Prelab: Batteries

Everyday thing: It is hard to overestimate the importance of batteries in the modern age. While in the old days, you would have a cell in a flashlight or a Game Boy (I'm old, OK?), nowadays batteries power almost everything, from cell phones to cars. Battery technology has beome multi-billion dollar industry.

It is physics (and chemistry): even the most advanced batteries today are based on the principle of moving charge around: two different metals, a way to move negative charge – a wire – and a way to move positive charge – for instance, an acid.

Electrochemical cell

Watch this video: https://www.youtube.com/watch?v=9OVtk6G2TnQ

So many people have built a lemon battery: roll a lemon around a bit, stick a copper nail and a zink-coated nail into it, and connect a wire between both nails, and viola, there is current in the wire. (If you use a couple of lemons, you can power a small electronic device.)

All batteries have these three main ingredients:

- A **anode** and **cathode**, in this case zinc and copper
- and an **electrolyte**, in this case lemon juice.

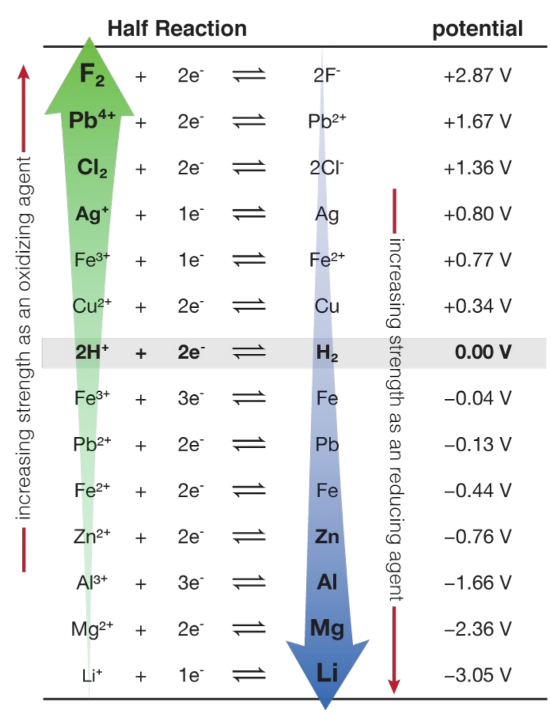
But why do we need these three consitutents?

Cathode and Anode

Ultimately, we would like to move electrons from one electrode to another. To see how this can work, we'll first recall that some materials love electrons more than others. This property is called the **reduction potential** (chemists call the acquisition of electrons "reduction") and it explains which way the electrons go when two insulators are rubbed against each other: the material with the higher reduction potential ends up negatively charged.

One the right, you will find the table of elements arranged by reduction potential, i.e., their desire to absorb electrons. For our battery, we picked **zinc** (**Zn**) and **copper** (**Cu**):

- Zinc (Zn) has lower reduction potential, and the electrode with that property called the **anode**. It will tend to give electrons, which is called **oxidation**.
- Copper (Cu) has higher reduction potential, and the electrode with that property called the **cathode**. It will tend to receive electrons, which is called **reduction**.



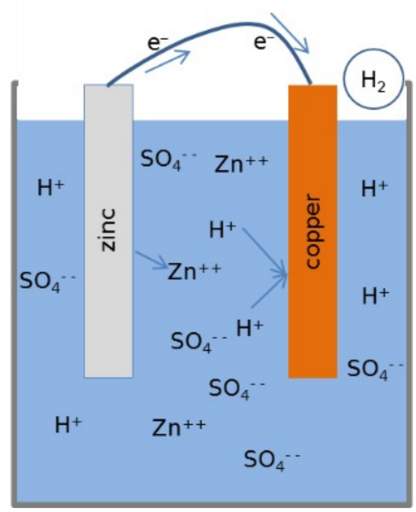
On the last column of the table you see the energy difference per unit of charge, which is called **potential** or **voltage**, and its SI unit is the **Volt** (**V**). The difference in potential gives us the maixmum voltage of the battery, in this case it is 0.34 V – (–0.76 V) = 1.1 V, which is not bad at all! (In a lemon battery, it is difficult to get more than 0.9 V due to the properties of lemon juice.)

Electrolyte

So, we've established that the electrons **want** to move from the anode (zinc) to the cathode (copper). But how do we get them to move?

We cannot just put copper and zinc next to each other. Once electrons start moving from zinc to copper, the zinc atoms get positively charged and copper atoms get negatively charged, which pulls the electrons right back to the zinc. Zinc atoms with two electrons missing are called **zinc ions** – they are written as Zn^{++} to indicate that they have two additional positive charges. We need some way to move these zinc ions out of the way.

The solution is to put zinc and copper into an **electrolyte**. An electrolyte is (in most cases a fluid), which partly separates into negative and positive ions. It turns out that the citric acid in the lemon (which is also in coke) is such an electrolyte. Another one, depicted on the right, is sulfuric acid (H_2SO_4). We see that some of the acid has separated into negative SO_4^{--} and positive H^+ ions.[1] Because they separate into ions, all electrolytes conduct electricity.



The electrolyte now allows us to get rid of the problem: the anode emits **both** electrons along the wire **and** zinc ions (Zn^{++}) into the electrolyte. The zinc ions recombine with the negative SO_4^{--} ions from the electrolyte, to form zinc sulfate (Zn_2SO_4).

Meanwhile, the cathode receives both the electrons from the wire and positive H^+ ions from the electrolyte. These are recombined to form molecular hydrogen H_2, which bubbles off of the copper electrode.

We can use the electrons running through the wire to power stuff, like a light bulb!

One might ask, well if both the electrons and the ions of the zinc go away, what becomes of the zinc anode? The simple answer is: it will eventually disappear.

1 *We are going to use coke or lemons rather than sulfuric acid in the experiments, because sulfuric acid is one of the nastiest things in chemistry: it causes dreadful chemical burns, and when one tries to wash it off with water, it starts boiling instead, adding severe thermal burns. Do me a favour and do not google "sulfuric acid injury". I'm serious.*