Hewitt/Lyons/Suchocki/Yeh

Conceptual Integrated Science

Chapter 7

ELECTRICITY AND MAGNETISM

Electric Force and Charge

Electric forces can attract some objects and repel others

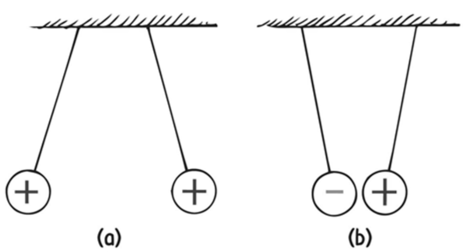
Electric charge:

- the fundamental quantity that underlies all electric phenomena
- comes in two kinds:
  - positive such as protons
  - negative such as electrons

Electric Force and Charge

Fundamental rule for electricity:

Like charges repel; unlike charges attract.



Electric Force and Charge

The charging of bodies relates to the structure of atoms.

Fundamental facts about atoms:

- Every atom is composed of a positively charged nucleus that contains protons.
- Each atomic nucleus is surrounded by negatively charged electrons.

Electric Force and Charge

More fundamental facts about atoms:

- All electrons are identical with the same amount of negative charge
- All protons are identical with the same amount of positive charge, equal in amount to the negative charge of an electron.

Electric Force and Charge

Even more fundamental facts about atoms:

- Protons and neutrons compose the nucleus. Protons are about 1800 times more massive than electrons.
- Neutrons, with no charge, have slightly more mass than protons.

Electric Force and Charge

Normally, an atom is electrically neutral—it has the same number of electrons outside the nucleus as protons in the nucleus.

In the atoms of metals, outer electrons are loosely bound and can move freely and are available to join or flow by other atoms.

Electric Force and Charge

The gain or loss of electrons from individual atoms forms ***ions***.

Atom losing 1 or more electrons $\Rightarrow$ positive ion
Atom gaining 1 or more electrons $\Rightarrow$ negative ion

The amount of work required to pull an electron away from an atom varies for different substances.

Electric Force and Charge

The Law of Conservation of Charge:

When electrons are transferred from one material to another—none are created or destroyed.

Electric Force and Charge

Unit of charge is measured in coulombs, C.

The charge of an electron is the fundamental charge =

$$1.6 \times 10^{-19}\ \text{C}$$

Coulomb's Law

Coulomb's Law describes the forces between electrical charges:

For a pair of charged objects that are much smaller than the distance between them, the force between them varies directly as the product of their charges and inversely as the square of the separation distance.

$$F = k\frac{q_1 q_2}{d^2}$$

Coulomb's Law

K is the proportionality constant that converts units of charge and distance to force:

$$9.0 \times 10^{9}\ \text{N} \bullet \text{m}^2/\text{C}^2$$

$$F = k\frac{q_1 q_2}{d^2}$$

Coulomb's Law

The size of force depends on the product of charges of the two objects.

For like signs of charge, the force is repulsive.

For unlike signs of charge, the force is attractive.

$$F = k\frac{q_1 q_2}{d^2}$$

Coulomb's Law vs. Gravity

Differences and similarities between gravitational and electrical forces:

• Gravitational forces are only attractive, and electrical forces may be either attractive or repulsive.

• Both can act between things that are not in contact with each other.

Coulomb's Law vs. Gravity (cont.)

• Both gravity and electrical forces are inversely proportional to the square of the distance between the objects.

• Gravitational forces are much smaller than electrical forces by a large factor (G vs. K).

Coulomb's Law vs. Gravity (cont.)

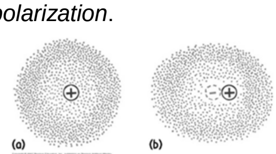
• Gravitational forces act in a straight-line direction between masses, and electrical forces act in a straight-line direction between charges.

• A force field surrounds any mass (gravitational field) and any charged object (electric field).

Charge Polarization

Molecules can't move from their relatively stationary positions, but their "centers of charge" can move.

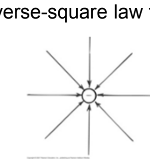
This distortion of charge in the atom or molecule is *electric polarization*.



Electric Field

An Electric Field:

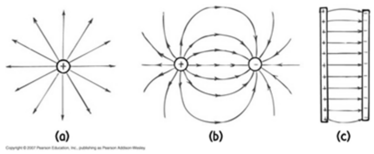
- is the space that surrounds any charged object
- is a vector quantity having magnitude and direction
- magnitude of field at any point is force per unit charge
- obeys the inverse-square law for a point source



Electric Field

Field lines:

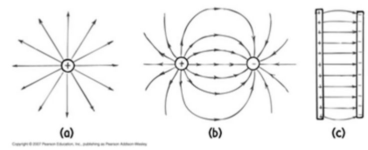
- are used to visualize electric field
- show direction of electric field—away from positive and toward negative



Electric Field

Field lines:

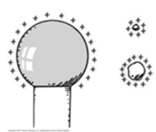
- show intensity of electric field:
  bunched together ⇒ field is strongest
  lines farther apart ⇒ field is weaker



Electric Potential Energy

Electric Potential Energy is the energy possessed by a charged particle or other object due to its location.

If particle is released, it accelerates away from (or toward) the sphere, and its electric PE changes to KE.



Electric Potential Energy

Batteries and generators pull negative charges away from positive ones, doing work to overcome electrical attraction.

The amount of work done depends on the number of charges and separation distance.

Work done by the battery and generator becomes available to a circuit as electrical potential energy.

Electric Potential

Electric potential is:

- the electric potential energy per charge
- the energy that a source provides to each unit of charge

$$\text{Electric potential} = \frac{\text{electric potential energy}}{\text{charge}}$$

Electric Potential

Electric potential and voltage are one and the same.

Unit of measurement is the *volt*.

$$1 \text{ volt} = \frac{1 \text{ joule}}{\text{coulomb}}$$

Conductors and Insulators

Electric Conductors are materials that allow charged particles to pass through them easily.

Atoms of metals have free electrons that conduct through a metallic conductor when a potential difference exists. The result is electric current.

Electric Insulators are materials having tightly bound electrons.

Conductors and Insulators

Semiconductors are materials that are neither good conductors nor good insulators, whose resistance can be varied.

Superconductors are certain materials that acquire infinite conductivity (zero resistance) at low temperatures.

Voltage Sources

Potential difference exists when the ends of an electrical conductor are at different electric potentials.

Batteries and generators are common voltage sources.

Voltage Sources

Charges in a conductor tend to flow from the higher potential to the lower potential.

The flow of charges persists until both ends reach the same potential.

Without potential difference, no flow of charge will occur.

Electric Current

Electric current:

- is the flow of electric charge
- is measured in amperes (“amps”)
- in metal—conduction electrons
- in fluids—positive and negative ions

Electric Current

One ampere is the rate of flow of 1 coulomb of charge per second or 6.25 billion billion electrons per second (recall that the charge on one electron is 1.6×10^{-19} C).

The actual speed of electrons is slow through the wire, but an electric signal travels near the speed of light.

Electric Current

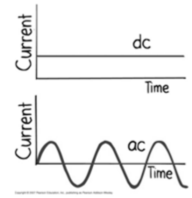
Sustained electric current requires a suitable voltage source, which works by pulling negative charges apart from positive ones (available at the terminals of a battery or generator).

This energy per charge provides the difference in potential (voltage) that provides the “electrical pressure” to move electrons through a circuit joined to those terminals.

Electric Current

Electric current may be

- DC—direct current
  charges flow in one direction
- AC—alternating current
  charges alternate in direction



AC can be converted to DC and vice-versa via alternators and other devices.

Electrical Resistance

Electrical resistance:

- describes how well a circuit component resists the passage of electric current
- is defined as the ratio of the voltage of the energy source to the current moving through the energy receiver
- is measured in ohms (Ω) after 19th century German physicist Georg Simon Ohm.

Electrical Resistance

Factors affecting electrical resistance:

- thin wires resist electrical current more than thicker wires
- long wires offer more electrical resistance
- higher temperature (greater jostling of atoms) = greater resistance

Electrical Resistance

Other factors affecting electrical resistance:

- materials:
  - ❖ copper has a low electrical resistance, so it is used to make connecting wires
  - ❖ rubber has an enormous resistance, so it is used in electrical insulators

Ohm’s Law

Ohm’s Law is a relationship between current, voltage, and resistance

Electrical resistance is measured in ohms (Ω)

Current in a circuit varies in direct proportion to the potential difference (voltage) and inversely with the resistance:

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} \quad \text{or} \quad I = \frac{V}{R}$$

Electric Shock

Damaging effects of electric shock are the result of current passing through the body:

- tissue damage due to conversion of electrical energy to heat
- nerve damage due to disruption of normal nerve functions

Electric Shock

Resistance of one's body depends on its condition.

To receive a shock, there must be a potential difference between one part of the body and another part.

Electric Plugs

Prongs on electric plugs and sockets:

- two flat prongs for the current-carrying double wire, one part live and the other neutral
- third prong is longer and the first to be plugged into socket; path to ground prevents harm to user if there is an electrical defect in the appliance

Electric Circuits

An electric circuit is any closed path along which electrons can flow

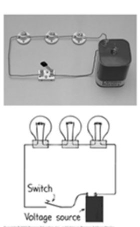
for continuous flow—no gaps

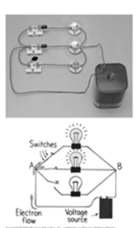
(such as an open electric switch)

Electric Circuits

Devices connect to a circuit in one of two ways:

- Series
- Parallel





Electric Circuits

Series:

- A single-pathway circuit is formed for electron flow between the terminals of the battery, generator, or wall socket.
- A break anywhere in the path results in an open circuit; electron flow ceases.
- Total resistance adds, current decreases as more devices are added.

Electric Circuits

Series:

- Main disadvantage:
  If one device fails, the entire circuit ceases, and none of the devices will operate.

Electric Circuits

Parallel:

- A branched pathway is formed for the flow of electrons through a circuit, connected to the terminals of a battery, generator, or wall socket.
- A break in any path does not interrupt the flow of charge in the other paths.

Electric Circuits

Parallel:

- A device in each branch operates independently of the others.
- Total current in the branches adds; total resistance decreases to less than the resistance of any lamp in the circuit. This means that total current increases.

Electric Power

Electric power

is the rate at which electrical energy is converted into another form, equal to the product of current and voltage.

Electric power = current × voltage = *IV*

1 watt = 1 ampere × 1 volt

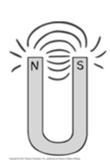
Magnetic Force

Magnetic poles produce magnetic forces.

Can repel and attract without touching depending on which ends of the magnets are held near one another

All magnets have a

- north pole (end that points “northward”)
- south pole (end that points “southward”)



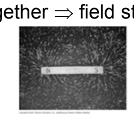
Magnetic Fields

Magnetic fields:

- space around a magnet
- produced by moving electric charges

The shape of a field is revealed by magnetic field lines that spread out from one pole, curve around the magnet, and return to the other pole.

Lines closer together ⇒ field strength is greater



Magnetic Fields

Magnetic domains are clustered regions of aligned atoms.

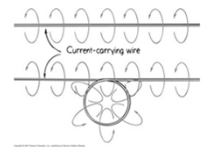
- When domains are oriented in random fashion, the magnetic fields produced by each cancel the fields of others.
- When these regions are aligned with one another, the substance containing them is a magnet.
- The strength of a magnet depends on the number of magnetic domains that are aligned.

Magnetic Fields

Electric Currents and Magnetic Fields

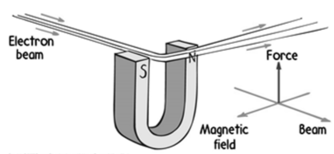
A magnetic field is produced by the motion of electric charge.

A magnetic field surrounding a current-carrying wire makes up a pattern of concentric circles.



Magnetic Forces on Moving Charges

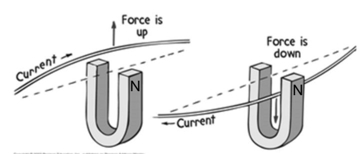
Charged particles moving in a magnetic field experience a deflecting force - greatest when moving at right angles to magnetic field lines.



Magnetic Forces

Magnetic forces on current-carrying wires

A current of charged particles moving through a magnetic field experiences a deflecting force. If the particles are deflected while moving inside a wire, the wire is also deflected.



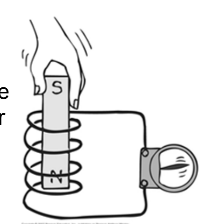
Magnetic Forces on Moving Charges

An electric meter is operated by a current-carrying wire deflected in a magnetic field.

An electric motor operates like an electric meter, except that the current is made to change direction each time the coil makes a half rotation.

Electromagnetic Induction

- Electric current can be produced in a wire by moving a magnet into or out of a coil of wire.
- Voltage is induced by the relative motion between a wire and a magnetic field. Whether it moves near a stationary conductor or vice versa, voltage is induced either way.

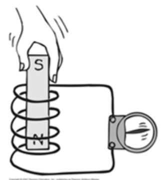


Electromagnetic Induction

- The greater number of loops of wire moving in the magnetic field, the greater the induced voltage.

V ~ N

- Pushing a magnet at the same speed into a coil with twice as many loops induces twice as much voltage.



Electromagnetic Induction

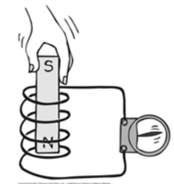
- The faster the magnetic field changes inside the coil, the larger the induced voltage becomes.

$$V \sim \Delta B / \Delta t$$

or

$$V \sim N \, \Delta B / \Delta t$$

Where B is the magnetic field strength.



Electromagnetic Induction

The modern view of electromagnetic induction states that electric and magnetic *fields* can induce each other.

An electric field is induced in any region of space in which a magnetic field is changing with time.

or

A magnetic field is induced in any region of space in which an electric field is changing with time.

Electromagnetic Waves and Light

- When electric charges or an electric field are set into vibration in the range of frequencies that match those of light, the waves produced are those of light.
- Light is simply electromagnetic waves in the range of frequencies to which the eye is sensitive.