B. Circuits

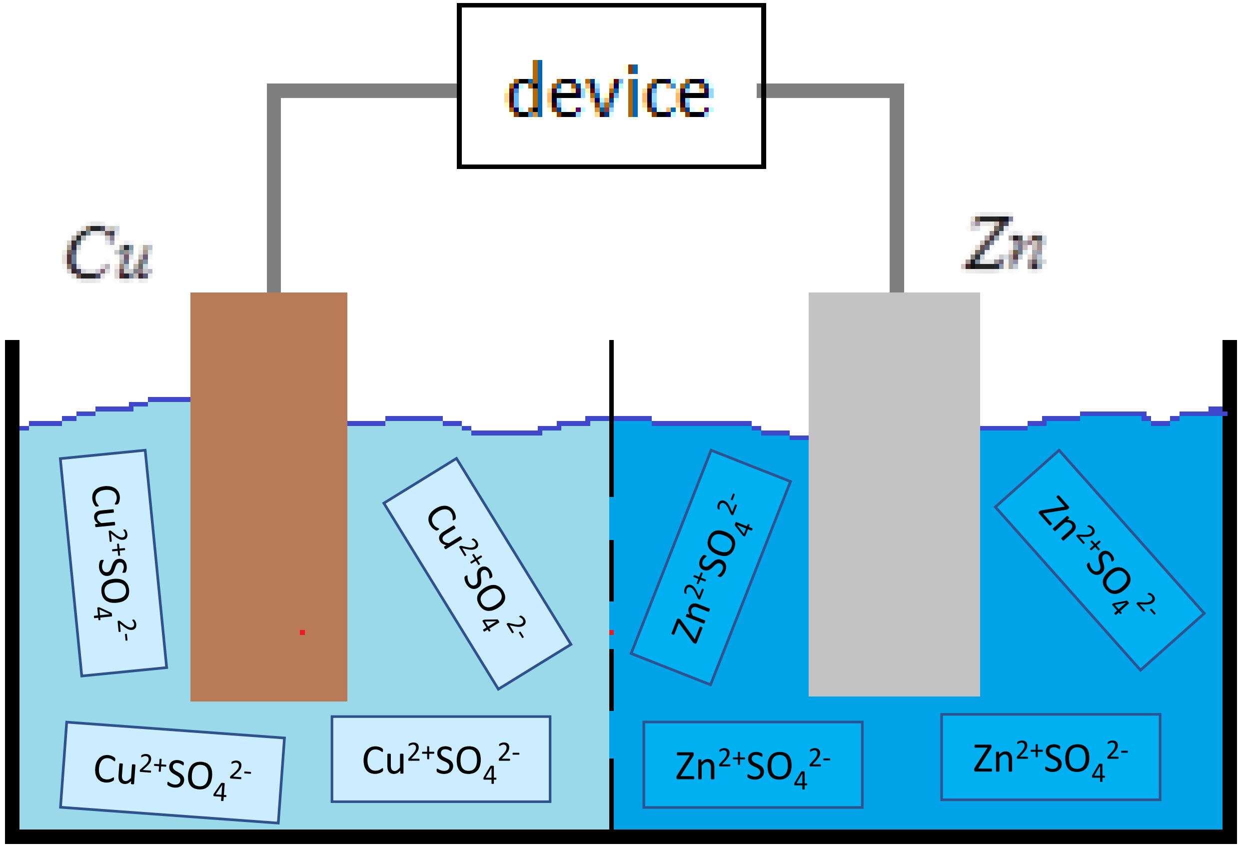
We've now delineated, at least to the degree we shall find necessary, the theory of electric fields. Now we want to see how we can apply it to stuff. There are three aspects to this:

1. Harnessing/storing the potential energy in the electric field. This is usually done with batteries and/or capacitors.
2. Delivering this electric potential energy to our device. This is usually done with wires, though there are wireless forms of energy transfer.
3. Designing the device in such a way as to convert this electric potential energy into some other useful form of energy like thermal energy (heat, light), or mechanical energy (motors). It's easy to convert electric potential energy into thermal energy and this is what we'll examine first (later). Converting the electric potential energy into mechanical energy is more complicated, at least in its practical forms, and will have to await the introduction of magnetic fields (part C), for a fruitful discussion.

So then, putting all three of these things together would comprise a 'circuit'.

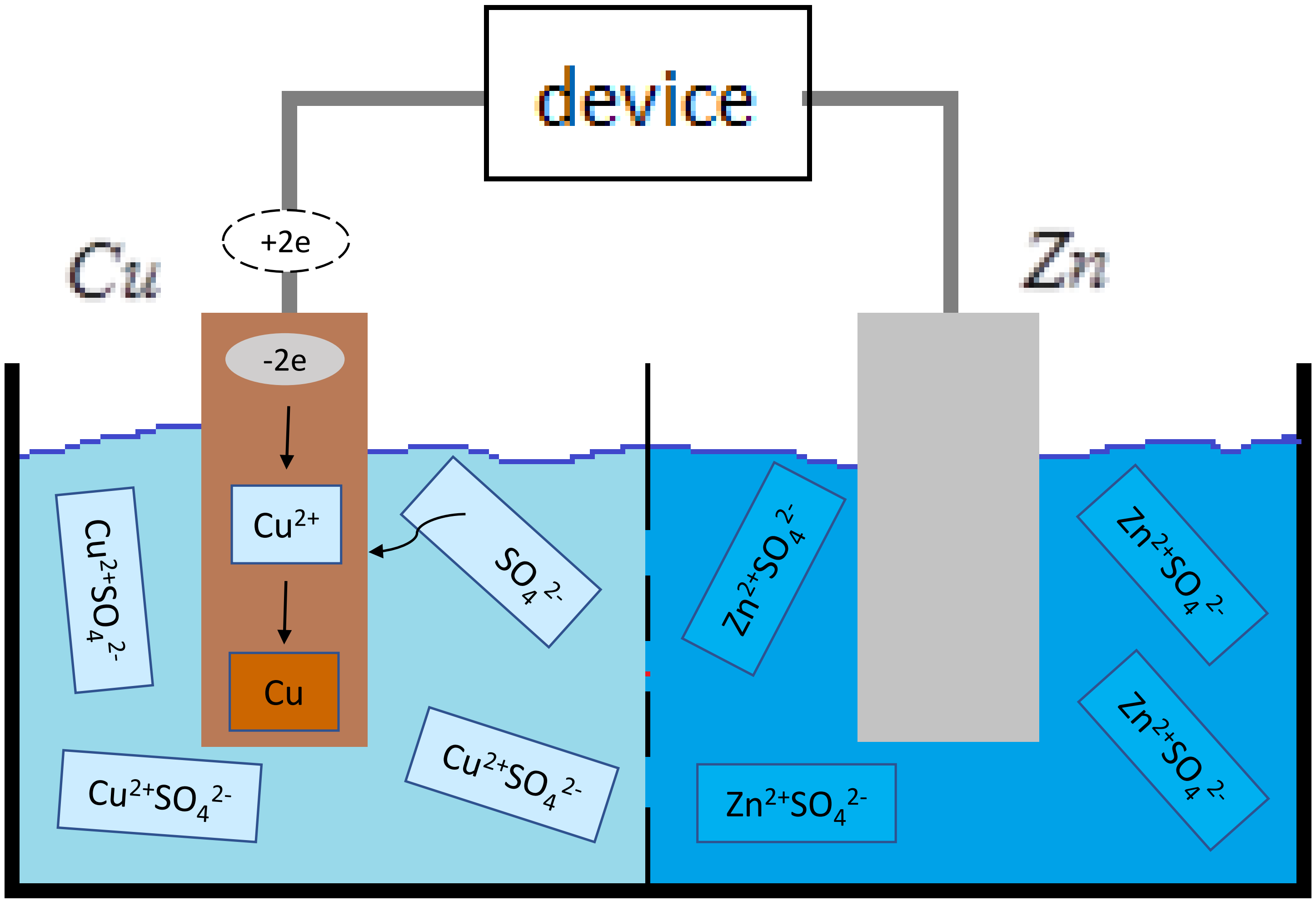
B.1 Batteries

First we'll take a look at batteries. Most of their operational details are to be found in chemistry books, i.e., not my head. So this will be just a cursory review. There are many types of batteries. A prototypical 'wet' cell battery would consist of a copper sulfate solution separated from a zinc sulfate solution by a membrane permeable only to the sulfate ion, and a neutral copper 'anode', and a neutral zinc 'cathode'.



And we're about to discuss the series of simple chemical reactions that take place and serve to transport electrons from one side of the battery to the other. Chemical reactions are governed by two laws: they must conserve energy, and they must maximize entropy. So our battery's chemical reactions will of course conserve the energy of the molecules + electrons, and moreover it will *proceed* because it maximizes the entropy of the molecules + electrons. It's for these same reasons that a gas will inevitably expand to fill whatever container it enters.

B.1 Batteries



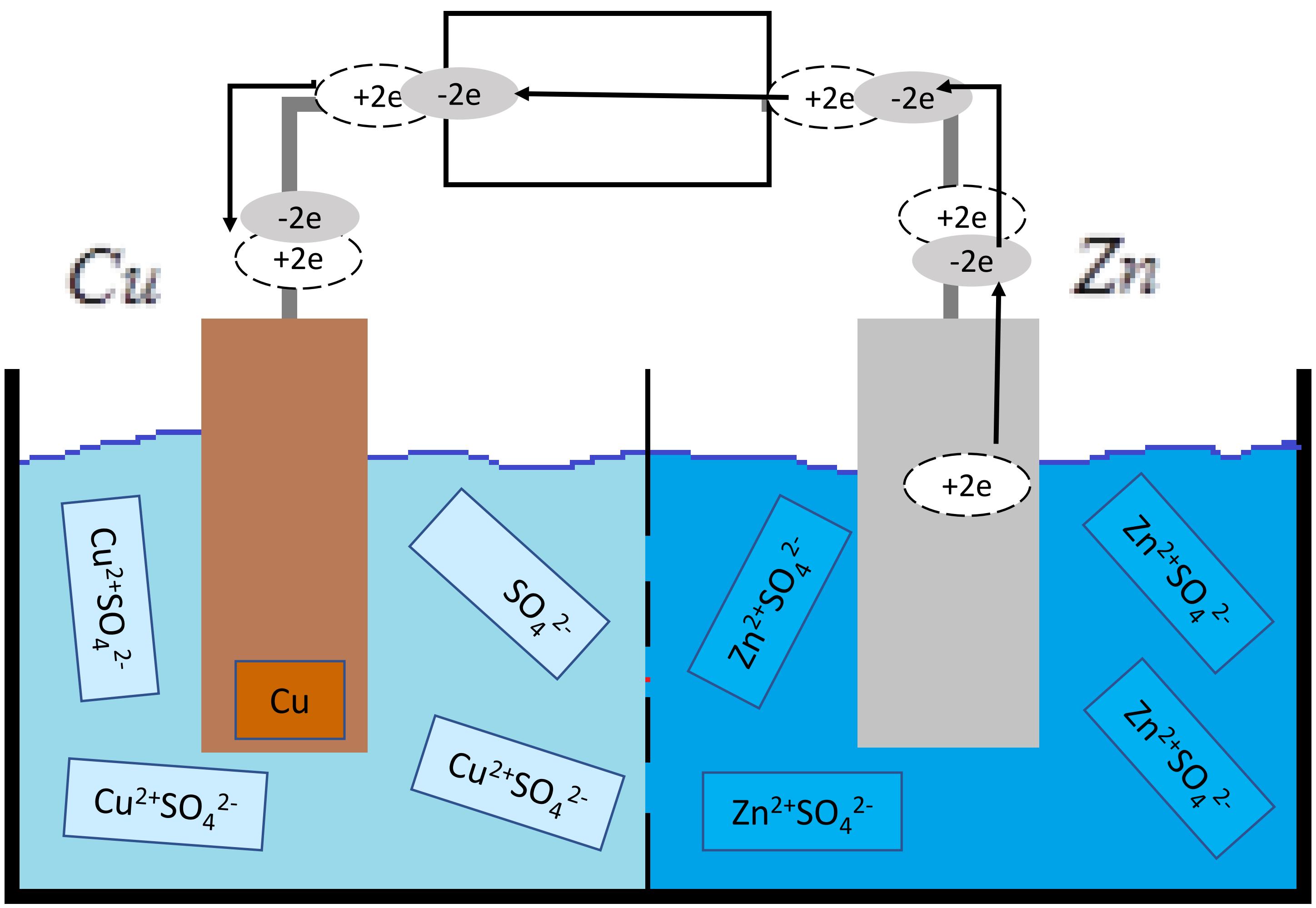
Cu^{2+} will 'want' to come out of solution and plate onto the Cu anode.

Once it does, its positive charge will attract 2 electrons from the wire to come neutralize it and form Cu.

This will leave an effectively +2e charged 'hole' in the wire, where the electrons vacated.

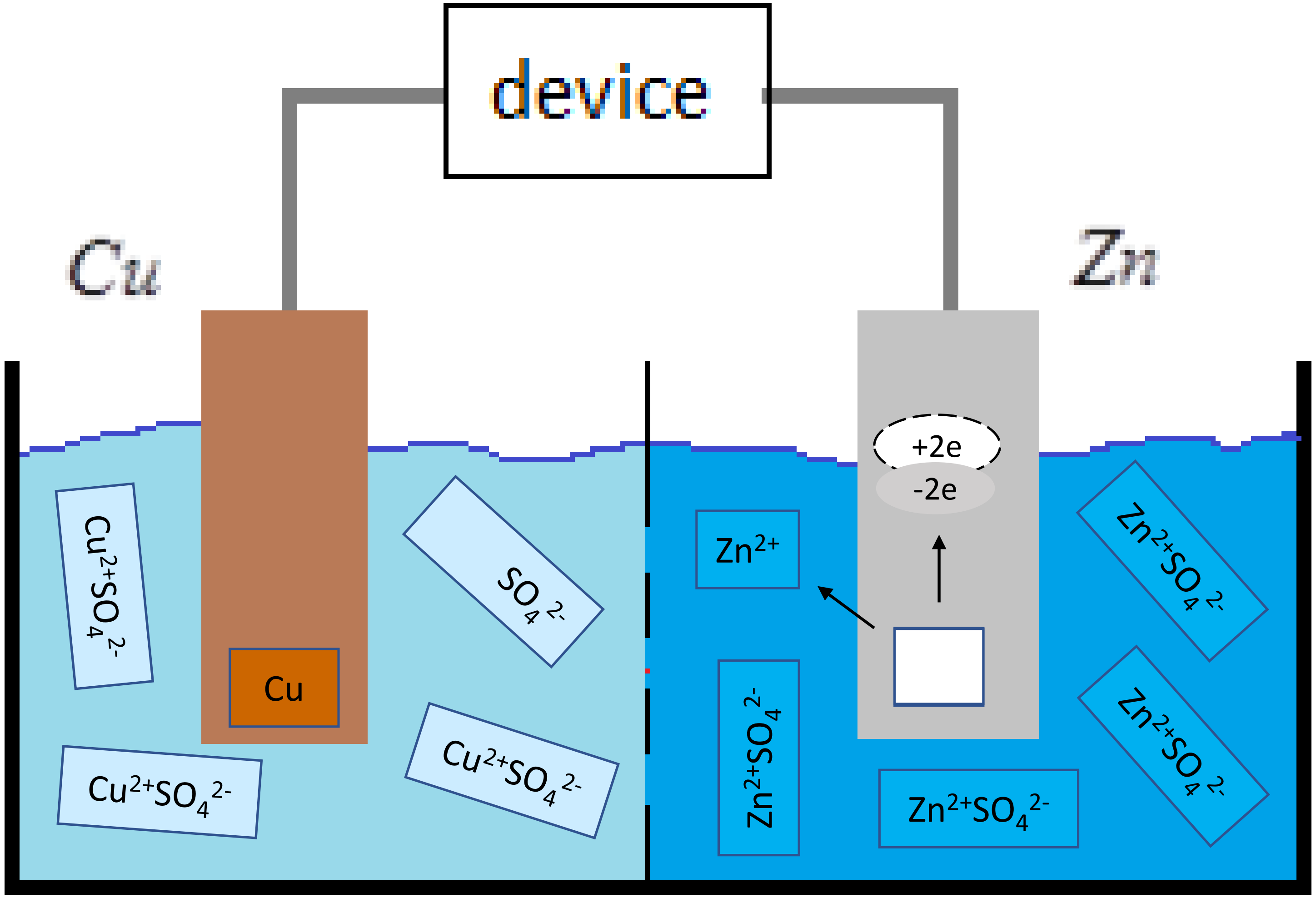
And don't forget we now have a dangling sulfate ion in solution

B.1 Batteries



So now with a +2e hole in the wire, electrons from further parts of the wire will be attracted to the that region to fill and neutralize it, leaving +2e holes where they vacated, and so on, until we get to the Zn cathode.

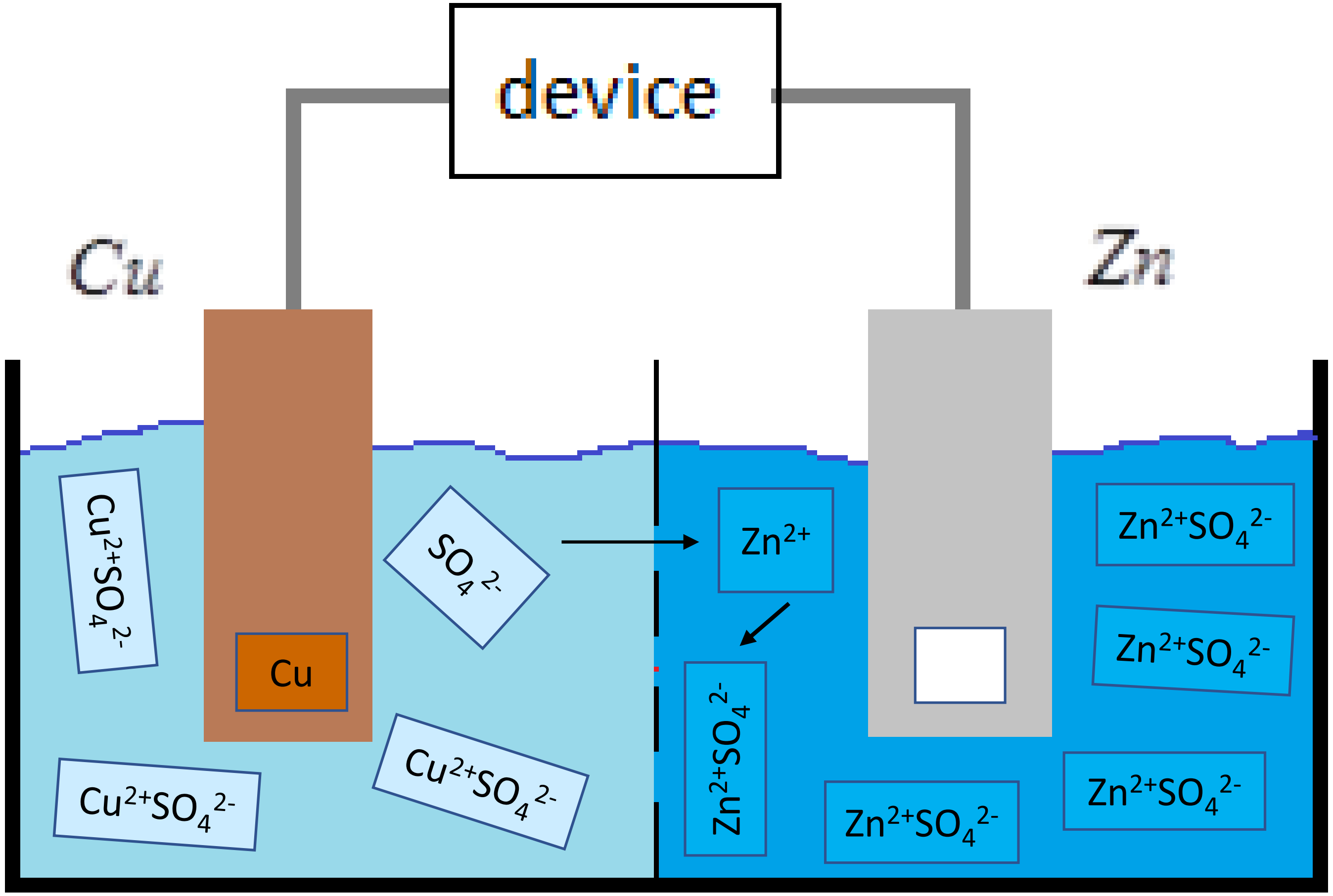
B.1 Batteries



Now with an electron hole in the Zn anode, a Zn atom will ‘want’ to give up two of its electrons to neutralize it, and then detach into the zinc sulfate solution.

Now we have a dangling Zn^{2+} ion in solution, and guess whose gonna want to visit?

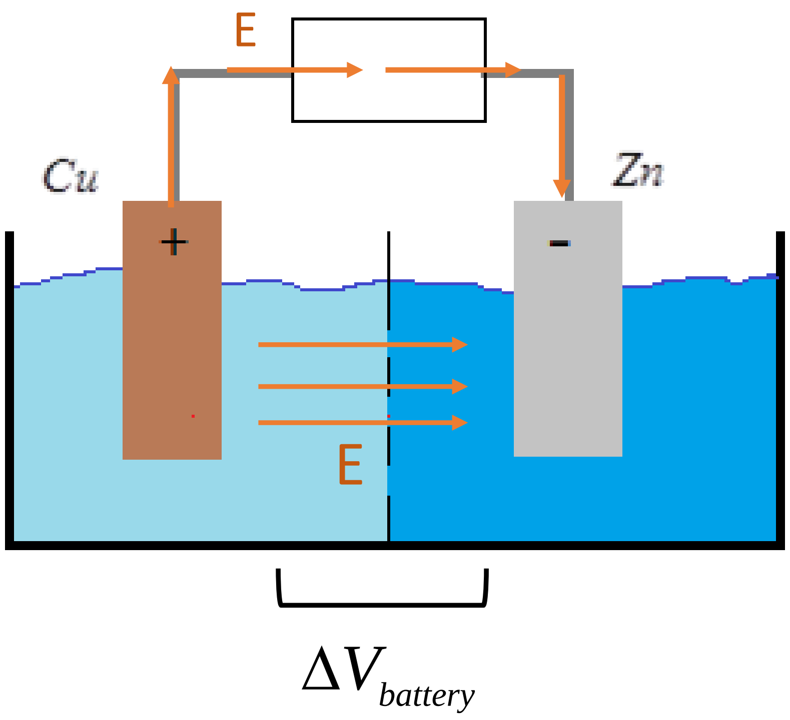
B.1 Batteries



Now the sulfate ion will diffuse through the membrane to connect with the Zn ion.

And then the process will repeat. As you can see, eventually it must come to an end since on the left, all the Cu is plating onto the anode, all the sulfate is migrating to the right, and the Zn cathode is dissolving.

B.1 Batteries



Positive current convention:
So you see that the electrons were traveling counterclockwise. But it's convenient to think of it differently (but equivalently), that the positively charged 'hole' was traveling clockwise. This is the convention used in circuit analysis.

A battery can transport only so much charge Q_{max} before it, in this case, dissolves.

The work the battery does on a charge q (q was 2e in our example, but generalizing now) as it crosses the terminals, is: $W = \Delta PE_E = q\Delta V$.

The rate at which it does work is the power: $P = dW/dt = (dq/dt)\Delta V = I\Delta V$, where we define the current $I = dq/dt$.

Synopsis:
1. Cu^{2+} plates onto anode making it positive.
2. Zn^{2+} dissolves off cathode, making it negative.
3. Electric field, **E**, is set up pulling electrons through wire from cathode to anode through potential difference ΔV but opposing their return.
4. Chemical reaction transports electrons back to cathode.