Redox Reactions: Crash Course Chemistry #10

Crash Course: Chemistry
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The electron is to chemistry what money is to capitalism. It's all about who has it, who wants it, and what they're willing to do to get it. Electrons are what make it possible for an atom to bond with other atoms to form molecules. And when that happens, a tremendous amount of energy can be exchanged in the process. But not all chemical reactions involve electrons changing hands. Acid base reactions, you recall, are more about swapping protons.

But because electrons are the real coin in the realm of chemistry, the most important reactions to take place on Earth involve the transfer of one or more electrons from one atom to another. These are redox reactions. Redox, which is a portmanteau of 'reduction', 'oxidation'.

=====Definitions (00:48)=====

But what's up with those words? You know what reduction is, making less of something. And then oxidation maybe has something to do with oxygen. Well, sometimes, not always. These are actually super terrible choices for what is actually happening in redox reactions, but we are stuck with them.

Reduction is when a substance gains electrons. Yes, it gains, which is the opposite of what the word 'reduce' means, fantastic. And yes, sometimes I want to punish the people who name these things so inaccurately but they didn't know any better and they're all dead, so we can't do anything about it.

Proto chemists would make pure metals by heating or smelting their ores. And they notice, during the smelting, that these substances would become lighter. So I guess it's not crazy that they decided to say these substances were being reduced.

Our old French friend, Antoine Lavoisier, figured out that this was because oxygen gas was actually leaving the compound, making it lighter. What he didn't know, was the actual chemistry involved.

Oxygen is, unsurprisingly, the quintessential oxidizer. It pulls electrons off of one molecule to make itself more stable. But if you heat it up enough, it gets all energetic.

Today, we understand that oxidation and reduction are all about electron transfers. So you might think that we renamed them. And some chemists have tried, using terms like electronation and de-electronation. But once a set of terms is decided upon and used for a while, it's pretty difficult to uncreate it, so we're stuck.

To keep these seemingly nonsensical names straight, I rely on the phrase 'OILRIG': "Oxidation is loss of electrons, reduction is gain of electrons."

We just gotta know these stuff, because it's everywhere. When your cells convert sugar into energy so you can move and breathe and think? That's redox. When plants photosynthesize sunlight into food? That's redox. The battery powering your laptop? Redox. Fire? Also redox!

Since electron swapping is the name of the game here, when you study redox reactions, it's important, critical, absolutely essential, to keep track of the electrons. Think of them as dollars or pesos or pounds or euros; in any transaction, one person is going to gain them and the other is going to lose them. And to stay on top of things, you have to keep tabs on who's ahead and who's behind.

Atoms are fond of sharing electrons though, forming covalent bonds, so sometimes keeping track of where they are and where they're gonna end up isn't quite so simple.

=====Oxidation States (03:06)=====

Let's think of every covalent compound like a marriage. Though it's gonna be weird marriage, because like, there might be like six people in it, sometimes the same person several times. Without commitment, no commitment and also no emotions. Don't think too much about it.

Like in a marriage, where money gets shared, covalent compounds share electrons. The trick, is figuring out who get the cash when the vows break. So we've created a useful little system assigning electrons one hundred percent to atoms that are, actually at the moment, sharing them.

The number that we assign is the atoms' 'oxidation state' or oxidation number. Even though we are of course aware of covalent bonds and the sharing of electrons, the processes are easier to follow if we imagine the atoms are already splitting up the bank account, as if they were in an ionic or non-sharing bond. So an atom's oxidation number is basically what its charge would be, if it actually owned all its electrons exclusively like the newly-minted bachelors that they may become.

=====Figuring Out Oxidation States (04:00)=====

So to figure out those oxidation states, or oxidation numbers, we have some simple rules for some atoms:

First, the oxidation number for any element by itself, whether it's monatomic, diatomic, or polyatomic, like an atom of calcium or molecule of H_2 or even bigger molecule of sulfur (S_8), the oxidation number is 0. Atoms, by definition, do not have a charge. If they had a charge they would be ions. And if they're sharing with themselves, they share it equally.

Second, for a monatomic ion, basically a charged atom, it's simply the size or number of its charge. So the iron (II) in Fe^{2+} has an oxidation state of plus two, while the chloride ion is minus one.

Third, oxygen, which is unsurprisingly all over redox chemistry, almost always has an oxidation of negative two, unless it happens to be in a peroxide molecule like hydrogen peroxide.

Fourth, hydrogen, is plus one.

And fifth, fluorine, is negative one. As are all the other halogens most of the time, pretty much, unless they're bonded to fluorine or oxygen, cuz fluorine or oxygen are so bad that they could make anybody's oxidation number a positive, if you know what I mean?

And those are the rules!

That's all you need to know.

Now, the total of all the oxidation numbers of all the atoms in a neutral compound will add up to zero. Like water: with one oxygen, with a negative two oxidation state; two hydrogens of plus one; and voila, a neutral compound had an oxidation number of zero.

A polyatomic ion, on the other hand, has to work out to have an oxidation state that matches its charge. So SO_4^{2-}, the sulfate ion, has four oxygens for a total of negative eight, but we don't have a rule for sulfur so I guess we just give up and walk away, who cares anymore?

No!

We use like, third-grade algebra. Because we have to end up with an oxidation number of negative two for the whole compound, we know that sulfur, in this particular compound, has an oxidation state of plus six.

But, sulfur's oxidation state isn't always plus six, and that's why we don't have a rule for sulfur or a lot of other elements for that matter, because oxidation states of most elements change depending on what they're bonded with.

=====Redox Equations, Example 1 (05:59)=====
Now we can use the same logic to figure out what happens when these compounds interact in redox reactions.

Molecular divorce courts of electrons: changing hands, being haggled over, and traded, with some players taking big profits while others lose nearly everything. Them's the breaks.

Let's start out with a simple example, a chemical reaction that I believe has saved more lives than any other in the history of chemistry, created by a war criminal to blow people up during World War One: the Haber process. The Haber process removes the ultra-stable elemental nitrogen from the air and combines it hydrogen to form NH_3, ammonia for use in bombs and also in fertilizer, increasing the carrying capacity of the Earth by billions.

Nitrogen in the air exists as elemental diatomic nitrogen, and hydrogen, likewise, is also diatomic H_2. So we know that starting out all of the atoms have an oxidation state of zero. Product of the reaction, ammonia, is a neutral compound with one nitrogen and three hydrogens. The hydrogens, each have an oxidation state of plus one - remember the rules - so nitrogen must have an oxidation state of minus three.

Nitrogen thus gained electron, its oxidation state went down and so it was reduced. So at least when talking about what oxidation states are doing, the word 'reduced' make sense. Hydrogen lost electrons, the oxidation state went up and it was oxidized.

=====Balancing Redox Equations (07:18)=====

Now this is pretty simple equation to balance, but redox equations can be a huge headache sometimes because the number of individual atoms involved, so we often have to balance them in half-reactions. So even though we don't really need to do the half-reactions, because this is a pretty simple equation, we're going to do them anyway, just because it's an example that's simple to start with.

So we start out with nitrogen getting reduced. We have N_2 with an oxidation state of zero becoming NH_3 with an oxidation state of negative three. First we balance the number of nitrogens then add the number of electrons that we need to have to have there be the same number of electrons on each side. Do the same with the oxidation half of the reaction and then combine them to get your whole reaction with the electrons cancelling out.

Now yes, maybe that seems like an unnecessary step, but allow me to show you a more complicated example that will prove how necessary it may be.

=====Redox Equations, Example 2 (08:03)=====
In this flask, is silver diamine, we're going to use some redox chemistry to get the elemental silver out of it nice and clean and shiny and it's not gonna be no simple Haber process.

Silver diamine is going to react with an organic aldehyde. Any aldehyde actually. The business end of the aldehyde is the CHO and the R in organic chemistry is a symbol for some organic group of atoms and in this reaction those atoms don't matter. Silver diamine reacts with the aldehyde and hydroxide to create a carboxylic acid, ammonia, and water.

First, let's assign ourselves some oxidation states. Silver is in a complex with two neutral ammonias that are going to remain unreacted throughout the equation, so we can treat them like a single species with an oxidation state of zero. Since the silver diamine has a charge of plus one and the ammonias don't affect that, silver's oxidation state must also be plus one. The aldehyde has one hydrogen at plus one and one oxygen at minus two but is neutral overall so the carbon must be plus one as well. The hydroxide ion is simple: minus two for the oxygen plus one for the hydrogen and an overall charge and oxidation state of minus one.

On the reactant side, the silver is now atomic, so its oxidation state is zero. The carboxylic acid has two oxygens and one hydrogen so the carbon now has an oxidation state of plus three. NH3 remains at zero and the hydrogen and oxygen of water also haven't changed oxidation states. So silver's oxidation state decreased, or was reduced, from plus one to zero, while carbon was oxidized from plus one to plus three.

Half-reaction time!

Silver was reduced, gaining one electron, forming elemental silver and ammonia from silver diamine. The aldehyde was oxidized, forming carboxylic acids and requiring two electrons.

With the help of those electrons, we know that at the very least we have to double the reduction half of the equation entirely in order to get the right number of electrons on both sides.

We do that and oh god, that's Good Stuff!

Then we combine them together, for a perfectly balanced redox equation. And now, watch me take those electrons and turn them into money. And there you have it folks. That is pure silver coating the inside of a flask.

=====Summary (10:08)=====

Thank you for watching this episode of Crash Course Chemistry. If you were paying attention, you'd learn that: any reaction where electrons move around from atom to atom is a redox reaction, that oxidation is the loss of electron and reduction is the gain of electrons, and that oxidation numbers are assigned to atoms to take part in reactions in order to keep track of what their electrons are up to.

You'd also learn a few simple tricks to help figure out what an atom's oxidation state is and got a little practice figuring out how to assign oxidation states and balance oxidation reactions, with two examples: one pretty simple and another a little less so.

=====Credits (10:41)=====

This episode of Crash Course Chemistry was written by Kim Krieger and myself, our script editor was Blake de Pastino, our chemistry consultant is Dr. Heiko Langner and a troop of chemistry teachers also advised and edited this one, so thanks very much to all of them.

This episode was filmed, edited and directed by Nicholas Jenkins, our sound designer and script supervisor is Michael Aranda, and our graphics team is Thought Cafe.