Electrochemistry: Crash Course Chemistry #36

Crash Course: Chemistry
https://youtube.com/watch?v=IV4IUsholjg
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Aaah, the controlled flow of electrons, making possible laptops and phones and cars and pacemakers. Batteries, just like everything else in life, is just chemistry raised to the power of awesome.

===== Electrochemical Reactions =====

The kind of chemistry that happens inside of a battery is called electrochemistry because it involves reactions that produce or consume free electrons. Specifically, they are oxidation or redox reactions, the ones where electrons are exchanged.

I've told you about redox reactions before and if you haven't seen that episode yet, you should probably go watch that before you watch this. Don't worry, I will still be here when you get back.

Now, when the flow of electrons in these kinds of reactions are sent through a conductor, like a piece of metal, it can be used to do all sorts of work. Like, for example, this kind of work. The amount of work that can be done depends on how strong the push or pull on electrons is between the two reactants. This is the reaction's electrical potential, but to its friends, it's known simply as voltage. Basically, if the voltage is high, each electron can do a lot more work than if the voltage is low.

Many of the wonderful things in our modern lives are based on one simple premise: putting a device between the two halves of just such a reaction; the half that donates electrons, and the half that accepts them. By harnessing that energy, a lot of the coolest things you've done today, up to and including watching this episode of Crash Course Chemistry, has been made possible.

[intro music]

Part of what makes redox reactions so powerful, and powerfully excellent, is that they are complicated. Because in each reaction, there's at least two things going on there's the part of the reaction where the electrons are being released and another part where they're being eagerly demanded. So when we deal with electrochemistry, we usually think of reactions in terms of half reactions.

===== Half Reactions / How A Battery Works =====

Let's start with a typical redox reaction that happens in this alkaline battery as an example. In here elemental zinc is going to react with manganese dioxide, also known as manganese four oxide, to produce manganese three oxide and zinc oxide. You break this down in to half reactions, first you have elemental zinc with an oxidation number of zero being oxidized to zinc two ion. At the same time manganese four is being reduced to manganese three.

When we balance the half reactions, we see that two electrons are released during the oxidation of each zinc atom, and one electron is consumed by each manganese four atom. The water and hydroxide ions, by the way, come from a solution of potassium hydroxide. Which is a basic, or alkaline compound. Which is why we call these things alkaline batteries.

Now if each of these half reactions occurred in contact with the other one, they'd just spontaneously go to equilibrium releasing energy as a bunch of heat which wouldn't be very helpful. So batteries are designed to harness that energy by isolating the half reactions from each other. This allows excess electrons to build up in the negative terminal, called the cathode, while an electron vacuum of sorts occurs in the positive terminal, the anode.

Electrons can then cross from one half reaction to the other, only when we connect the cathode and the anode of the battery via conductors. So the current can be used to do work. Which I can do by licking this 9 volt battery. Ahhh - *laughs*

In these batteries, the zinc is in the center surrounded by a layer of cellulose that allows ions to pass through. The manganese oxide is in the outer layer that surrounds the zinc core, but the cellulose barrier doesn't allow the zinc and the manganese to mix.

===== Galvanic Cell =====

Alkaline batteries are a type of galvanic cell. Which is generally defined as an apparatus that generates electrical energy from a redox reaction. Here's another example of a galvanic cell, one where the interesting part is the flow of whole ions instead of the flow of electrons.

In this case, wires connect metal rods that are suspended in the solution. They're are the anode and cathode here. What's noteworthy, is that the metal atoms are actually consumed. They're used up from the anode rod as they're oxidized, and the metal slowly wears away. Meanwhile, the opposite happens at the cathode rod, where metal ions from the solution gain electrons and precipitate on to the cathode as pure metal, gradually growing larger.

The circuit is completed by the wire, but also by a salt bridge which is also a U-shaped tube that contains a salt solution that allows the metal ions to go from the anode to the cathode. So, now you know how batteries work: developing and transferring a charge using electrochemistry. But before any redox reaction can be used to text your boyfriend or girlfriend or whatever, we need to know how much voltage it can generate.

===== Calculating Voltage =====

Fortunately all of those amazing chemists who have come before us have done a lot of the work once again. The voltage generated by many half reactions is already known and can be found in most textbooks or online. And as I mentioned earlier, voltage is really just a way of expressing the electrical potential of each half reaction. The difference between the chemical demand for the electrons in one half, versus the tendency to lose them in the other.

===== Standard Reduction Potential =====

These measurements are done at standard conditions, which we discussed in the enthalpy and entropy episodes. And by convention they are written as if the substance is being reduced, not oxidized. For this reason the value is known as the standard reduction potential of a substance.

To see how reduction potentials work in half reactions and combine in an overall reaction, let's consider a galvanic cell where zinc is oxidized and copper ions are reduced. Keep in mind that potentials are determined at standard state: 25 degrees Celsius and 1 molar solutions of the copper and zinc ions. Our cell needs to be set up under the same conditions or the voltage will be a bit different than expected.

The half reactions show more clearly what the electrons are doing.

We can see that the zinc is oxidized and the copper is reduced.

Now all standard reduction potentials are measured relative to the reduction of hydrogen ions to hydrogen gas, which is set at zero, just as a baseline. When copper is reduced, for example, it generates 0.34 volts more than hydrogen does, so we say its standard reduction potential is +0.34 volts. The standard reduction potential for zinc is -0.76 volts, but because zinc is oxidized in this reaction, we can't use the reduction potential directly. Instead, as a general rule, when you convert a reduction half reaction to oxidation, the sign of the voltage is simply reversed. So, the -0.76 volts for the reduction potential of zinc becomes +0.76 volts for the oxidation potential of zinc ions.

===== Standard Cell Potential =====

And the electrical potential for the whole reaction, called the standard cell potential, is just the sum of the standard potentials of both half reactions. In this case, that would be 1.1 volts.

Now I gotta point out here that the electrical potential of a redox reaction is related to its equilibrium constant. There's actually a way to determine the equilibrium constant from a measured voltage, and vice versa.

Both of these constants have a lot to do with the energy the reaction can release, or its Gibbs free energy. But in brief, the higher the voltage, the more electrical energy can be produced, so if the voltage is positive, it means that under standard state conditions, the reaction will spontaneously go forward. If the sign is negative, the reaction will proceed backward.

And it totally makes sense, when you think about it, that reactions like this are used to make battery cells. The reactions in batteries need to be spontaneous because their whole purpose is to release energy, not consume it.

So what if we don't want to power a phone or a laptop or a toy shuttle. What if instead we want to plate an iron car bumper with chrome? This cannot be done with a spontaneous reaction.

Instead, a different electrochemical process is needed, one that you've probably heard of: electroplating. This is done by immersing an object in a solution that contains an excess of ions of the coating metal. A bar of the coating metal, in this case chromium, is used as the anode and the item to be plated, the iron bumper, acts as the cathode.

===== Electrolysis =====

When an electric current is applied, a redox reaction occurs in the solution and atoms of the coating metal are deposited on the cathode. This is essentially the opposite of a galvanic cell, known as an electrolytic cell, and it performs electrolysis, which uses electricity, electro-, to do the breaking apart, -lysis.

In this case molecules in the solution are being broken down so that the metal atoms can be deposited on the surface. Electrolysis is used for lots of other things too, like coating jewelry or flatware with gold or silver, refining metals or separating mixtures of metal ions. Also, converting water into hydrogen gas and oxygen.

So if you didn't already understand how much impact chemistry has in our daily lives, you certainly should be able to see it now.

Not only are all the materials around you made of chemicals, but even the electrical devices that power our lives depend on the reactions of electrochemistry.

Thank you for watching this episode of Crash Course Chemistry. If you were listening, you learned that electrochemical reactions are redox reactions that we describe in terms of half reactions.

You learned how an alkaline battery works and what's inside of it, what a galvanic cell is and how it can be set up and how to calculate the voltage that can be generated by a half reaction, the standard reduction potential, and by the overall reaction, the standard cell potential. You also learned how electrolysis and electroplating work.

This episode was written by Edi Gonzalez and edited by Blake de Pastino. Our chemistry consultant was Dr. Heiko Langner. It was filmed, edited and directed by Nicolas Jenkins. Michael Aranda is our sound designer and Thought Cafe is our graphics team.