Workshop Tutorials for Introductory Physics

Solutions to EI4: **Voltage and Current**

A. Review of Basic Ideas;

Voltage, Current and Resistance

Taps are always placed at the **bottom** of water tanks rather than at the top or halfway down. This is so that when the tap is turned on water will flow out. Unless some other force is provided, like pressure from a pump, water will always flow **downwards**, from a region of high gravitational potential to one of lower gravitational potential. This is why water tanks are often placed up on stands or **towers**, so the water can run down to the houses. The difference in **gravitational** potential is what makes the water flow and gives you a current. In a similar way a battery provides an electrical potential difference, (PD or voltage, measured in **volts),** to produce a current in a circuit. In a plumbing system there is a current of water, in a circuit it is a current of charge (electrons) which flows *through* the circuit. The current, I, at some place in a circuit is equal to the rate at which charge flows past that place. If the flow is steady then $I = q / t$. The SI unit of current is the ampere, A (often called the **amp**).

When you open a **tap**, so that water can flow out, you are **decreasing** the resistance to flow. The more you open the tap, the less the resistance and the greater the current of water. For an electrical current flow, the **greater** the resistance, the smaller the current. Almost any path, for either water or charge, will have some resistance which will depend on the width of the channel, its length and the nature of any stuff inside which may impede the flow. For example, narrow pipes have greater resistance than wide pipes and allow **less** water to flow. Less conductive materials, which have greater resistance, allow less charge to flow.

In electric circuits the current, I, through a component, depends on its resistance, defined as $R = V / I$, where V is the potential difference between the ends of the component. Any device whose resistance stays the same when the potential difference across it is changed is said to obey Ohm's law, which says $V = IR$. If you have only a single path, then the more resistance you put in, the greater the total resistance and the less current will flow for a given potential difference.

If you want to get a lot of water quickly from a tank you open more than one tap, and put a bucket under each one, so that there are multiple paths for the current to flow along. Similarly, when you connect resistors in **parallel** in a circuit the current is larger than if you use only a single resistor, because just as with plumbing there are many paths for the **current** to take.

Discussion question

A battery or power supply provides electrical potential energy, which drives a current around the circuit. The greater the resistance, the less current will flow, because electrical potential energy is dissipated as heat or thermal energy when there is a current flow through any object which has resistance. (Note that the electrons do not "bank up" in the resistor, the current is constant around a single loop circuit, resistor just reduce the flow, not accumulate electrons.)

B. Activity Questions:

1. Ohm's law

Resistors are designed to obey Ohm's law, which says that the resistance is $R = V/I$. Using your measurements of the voltage and current you can calculate the resistance of the mystery resistor.

2. Measuring current and voltage

The ammeter measures the current, which is the number of charges per unit time passing through a given point on the circuit. To be able to count the charges, the ammeter must be part of the circuit and have a very low internal resistance so that it does not affect the current through the circuit.

The voltmeter is connected in parallel, because it measures the difference in potential between two points. It has a very high internal resistance so that very little current will flow through it, thus having little effect on the circuit.

3. Batteries II

The person responsible for naming positive and negative charge was Benjamin Franklin who did not know that the charge carriers in a metal are really negatively charged electrons. So we are stuck with the notion of conventional current which we imagine to be a flow of positive charge, out of a battery's positive terminal, through a conducting path, and into its negative terminal. Some people like to be more realistic and imagine the actual flow of electrons in the opposite direction. Provided either convention is kept constant in calculating variables in a circuit, you will obtain the correct answer.

The battery provides an electrical potential difference which causes a current to flow.

4. Current, potential and resistance - a fluid model

You can measure the average current by timing how long it takes some amount of water to flow out of the tube. Increasing the gravitational potential difference is like increasing an electrical potential difference and will increase the current flow. (Note that this is not the same as giving each fluid molecule, or electron in a circuit, more kinetic energy.)

Squeezing the rubber pipe increases the resistance to flow and hence decreases the current.

C. Qualitative Questions:

1. Voltage and current.

a. Voltage is like gravitational potential difference, or a difference in height. If you have two containers linked by a pipe, water will flow until the water is at the same height in both containers. If it is already at the same height there will be no flow. A voltage is a difference in electrical potential. A voltage or electrical potential difference is necessary to make an electric current flow.

b. You *can* have a voltage without a current. Any time that charges are separated there is a voltage, for example in a battery or across a cell membrane. Current only flows if there is a path for it to flow along.

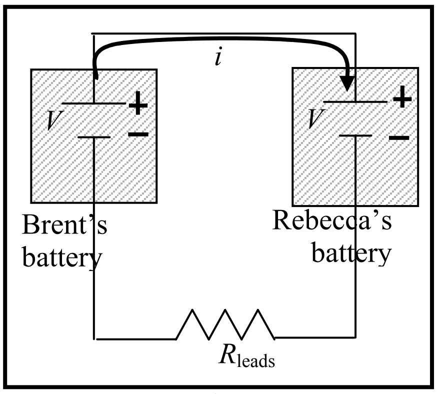
c. You *cannot* cause a current to flow without a voltage. In normal materials there must be an accompanying voltage to allow current flow to continue. In a superconductor the voltage can be removed once the current is established, and the current will continue to flow.

d. Whenever there is a voltage across a conductor there is an electric field inside the conductor, and that field pushes the charges, e.g. electrons, and makes them flow, which is a current. A current can flow in a superconductor if there was a voltage applied to establish the current, which will continue to flow once the voltage is turned off. In normal materials there is resistance, so a voltage needs to be applied to maintain the current. This is true of most movement or flow - a force must be applied to begin the flow, which will then continue even if the force is removed. However in most circumstances there is some sort of resistance, such as friction, which will stop the movement unless a force continues to be applied. Superconduction is analogous to frictionless flow.

2. Brent is recharging Rebecca's car battery using his car's battery.

a. Brent should connect the positive terminals of the two batteries together, and connect the two negative terminals together. This will allow the good battery to push charges through the weak battery from the positive to the negative, and recharge it.

b. See diagram opposite. The current will flow to push positive charge to the positive terminal of Rebecca's battery, recharging it.



D. Quantitative Question:

A cell membrane is about 6.0 nm thick, and has an electric field of around 1.0×10^{7} V.m^{-1}across it.

a. Assuming a uniform field, $E = V/d$. Rearranging for V gives

$V = Ed = 1.0\times10^{7}$ V.m^{-1} $\times\ 6.0\times10^{-9}$ m = 0.060 V = 60 mV.

b. Given the potential difference across the membrane and the current flowing through the membrane we can use Ohm's law to calculate the membrane resistance: $R = V/I$ = 0.060 V/ 0.1×10^{-3} A = 600Ω.

c. If the membrane resistance was 100 Ω, the current would be

$I = V/R$ = 0.060 V /100 Ω = 6×10^{-4} A Ω = 0.60 mA.