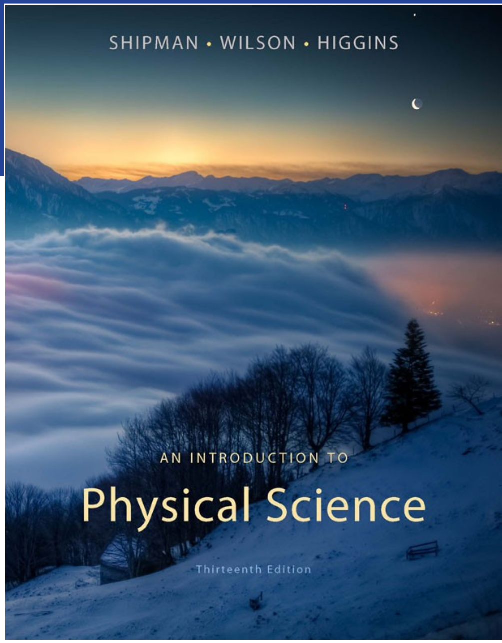


BROOKS/COLE
CENGAGE Learning™

James T. Shipman
Jerry D. Wilson
Charles A. Higgins, Jr.

Chapter 8

Electricity and Magnetism

Electric Charge and Electric Force

- Electric charge is a fundamental quantity – we don't really know what it is
  - But we can describe it, use it, control it
  - Electricity runs motors, lights, heaters, A/C, stereos, TV's, computers, *etc*.
- Electric Forces – at the microscopic level they hold atoms and molecules together
  - Electric Forces hold matter together
- Gravitational Forces hold the universe together
- Magnetism is also closely associated with electricity

Audio Link

Electric Charge and Electric Force

- Experimental evidence leads us to conclude that there are two types charges
  - Positive (+)
  - Negative (-)
- All matter is composed of atoms, which in turn are composed of subatomic particles
  - Electrons (-)
  - Protons (+)
  - Neutron (neutral)

Properties of Electrons, Protons, and Neutrons

- Note that the Proton and Neutron each have about 1000x more mass than the Electron
- If the atom has the same number of protons and electrons it is electrically neutral

Table 8.1 Some Properties of Atomic Particles

Particle	Symbol	Mass	Charge
Electron	e^-	9.11×10^{-31} kg	-1.60×10^{-19} C
Proton	p^+	1.673×10^{-27} kg	$+1.60 \times 10^{-19}$ C
Neutron	n	1.675×10^{-27} kg	0

Coulomb (C) = Unit of Electric Charge

- Named after a French scientist – Charles Coulomb (1736-1806)
- Note that the charge on a single electron (-) or proton (+) is 1.60 x 10^{-19} C (very small!)
- q usually designates electric charge
  - Excess of positive charges $+q$
  - Excess of negative charges $-q$

Electric Force

- An electric force exists between any two charged particles – either attractive or repulsive

Law of Charges

- Law of Charges – like charges repel, and unlike charges attract
  - Two positives repel each other
  - Two negatives repel each other
  - Positive and negative attract each other
- The force between two charged bodies is directly proportional to the product of the two charges & inversely proportional to the square of their distance apart.
  - This is called Coulomb’s Law

Negative/Positive

- An object with an excess of electrons is said to be negatively charged
- An object with a deficiently of electrons is said to be positively charged
- Static electricity is the study of charges at rest.

Charging by Friction

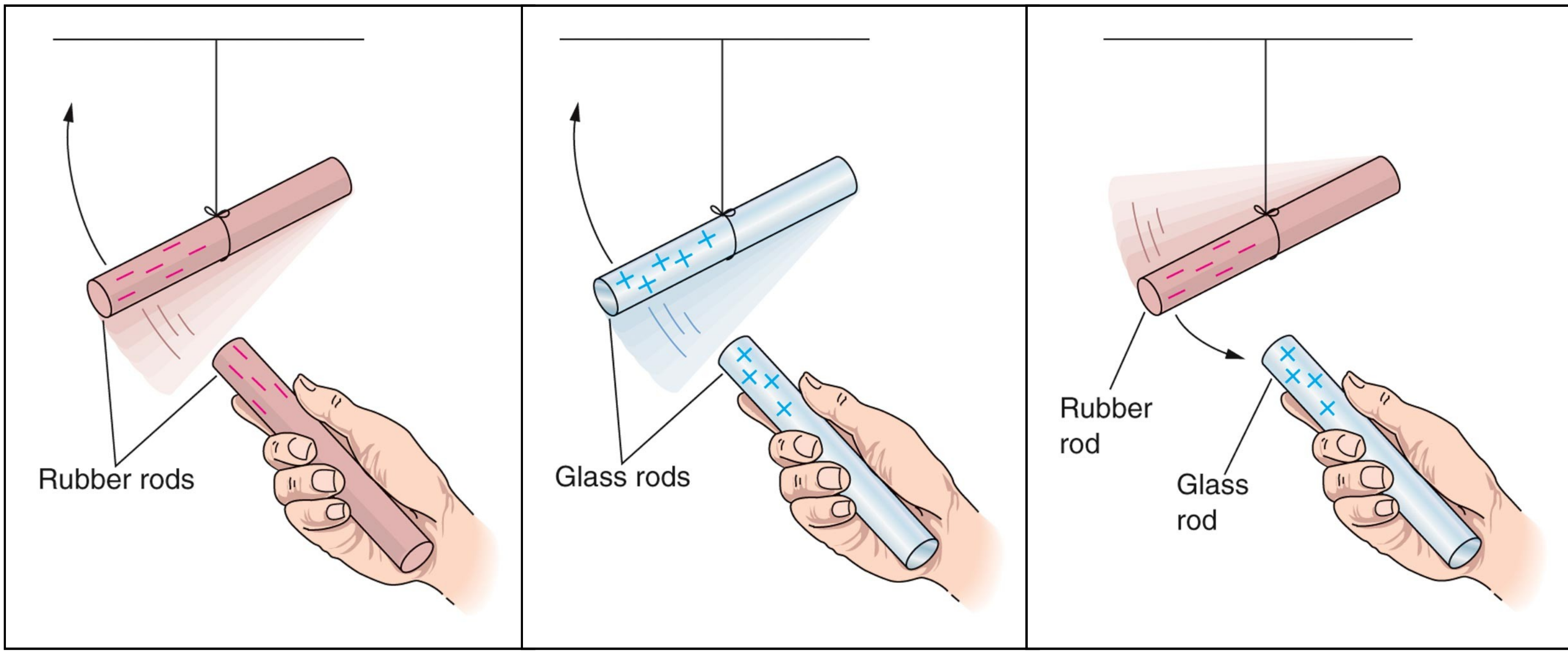
- Is the transfer of charge by rubbing

Repulsive and Attractive Electrical Forces

Two negative charges repel

Two positive charges repel

One negative and one positive attract

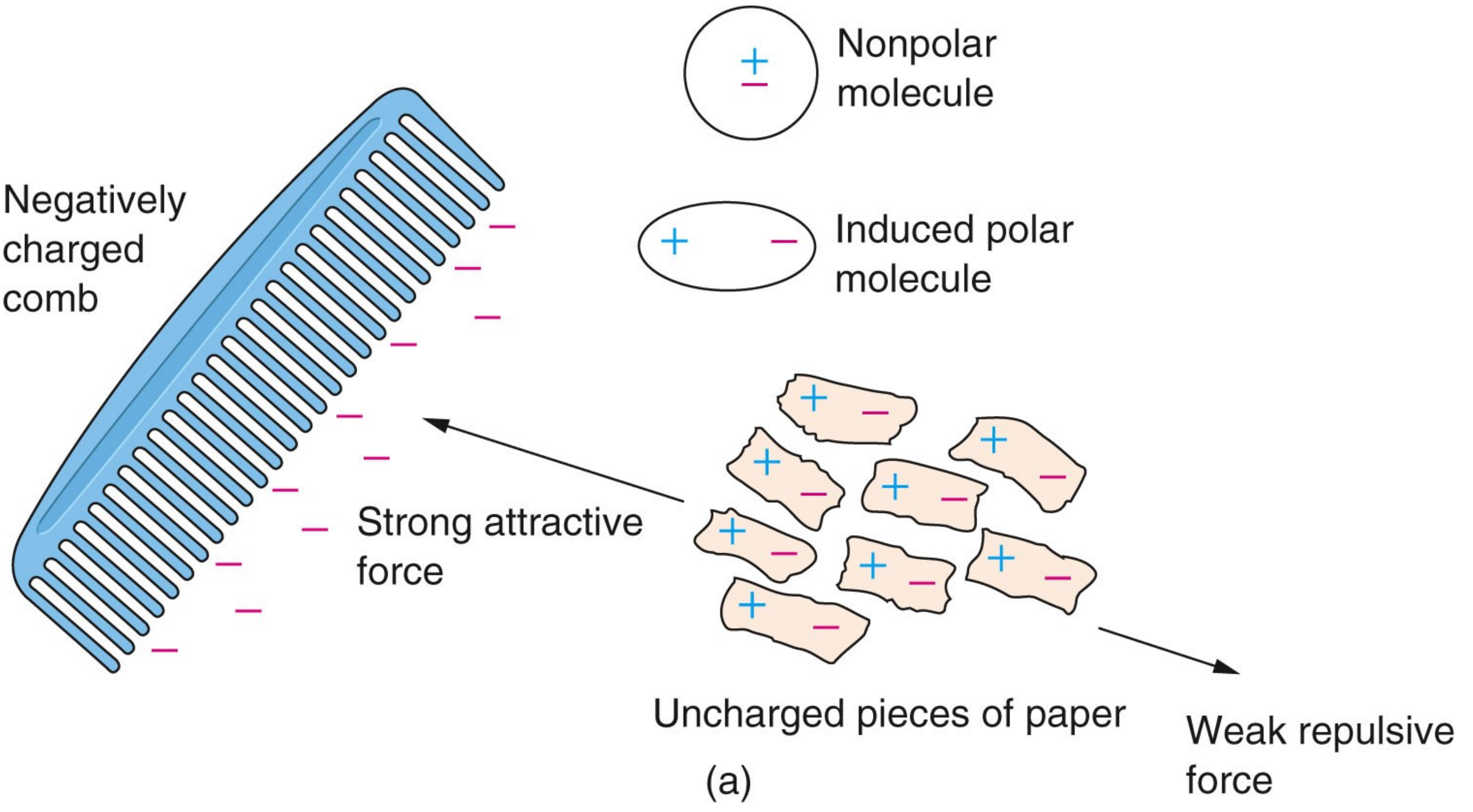


Repulse

Repulse

Attract

Charging by Induction



Coulomb's Law

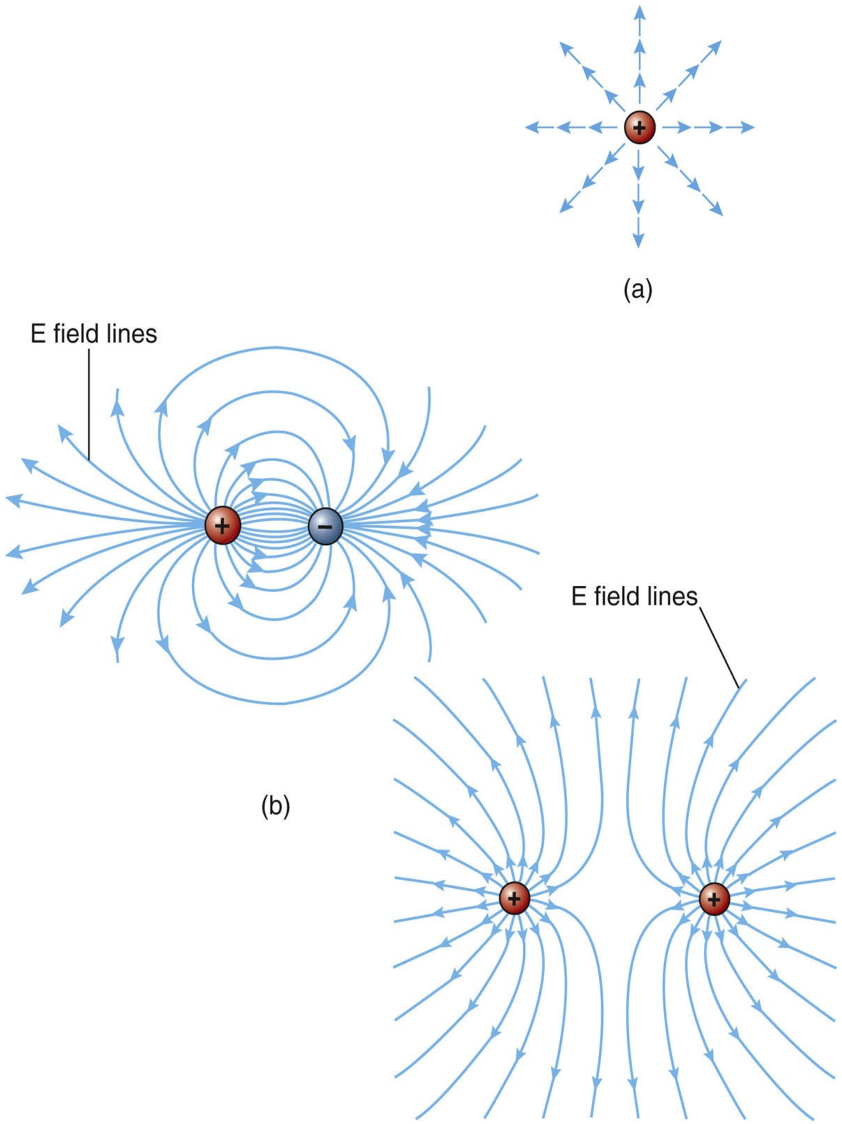
- Force of attraction/repulsion between two charged bodies is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them
- $F = (kq_1q_2) / r^2$
  - F = force of attraction or repulsion
  - q_1 = magnitude of the first charge
  - q_2 = magnitude of the second charge
  - r = distance between charges
  - k = constant = 9.0×10^9 N-m^2/C^2

Comparison of Coulomb’s Law & Newton’s Law of Universal Gravitation

- Equations look similar
  - $F = kq_1q_2 / r^2$ & $F = Gm_1m_2 / r^2$
- Both depend on r^2
- Coulomb’s law can describe either an attractive or repulsive force – gravity is always positive
- Electrical charges are much stronger than gravitational forces

Electric Field

Action-at-a-distance concept replaced by the Electric Field which surrounds the charge and represents the physical effect in nearby space.



Current – time rate of flow of electric charge

- I = charge/time = q/t
  - I = electric current (amperes)
  - q = electric charge flowing past a point (coulombs)
  - t = time for the charge to pass point (seconds)
- 1 ampere (A) = flow of 1 Coulomb per second
- Rearrange equation above:
  - $q = It$ or 1 coulomb = 1 ampere x 1 second
- Therefore, 1 coulomb is the amount of charge that flows past a given point in 1 second when the current is 1 ampere

Conductors/Insulators

- Electrical conductor – materials in which an electric charge flows readily (most metals, due to the outer, loosely bound electrons)
- Electrical insulator – materials that do not conduct electricity very well due to very tight electron bonding (wood, plastic, glass)
- Semiconductor – not good as a conductor or insulator (graphite)

Audio Link

Finding the Amount of Electric Charge - Example

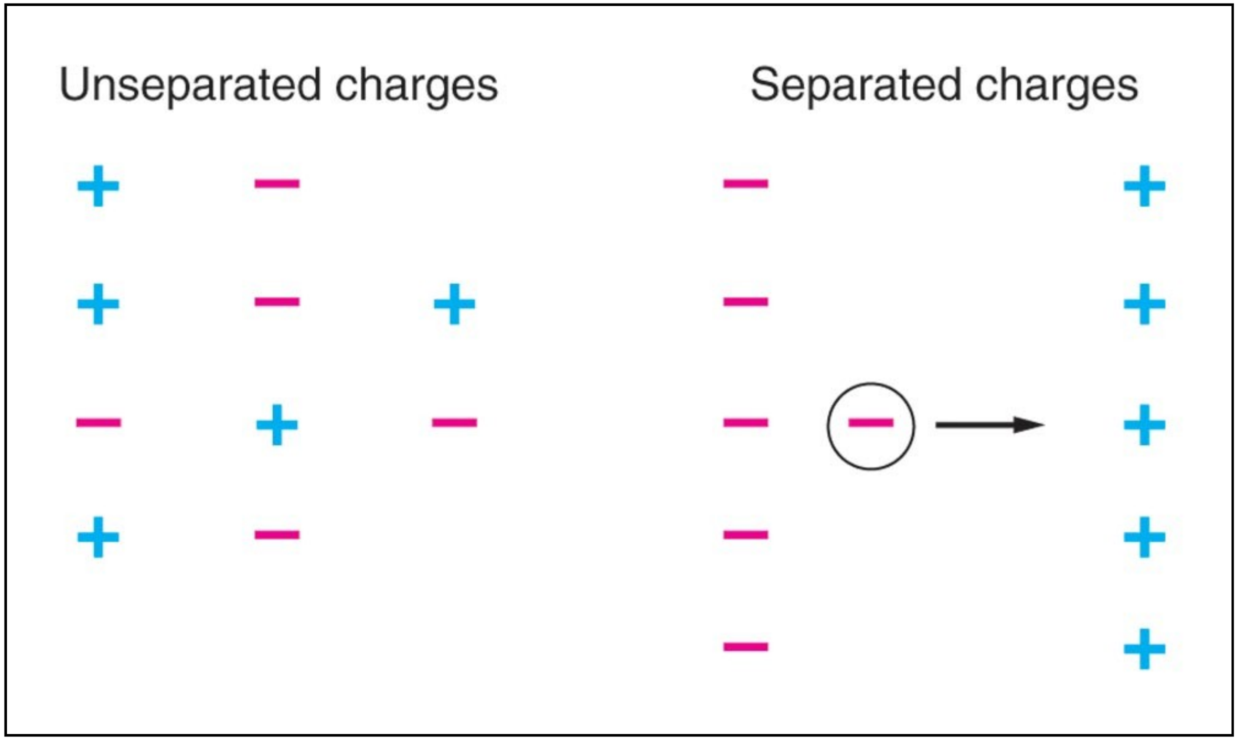
- *A wire carries a current of 0.50 A for 2 minutes.*
  a) how much (net) charge goes past a point in the wire in this time?
  b) how many electrons make up this amount of charge?
- GIVEN: I = 0.50 A, t = 2 minutes (120 seconds)
- WANTED: q (charge) & *n* (number of electrons)
- (a) $q = It$ = (0.50 A)(120 s) = 60 C (coulombs)

Finding the Amount of Electric Charge - Example

- *A wire carries a current of 0.50 A for 2 minutes.*
  - a) how much (net) charge goes past a point in the wire in this time?
  - b) how many electrons make up this amount of charge?
- To solve for (b), we know that each electron has a charge of 1.6×10^{-19} C and we know the total charge from part (a) = 60 Coulombs
- $n = 60/(1.6 \times 10^{-19}$ C / electron) = <u>3.8×10^{20} electrons</u>

Electric Potential Energy

- When work is done to separate positive and negative charges, we have electric potential energy



Voltage

- Instead of measuring electric potential energy, we measure the *potential difference*, or voltage
- Voltage – the amount of work it would take to move a charge between two points, divided by the value of the charge
- Voltage = *work / charge* = $V = W/q$
- Measured in volts (V) = 1 joule/Coulomb
- When we have electric potential energy, this may be used to set up an electrical current

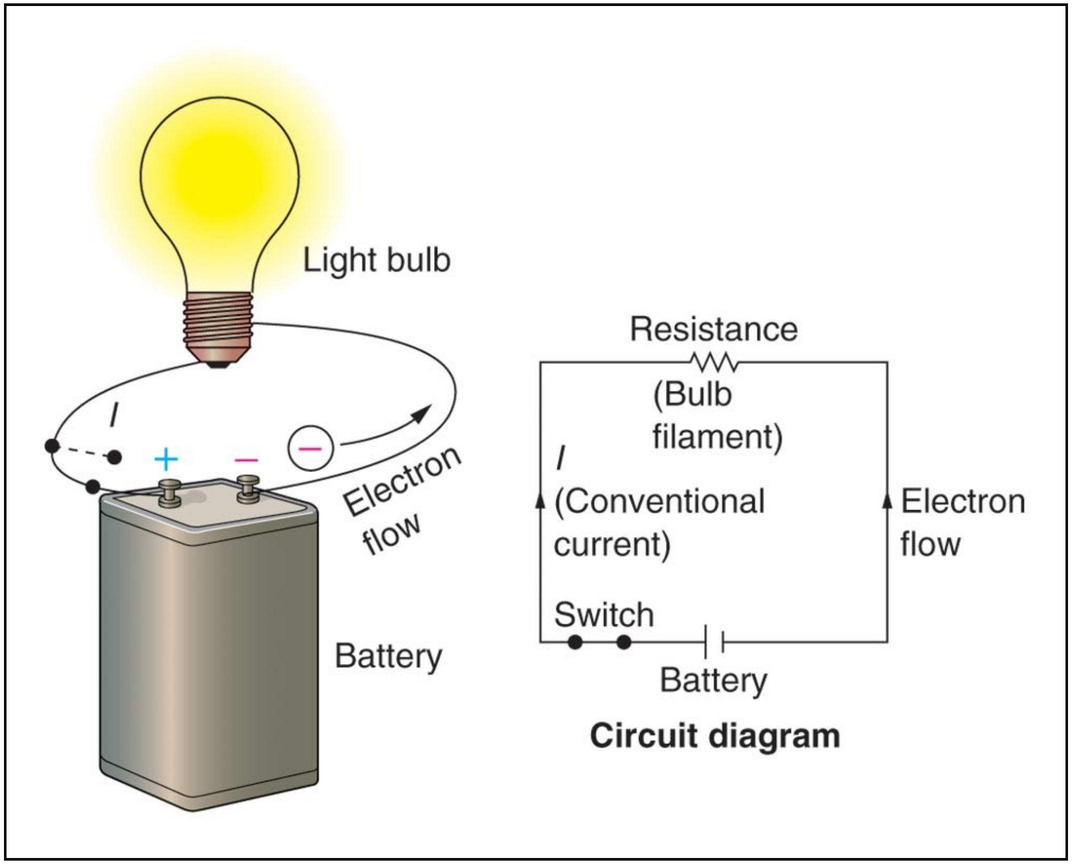
Ohm's Law

- Whenever there is an electrical current, there is resistance (R) within the conducting material
  - *R is due to atomic/subatomic collisions*
- Georg Ohm (1787-1854) – formulated a simple relationship between voltage, current, and resistance
- Ohm's Law → $V = IR$
  - *V = voltage in volts, I = current in amperes, and R = resistance in ohms*
- 1 ohm = 1 volt/1 ampere ($R=V/I$)

Simple Electrical Circuit

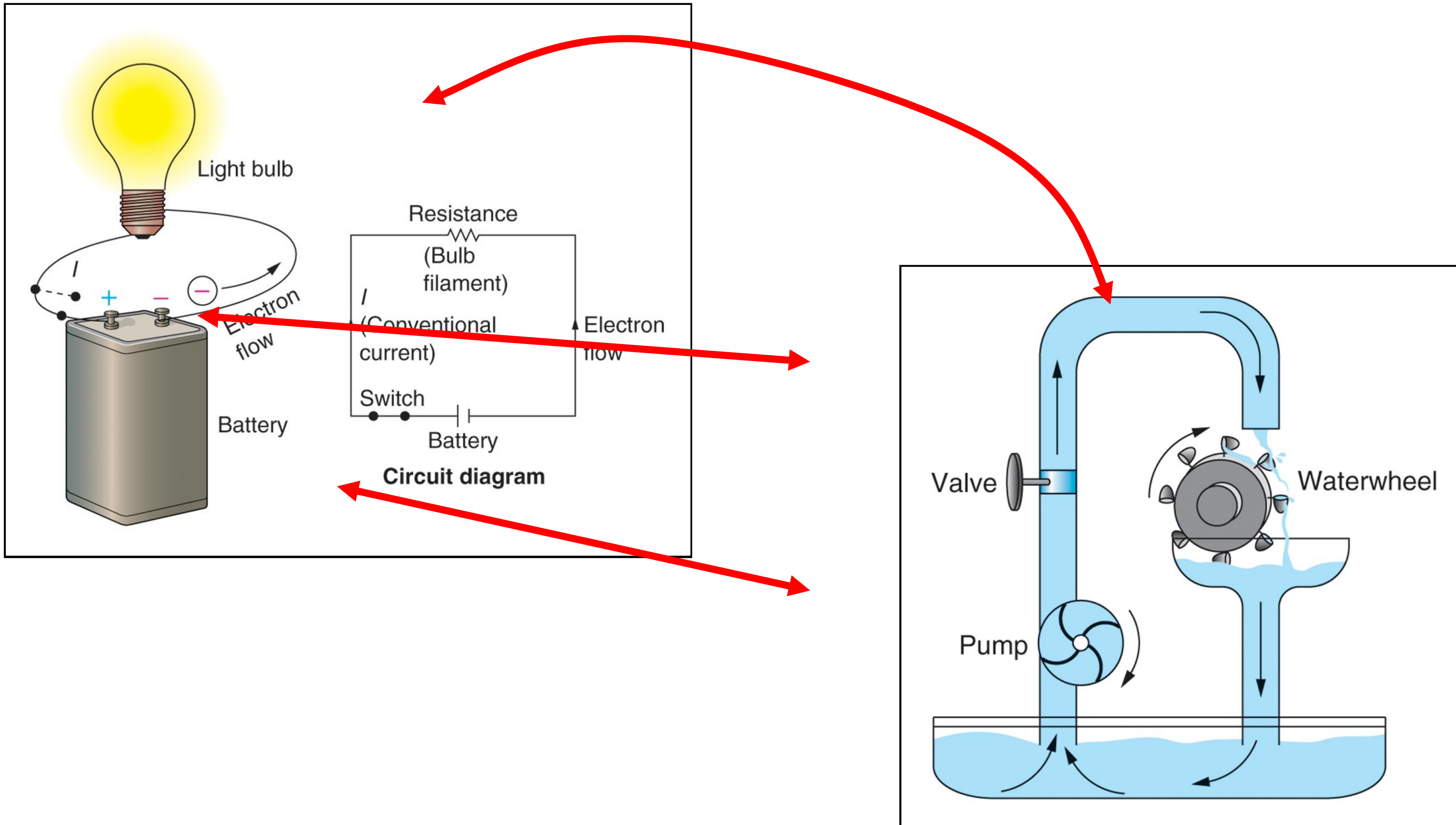
- Electrons flow from negative terminal to positive terminal (provided by the chemical energy of the battery) -- negative to positive
- Open switch – not a complete circuit and no flow of current (electrons)
- Closed switch – a complete circuit and flow of current (electrons) exists
- Closed Circuit Required – to have a sustained electrical current

Simple Electrical Circuit



The light bulb offers resistance. The kinetic energy of the electric energy is converted to heat and radiant energy.

Electrical Circuit & Waterwheel Analogy



Electrical Power

- Recall: $P = W/t$ (Power = work/time) – Ch. 4
- $V = W/q$ (Voltage = work/charge) – Ch. 8
- Rearrange $V = W/q$ → $W = qV$
- Substitute $W = qV$ into $P = W/t$ equation
- Result → $\mathrm{P} = qV/t$
- Recall that $I = q/t$ (Current = charge/time)
- $\therefore P = IV$ (Electric power = current x voltage)
- also $P = I^2R$ (substitute in $V = IR$)
- P in watts, I in amperes, R in ohms, V in volts

Finding Current in Resistance -Example

- Find the current and resistance of a 60-W, 120-V light bulb in operation.
- Given: P = 60W, V = 120 V
- Find: I (current in amperes), *R* (resistance in ohms)
- Since $P = IV$ → $\boldsymbol{I} = P/V$ = 60 W/120 V = **0.50 A**
- Since $V = IR$ → $\boldsymbol{R} = V/I$ = 120 V/0.50A = **240 Ω**
- Since $\mathrm{P} = \mathrm{I}^2\mathrm{R}$ → $\boldsymbol{R} = \mathrm{P}/\mathrm{I}^2$ = 60 W/(0.50 A)2 = **240 Ω** (same answer as above)
  - **Ω** stands for ohm

Confidence Exercise - Example

- A coffeemaker draws 10 A of current operating at 120 V. How much electrical energy does the coffeemaker use each second.
- Given: I = 10 A, V = 120 V
- Find: P (electrical energy in watts)
- $P = IV$
- $\boldsymbol{P}$ = (10 A) x (120 V) = **1200 W** or 1200 J/s

Equation Review – Sections 8.1 & 8.2

- Current: $I = q/t$
  - I = *current (amperes),*
  - q = *electric charge (coulombs),*
  - t = *time (seconds)*
- Coulomb's Law: $F = kq_1q_2/r^2$
- Voltage: $V = W/q$ [Work is in joules (J)]
- Ohm's Law: $V = IR$
- Electrical Power: $P = IV = I^2R$

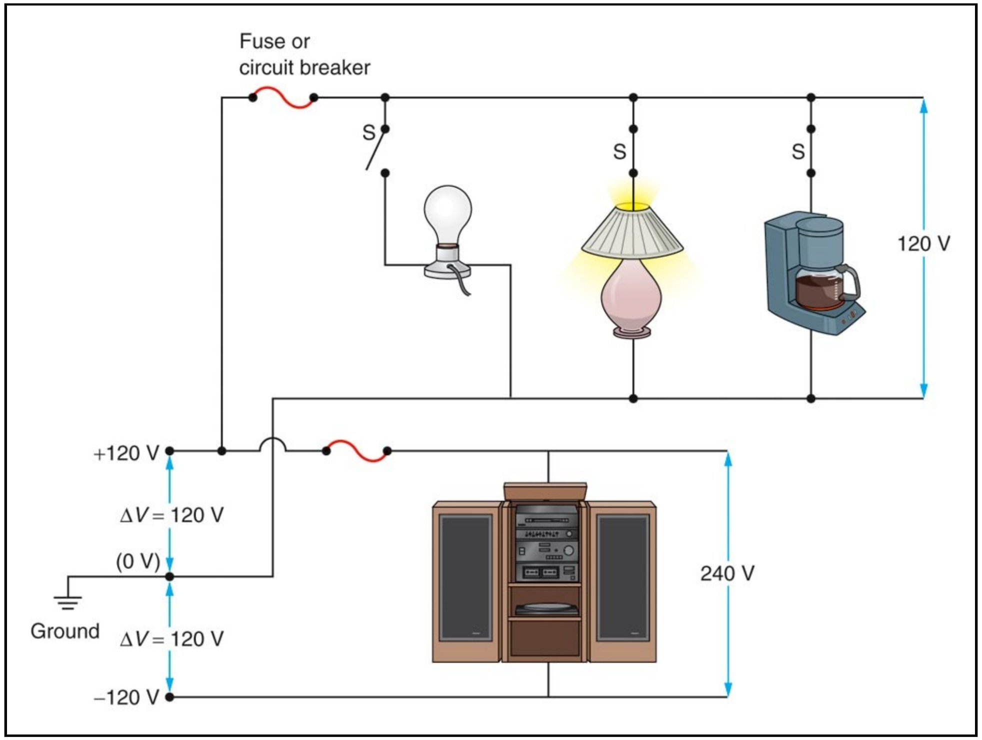
Audio Link

Forms of Electric Current

- Direct Current (DC) – the electron flow is always in one direction, from (-) to (+)
  - Used in batteries and automobiles
- Alternating Current (AC) – constantly changing the voltage from positive to negative and back
  - Used in homes.
  - 60 Hz (cycles/sec) and Voltage of 110-120 V

Household Circuits110-120 V

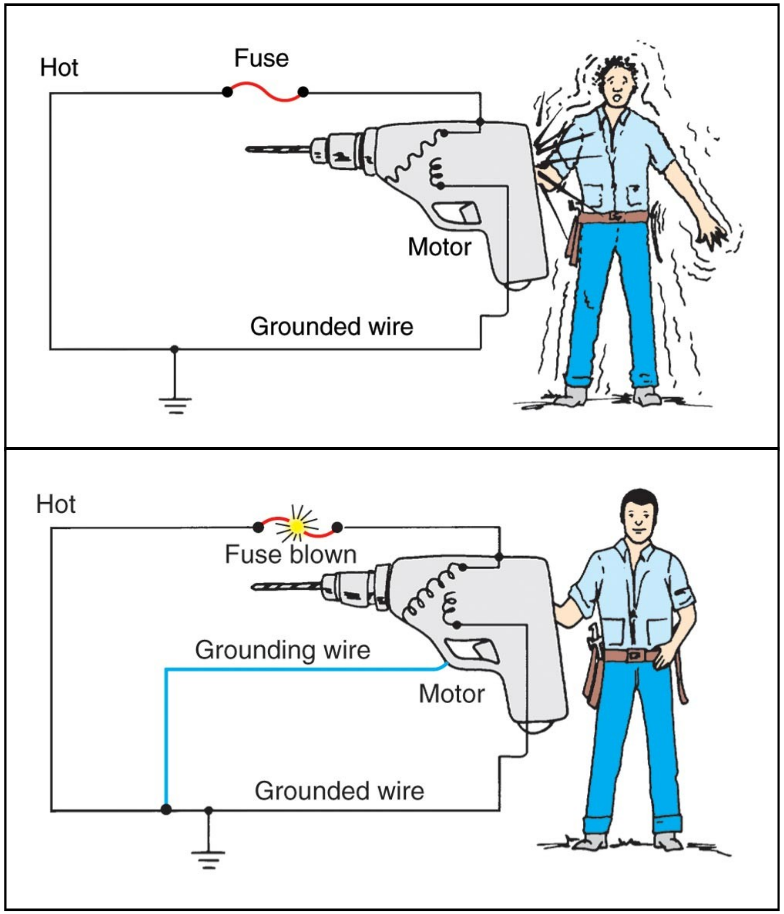
- Wired in parallel independent branches any particular circuit element can operate when others in the same circuit do not.



Electrical Safety

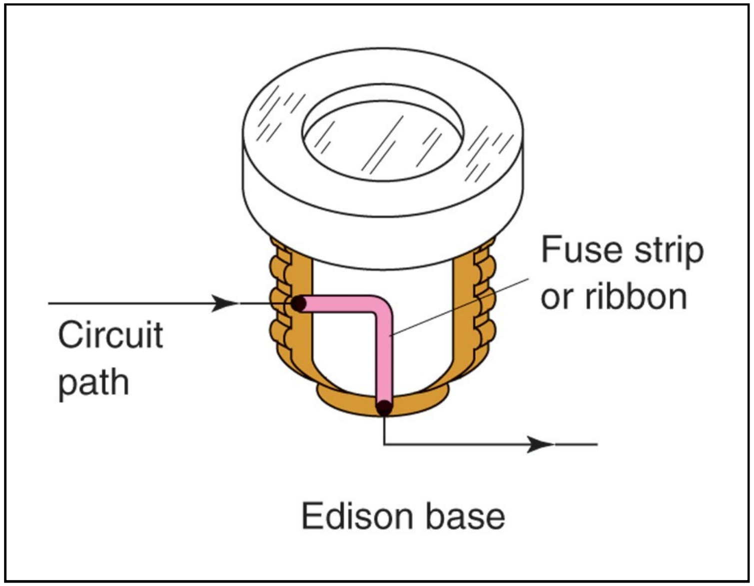
- Wires can become hot as more and more current is used on numerous appliances.
- Fuses are placed in the circuit to prevent wires from becoming too hot and catching fire.
- The fuse filament is designed to melt (and thereby break the electrical circuit) when the current gets too high.
- Two types of fuses: Edison and S-type
- Circuit Breakers are generally now used.

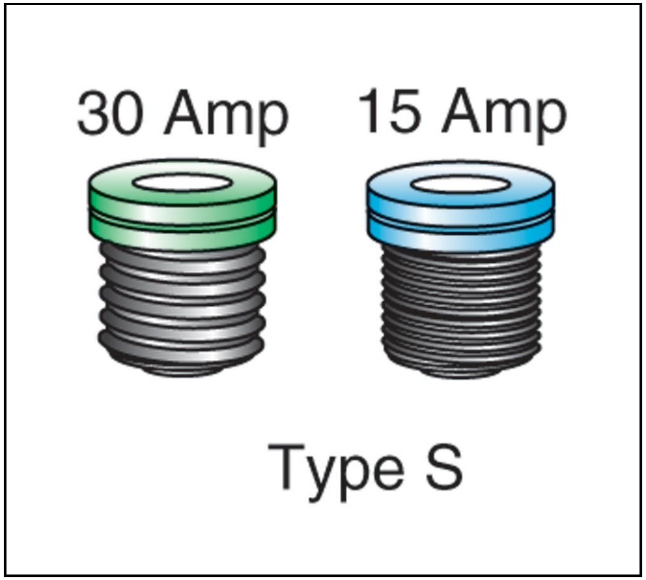
Electrical Safety with Dedicated Grounding



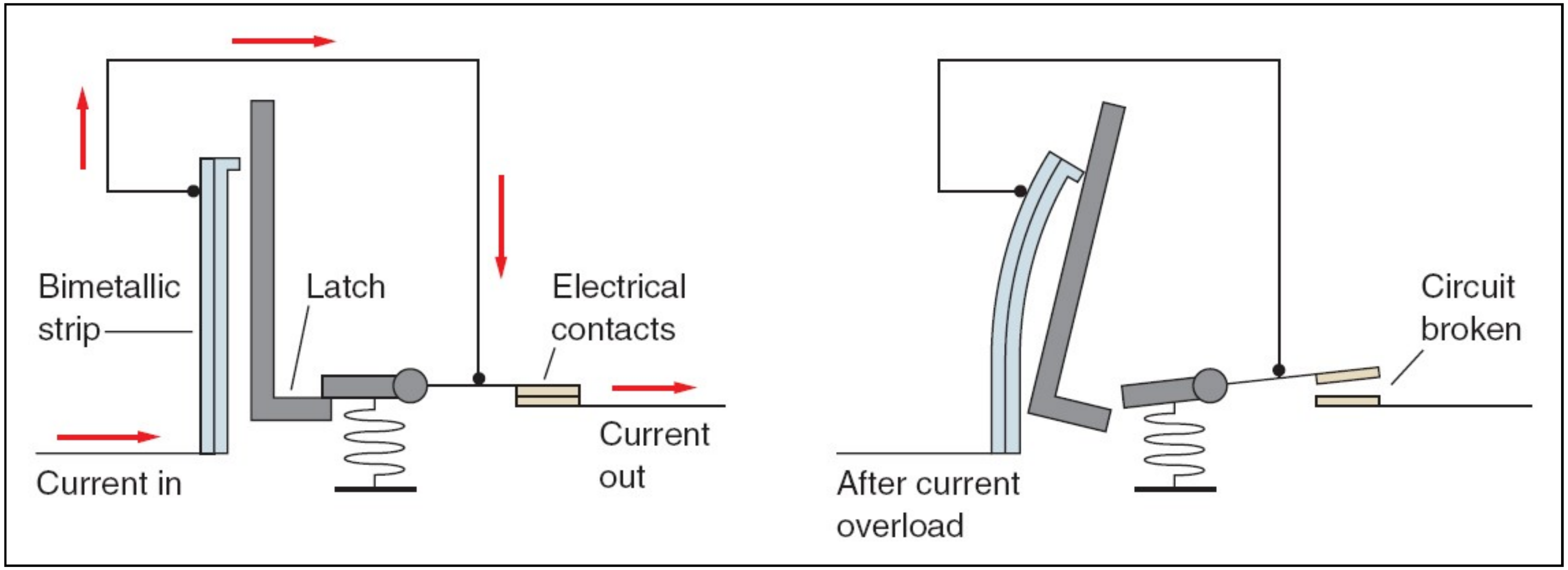
- A dangerous shock can occur if an internal 'hot' wire comes in contact with the metal casing of a tool.
- This danger can be minimized by grounding the case with a dedicated wire through the third wire on the plug.

Fuses


Fuse strip
or ribbon
Circuit
path
Edison base


30 Amp
15 Amp
Type S

Thermal type Circuit Breaker – as the current through the bimetallic strip increases, it becomes warmer (joule heat) and bends – “tripping” the circuit breaker.



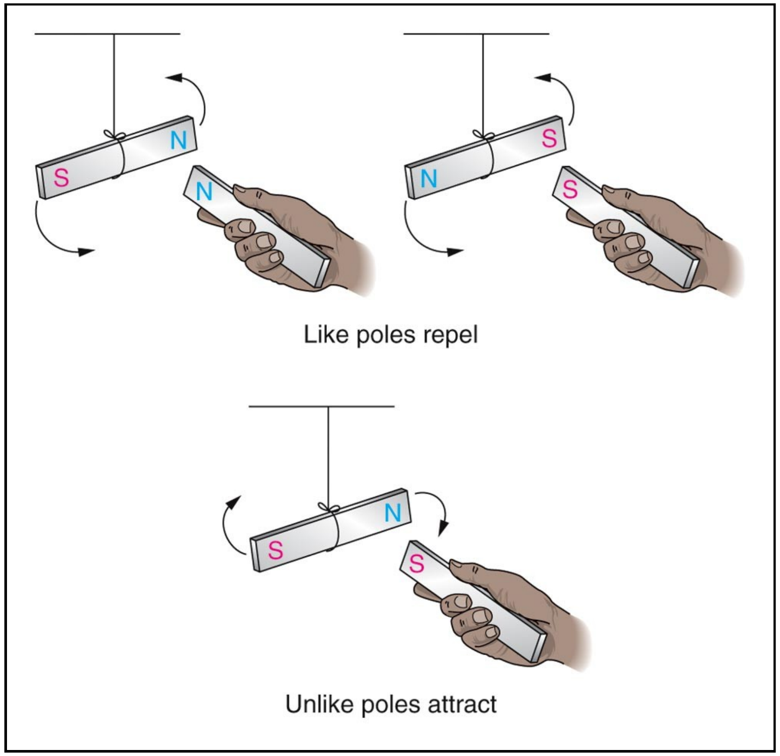
Magnetism

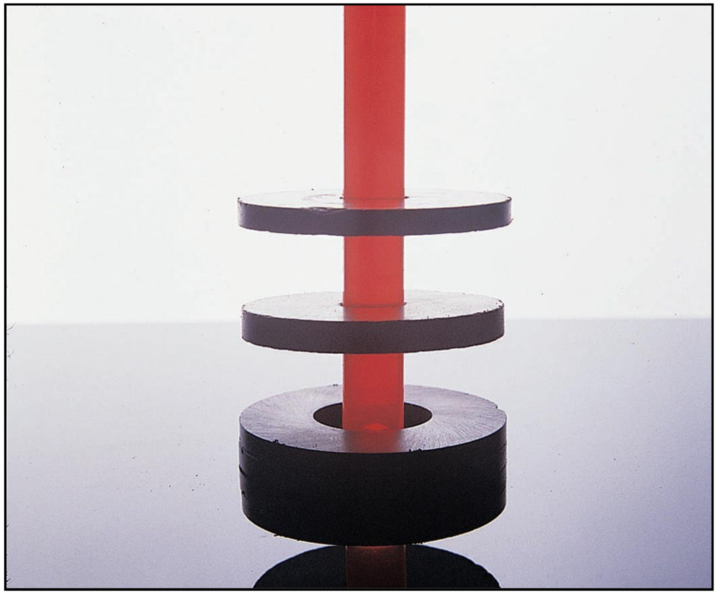
- Closely associated with electricity is magnetism.
- In fact electromagnetic waves consists of both vibrating electric and magnetic fields. These phenomena are basically inseparable.
- A bar magnet has two regions of magnetic strength, called the poles.
- One pole is designated “north,” one “south.”

Magnetic Poles

- The N pole of a magnet is “north-seeking” – it points north.
- The S pole of a magnet is “south-seeking” – it points south.
- Magnets also have repulsive forces, specific to their poles, called …
- <u>Law of Poles</u> – Like poles repel and unlike poles attract
  - N-S attract
  - S-S & N-N repel

Law of Poles





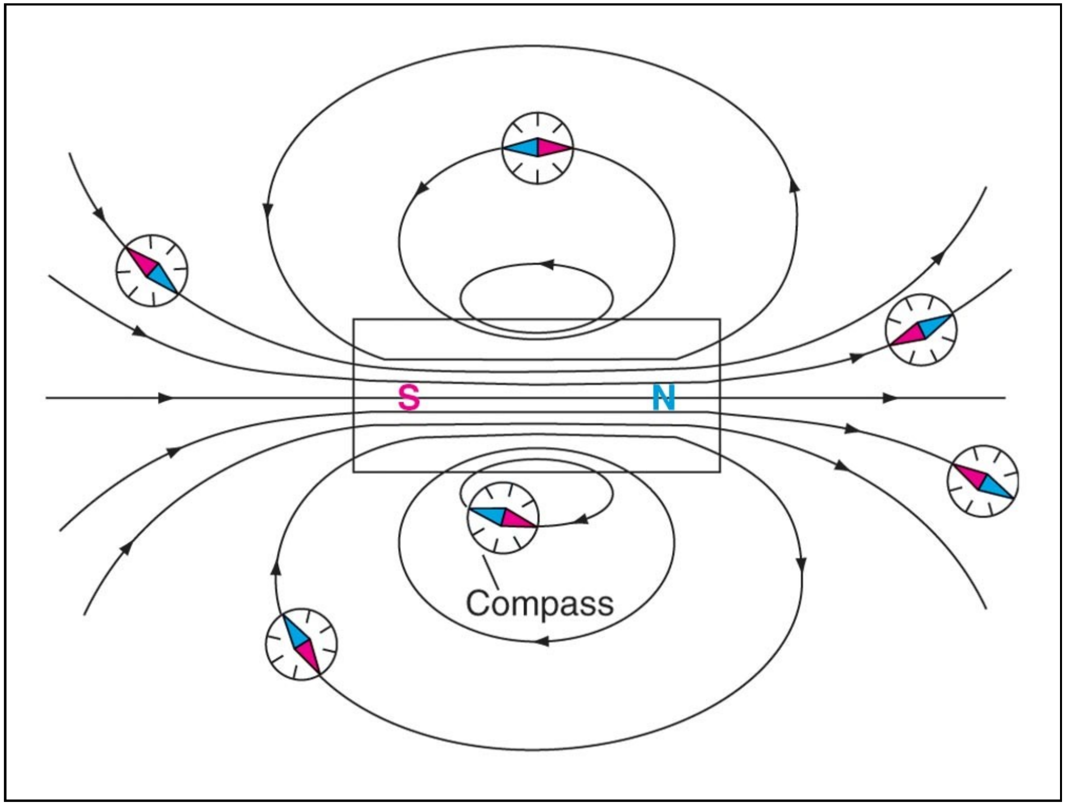
All magnets have two poles – they are dipoles

Magnetic Field

- <u>Magnetic field</u> - a set of imaginary lines that indicates the direction in which a small compass needle would point if it were placed near a magnet
- These lines are indications of the magnetic force field.
- Magnetic fields are vector quantities.

Magnetic Field

- The arrows indicate the direction in which the north pole of a compass would point.



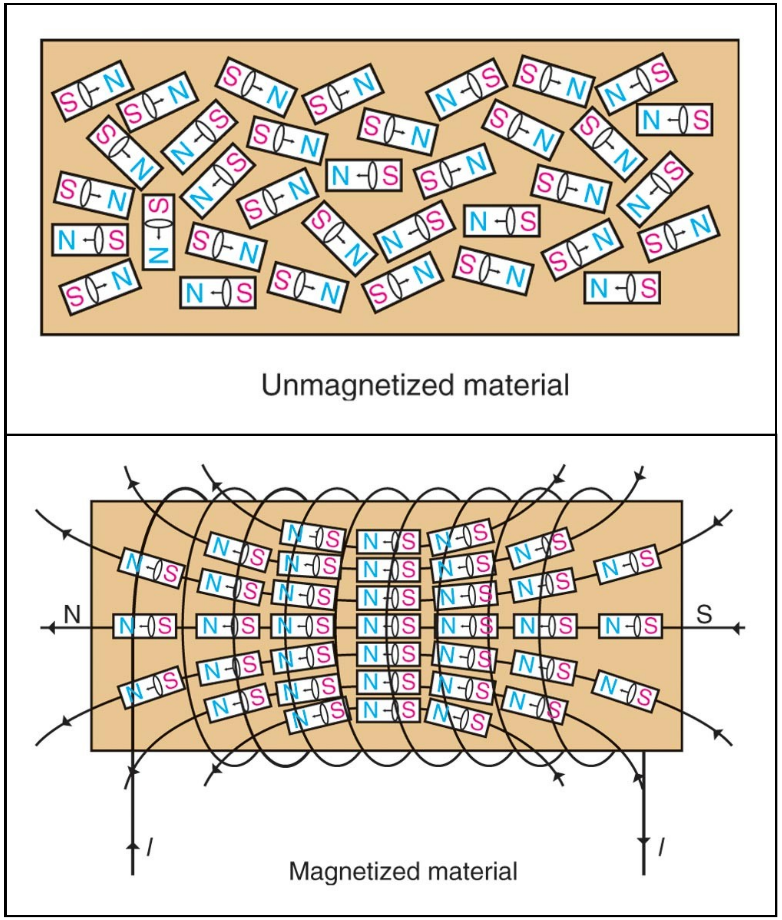
Source of Magnetism

- The source of magnetism is moving and spinning electrons.
- Hans Oersted, a Danish physicist, first discovered that a compass needle was deflected by a current-carrying wire.
  - Current open → deflection of compass needle
  - Current closed → no deflection of compass needle
- A current-carrying wire produces a magnetic field: stronger current → stronger field
- Electromagnet – can be switched on & off

Magnetic Materials

- Most materials have many electrons going in many directions, therefore their magnetic effect cancels each other out ➔ non-magnetic
- A few materials are ferromagnetic (iron, nickel, cobalt) – in which many atoms combine to create magnetic domains (local regions of magnetic alignment within a single piece of iron)
- A piece of iron with randomly oriented magnetic domains is not magnetic.

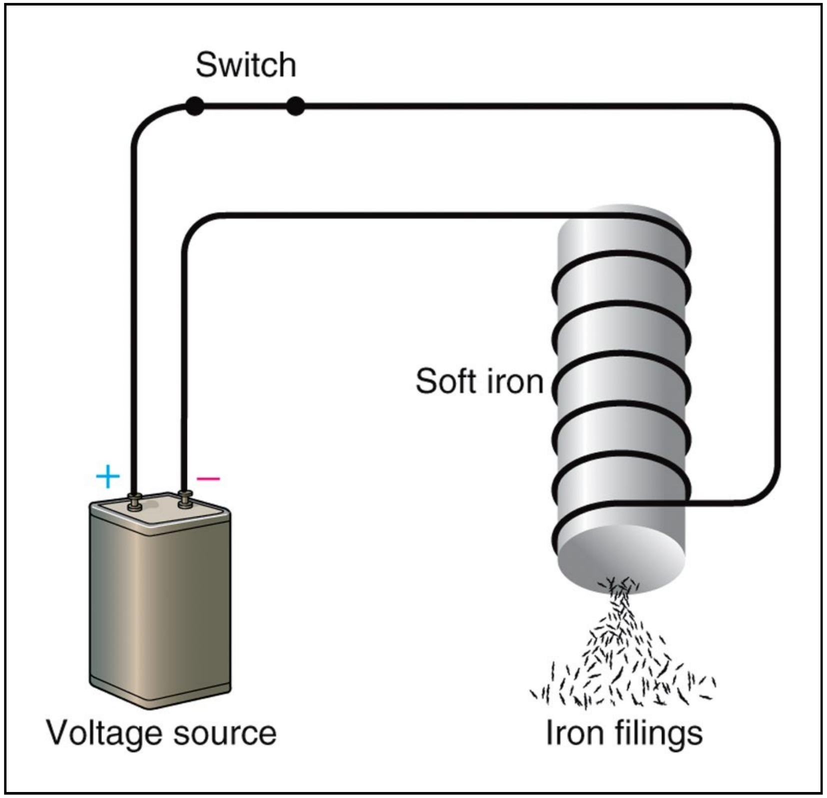
Magnetization



- The magnetic domains are generally random, but when the iron is placed in a magnetic field the domains line up (usually temporarily).

Electromagnets

- A simple electromagnet consists of an insulated coil of wire wrapped around a piece of iron.
- Stronger current → stronger magnet
- Electromagnets are made of a type of iron that is quickly magnetized and unmagnetized – termed “soft.”



Curie Temperature & Permanent Magnets

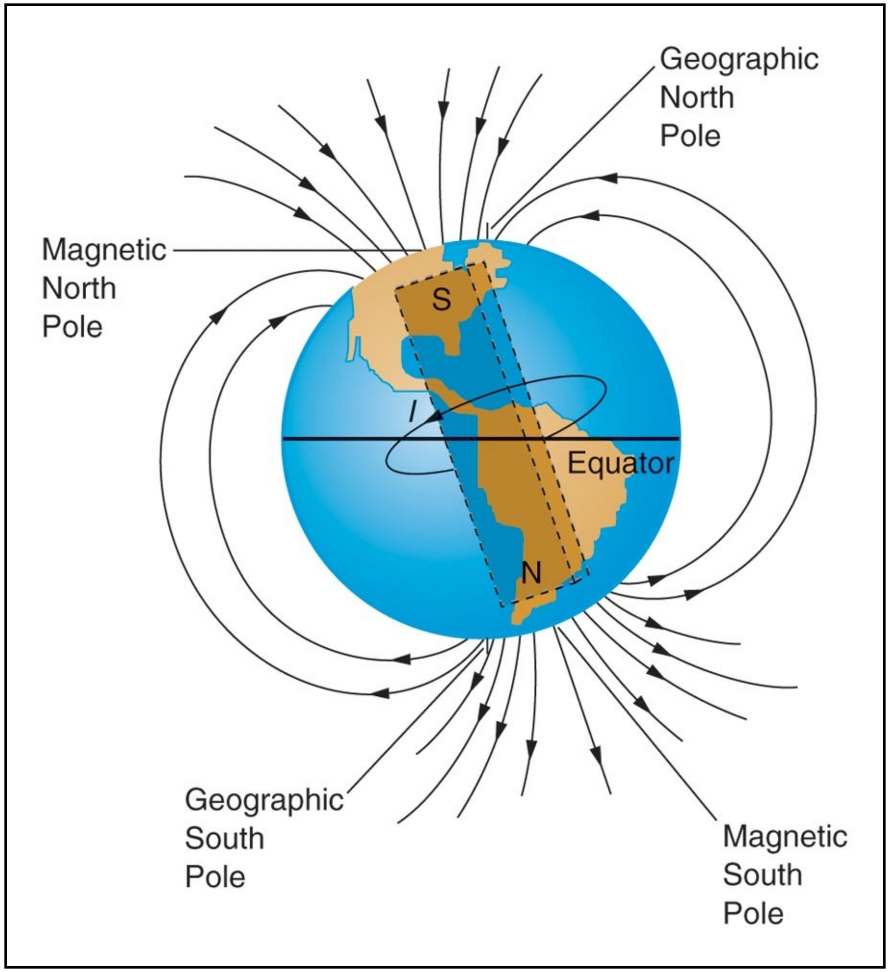
- Materials cease to be ferromagnetic at very high temperatures – the “Curie temperature” (770^{0}C for iron)
- Permanent magnets are made by permanently aligning the many magnetic domains within a piece of material.
- One way to create a permanent magnet is to heat the ferromagnetic material above the Curie temperature and then cool the material under the influence of a strong magnetic field.

Earth’s Magnetic Field

- This planet’s magnetic field exists within the earth and extends many hundreds of miles into space.
- The *aurora borealis* (northern lights) and *aurora australis* (southern lights) are associated with the earth’s magnetic field.
- Although this field is weak compared to magnets used in the laboratory, it is thought that certain animals use it for navigation.

Earth's Magnetic Field

- Similar to the pattern from a giant bar magnet being present within the earth (but one is not present!)



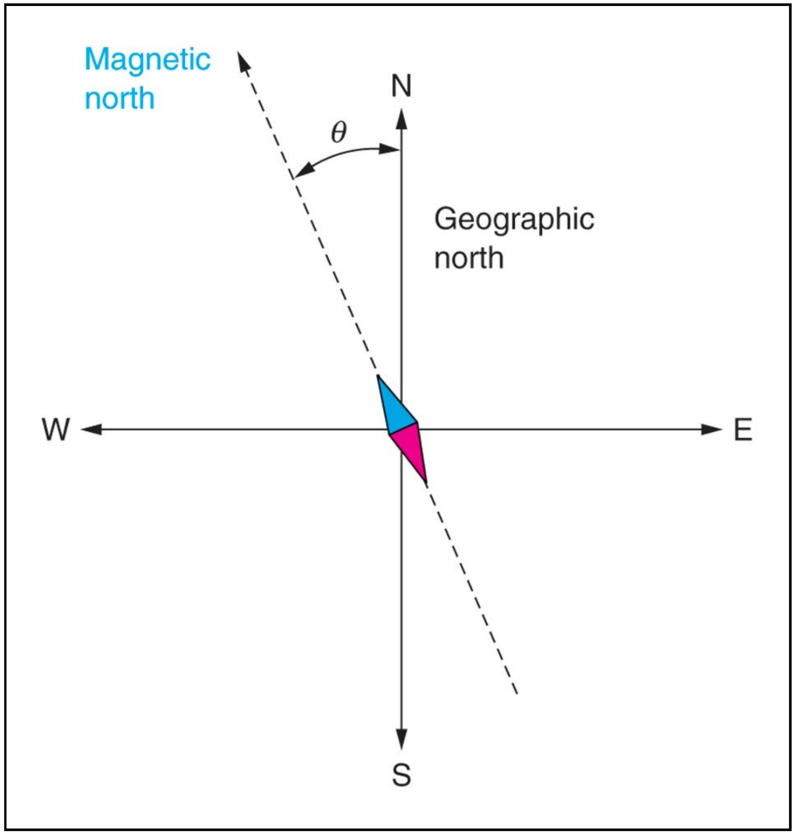
Earth’s Magnetic Field

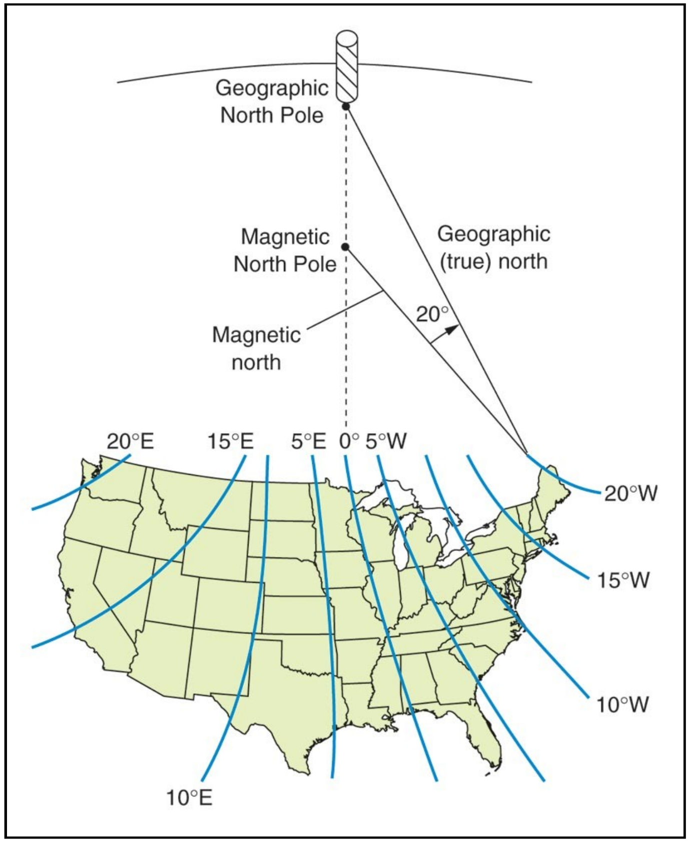
- The origin of the earth’s magnetic field is not completely understood.
  - Probably related to internal currents of electrically charge particles in the liquid outer core of the earth, in association with the earth’s rotation
- The temperatures within the earth are much hotter than the Curie temperature, so materials cannot be ferromagnetic.
- The positions of the magnetic poles are constantly changing, suggesting “currents.”

Magnetic Declination

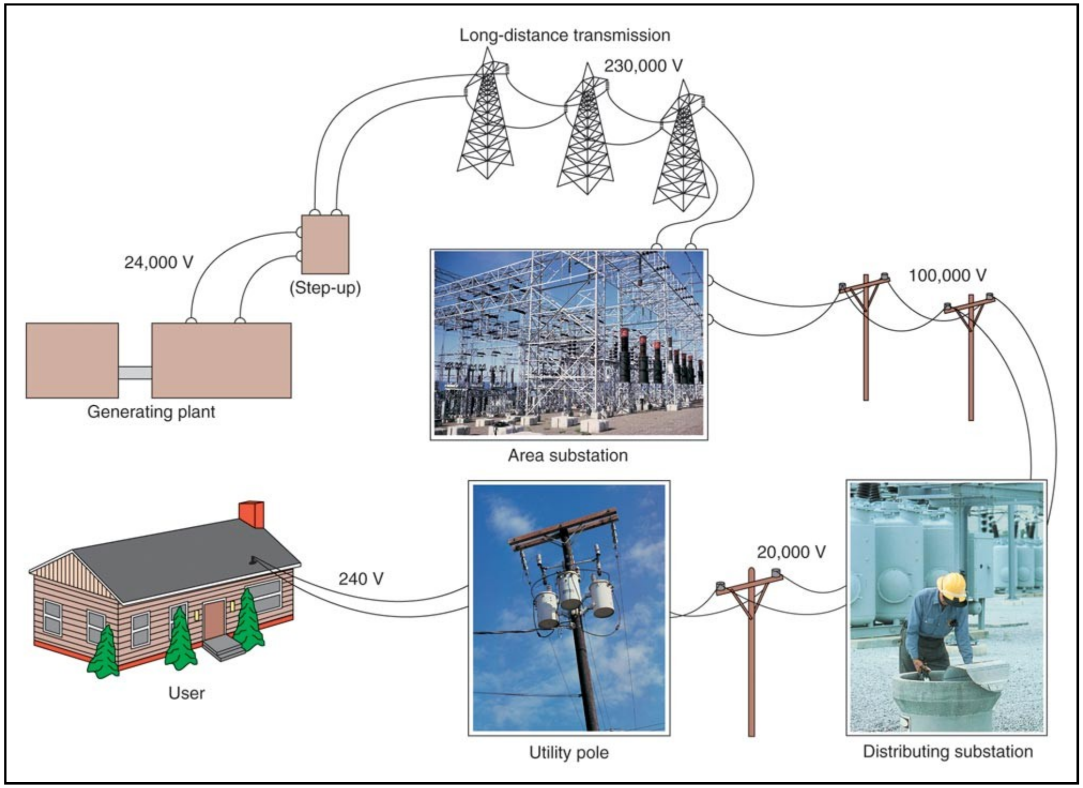
- <u>Magnetic declination</u> – the angle between geographic (true) north and magnetic north
- The magnetic declination varies depending upon one’s location on Earth.
  - In the northern hemisphere the magnetic North Pole is about 1500 km from the geographic North Pole.
- Therefore, a compass does not point to true north, but rather magnetic north.
  - An adjustment (magnetic declination) must be made to determine true north from a compass.

Magnetic Declination Needs to be known for proper navigation





Electrical Transmission System



Voltage is dramatically stepped-up at the generating plant to minimize joule heat loss during long-distance transmission. The voltage must then be stepped-down for household use.

Chapter 8 - Important Equations

- $F = kq_1q_2/r^2$ Coulomb's Law
- $I = q/t$ Current
- $V = W/q$ Voltage
- $V = IR$ Ohm's Law
- $P = IV = I^2R$ *Electric Power*

Chapter 8 - More Important Equations

- $R_s = R_1 + R_2 + R_3$... Resistance in Series
- $1/R_p = 1/R_1 + 1/R_2 + 1/R_3$ .... Resistance in Parallel
- $R_p = (R_1R_2)/(R_1 + R_2)$ Two Resistances in Parallel
- $V_2 = (N_2/N_1)V_1$ Transformer (Voltages and Turns)