PowerPoint Lectures
to accompany
Physical Science, 8e

Chapter 6
Electricity

New Symbols for this Chapter

q-Charge
I-Current
V-Electrical Potential
R-Resistance
Ω-Ohms

$$F = k\frac{q_1 q_2}{r^2}$$
$$I = \frac{q}{t}$$
$$V = IR$$
$$P = IV$$
$$R_{\text{total}} = R_1 + R_2 + R_3$$
$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Core Concept

Electric and magnetic fields interact and can produce forces.

Electromagnetism

The early Greek Philosophers knew that if you rubbed a piece of amber, it would attract bits of straw.

The Greeks also observed that some naturally occurring stones would attract Iron.

The Electric Force

Since all matter has mass there is an attractive force between matter called **The Gravitational Force.**

Some mater also has a property called charge and the force between matter due to this property is called **The Electric Force**.

Electric Charge

Charge is found in Protons and Electrons.

Electrons have Negative Charge
Protons have Positive Charge

Overall matter usually has the same number of protons and electrons which means equal amounts of positive and negative charge.

Ions

Neutral Atoms

Negative Ion

Positive Ion

When an atom gains or loses an electron it becomes an **Ion**.

(+) and (-) Charge

The "Positive" and "Negative" labels and signs for electric charge were chosen arbitrarily by Benjamin Franklin.

Units of Charge

Charge is measured in **Coulombs** (**C**). The coulomb is like the kilogram is for mass.

Electric Charge

- Unit of charge = coulomb (C)
  - Equivalent to charge of 6.24×10^{18} electrons!
  - Metric unit of charge
- Electron charge
  - Fundamental charge
  - Smallest seen in nature
  - Quantity of charge and the number of electrons

Quantity of charge → $q = ne$ ← Electron charge; Number of electrons ↑ (n)

$$e = \frac{q}{n} = \frac{1.00\ coulomb}{6.24 \times 10^{18} electron}$$

$$= 1.60 \times 10^{-19} \frac{coulomb}{electron}$$

Conductors and Insulators

In some materials, such as metals, some of the negative charge can move rather freely. We call such materials **Conductors**.

In other materials like plastic, none of the charge can move freely. We call these materials **Nonconductors** or **Insulators**.

Semi-Conductors

Semi-conductors, such as Silicon and Germanium, are materials that are intermediate between conductors and insulators.

Static Electricity

Electrostatic charge
- Stationary charge confined to an object

Charging mechanisms
- Friction
- Contact with a charged object
- Polarization (reorientation induced without changing net charge)

Coulomb's Law

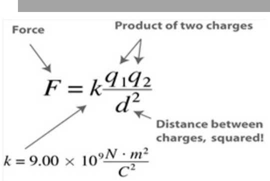
If two charged particles have charges $\mathbf{q_1}$ and $\mathbf{q_2}$ and are separated by a distance $\mathbf{d}$ then the electrostatic force of attraction or repulsion between them has the value given by:

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

Where *k* is a constant that tells us the strength of the force.

$$k = 9.0 \times 10^9 \frac{N \cdot m^2}{C^2}$$

Electrostatic Forces



Coulomb's law
- Relationship giving force between two charges
- Similar to Newton's law of gravitation
- k versus G implies gravity weaker

$G = 6.67 \times 10^{-11} N \cdot m \cdot kg^{-2}$

$$F = \frac{Gm_1 m_2}{d^2}$$

$$\frac{k}{G} = \frac{9.00 \times 10^9}{6.67 \times 10^{-11}} = 1.4 \times 10^{20}$$

Attractive or Repulsive

If the charges have different signs then the force will be attractive.

If the charges have the same sign then the force will be repulsive.

In both cases the objects will move along the straight line connecting them.

Action at a Distance

Some forces we can see how the forces is being applied. This is called a **Contact Force**.

Some forces act over large distances and the objects do not have to be in contact for the force to act. To understand these forces we use the idea of a **Field**.

The Electric Field of ±Charge

Each Charged object produces an electric field (***E***) in all the space around it.

The direction of an electric field is always away from positive charges and towards negative charges.

Electric Potential

- Scalar field associated with potential energy
- Units = volts (V)
- Related to work involved in positioning charges
- Potential difference important in producing forces and moving charges
- Analogous to moving masses in gravitational fields

Electric Current

Earlier - electrostatics
- Charges more or less fixed in place

Now - charge allowed to move
- Electric current
  - Flow of charge
  - Reason for charge flow - potential (voltage) differences
- Electric circuits
  - Structures designed to localize and utilize currents

Electric Current

If we insert a battery into a loop of wire then the wire is no longer at a single potential and charges will start moving from the high potential to the low potential.

The Electric Circuit

Structure
- Voltage source
  - Energy input
  - Necessary for continuing flow
- Circuit elements
  - Energy used up as heat, light, work, …
- Current flow convention: from high potential to low potential through the external circuit
- Water/pump analogy

The Nature of Current

- Historically - nature of "electrical fluid" unknown
- Current thought to be a flow of positive charge
- Reality - more complicated, depending on material
- Opposite correct in metals, current = electron flow

Current Mechanisms

Liquids and gases
- Both positive and negative charges move, in opposite directions

Metals
- Delocalized electrons free to move throughout metal
- "Electron gas"
- Drift velocity of electrons slow
- Electric field moves through at nearly light speed

More Current Details

- Current = charge per unit time
  Units = ampere, amps (A)
  Direct current (DC)
  - Charges move in one direction
  - Electronic devices, batteries, solar cells

  Alternating current (AC)
  - Charge motion oscillatory
  - No net current flow

Electrical Resistance

- Loss of electron current energy
- Two sources
  - Collisions with other electrons in current
  - Collisions with other charges in material
- Ohm's law

Example 1 (Parallel Exercise Group B #6)

1) There is a current of 0.83A through a light bulb in a 120V circuit. What is the resistance of this light bulb?

Units of Resistance

The SI unit for resistance is the Volt per Ampere. This combination occurs so often that we give it a special name the Ohm (Ω).

$$1\ Ohm\ = 1\,\Omega = 1\frac{V}{A}$$

A conductor whose function in a circuit is to provide a specified resistance is called a **Resistor**.

We represent a resistor in a circuit diagram with the symbol 

More on Resistance

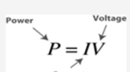
- Resistance factors
  - Type of material
  - Length
  - Cross-sectional area
  - Temperature
- Superconductors
  - Negligible resistance at very low temperatures

Electrical Power and Work

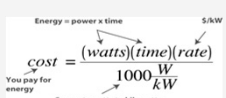
Three circuit elements contribute to work

- Voltage source
- Electrical device
- Conducting wires
  - Maintain potential difference across device
  - Input wire at higher potential than output wire
  - Output wire = "ground" for AC circuits
  - No potential difference, no current (bird on a wire)

Power in circuits



Electric bills



Example 2 (Parallel Exercise Group B #11)

1) An electrical motor draws a current of 11.5 A in a 240 V circuit. What is the power of this motor in Watts?

Magnetism

Earliest ideas
- Associated with naturally occurring magnetic materials (lodestone, magnetite)
- Characterized by "poles" - "north seeking" and "south seeking"
- Other magnetic materials - iron, cobalt, nickel (ferromagnetic)

Modern view
- Associated with magnetic fields
- Field lines go from north to south poles

Magnetic Poles and Fields

- Magnetic fields and poles inseparable
- Poles always come in north/south pairs
- Field lines go from north pole to south pole
- Like magnetic poles repel; unlike poles attract

Sources of Magnetic Fields

- Microscopic fields
  - Intrinsic spins of subatomic particles (electrons, protons, …)
  - Orbital motions of electrons in atoms
- Macroscopic fields
  - Permanent magnets
  - Earth's magnetic field
  - Electric currents
  - Electromagnets

Permanent Magnets

- Ferromagnetic materials

  Atomic magnetic moment
  - Electron/proton intrinsic moments
  - Electron orbital motion

  Clusters of atomic moments align in domains

  Not magnetized - domains randomly oriented

  Magnetized - domains aligned

Earth's Magnetic Field

- Originates deep beneath the surface from currents in molten core
- Magnetic "north" pole = south pole of Earth's magnetic field
- Magnetic declination = offset
- Direction of field periodically reverses
  - Deposits of magnetized material
  - Last reversal - 780,000 yrs. ago

Electric Currents and Magnetism

- Moving charges (currents) produce magnetic fields

Electromagnets

- Structure
  - Ferromagnetic core
  - Current carrying wire wrapped around core
- Field enhanced by the combination
- Can be turned on/off
- Used in many applications: meters, switches, speakers, motors…

Electric Motors

- Convert electrical energy to mechanical energy
- Two working parts
  - Field magnet - stationary
  - Armature - moveable electromagnet
- Armature rotates by interactions with field magnet
  - Commutator and brushes reverse current to maintain rotation

Electromagnetic Induction

Causes:

- Relative motion between magnetic fields and conductors
- Changing magnetic fields near conductors

Effect:

- Induced voltages and currents

Induced voltage depends on:

- Number of loops
- Strength of magnetic field
- Rate of magnetic field change

AC Generators

Structure

- Axle with main wire loops in a magnetic field
- Axle turned mechanically to produce electrical energy

AC generator

- “Alternating current”
- Sign of current and voltage alternate

DC Generators

DC generator

- “Direct current”
- Sign of current and voltage constant

Circuit Connections

- Alternating current
  - Practically all generated electricity
  - Transmitted over high voltage lines and stepped down for use in homes and industry
- Direct current
  - Used in automobiles, cell phones, mp3 players, laptops, …
  - Moveable and portable applications
  - Main current source is chemical batteries

Transformers

The general energy transmission rule: Transmit at the highest possible voltage and the lowest possible current.

So we need a device to raise the voltage for transmission and then lower for household use.

The transformer is such a device.

The Ideal Transformer

The ideal transformer consists of two coils, with different numbers of turns, wound around an Iron core.

The primary winding, of N_p turns, is connected to an alternating-current generator with an alternating current.

The secondary winding, of N_s turns, is connected to a device which will use the electric energy.

Transformers

- Problems in power transmission
  - High currents - large resistive losses
  - High voltages - dangerous potential differences
- Solution: transformers boost/lower AC currents and voltages
- Basic relationships
  - Power in = power out
  - Number of coils to voltage

Voltages in primary/secondary coils

$$\frac{V_p}{N_p} = \frac{V_s}{N_s}$$

Number of turns in primary/secondary coils

Series Circuits

There are two ways that you can connect circuit elements together. The first way to connect elements together is called in **Series**.

Circuit elements in series have the following properties:

1)They all have the same current going through them.
2)They all have a voltage across them that depends on their resistance.

$$R_{\text{total}} = R_1 + R_2 + R_3$$

Parallel Circuits

The other way to connect circuit elements is called in **Parallel**.

Circuit elements in parallel all have the following properties.

1)They all have a different current going through them which will depend inversely on their resistance.
2)The same voltage across them.

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Household Circuit Safety

- Potential difference from two wires per device
  - Energized load carrier
  - Grounded or neutral wire
- Three-pronged plug
  - Provides another grounding wire
- Other devices: polarized plugs, ground-fault interrupter (GFI)