Note on Posted Slides

- These are the slides that I intended to show in class on Mon. Mar. 18, 2013.
- They contain important ideas and questions from your reading.
- Due to time constraints, I was probably not able to show all the slides during class.
- They are all posted here for completeness.

PHY205H1S Physics of Everyday Life

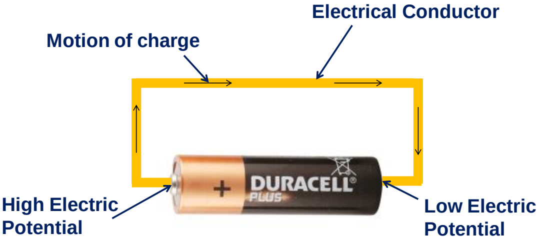
Class 17: **Electric Current**

- Flow of Charge
- Electric Current
- Voltage Sources
- Electrical Resistance
- Ohm's Law
- DC and AC
- Speed and Source of Electrons in a Circuit
- Electric Power
- Light bulbs
- Electric Circuits

[image from http://torontoist.com/2013/02/toronto-invents-the-incandescent-light-bulb/]

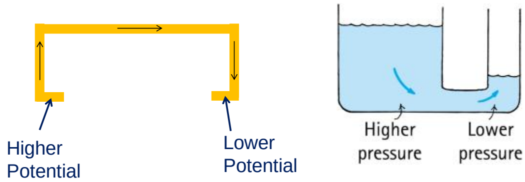
Flow of Charge

- When the ends of an electrical conductor are at different electric potentials—when there is a **potential difference**—charge flows from one end to the other.



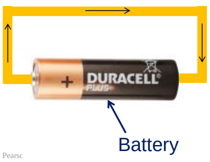
Electricity/Water Analogy:

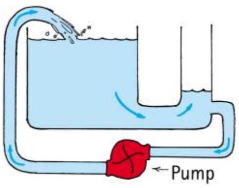
- Electric charge flows from higher potential to lower potential, if it can.
- Water flows from higher pressure to lower pressure, if it can.



Continuing the Analogy…

- To maintain a continuing flow of charge in a conductor, a **battery** must be provided to maintain the potential difference (=voltage).
- To maintain a continuing flow of water in a pipe, a **pump** must be provided to maintain the pressure difference





Electric Current

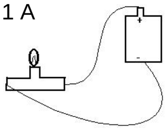
- When charged particles move, transferring electric charge from one place to another, this is called **electric current**
- A **"conductor"** is a material having free charged particles that easily flow through it when an electric force acts on them
- In a conducting solid metal, negatively charged electrons are free to move around while the positive nuclei remain fixed in the atomic lattice
- In certain types of solid semiconductors, positively charged electron holes are free to move around
- In ionic liquids, positive or negative ions can carry electric charge from one place to another

Electric Current is a Number

- Electric current is the **rate** that charge moves from one point to another
- The common symbol for current is I

$$I = \frac{\Delta q}{\Delta t}$$

- The unit of current is Coulombs per second (C/s)
- 1 C/s = 1 Ampere = 1 Amp = 1 A



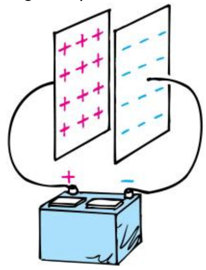
[image from http://people.oregonstate.edu/~joneski/electric.htm]

Electric Current
CHECK YOUR NEIGHBOR

A capacitor begins with two neutral metal plates.
A battery is attached and charges up the capacitor, so that 6 seconds later there is +3 Coulombs of charge on the positive plate, and -3 Coulombs of charge on the negative plate.

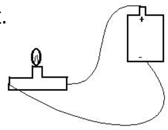
What was the average current running through the battery as the capacitor was charging?

A. Zero
B. 0.33 Amps
C. 0.5 Amps
D. 1 Amp
E. 2 Amps



Voltage is a Number

- Electric potential difference is called “voltage”
- Voltage between two points causes electric current in a conductor flow from higher potential to lower potential.
- No current flows when the voltage is zero
- The unit of voltage is Volts
- 1 Volt = 1 V = 1 Joule per Coulomb
- We say that when voltage is set up *across* a conducting object, it can cause a current to flow *through* the conducting object.



[image from http://people.oregonstate.edu/~joneski/electric.htm]

How Does a Battery Work?

- Energy is stored in a battery in chemical bonds
- When current flows through a battery, work is done by chemical disintegration of zinc or lead in acid
- This energy is carried by the electric charges as they travel through the circuit, and can be used to power a light-bulb, for example

Electric Current
CHECK YOUR NEIGHBOR

What does a good DC battery supply you with, such as this brand-new Duracell?

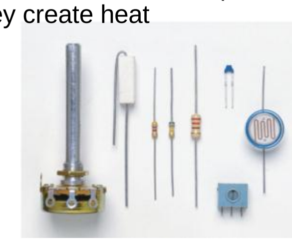
A. A steady supply of **current** to put into a circuit.
B. A steady rate of **energy** flow into a circuit.
C. A constant **voltage** to apply across a circuit.

Electric Resistance

Current in a circuit depends on:
- voltage.
- electrical resistance.

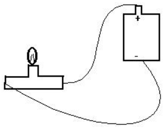
Resistors are circuit elements that use up energy; usually they create heat

In a circuit diagram, the symbol for a resistor is: —\/\/\/—



Resistance is a Number

- When you apply a voltage across an object, the amount of current depends on the object's resistance.
- Resistance of an object is measured in Ohms
- 1 Ohm = 1 Ω = 1 Volt per Amp
- The higher the resistance of an object, the less current will flow through it for a given voltage.

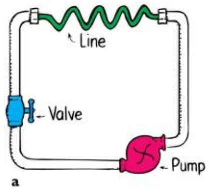


[image from http://people.oregonstate.edu/~joneski/electric.htm]

Electric Current
CHECK YOUR NEIGHBOR

A pump is pushing water through a narrow wiggly pipe, called a "line".
If you increase the length of the line, without changing the pressure of the pump, how will this affect the rate that water flows through it?

A. The flow rate will decrease
B. The flow rate will increase
C. The flow rate will stay the same



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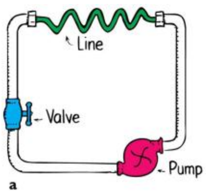


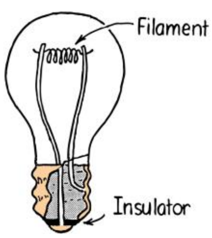
Electric Resistance

- Factors affecting electrical resistance of an object:

1. Material
   – Rubber is much more resistive than copper
2. Cross-sectional area
   – Thin wires have more resistance than thick wires
3. Length
   – An object twice as long has twice as much resistance.

Electrical Resistance

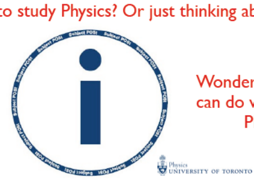
- For some materials, the resistance can increase dramatically with temperature
- For example, the filament in a light bulb increases its resistance after it has been on for a short time, as it warms up.
- The current is high at first, then decreases.



U of T Physics POSt Information Sessions

Always wanted to study Physics? Or just thinking about it?

Surprised how much you enjoyed your Intro Physics courses?



Wondering what you can do with a B.Sc. in Physics?

Come to the Physics Info Sessions during POSt Enrollment Open House!

- Physics Lounge, MP110 (behind Burton Tower elevators)
- Wednesday, March 20, 1-3 p.m. (slide presentation at 1 p.m.).
- Thursday, March 21, 2-4 p.m. (slide presentation at 3 p.m.).

Instructors and coordinators will be available to discuss the U of T physics program during both sessions. Come get info, brochures, and refreshments.

Ohm's Law

- The current in a circuit varies in direct proportion to the potential difference, or voltage, and inversely with the resistance

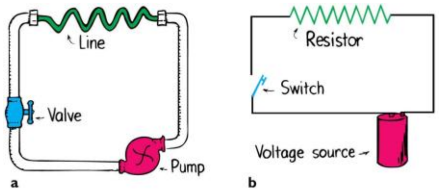
$$\text{Current} = \frac{\text{voltage}}{\text{resistance}}$$

$$I = \frac{V}{R}$$

Examples:
- 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.

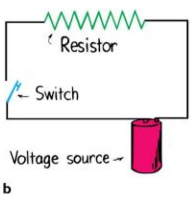
Continuing the Analogy…

- If you increase the pressure on the pump, water will flow **faster** through the line (analogous to increasing **voltage**)
- If you keep the pressure the same, but make the line longer or narrower, water will flow **slower** through the line (analogous to increasing **resistance**)



Electric Current
CHECK YOUR NEIGHBOR

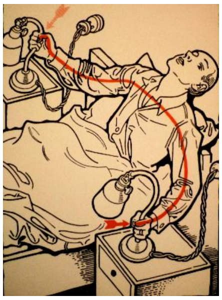
A battery is set up to push current through a resistor. The battery has a voltage of 100 V. The resistor has a resistance of 500 Ω.
When you close the switch, what is the current flowing around the circuit?



A. 0.2 A
B. 5 A
C. 100 A
D. 500 A
E. 50,000 A

You are a resistor!!

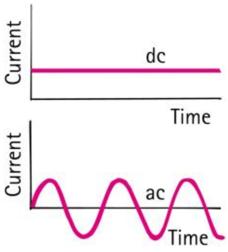
- The human body has a resistance, which depends on the exact path through your body, and whether your hands are wet or dry.
- If your hands are moist, the resistance between them can be as low as 500 Ω
- So if there is a voltage of 100 V between your hands, this will set up a current of 0.2 A, straight through your heart!
- Electrical current traveling through your body can damage tissue, and interfere with the beating of your heart (which is electrical)



[image from http://www.retronaut.com/2012/10/30-ways-to-die-by-electrocution]

Direct and Alternating Current

- Direct current (dc)
  - Flows in one direction only.
  - Current always flows from the positive terminal toward the negative terminal.
- Alternating Current (ac)
  - Current in the circuit flows first in one direction and then in the opposite direction, alternating to and fro many times per second.
  - This is accomplished by alternating the polarity of voltage at the generator or other voltage source.



Direct and Alternating Current

- Commercial electricity in North America is alternating current (ac):
  - 60 cycles per second
  - Voltage is 120 V
- Power transmission is more efficient at higher voltages.
  - Europe and China adopted 220 V as their standard.
  - Canada and the U.S. continued with 120 V because so much equipment was already installed.

Direct and Alternating Current

- Converting from ac to dc
  - Household current is ac, but current in laptop or cell phone is dc.
  - The AC to DC converter uses a *diode,* a tiny electronic device that acts as a one-way valve to allow electron flow in one direction only.

Electric Current
CHECK YOUR NEIGHBOR

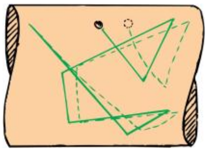
When you turn on a light switch,

A. An electric field is set up in along the wire, which immediately begins pushing electrons in the light.
B. Electric current immediately begins flowing in the switch, which pushes electrons who bump into neighbouring electrons, all the way up to the light, like a sequence of dominoes.
C. The switch sends a stream of electrons toward the light, which, when it reaches the light, makes the light go on.

Speed and Source of Electrons in a Metal Wire

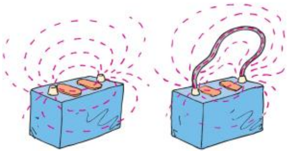
When we flip the light switch on a wall and the circuit, an electric field is established inside the conductor.

- The electrons continue their random motions while simultaneously being nudged by the electric field.
- Current is established through the wires at nearly the speed of light.
- It is *not* the electrons that move at this speed.
- It is the electric field that can travel through a circuit at nearly the speed of light.



Speed and Source of Electrons in a Circuit

- If the voltage source is dc, like the battery, electric field lines are maintained in one direction in the conductor.
- Conduction electrons are accelerated by the field in a direction parallel to the field lines.
- Before they gain appreciable speed, they “bump into” the anchored metallic ions in their paths and transfer some of their kinetic energy to them.



Speed and Source of Electrons in a Circuit

Misconceptions about electric current:

“Current is propagated through the conducting wires by electrons bumping into one another.”

- NOT true: Electrons that are free to move in a conductor are accelerated by the electric field impressed upon them.
- True, they do bump into one another and other atoms, but this slows them down and offers resistance to their motion.
- Electrons throughout the entire closed path of a circuit all react simultaneously to the electric field.

Speed and Source of Electrons in a Circuit

Misconceptions about electric current:

“Electrical outlets in the walls of the homes are a source of electrons.”

- NOT true: The outlets in homes are ac. Electrons make no net migration through a wire in an ac circuit.
- When you plug a lamp into an outlet, *energy* flows from the outlet into the lamp, not electrons. Energy is carried by the pulsating electric field and causes vibratory motion.
- Electrical utility companies sell *energy.* You provide the electrons.

Electric Power

- Power is the rate at which electric energy is used up in a circuit.
- Power = current × voltage
- In units:

$$\text{Amps} \times \text{Volts} = \left(\frac{\cancel{\text{Coulombs}}}{\text{second}}\right) \times \left(\frac{\text{Joules}}{\cancel{\text{Coulomb}}}\right) = \left(\frac{\text{Joules}}{\text{second}}\right) = \text{Watts}$$

Check your neighbour

- How much current is drawn by a 100 Watt light bulb, when used with a normal 120 Volt power supply?

A. 0.8 A
B. 1.2 A
C. 100 A
D. 120 A
E. 12,000 A

Example

- An electric iron is connected to a 120 Volt source, and draws 9 A of current.
- How much heat does the iron generate in one minute?
- How much charge flows through the iron in one minute?

Compact Fluorescent Lamps (CFLs)

- Incandescent bulbs dissipate most of their energy in the form of heat, not light. So, they are not energy efficient.
- Fluorescent lamps, on the other hand, emit much less heat, which is why you can touch them without burning yourself.

- Compact fluorescent lamps (CFLs) are a type of fluorescent lamp that fits into a standard lightbulb socket.
- For the same wattage, CFLs emit much more light and much less heat than incandescent bulbs.

Light-Emitting Diodes (LEDs)

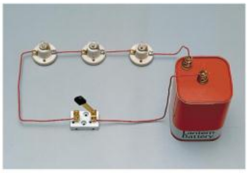
- Another light source even more long-lasting is the light-emitting diode (LED).
  - The most primitive being the little red lights that tell you whether your stereo is on or off
- Between CFLs and LEDs, common-use incandescent bulbs will soon be history!

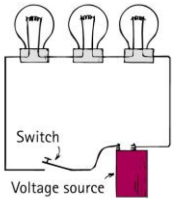
Electric Circuits

- 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

Series Circuits

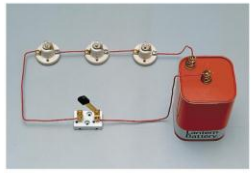
- Characteristics of series circuits
  1. Electric current through a single pathway.
  2. Total resistance to current is the sum of individual resistances.
  3. Current is equal to the voltage supplied by the source divided by the total resistance of the circuit.

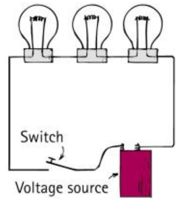




Series Circuits

- Characteristics of series circuits
  4. The sum of the voltage drops across the series resistors is equal to the total voltage supplied by the source.
  5. The voltage drop across each device are proportional to its resistance.
  6. If one device fails, current in the entire circuit ceases.





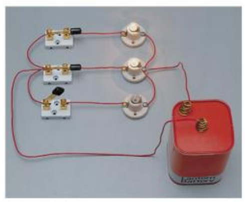
Electric Circuits
CHECK YOUR NEIGHBOR

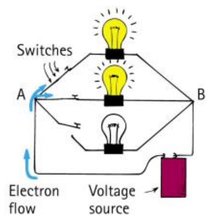
When two identical lamps in a circuit are connected in series, the total resistance is

A. less than the resistance of either lamp.
B. the same as the resistance of each lamp.
C. more than the resistance of either lamp.

Parallel Circuits

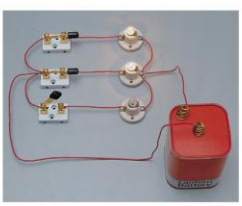
- Characteristics of parallel circuit
  1. Voltage is the same across each device.
  2. The total current in the circuit divides among the parallel branches.
  3. The total current in the circuit equals the sum of the currents in its parallel branches.

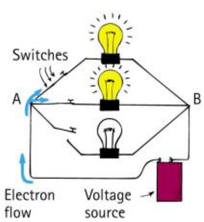




Parallel Circuits

- Characteristics of parallel circuit
  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.





Electric Circuits
CHECK YOUR NEIGHBOR

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. more than the resistance of either lamp.

Parallel Circuits

- The more parallel resistors are added, the lower the total resistance of the circuit, since there are more paths for the current to go through
- If one path breaks, the current continues through the remaining paths

Before class on Wednesday

- Please read Chapter 24, or at least watch the 10-minute pre-class video for class 18.

- Something to think about:
- What is an electromagnet, and how does it work?