H: Explain Current Subatomically
Level 4
Prerequisite: Explain Circuits with Voltage Current Resistance and Power
Points to: Explain Voltage Subatomically

Objectives:

The overall goal of this quiz and 'Explain Voltage Subatomically" is to explain using the theories of electrons and nuclei how and why electric circuits work as they do.

These questions are addressed by this quiz:

- What particle moves around the circuit?
- How fast do electrons move around a circuit?
- How many electrons move at a time around a circuit?

When I ask these questions to new physics students, most of them think of answers that are logical, but incorrect. Truly understanding these concepts means that you should be able to address these common misconceptions. In addition to knowing the correct answer, you should be able to explain why *common wrong answers is wrong*.

- You should also be able to draw a diagram showing how an electron moves around a circuit. Your diagram should explain the drift velocity and the electric field.

Part 3: Where does current come from

What is current:

Current a net flow of charge through a conductor. It occurs whenever there is a potential difference across an electrical conductor!

What makes current:

- inside of a conductor, the valence electrons (electrons on the outer shell) are not attached to particular nuclei but allowed to move freely across all nuclei
- when there is no potential difference, these electrons move randomly (similarly to moving molecules we learn about in thermal physics)
- when there is a potential difference across the wire (because it is connected to the anode and cathode of a battery), there is an *electrical field* inside of the wire
- the electrons continue to move randomly….however, in net they move in the direction towards the cathode (actually opposite the electric field)
- the electrons do not actually 'move' around the wire, they move completely randomly and the 'drift' around the wire

Counterintuitive facts about current 1: it isn't actually *moving* electrons, it is *drifting* electrons, that create current

- current is not actually motion of charge, it is *net* motion of charge! The electrons are not actually moving straight through the circuit, rather, they are moving in all directions, randomly, but they move *more* from anode to cathode than any other way, creating *net motion*.
- the speed at which electrons 'drift' is actually very slow, for example if the current is one amp the drift velocity is only about 3 inches per hour
- but, because there are so many *moles* of free electrons present in the wire, even when they drift so slow, millions upon millions of electrons are passing through each point

Counterintuitive facts about current 2: *all* of the electrons are moving

- electrons do not actually move all the way around the circuit - an electron needs to leave the anode, and an electron needs to attach to the cathode, but they are not the same electron….rather, *every single valence electron* within the wire is moving, thus allowing electrons to constantly leave the anode and arrive at the cathode
- what makes a good *conductor* is not that a conductor allows electrons to move through it, any material can allow electrons to move through - what makes a good *conductor* is that there are free electrons inside of the conductor…. - the *current* moves becomes *all* of these free electrons begin moving)drifting)

Why does a light bulb turn on instantaneously when you flip a switch?

- if electrons move so slowly around a circuit, why does a light bulb turn on the instant you flip the switch
- the electric field, which creates the current , moves through the wire at the speed of light, which is why electricity begins instantaneously when a switch is closed and ends instantaneously when it opens
- when the electric field arrives (nearly instantaneously), the electrons already inside of the bulb start drifting

Counterintuitive fact about current 3: whenever we do math, current moves backwards

- current is caused by negative charges moving from anode to cathode, but due to an convention, when mathematically analyzing electrical circuits, we say that a positive charge is moving from cathode to anode. This is actually mathematically equivalent to the true situation.
- think mathematically: the if negative charge is drifting to the right, it is actually mathematically equivalent as positive charge moving to the left
- if negative charge moves anode to cathode, it is actually mathematically equivalent to positive charge moving from cathode to anode
- this weirdness happens because *electric current* was discovered before electrons and protons. By the time scientists figured out what creates electric current, they had decided that electrons were negative. If they could go back in time, they'd make the electrons positive.
- this weirdness is called "conventional current."

Free Electrons and Current

Electric Current is the motion of charge.
A higher current on a circuit means that *more electrons pass through that circuit*.
A lower current on a circuit means that *fewer electrons pass through that circuit.*

Two factors determine what the current will be:
- How fast the electrons move through [drift velocity]
- How many free electrons there are

The drift velocity is usually *very very* **slow**. [On the order of 1 inch per hour fro typical classroom circuits.]
But the number of free electrons is *very very* **high**. In a copper wire, each atom of copper contributes a single free electron. One mole (64 grams) of copper has 6.02×10^{23} free electrons! And, when there is a current in a wire, *every single one* of those electrons moves.

The reason why electric current is *so powerful* is actually that *massive number of free electrons*. Even if it takes an electron 24 hours to travel from the anode to the cathode of a circuit, if that circuit has a mole of free electrons it means that charge equivalent to 70 *billion billion* electrons will cross that circuit every *second*. [Note that the two *billions* aren't a typo. It means 18 zeros!).

It's as though you are watching a gigantic crowd of people move slowly forward. Sure, they are moving slowly, but you cannot ignore a crowd so large.

This website discuses these concepts with more mathematical rigor and calculations:
http://hyperphysics.phy-astr.gsu.edu/hbase/electric/miccur.html