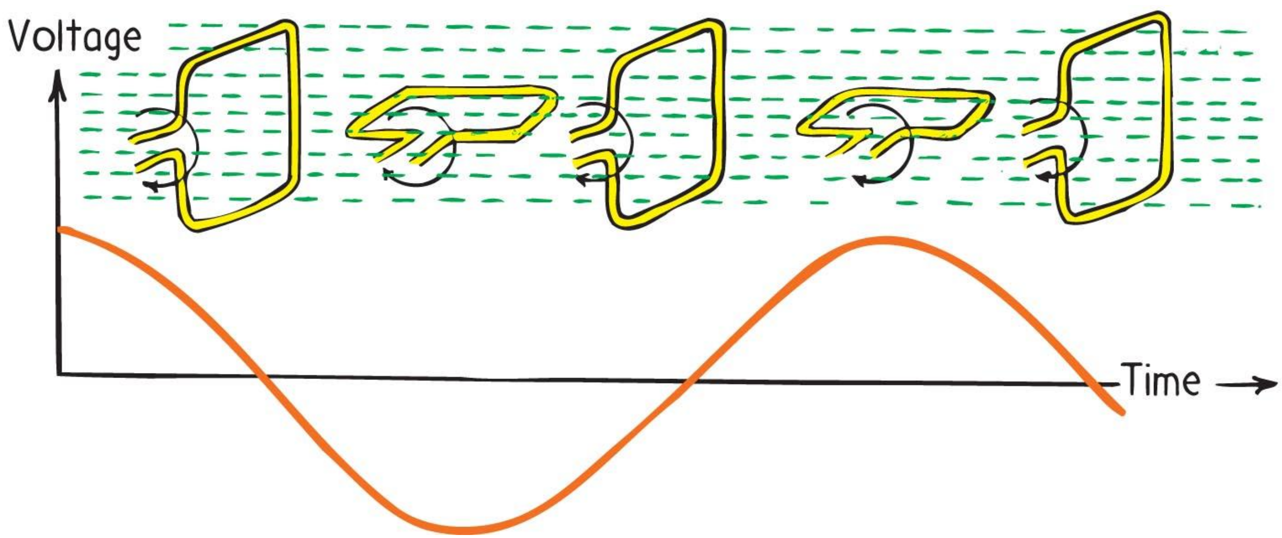
Generators and Alternating Current

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



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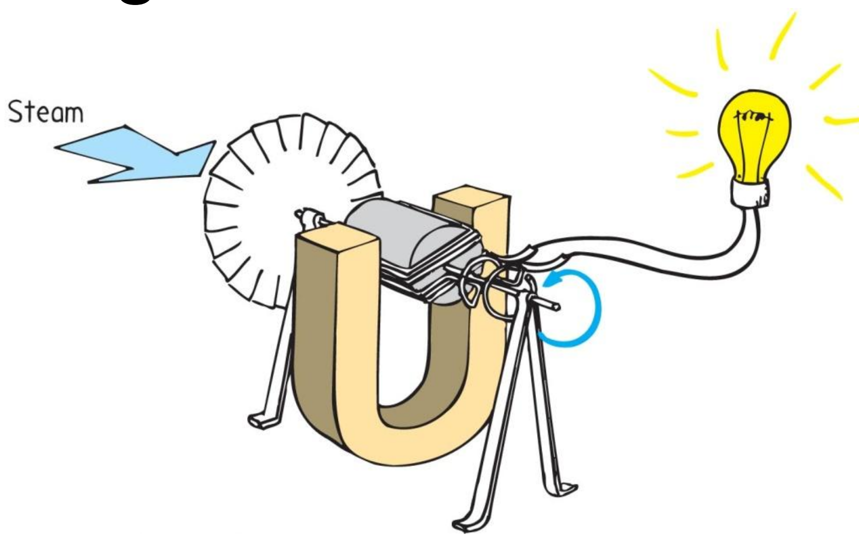
Power Production

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.



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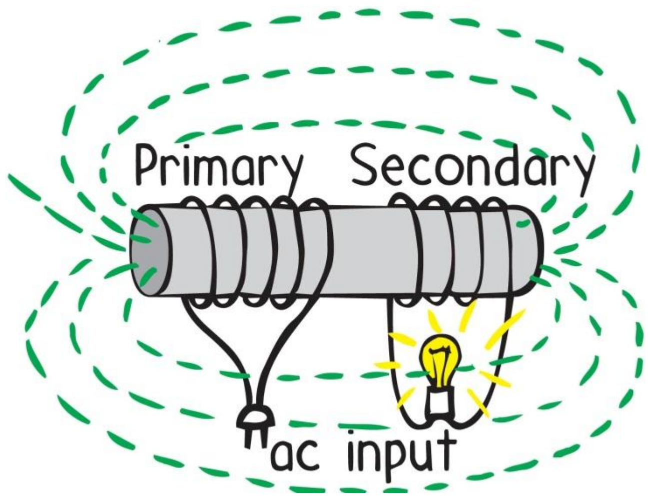
The Transformer—Boosting or Lowering Voltage

Transformer



- input coil of wire—the primary powered by AC voltage source
- output coil of wire—the secondary connected to an external circuit

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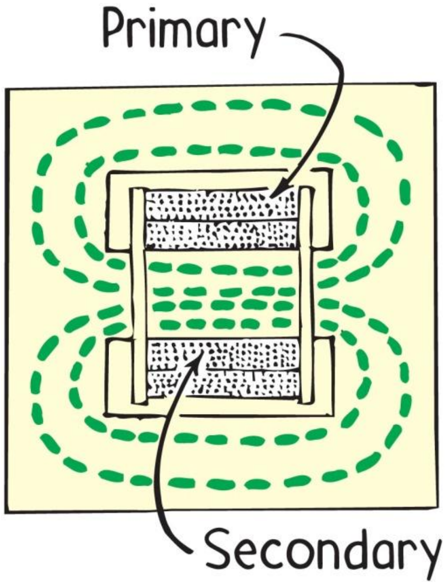
The Transformer—Boosting or Lowering Voltage

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



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The Transformer—Boosting or Lowering Voltage

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

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The Transformer—Boosting or Lowering Voltage

Transformer relationship:

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

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The Transformer—Boosting or Lowering Voltage

Transformer transfers energy from one coil to another

- rate of energy transfer is power
- power into primary = power into secondary

  or
- $(\textit{voltage} \times \textit{current})_{\textit{primary}} = (\textit{voltage} \times \textit{current})_{\textit{secondary}}$

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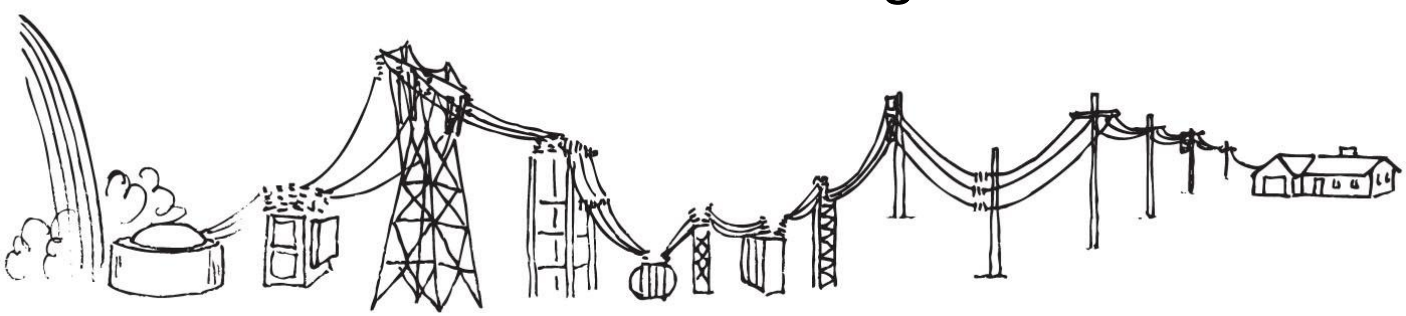
The Transformer—Boosting or Lowering Voltage

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 supplying to businesses and consumers through substations



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The Transformer—Boosting or Lowering Voltage
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

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The Transformer—Boosting or Lowering Voltage
CHECK YOUR ANSWER

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

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

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The Transformer—Boosting or Lowering Voltage
CHECK YOUR NEIGHBOR

An efficient transformer in an AC electric circuit can change

A. current.
B. energy.
C. power.
D. all of the above

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The Transformer—Boosting or Lowering Voltage
CHECK YOUR ANSWER

An efficient transformer in an AC electric circuit can change

A. **current.**
B. energy.
C. power.
D. all of the above

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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

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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.

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Field Induction
CHECK YOUR ANSWER

The mutual induction of electric and magnetic fields can produce

A. light.
B. energy.
C. sound.
D. none of the above.

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Field Induction

- 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!

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