# Science-1A Lab: Week 5, Wednesday, September 9, 2020

This lab is about static electricity, the kind that makes a spark when you walk across a rug on a dry winter night, and then touch a door knob. Electricity is more difficult to understand because we usually cannot see or feel it. Of course, large amounts of electricity can be seen as lightning or sparks, and felt as a shock that can kill a person.

Watch the following videos, but do not let yourself be discouraged if you feel that you cannot follow them completely. Learn what you can, and maybe replay parts a second time. What you will be tested on, however, will be the material in the Practice Quizzes.

Needless to say, an online lab is nowhere as good as in-person, but we do what we must.

### Electric Charge (CC 25) 9 min 41 s

*https://www.youtube.com/watch?v=TFlVWf8JX4A&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=26*

> All of this is relevant to Science-1A. However, you will not be tested on the Coulomb's Law formula for calculating the force between charges even though it is at the top of the 3rd page of your Equation Sheet. Just remember that it is like Newton's gravitation law except the electric forces can either attract or repel whereas gravitational forces always attract.

I start an on-campus lab on static electricity by demonstrating my Kelvin Water Dropper. It is described on pages 106-108 of the printed handouts which is a copy of a Wikipedia article at https://en.wikipedia.org/wiki/Kelvin_water_dropper

A typical object like a plastic rod has about $10^{25}$ electrons surrounding its atoms. About 1 in 20 of those are just loosely held to the outermost regions of those atoms. It takes only about $10^{13}$ electrons to make a noticeable spark. So, it is not surprising that rubbing different materials against each other, or pulling apart different materials like tape from a table, or taking off a shirt can move enough electrons from one material to the other to create a sufficient charge difference to produce a spark. Normally, moisture in the air prevents this from being noticed, but when the humidity is low, such as on a cold winter night while in a warm house, taking off a T-shirt at night can produce an exciting light show as it brushes against a full head of dry hair.

Similarly, when a stream of water breaks into droplets, each droplet may have an unbalanced electric charge. As explained in the Wikipedia article and the following video, the cross-wiring of the Water Dropper allows a tiny initial charge difference to be magnified until a spark results. As the charge builds up, a point is reached where the parts of the droplets push against each other causing the droplets become a spray of smaller droplets reducing sound they make when landing in the catch bucket.

A video entitled "Kelvin Water Dropper and How it Works/Lord Kelvin's Thunderstorm" is at *https://www.youtube.com/watch?v=sArNxGnYhNU* .
I usually hang aluminum foils spaced by about 2 cm from the oppositely-charged sides. As the charge builds up, the foils pull together and "kiss" with a spark that releases that charge, causing the charging to start all over again.

I also discuss the handout entitled "Soaring Birds, Thunderstorms, and Atmospheric Electricity" on page 98 of your printed handouts and also at
*http://yosemitefoothills.com/Science-1A/Handouts/Week-06/AtmosphericElectricity.pdf* .
Be sure to read that handout since a future quiz or test question you are likely to see is built around it.

A page of links about lightning that you will not be tested on, but may save your life, is at page 110 of the printed handouts and also at
*http://yosemitefoothills.com/Science-1A/Handouts/Week-06/LightningLinks.pdf* .
I once went up a mountain trail, got caught in a lightning storm, and on the way back down saw that a tree next to the trail had been blown apart by a lightning strike while I was higher up on the trail.

On another hike with some friends to Cloud's Rest in Yosemite National Park, a thunderstorm developed and I decided to eat my lunch and turn around. My friends continued, and when I met them again at the car, they reported that the electric field from the thunder cloud was so large that small loose grains of granite were floating above the rock after having become electrically charged. Also, long hair was charged and splayed out. Luckily, no one was struck by lightning, but that was the kind of extremely dangerous situation that should be avoided!

## Electric Fields (CC 26) 9 min 56 s

*https://www.youtube.com/watch?v=mdulzEfQXDE&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=27*

You will not need to use the formula for electric field, but do remember that when the electric field is represented by arrows, the arrows point away from a positive change and into a negative charge. The arrows are not real, they are just one way we visually represent an electric field.

The idea of electric dipoles is important, particularly when discussing some aspects of chemistry.

I am pleased with the discussion about capacitors since the textbook does not talk about them. Below, I will discuss demonstrations I do with capacitors in lab.

I have created animations of electrons moving around in a metal. See one at *http://yosemitefoothills.com/Science-1A/Handouts/Week-06/CapacitorAnimation.gif* .
It shows electrons moving in a capacitor made from two closely-spaced metal cylinders shown using side and end views of each side of the capacitor. It starts with fifty extra electrons within the metal on one side and 50 fewer within the other side. Opposite charges attract, so they will try to pull as close to each other as possible, and they end up on each side of the narrow gap. At the same time, the charges within each side have the same charge and repel each other. They are trying to spread out. A balance of those forces determines the final charge configuration.

My computer program combined Newton's 2nd Law with Coulomb's Law governing the force between charges. The animation starts with the positive charges randomly spaced in the interior of the left cylinder and shown using green dots. Negative charges in the right cylinder are shown using blue dots. Within each side of the capacitor, they repel each other, and flee to the outer surface of their cylinder. When they get there, the program turns their colors to orange, and cyan, respectively. By the end, all charges are on the outer surface of their respective cylinders with most snuggled close to opposite charges on other side of the small gap between cylinders. In real life, the capacitor charges do this within a few millionths of a second. The capacitor is now charged and holding electrical energy.

## Voltage, Electric Energy, and Capacitors (CC 27) 10 min 13 s

*https://www.youtube.com/watch?v=ZrMltpK6iAw&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV&index=28*

The discussion of electric potential vs electric potential energy can be confusing. Don't worry about understanding everything, just remember that the electric potential is measured as a voltage. We will talk a lot about voltages, not about electric potential or electric potential energy.

Ignore the discussion about "integrating" over an electric field. That is a term from the mathematics of calculus which we do not discuss.

If you are into hiking and use topographic maps, the equipotential lines should remind you of lines of constant elevation, and the electric field lines should make you think of the quickest way down or up a hill.

You will not be asked to use the formula $C = k\,\epsilon_0 \frac{A}{d}$ although you might remember that a large plate area and a small distance between the capacitor plates makes for a large capacitance and therefore for a larger amount of energy storage. Also, don't worry about energy density.

There is a demonstration that I like to do with 45 capacitors connected together in a long chain held by insulating plastic. These high-quality commercial capacitors can be charged with a maximum of 250 volts. In the past, I used twenty-two 9-volt batteries to get 198 V, but that got expensive each year so I built a gadget I could plug into a wall outlet to give me 200 V. I made it so it could not provide enough electric current to be felt, but would adequately charge the capacitors in the chain. After giving each of the 45 capacitors 200 V of charge, I would bring a wire from one end of the capacitor chain close to the other end until a 7-mm long spark would jump across with a loud snap. That spark had about 45x200V=9000V of voltage and was dangerous because it had more energy than a typical 10000 V static spark you might zap a sibling with. It is electric current that hurts people, not necessarily voltage. The 9000 V spark briefly had a lot of current.

**Using a Digital Multimeter**

Usually the voltages we need know about are too weak to sense. We need an instrument to tell us about various electrical variables like voltage. A common and relatively inexpensive such instrument is the hand-held multimeter like the one shown at the right.


There is a water analogy for electric flow that can be useful for K-6 students, but must not be taken too seriously. That analogy identifies voltage with pressure, and water flow with electric current. Hose geometry (diameter and length) that opposes water flow is identified with electrical resistance. A battery is seen to be like a water pump.

With this analogy in mind, one might consider a battery connected to a light bulb through wires with an on-off switch as being like a pump taking water from a pond with a faucet connected by a hose to a sprinkler in the middle of the pond. Water flows in a loop from the pond through the pump, faucet, through the hose to the sprinkler and back to the pond.

A battery is a chemical "pump" that takes electrons in at its negative end and moves them to its positive end.

When we use the meter, connection leads are plugged into the two jacks at the bottom right labeled "COM" and "VΩHz" representing voltage V, resistance Ω, and frequency Hz. The symbol Ω is the capital letter Omega used as the abbreviation for the unit of electrical resistance, the ohm.

**Measuring battery voltages**

We then use D-cell batteries put into convenient holders that allow us to connect in them in series (+ to - to + to -) or in parallel (+ to + and – to –). We use the meters with the central knob set to V (one click in the CCW direction from "OFF") to measure the voltage. The result for a single battery is close to 1.50 V. Two batteries in series measure 3.00 V and two batteries in parallel measure 1.50 V.

You may wonder what is gained by putting two batteries in parallel. Each D-cell battery holds about 40 kJ of energy, putting two in parallel can provide twice that amount of energy at the same 1.5 V level. A 1.5 V light bulb will operate for twice as long with two D-cell batteries in parallel. A tiny AAA battery also provides 1.5 V, but can supply only about 5 kJ of energy. The 12-V batteries I use to store energy from my solar panels can each hold 4.3 MJ of energy. A pair of those hold enough energy to power a freezer and computer system for about 30 hours without sunlight to recharge them. In full daylight, the 1.1 kW of solar panels can recharge the batteries in about 3 hours.

**Measuring electrical resistance**

Electrical resistance for an electrical circuit represented by an *R* with units of ohms (abbreviated by an Ω) usually follows a rule called Ohm's Law that states

$$V = I \cdot R$$

Here, *V* is the voltage with units called volts (abbreviated by a V) that is measured across a circuit through which an electric current *I* with units of amperes (abbreviated by an A) is flowing. Many conductors obey Ohm's law, but incandescent lamps, semiconductor devices like transistors and diodes, and solar panels do not. It is a useful rule that helps us work with electricity, but is not an absolute law of physics. Devices called resistors that do obey Ohm's Law are sold with values of *R* ranging from 0.01 Ω up to 1 GΩ, a span of 11 orders of magnitude. Sometimes resistances with even much smaller or larger values than these are important.

To measure electrical resistance, we must be sure to disconnect the multimeter lead wires from any voltage sources, and then switch the main dial two clicks to the left. The "Select" button might need to be pressed to get it into resistance mode rather than one of the other possible modes. Resistance is a measure of how much a circuit opposes the flow of electricity. The meter puts a gentle known voltage across the circuit and measures the current flow. It then uses Ohm's Law to report a resistance value.

Pinching the red lead wire in one hand and the black lead wire in the other hand will allow the multimeter, set to resistance, to measure the resistance across your body. It will be a few MΩ down to a few 100 kΩ depending on how much you might be sweating or how tightly you pinch the leads. This can be thought of as a crude lie detector.

I pass out two 10 kΩ resistors and two 1 kΩ resistors and ask students to measure each. They get values like 998 Ω and 1003 Ω for the 1 kΩ resistors since the resistors do not actually have their exact marked values. They next measure the 1 kΩ resistors in series and get the sum of the resistances, 2 kΩ. The resistance of resistors in series is somewhat like connecting two water hoses in series – the combination has less flow for the same water pressure. The resistors in series have half the electric current flow for the same voltage and therefore act like a resistor of double the resistance. Putting two 1 kΩ resistors in parallel allows the electric current two alternate paths to flow and makes the combination act like a resistor of half the resistance, 500 Ω .

**Measuring electrical current**

We avoid doing electrical current measurements in class because it is very easy to blow a fuse in the meter by setting it to current measurement and then accidentally connecting it to a battery. To measure current, the circuit must be opened and its current run through the meter.

**Measuring capacitance**

I pass out small brown capacitors, the same type I used in the capacitor chain. The have a capacitance value of 0.22 μF, $2.2\times10^{-7}\mathrm{F}$ where F is the unit for capacitance called farad. It is a large unit, so most capacitors have values that are expressed in micro-, nano-, and pico-farads. When I was playing with electronics in high school, the biggest capacitor I could get my hands on at a "war surplus" store, was about 450 μF. Capacitor technology has advanced considerably, and now capacitors of 20000 times that size are available, although only for use with rather low voltages, like 5 V.

To measure capacitance, the meter shown above must have its knob turned left two clicks from the vertical "OFF" position, and also the "Select" button must be pokes one or two times. Then when the leads are put across the 0.22 uF capacitor, the meter will read something close to 220 nF. If two capacitors are put in parallel, their values will add since each can hold some charge and together they can hold twice that charge. If on the other hand, the capacitors are connected in series, the voltage the meter puts across them is half for each capacitor. The net result is that the measured capacitance is one-half the value for a single capacitor. So why ever put them in series? Because in series they can withstand a larger voltage than they can individually. Everything is a trade-off.

**Measuring temperature**

The meter also comes with a special temperature probe that has two plugs that go into the "COM" jack and into the one to its left labeled "TEMP". The main knob is then turned two clicks to the right to the "TEMP" position. It will then read the temperature of the end of its temperature probe in either °C or °F units depending on the button below the display labeled "°C/°F".

## To earn credit for this lab, report that you have done the following:

1. Read this note, and tried to imagine using the multimeter to measure batteries, resistors, capacitors and temperatures.
2. Watched the 3 Crash Course videos.
3. Read the "Soaring Birds..." note.
4. Watched the animated gif about the charges in a capacitor.