Advanced Current 1: How Electrons Move Name _____

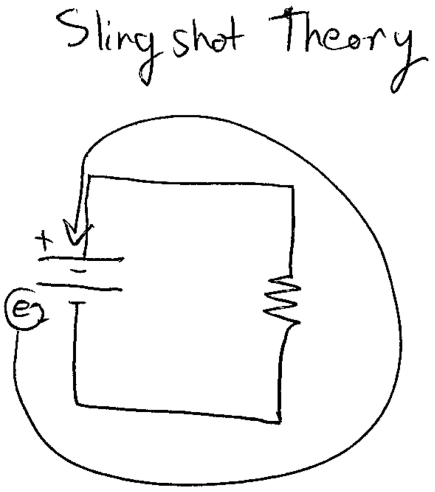
Previously, we established that electric circuits work because tiny particles called *electrons* that are a part of all matter move around an electric circuit.

In this section, we are going to ask the question *how* electrons move and *how fast* electrons move.

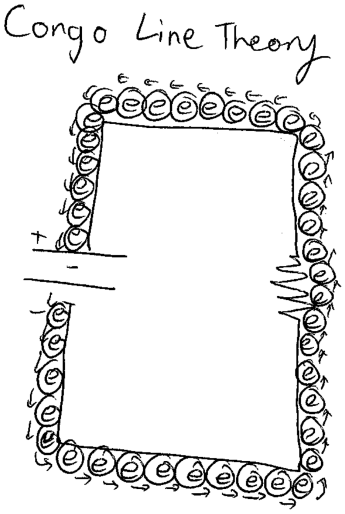
Part 1: How do electrons move:
A physics teacher shows a simple electric circuit to two friends, and tells them it works because electrons move around the circuit from the *negative end* of the battery (the anode) to the *positive end* of the battery (the cathode). But the teacher stops there, he doesn't elaborate.

Later that day, the two friends have an argument about what the teacher left out.

Friend #1 invents a theory called "The Slingshot Theory":
"It's like a slingshot! The battery loads up the electron at the negative end and then fires it around *super fast* all the way to the positive end."



Friend #2 invents a different theory called "The Conga-Line Theory":
"No, it's more like a Conga-line. There's tons of electrons inside the wire, lined up, all the way from the negative end to the positive end. And all the electrons *repel* each other. One electron gets released from the positive end, and it pushes the electron in front, and it pushes the electron in front of it, so on and so on, until an electron all the way at the other end of the circuit gets pushed into the positive end of the battery."



Part 2: How fast do electrons move:
Then they get into a question about how fast the electrons. Both people notice that when you close an electric circuit, the light bulb turns on immediately, without a moment.
Friend #1, describing The Slingshot Theory
"The electrons move at the speed of light! That is the only way the light could turn on so fast."

Friend #2 describing the Conga-Line Theory
"I don't know how fast they move, but it can't be that fast. Certainly not as fast as the speed of light. In fact, I don't think it matters because the electrons that light the bulb are already there and just get pushed into the bulb."

The answer:
It turns out that Friend #1 [the slingshot] is incorrect and friend #2 [the conga-line] is correct.
That is, the conga-line method is the correct explanation of how electrons move around an electric circuit. And in fact, they move very very slow. In the small electric circuits we have built in class, electrons move about 1 centimeter per hour, but there is still current everywhere because they are pushing each other.

Questions:

1. How fast do electrons move around the circuit?

A. The speed of light (300,000,000 m/s)
B. The speed of sound (334 m/s)
C. The speed of an Olympic sprinter (10 m/s)
D. The speed of a lazy snail. (a few centimeters per hour)

Please explain why you picked your answer:

2. Which statement is true:
A. Every electron that leaves the negative end of a battery eventually reaches the positive end.
B. After one electron leaves the negative end of the battery, a totally different electron arrives at the positive end.

Please explain:

3. Why do electrons move all the way around the circuit?

A. because the battery pushes them super fast
B. because electrons repel each other

Please explain why you picked your answer:

4. When a switch is closed, the light bulb turns on immediately. Why?

A. because an electrons traveled very fast from the battery to the light bulb
B. because the electrons responsible for lighting the bulb were *already located* in the light bulb, and simply started moving.

Please explain why you picked your answer:

Why don't electrons move at the speed of light?

Every single year, in physics class, when asked how fast electrons move, many students respond that electrons move at the *speed of light*. this is not true.

Electrons do not move at the speed of light. Period.

I came up with a set of reasons why this couldn't be true, in increasing order to complexity:

a) Because it is called the speed of *light*. If electrons moved at that speed, it would be called the speed of electrons.

b) Because the wire is full of atoms and other electrons. Anything flying through the wire super fast would end up bumping into other pieces or being deflected. One advantage of the Conga-line theory is that all of the charges that are inside the wire are *used* to create the current.

c) Imagine that, in a small circuit, you grab a bare wire. Now imagine that super fast, super powered electrons are flying though that wire. Wouldn't some electrons jump move into your hand and burn you? Remember that they repel each other! In fact, this doesn't happen. It's perfectly safe to grab that wire.
Birds can even land on transmission lines without being burned! Would that be possible if electrons were flying at the speed of light through the wire?

d) To accelerate an electron to the speed of light, the battery must exert an enormous amount of energy. It would need to exert an enormous amount of energy on the other end to slow it down. It is far, far more efficient to simply expel one electron at a very slow speed, as dictated in the Conga-line method.

[requires some more advanced knowledge of physics]
e) Any object moving neat the speed of light experiences what are called *relativistic effects*, such as time lasting longer, mass growing higher, or lengths getting shorter.

[requires some more advanced knowledge of physics]
f) An electron is called a *quantum particle*, which means it cannot have both a precise speed and a precise location. For an electron to travel from the anode to the cathode at the speed of light, it would need to have both a precise speed and a precise location.

In short, electrons don't move at the speed of light because the *congo-line* theory is far more plausible! The circuit works because each electron *pushes* the electron that is in front of it. This method takes advantage three crucial facts about electrons:
- they are everywhere
- they are free to move inside of metals
- and they repel each other.

Questions:

5. Draw a diagram to explain *how* electrons move around an electric circuit.

6. At what speed do electrons move around the electric circuit? Explain why this is plausible:

7. When you close an electric circuit, the light bulb turns on *right away*. Immediately. Explain why this happens, and remember that electrons do not move at the sped of light

8. Go to the circuit simulator at:
https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc
Build a very simple circuit, with simply one battery and one resistor.
In the simulator, they show you electrons moving around the circuit.
Explain how they move? Does it follow what is discussed here: