Circuit Concepts 2: Atoms, Particles, and Circuits Name _____

The point of this packet:

The overall goal is to explain, from the subatomic point of view, what is happening in an electric circuit. Explain how and why individual electrons move.

What you need to learn

You should be able to answer these questions:

- What particle moves around the circuit?
- How fast do electrons move around a circuit?
- How many electrons move at a time around a circuit?
- Where do they come from? How did electrons get into the electric circuit at all?
- Why do the electrons move around the circuit?
- How do they know where do go? Why do they move only through a wire, and not anything else?

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.
- You should be able to draw a diagram showing how a battery works.

NOTE: This packet is incomplete at the moment, It should be studied together with the PowerPoint on this topic.

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Part 1: Review of basic vocabulary

Voltage The *push* that moves electrons around a circuit.
Potential Difference Another, more precise, term for voltage. Potential difference refers to the amount of potential energy that is released when electrons move around a circuit.
Battery The battery is the part of the circuit that releases voltage (potential difference).

Part 2: Where does potential difference (voltage) come from?

Electrochemistry basics

What a battery does: A battery uses a chemical reaction to create a POTENTIAL DIFFERENCE (voltage), which is the energy that allows a circuit to work.
A battery can be created whenever a) there is an exothermic reaction between two metals (releases energy). the most common example is zinc and copper b) the reaction involves the exchange of an electron from one metal to the other (called a *oxidation-reduction reaction*)
A battery is used up when this reaction is completed!

Battery vocabulary:

- the two metals are called the electrodes
- the positive electrode (which receives electrons…oxidizes) is called a cathode and the negative electrode (which gives electrons…reduces) is called the anode
- positive ions need to be able to travel between the electrodes, typically through a liquid called an *electrolyte* in a wet cell battery or a solid material in a dry cell battery

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How charges move:

- if a wire connects the two electrodes, then the electrons can travel *through that wire* in order for the reaction to occur - this is why only chemical reactions that involve electron exchange (oxidation-reduction reactions) can be converted into batteries.
- as the electrons move across the wire from anode to cathode, positive ions *also* move from anode to cathode through the electrolyte….so in fact the charge is moving both ways and the reaction is electrically neutral

Energy in batteries:

- because the reaction between anode and cathode is *exothermic*, that electron is able to release energy as it travels
- when the electron is on the anode, it has potential energy (electrochemical potential energy)
- as it moves across the wire, that electrochemical potential energy converts into kinetic energy (called *electrical energy*)…just like a ball rolling down a hill
- however, in an Ohmic electric circuit, that electron's kinetic energy (electrical energy) is *always* immediately released into some other type of energy (like light or heat energy)
- the ability to release potential energy into another type of energy creates a situation called a *potential difference*! (which is also called *voltage*)!

Types of batteries

Wet cell battery The electrolyte is a liquid substance. Car batteries are wet cell batteries.
Dry cell battery The electrolyte is a solid substance. Most batteries you use are dry-cell.
Lemon battery A typical school project, in turning a lemon or potato into a battery. In this lemon battery, however, the energy *does not* come from the lemon! Energy comes from the electrodes: the zinc and copper materials pushed into the lemon. The lemon juice is the electrolyte!

A lemon battery is really a primitive *wet cell* battery.

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

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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."

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

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Vocabulary Exercise:

Match each word or phrase to the proper definition

1. Electrochemical potential Energy	**A.** physicists say that current is going positive to negative, even though it is really opposite
2. Conventional Current	**B.** charged particle that moves in an electric circuit
3. Electric Field	**C.** force affecting charged particles from a distance
4. Conductor	**D.** to gain electrons in a chemical reaction
5. Electron	**E.** material that allows positive charges to move and complete a battery reaction
6. Oxidize	**F.** a material containing electrons that are free to move amongst atoms
7. Electrolyte	**G.** to lose electrons in a chemical reaction
8. Reduce	**H.** energy contained within two chemicals that react in an exothermic, oxidation-reduction reaction

9. Cathode	**I.** net motion of electric charge
10. Battery	**J.** a chemical within a battery that gives up electrons
11. Current	**K.** a device which creates a potential difference across a wire
12. Electron Drift	**L.** a tiny charged particle moves randomly, but slightly more in

	one direction
13. Kinetic Theory of Matter	**M.** a chemical within a battery that accepts electrons
14. Potential Difference	**N.** matter is made of small particles that are always moving randomly
15. Anode	**O.** energy released when a charged particle moves around a circuit