Lesson 1 Ohm's Law

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<u>Lesson 1: Ohm's Law</u>

<u>A. Voltage:</u>

•example 1: fill in the following key facts about voltage

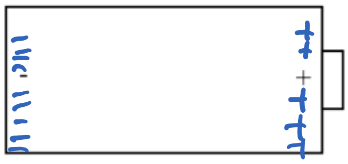
a) definition: energy per charge

b) units: $\frac{J}{C} = V$

V=voltage/potential (volt)=scalar
PE =Joules
q=test charge (Coulomb)

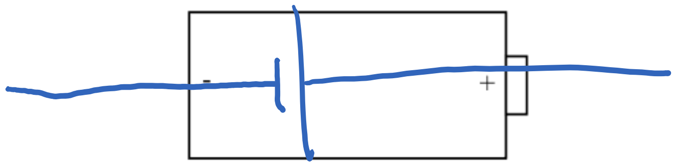
c) other words for voltage: potential

d) what happens inside a voltage source?



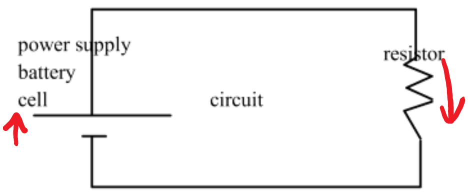
work is done separating charges

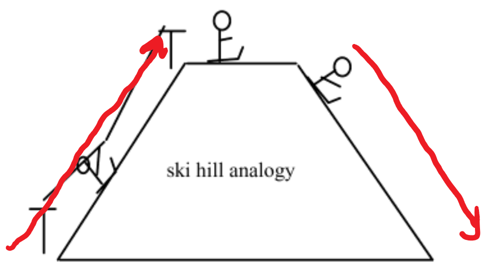
e) the circuit symbol for a voltage source:



•To help understand what is happening in electric circuits, it is helpful to have a mechanical analogy. The analogy we will use here is the ski hill analogy. Recall that in the previous lesson, we said that the gravitational analogy of voltage (PE/charge) is height (PE/mass /g).

So the voltage at a point in the circuit is like the height at a certain point on the mountain. The voltage gain in the cell is like the height a skier gains on the chairlift. The voltage drop in the resistor is like the height lost as a skier moves down a ski run



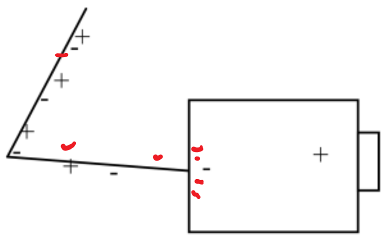


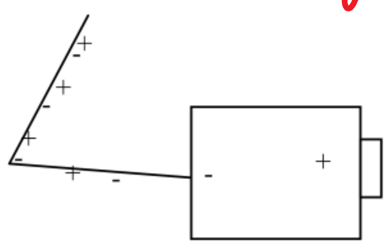
So, potential (or voltage) is like height. Positive charges want to fall downhill in the same way that a ball wants to roll downhill. PE_{grav} (mgh) is like PE_{elect} (qV). The only reason the V doesn't have a constant like "g" in front of it is due to how we defined the volt. $mgh \sim qV$

B. Electric Current

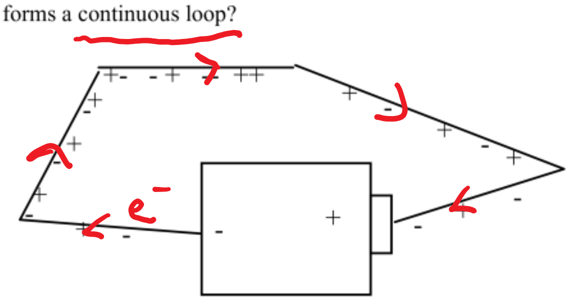
•example 2:
a) what happens if we connect a wire to one side of a voltage source?

nothing





b) what if the wire forms a continuous loop?

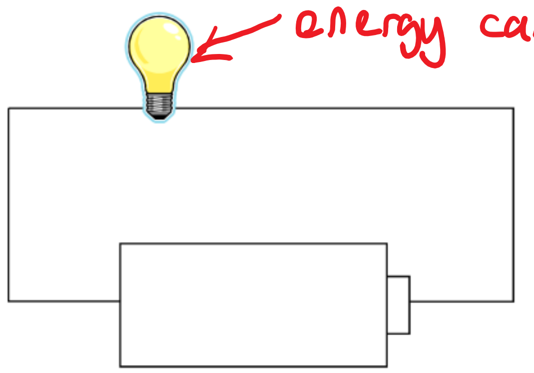


changes would flow

c) what is the problem with the circuit in part b ?

Nowhere for the energy to go. It will heat up the wires

d) why is this a better circuit?



energy can be lost in the bulb

So, electrons need a completed circuit for current to flow!

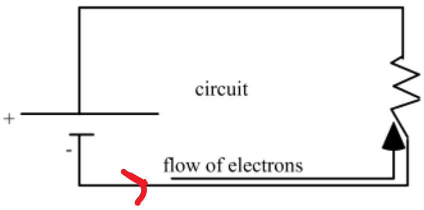
Video:Brainiac Electric Fence

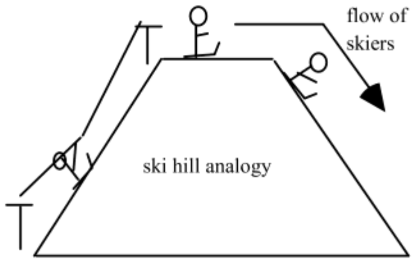
•Electric Current is defined as: the rate of flow of charge in a circuit

$$I = \frac{Q}{t} \qquad Q = It$$

I=current = Amp = C/s = scalar
Q = charge flow (Coulombs)
t= time (seconds)

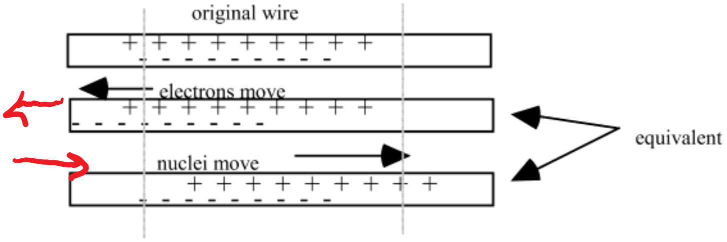
•In the ski hill analogy, the flow of charges in a circuit (Coulombs per second) is like the flow of skiers up and down a ski hill (kilograms per second). Since electrons flow at constant speed in a circuit, we will assume that skiers use their skis to control their speed and move down the hill at constant speed.





•One problem we encounter with this analogy is that in the circuit, is that it is electrons that flow, from the lower voltage (-) terminal through the wire to the higher voltage (+) terminal.

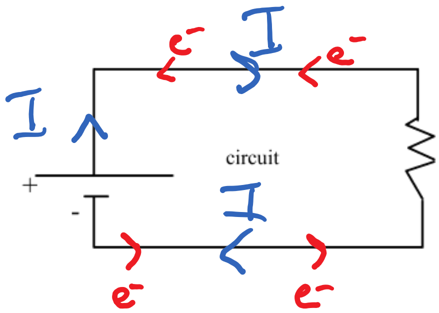
We would like to be able to say that current flows downhill, from higher (+) voltage to lower (-) voltage. For this reason, we choose to focus on the positive charges (nuclei). The uphill flow of electrons is entirely equivalent to a downhill flow of positive charges(as shown in the diagram), even though the positive charges don't actually move!

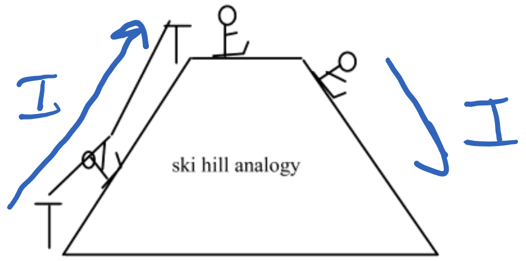


•what we call current then is actually the downhill flow of positive charges (some books call this 'conventional current'). If we are asked about the direction of electron flow we need to remember that it is opposite to the current.

•example 4: draw the direction of

a) electron flow red
b) current (conventional current) blue

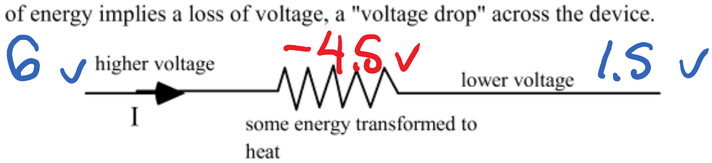




C. Ohm's Law and Resistance

•Every circuit offers some resistance (R) to the flow of charge. The circuit symbol for a resistor is a series of short angled lines, which you should recognize from Science 9:

•The resistance is due to 'electric friction' where electrons collide with the atoms of the material they are passing through, which causes them to lose energy. This energy lost by the electrons heats up the material they are passing through. A loss of energy implies a loss of voltage, a "voltage drop" across the device.

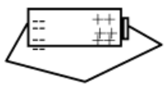


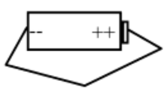
•the amount (I) of flow through the circuit depends on the total amount of resistance (R) and on the voltage applied (V) to the circuit

•example 5: a) what can be said about the current flow in each case? Fill in either large current flow OR small current flow

i) high resistance ---> low I

ii) low resistance---> high I

iii) large volt drop  --> higher I

iv) small volt drop  --> lower I

b) write a word equation relating current flow, voltage drop, and resistance

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

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

•as it is more commonly written:

$V = IR$

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

V=voltage drop across device (volt)
I=current through device (Ampere)
R= resistance of device=scalar

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

•technical comment: we should really write ΔV for voltage drop and Ohm's Law should really state ΔV = IR. But this notation is cumbersome and for this reason the Δ is dropped. So when speaking of circuits, we should read the symbol V as "voltage drop".

•the units of resistance are Ohms. One Ohm of resistance means that a voltage drop of 1 volt will give a current of 1 Ampere.

$$1\ \Omega = 1\frac{\text{V}}{\text{A}}$$

Good conductors have low resistance, and poor conductors (insulators) have large resistance.

•example 6: mix and match typical resistances

		resistance (R) in ohms (Ω)
1 metre of metal (copper) wire	.1 Ω	~~200 Ω~~
light bulb (very thin wire)	200 Ω	~~0.1 Ω~~
electric motor (coils of wire)	5 Ω	~~100 000 Ω~~
human skin	100000 Ω	~~5Ω~~
average lab resistor	2200 Ω	~~infinite~~
piece of glass	∞	~~2300 Ω~~

•technical comment: the value of the resistance R can change with changes in temperature, or in the amount of current, but we will ignore these effects and assume that a given resistor has a constant value.

•technical comment:

Although human skin is a good insulator (typically tens or hundreds of thousands of ohms), it will only protect us up to a certain point. When the voltage exceeds a certain value, the skin will break down (ionizing just like air does to create lightning). On the inside, we are basically salty water and this conducts electricity rather well.

Once beyond the skin, the danger to our health lies in two effects. Firstly there is the heating up of tissue as electricity flows. This can cause severe burns and destroy internal tissues and organs. Secondly the flow of electricity through the body can disrupt the body's own electrical nerve impulses, leading to temporary 'freezing' (or paralysis) of the muscles. when the muscles in question are the heart and the diaphragm, there is obviously great danger.

Once beyond the skin, the heating effect grows larger with larger currents. However the muscle paralysis effect is most pronounced around a current of 100 milliamps (which is called the 'death current'). If such a current flows through the heart, the heart will stop, or will twitch helplessly (fibrillate).

100 milliamps is not a particularly large current, so be careful when dealing with electricity!!

•in the ski hill analogy, resistors act like ski slopes that connect the top of the hill to the bottom. The amount of resistance (electric friction) is analogous to the depth of the snow.

high resistance = deep snow --> slower skier flow
low resistance = hard packed snow --> large skier flow

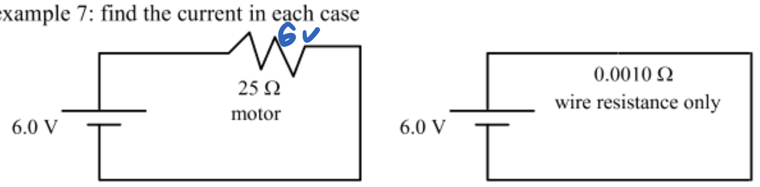
Ohm's Law for ski hills states that the flow of skiers varies directly with the height of the mountain, and inversely with the depth of the snow.

high mountain = high speed for skiers --> large skier flow
low mountain = low speed for skiers--> slower skier flow

$$\text{skier flow} = \frac{\text{height of mountain}}{\text{snow depth}}$$

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

•example 7: find the current in each case



$R = 25 \quad V = 6$

$I = \frac{V}{R} = \frac{6}{25} = .24\text{ A}$

$I = \frac{V}{R} = \frac{6}{.001} = 6000\text{ A}$

"short circuit"

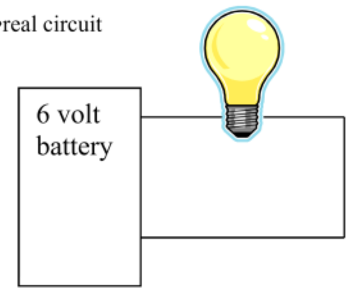
•technical comment:

The second diagram in example 6 is an example of what is known as a short circuit. The circuit is called short because it has very small resistance and therefore will experience very large currents. This depends of course on the voltage source. For instance, if you short circuit an AA cell using lab wires, you will quickly deplete the cell. If you short circuit a car battery using lab wires, the car battery has enough charge stored to make the wires very hot and possibly even melt them! Finally if you short circuit BC Hydro with a lab wire you will create a dangerous current in your house wiring that will cause a circuit breaker to interrupt (or a fuse to blow). As we will see in the next lesson, large currents mean that the wires will get hot and melt, possibly creating an electrical fire!

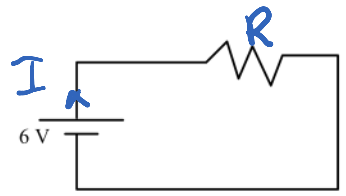
D. Electric meters

•current and voltage are measured using ammeters and voltmeters respectively. Consider the following circuit

•real circuit

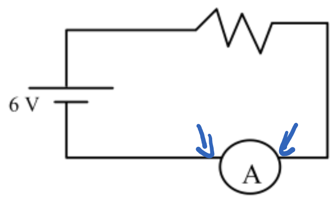


•circuit drawing



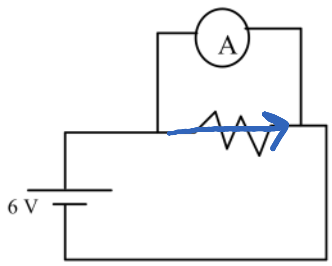
•To properly measure current, the ammeter should be connected so that all of the current in the circuit runs through it. We need to break the circuit and insert the ammeter in SERIES (more on this word in a later lesson)

correct



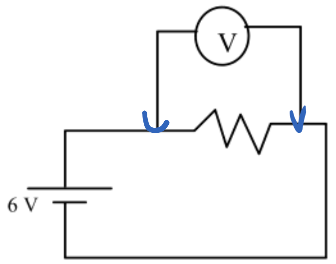
Series

incorrect



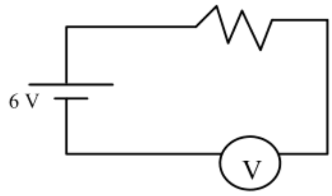
•to properly measure the voltage drop, the voltmeter should be connected with one lead on each side of the device. We do not break the circuit, and the voltmeter is connected in PARALLEL.

correct



parallel

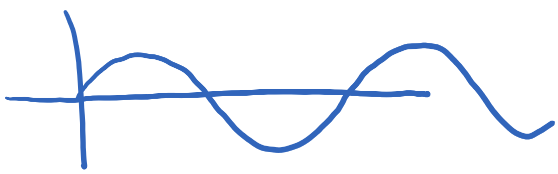
incorrect



•technical comment:

We have focused in our introduction on direct current. Direct current (DC) is always flows in same direction and has a constant value.

Much of what was said also applies to alternating current, Alternating current (AC) has a magnitude that varies as a sine function, and a direction that is continually changing. The AC power that BC Hydro delivers to our homes has a frequency of 60 Hz (so it changes direction 120 times in one second) and a voltage amplitude of 110 volts. In household circuit calculations in this unit we will use 120 volts ac for simplicity.



Lesson 1 Homework

1. If 2.0 A of current flow through a lightbulb for 20. minutes.
a) how many coulombs of charge (Q) have flowed thru the bulb?
(2400 C)

2. Find the current and direction

(6A, Clockwise)

3. If this circuit is connected for 60. minutes, find
a) the current (I)
b) the total charge flow through the circuit (Q)

(2.0A, 7200C)

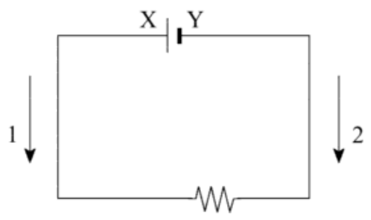
5. In a house circuit, take the voltage to be 120 volts. Find the current if we plug in
a) a 240 ohm light bulb
b) a 12 ohm hair dryer
c) a 20. ohm microwave
d) a 0.10 ohm wet finger (0.50 A; 10. A; 6.0 A; 1200 A)

6. The circuit breakers in your house are designed to 'break' the circuit if the current gets too large. Most circuit breakers are set to 'break' or 'trip' at 15 A. If the house voltage is 120 volts, what is the minimum resistance of an appliance? (8.0 Ω)

7. Why is it important to have circuit breakers (or fuses) for the circuits in our house? Explain using relevant principles of physics.
(if the current goes too high, the wires will heat up. Fire = bad.)

8. How is electron flow different from conventional current?
(Electrons flow from negative to positive. Current is defined to flow from positive to negative. In other words, they electron flow and current are in opposite directions)

9. Which of the following correctly labels arrows 1 and 2 and polarities X and Y in the circuit below?



	ARROW 1	ARROW 2	POLARITY X	POLARITY Y
A.	Electron Flow	Conventional Current	Positive	Negative
B.	Electron Flow	Conventional Current	Negative	Positive
C.	Conventional Current	Electron Flow	Positive	Negative
D.	Conventional Current	Electron Flow	Negative	Positive

Answer: C

I will email out a solution key on Wednesday. I will also send out the optional YouTube assignment.