This lecture will help you understand:

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

Electric force:
• a fundamental force of nature can attract some objects and repel others

Electric charge:
• fundamental quantity underlying electric force and 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

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

• atom is normally electrically neutral
• same number of electrons outside nucleus as protons in the nucleus
• outer electrons in metals
  - loosely bound
  - can move freely
  - can flow
  - can join with other atoms.
Electric Force and Charge

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

Amount of work varies in pulling electrons from atoms of different substances
- very little for metals and other good conductors
- more work for rubber and other good insulators
Conductors and Insulators

Electric Conductors
Materials that allow easy flow of charged particles.
• outermost electrons of atoms attracted loosely and are easily dislodged — as in metals.
• innermost electrons strongly attracted to nucleus

Electric Insulators
Materials having tightly bound electrons.
When you brush Fido’s fur and scrape electrons from it, the charge of Fido’s fur is

A. positive.
B. negative.
C. both A and B.
D. neither A nor B.
When you brush Fido’s fur and scrape electrons from it, the charge of Fido’s fur 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 Fido’s fur, the fur would have a negative charge.
Electric Charge

Conservation of Charge

• In any charging process, no electrons are created or destroyed.
• Electrons are simply transferred from one material to another.
Coulomb’s Law

For a pair of charged objects much smaller than the distance between them, 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

Unit of charge is measured in coulombs, C. The charge of an electron is the fundamental charge = \( 1.6 \times 10^{-19} \) C.

\( k \) is the proportionality constant \( 9.0 \times 10^9 \) N \( \cdot \) m\(^2\)/C\(^2\) that converts units to force in Coulomb’s law.

• like signs of charge — force is repulsion
• unlike signs of charge — force is attraction
Coulomb’s Law

Differences and similarities between gravitational and electrical forces:

• Gravity only attracts. Electricity can both attract and repel.

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

• Both forces act in a straight-line direction between masses or charges.

• A force field surrounds both: Gravitational field for mass and electric field for charge.
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.
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.

Comment:
Note the similarity to questions about gravity.
Molecules in solids 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.
Polarization

Charge polarization

• Why a charged rubber balloon sticks to a wall.

The charged balloon induces polarization of molecules or atoms in the wall. Negative charges on balloon pull positive sides of molecules near it. Hence a slightly positive induced surface charge on the wall. The balloon sticks.
Electric Field

Electric field:

- occupies 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:

- used to visualize electric field
- show direction of electric field—away from positive and toward negative
- show intensity of electric field:
  bunched together $\Rightarrow$ field is strongest
  lines farther apart $\Rightarrow$ field is weaker
Electric Field

Both Lori and the spherical dome of the Van de Graaff generator are electrically charged.
Electric Potential Energy

Electric potential energy

• Energy possessed by a charged particle due to its location in an electric field.
Electric Potential Energy

- Work is required to push a charged particle against the electric field of a charged body.

(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 Energy

Released particle accelerates away from the sphere — 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 depends on the number of charges and separation distance.

Work done by a battery or generator is then available to a circuit as electrical PE.
Electric Potential

Electric potential:

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

Electric potential = electric potential energy per charge
Electric Potential

Electric potential and voltage are one and the same.
Unit of measurement is the volt.

1 volt = \( \frac{1 \text{ joule}}{\text{coulomb}} \)
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.
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.
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.
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.

Comment:
Even when you get an electric shock, the source of electrons is your own body. The shock occurs when the random motion of electrons becomes an energetic motion in one direction. Ouch!
Voltage Sources

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

Batteries and generators are common voltage sources.

Charges in a conductor tend to flow from higher potential to lower potential. The flow of charges persists until both ends reach the same potential. Without potential difference, no flow of charge.
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)

• Water and electric circuits compared

(a) Valve

(b) Switch

Resistance

Voltage source
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 PE
Electric Current

Sustained electric current requires suitable voltage source

• works by pulling negative charges apart from positive ones (available at the terminals of a battery or generator)

• energy per charge at terminals provides the difference in potential (voltage) to provide “electrical pressure” to move electrons through a circuit
Electric Current

Electric current:
- is the flow of electric charge
- in metal — conduction electrons
- in fluids — positive and negative ions
- measured in amperes

One **ampere** is the rate of flow of 1 coulomb of charge per second or 6.25 billion billion electrons per second.

Actual speed of electrons is slow through a wire, but electric signal travels near the speed of light.
Which of these statements is true?

A. Electric current is a flow of electric charge.
B. Electric current is stored in batteries.
C. Both are true.
D. Neither are true.
Which of these statements is true?

A. Electric current is a flow of electric charge.
B. Electric current is stored in batteries.
C. Both are true.
D. Neither are true.

*Explanation:*
Voltage, not current, is stored in batteries. The voltage will produce a current in a connecting circuit. The battery moves electrons already in the wire, not necessarily those in the battery.
Electric Current

Electric current may be

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

Accomplished in a generator or alternator by periodically switching the sign at the terminals.
Electrical Resistance

Electrical resistance:

• describes how well a circuit component resists the passage of electric current
• defined as the ratio of energy-source voltage to the current moving through the energy receiver
• measured in ohms 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
- materials of wire:
  - 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
- temperature:
  higher temperature (greater jostling of atoms), greater resistance
Electrical Conductors

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

Superconductors
certain metals that acquire infinite conductivity (zero resistance) at temperatures near absolute zero
Ohm’s Law

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

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

\[ \text{current} = \frac{\text{voltage}}{\text{resistance}} \quad \text{or} \quad I = \frac{V}{R} \]
When you double the voltage in a simple electric circuit, you double the

A. current.
B. resistance.
C. Both of the above.
D. Neither of the above.
When you double the voltage in a simple electric circuit, you double the

A. current.
B. resistance.
C. both of the above.
D. neither of the above.

Explanation:
This is a straightforward application of Ohm’s Law.

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

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

Electric circuits:
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 for electron flow
- A break anywhere in the path results in an open circuit; electron flow ceases
- Total resistance adds, more devices, less current
Electric Circuits

Parallel:
• A branched pathway is formed for the flow of electrons
• A break in any path doesn’t interrupt flow in other paths
• A device in each branch operates independently of the others
• Total current in the branches add
Electric Circuits

Parallel circuits and overloading

• Homes are wired in parallel. As more and more devices are connected, more current moves through the wires. Each device can carry a certain amount of current before overheating. Excessive current can result in a fire.
Electric Circuits

Safety fuses

- wires melt when current is excessive
- connected in series along supply line to prevent overloading
- commonly replaced by circuit breakers

Circuit breaker

- automatic switch that turns off when the current is excessive
When two identical lamps in a circuit are connected in parallel, the total resistance is

A. less than the resistance of either lamp.
B. the same as the resistance of each lamp.
C. less than the resistance of each lamp.
D. none of the above.
When two identical lamps in a circuit are connected in parallel, the total resistance is

A. less than the resistance of either lamp.
B. the same as the resistance of each lamp.
C. less than the resistance of each lamp.
D. none of the above.

Explanation:
Resistors in parallel are like extra lines at a checkout counter. More lines mean less resistance, allowing for more flow.
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.
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.

*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. So charge flows *through* the entire circuit.
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