This lecture will help you understand:

- Electric Force and Charge
- Coulomb’s Law
- Electric Field
- Electric Potential
- Voltage Sources
- Electric Current
- Electric Resistance
- Ohm’s Law
- Electric Current
- Electric Power
Static and Current Electricity

“Electricity is really just organized lightning.”
—George Carlin
Electric Force and Charge

Central rule of electricity
• opposite charges attract one another; like charges repel
Electric Force and Charge

Protons
• positive electric charges
• repel positives, but attract negatives

Electrons
• negative electric charges
• repel negatives, but attract positives

Neutrons
• neutral electric charge
Electric Force and Charge

Fundamental facts about atoms

1. Every atom is composed of a positively charged nucleus surrounded by negatively charged electrons.

2. Each of the electrons in any atom has the same quantity of negative charge and the same mass.
Electric Force and Charge

Fundamental facts about atoms (continued)

3. Protons and neutrons compose the nucleus. Protons are about 1800 times more massive than electrons, but each one carries an amount of positive charge equal to the negative charge of electrons. Neutrons have slightly more mass than protons and have no net charge.

4. Atoms usually have as many electrons as protons, so the atom has zero net charge.
Electric Force and Charge

Ion

- positive ion—atom losing one or more electrons has positive net charge
- negative ion—atom gaining one or more electrons has negative net charge
Electric Force and Charge

Electrons in an atom

- innermost—attracted very strongly to oppositely charged atomic nucleus
- outermost—attracted loosely and can be easily dislodged
Electric Force and Charge

Electrons in an atom

Examples:

• When rubbing a comb through your hair, electrons transfer from your hair to the comb. Your hair has a deficiency of electrons (positively charged).

• When rubbing a glass rod with silk, electrons transfer from the rod onto the silk and the rod becomes positively charged.
When you brush your hair and scrape electrons from your hair, the charge of your hair is

A. positive.
B. negative.
C. both A and B
D. neither A nor B
When you brush your hair and scrape electrons from your hair, the charge of your hair is

A. **positive.**
B. negative.
C. both A and B
D. neither A nor B

*Comment:*
And if electrons were scraped off the brush onto your hair, your hair would have a negative charge.
Electric Force and Charge

Conservation of Charge

- In any charging process, no electrons are created or destroyed. Electrons are simply transferred from one material to another.
Electric Force and Charge

Van de Graaff generator

- [http://www.youtube.com/watch?v=T0J5q43MSw8](http://www.youtube.com/watch?v=T0J5q43MSw8)
Coulomb’s Law

Coulomb’s law

- relationship among electrical force, charge, and distance discovered by Charles Coulomb in the 18th century
- states that 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
Coulomb’s Law

Coulomb’s law (continued)

- If the charges are alike in sign, the force is repelling; if the charges are not alike, the force is attractive.
- In equation form:

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

- Unit of charge is coulomb, C
- Similar to Newton’s law of gravitation for masses
- Underlies the bonding forces between molecules

\[ k = 9,000,000,000 \text{ Nm}^2/\text{C}^2 \]
According to Coulomb’s law, a pair of particles that are placed twice as far apart will experience forces that are

A. half as strong.
B. one-quarter as strong.
C. twice as strong.
D. four times as strong.
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Coulomb’s Law

Differences between gravitational and electrical forces

• electrical forces may be either attractive or repulsive
• gravitational forces are only attractive
Coulomb’s Law

Charge polarization

- Atom or molecule in which the charges are aligned with a slight excess of positive charge on one side and slight excess of negative charge on the other.
- example: Rub an inflated balloon on your hair and place the balloon on the wall. The balloon sticks to the wall due to charge polarization in the atoms or molecules of the wall.
Electric Field

Electric field

• space surrounding an electric charge (an energetic aura)
• describes electric force
• around a charged particle obeys inverse-square law
• force per unit charge
Electric Field

Electric field direction

• same direction as the force on a positive charge
• opposite direction to the force on an electron
Both Lori and the spherical dome of the Van de Graaff generator are electrically charged.
Electric Potential

Electric potential energy

• Energy possessed by a charged particle due to its location in an electric field. Work is required to push a charged particle against the electric field of a charged body.

(a)  (b)
(a) The spring has more elastic PE when compressed. (b) The small charge similarly has more PE when pushed closer to the charged sphere. In both cases, the increased PE is the result of work input.
Electric Potential

Electric potential (voltage)

- energy *per charge* possessed by a charged particle due to its location
- may be called *voltage*—potential energy per charge
- in equation form:

\[
\text{electric potential} = \frac{\text{electric potential energy}}{\text{amount of charge}}
\]
Electric Potential

Electric potential (voltage) (continued)

- unit of measurement: volt, \( 1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} \)

example:

- twice the charge in same location has twice the electric potential energy but the same electric potential

\( 2 \frac{E}{2} q = 3 \frac{E}{3} q = V \)

- three times the charge in same location has three times the electric potential energy but the same electric potential

Electric potential energy is measured in joules. Electric potential, on the other hand (electric potential energy per charge), is measured

A. in volts.
B. in watts.
C. in amperes.
D. also in joules.
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A. in volts.
B. in watts.
C. in amperes.
D. also in joules.
Electric Potential (continued)

- high voltage can occur at low electric potential energy for a small amount of charge
- high voltage at high electric potential energy occurs for lots of charge
Voltage Sources

Conductor

• any material having free charged particles that easily flow through it when an electric force acts on them
When you buy a water pipe in a hardware store, the water isn’t included. When you buy copper wire, electrons

A. must be supplied by you, just as water must be supplied for a water pipe.
B. are already in the wire.
C. may fall out, which is why wires are insulated.
D. none of the above
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Voltage Sources

Electric potential difference

• difference in potential between two points
  – charges in conductor flow from higher potential to lower potential
  – flow of charge persists until both ends of conductor reach the same potential
  – maintained for continuous flow by pumping device
Voltage Sources

Electric potential difference (continued)

example: water from a higher reservoir to a lower one—flow continues until no difference

– no flow of charge occurs when potential difference is zero
Voltage Sources

Electric potential difference (continued)

• A battery or generator can maintain a steady flow of charge
  – work is done in pulling negative charges apart from positive ones
  – electromagnetic induction at the generator terminals provides the electrical pressure to move electrons through the circuit
Voltage Sources

Electric potential difference

• in chemical batteries
  – work by chemical disintegration of zinc or lead in acid
  – energy stored in chemical bonds is converted to electric potential energy
Electric Current

Electric current

- flow of charged particles
  - in metal wires
    - conduction electrons are charge carriers that are free to move throughout atomic lattice
    - protons are bound within the nuclei of atoms
  - in fluids
    - positive ions and electrons constitute electric charge flow
Electric Current

Rate of electric flow

- measured in ampere (1 coulomb of charge per second)
- speed of electrons (drift speed) through a wire is slow because of continuous bumping of electrons in wire
- charge flows *through* a circuit; voltage is established *across* a circuit
Electric Current

Direct Current and Alternating Current

Direct Current

• charges flow in one direction

example: in a battery, electrons move through a circuit in one direction, from the repelling negative terminal toward the attracting positive terminal
Electric Current

Alternating current

• electrons oscillate to and fro around fixed positions.
• movement is produced by a generator or an alternator that switches the signs of charge periodically.
• commercial AC circuits are used in most residential circuits throughout the world and can be stepped up to high voltage for transmission over great distances with small heat losses, or stepped down where energy is consumed.
Electric Resistance

Current in a circuit is dependent on

• voltage
• electrical resistance in ohms

Resistors

• circuit elements that regulate current inside electrical devices

Resistors. The symbol of resistance in an electric circuit is \( \mathbf{\text{~ | | |}} \).
Electric Resistance

Factors affecting electrical resistance

• inversely proportional to cross-sectional area
  – thin wires, more resistance than thick wires

• directly proportional to length
  – doubling the length, doubles the resistance

• material
  – rubber—much more resistance than copper of the same size
Factors affecting electrical resistance (continued)

- temperature
  - the higher the temperature, the more the resistance
Electric Resistance

Semiconductors

• refers to materials that can alternate between being conductors and insulators

example:

• germanium
• silicon
Electric Resistance

Superconductors

• materials with zero electrical resistance to the flow of charge
• flow of charge is without generation of heat

High temperature superconductors

• refers to ceramic materials that can carry much current at a low voltage
Ohm’s Law

Ohm’s law

• relationship between voltage, current, and resistance

• states that the current in a circuit varies in direct proportion to the potential difference, or voltage, and inversely with the resistance
Ohm’s Law

Ohm’s law (continued)

• in equation form: \( current = \frac{voltage}{resistance} \)

example:

• for a constant resistance, current will be twice as much for twice the voltage
• for twice the resistance and twice the voltage, current will be unchanged

Resistors

• circuit elements that regulate current inside electrical devices
When you double the voltage in a simple electric circuit, you double the

A. current.
B. resistance.
C. both A and B
D. neither A nor B
When you double the voltage in a simple electric circuit, you double the

A. **current**.
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*Explanation:*

This is a straightforward application of Ohm’s law.

\[
current = \frac{voltage}{resistance}
\]
Ohm’s Law

Paul Hewitt demo

- [http://www.youtube.com/watch?v=a6YyEeqFFDA](http://www.youtube.com/watch?v=a6YyEeqFFDA)
Ohm’s Law

Electric shock

• damaging effects of shock result from current passing through the body

• electric potential difference between one part of your body and another part depends on body condition and resistance, which can range from 100 ohms to 500,000 ohms
Electric Circuits

Circuits

- any path along which electrons can flow from the negative terminal to the positive terminal
- complete circuit allows continuous flow of electrons with no openings or gaps
Electric Circuits

Circuits

• connected in two common ways
  – series
    • forms a single pathway for electron flow between the terminals of the battery, generator, or wall outlet
  – parallel
    • forms branches, each of which is a separate path for the flow of electrons
Electric Circuits

Series circuits

• Characteristics of series circuit
  1. electric current through a single pathway
  2. total resistance to current is the sum of individual resistances
  3. current is equal to the voltage supplied by the source divided by the total resistance of the circuit
Electric Circuits

Series circuits

• Characteristics of series circuit (continued)

4. the total voltage impressed across a series circuit divides among the individual electrical devices in the circuit so that the sum of the “voltage drops” across the resistance of each individual device and is equal to the total voltage supplied by the source

5. the voltage drop across each device is proportional to its resistance

6. if one device fails, current in the entire circuit ceases
Electric Circuits

Parallel circuits

• Characteristics of parallel circuit
  1. Voltage is the same across each device.
  2. The total current in the circuit divides among the parallel branches. The amount of current in each branch is inversely proportional to the resistance of the branch.
  3. The total current in the circuit equals the sum of the currents in its parallel branches.
Parallel circuits

• Characteristics of parallel circuit (continued)
  4. As the number of parallel branches is increased, the overall resistance of the circuit is decreased.
  5. A break in one path does not interrupt the flow of charge in the other paths.
Consider a lamp powered by a battery. Charge flows

A. out of the battery and into the lamp.
B. from the negative terminal to the positive terminal.
C. with a slight time delay after closing the switch.
D. through both the battery and the lamp.
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A. out of the battery and into the lamp.
B. from the negative terminal to the positive terminal.
C. with a slight time delay after closing the switch.
D. through both the battery and the lamp.

Explanation:
Remember, charge is already in all parts of the conducting circuit. The battery simply gets the charges moving. As much charge flows in the battery as outside. Therefore, charge flows through the entire circuit.
Electric Circuits

Parallel circuits and overloading

- Homes are wired in parallel. As more and more devices are connected to a circuit, more current moves through the wires. There is an amount of current each device can carry before it overheats. When the current is excessive, overheating can result in a fire.
Parallel circuits and overloading (continued)

- Also, the addition of excess devices in a parallel circuit increases the amount of current moving through the wires, producing an overload and overheating of the system, which can result in a fire.
Electric Circuits

Safety fuses

• are wires that melt when the given current is exceeded
• are connected in series along the supply line to prevent overloading in circuits
• are replaced by circuit breakers in modern buildings

Circuit breaker

• automatic switch that turns off when the current is excessive
Electric Power

Electric power
• rate at which electric energy is converted into another form
• in equation form:
  \[ \text{power} = \text{current} \times \text{voltage} \]
• in units: watts
example: 100-watt lamp draws 0.8 ampere