Equilibrium: Crash Course Chemistry #28

Crash Course: Chemistry
https://youtube.com/watch?v=g5wNg_dKsYY
https://nerdfighteria.info/v/g5wNg_dKsYY

===== Introduction =====

Life is all about balance. You want to have a balanced bank account, balanced diet, balance between work and play, and a healthy inner ear to keep you from falling down all the time, and lots of things can mess up that balance- one bad night at the cheesecake factory and you might wake up with your finances, social life, and health out of whack.

In science, our word for balance is equilibrium. You've heard of it. When the balance of some natural system gets disrupted, we say that it's out of equilibrium, but that's not always a bad thing, because nature usually finds a way to restore the balance. Like if a population of deer in a forest suddenly goes nuts and there's too many of them, they'll run out of food and space, and predators will move in and the population will usually fall back to where the habitat can sustain it. Likewise, there's no reason that I can't enjoy the occasional hot pocket without destroying my so-called balanced diet, I just have to be sure to eat something that wasn't prepared in a salty lard factory to balance it out.

We tend to think of chemical reactions as having a beginning and an end- you start with some reactants, some chemistry happens, and you end up with the products, and that's that. But that's not that, because you don't usually end up with pure products. Many chemical reactions seek balance too, and just like us, they have to work through the stress in order to find it.

[Crash Course theme song plays]

===== Main Video =====

It's common, because it's usually helpful, to think of chemical reactions as simple straightforward processes, but in reality, many reactions never finish- ever.

When reactants react to form products, what we usually mean when we talk about chemical reactions, it's technically called the forward reaction. But sometimes, there's an opposite reaction that occurs with the products changing back into the reactants. We call this a reverse reaction. Now, exactly what kind of reactions do this, and why, is hard to describe without busting out some two hundred level chemistry kung fu, but it all goes back to our lesson about Gibb's free energy and reactions that occur spontaneously.

Reactions are reversible when they can go forward or backward without any extra energy being used. Remember, this isn't just one reaction happening once, it's billions and trillions of reactions, and some of them might be going one way while others are going another way. And when the forward and reverse reactions occur at the same rate, that's called chemical equilibrium. And even though we all like the idea of balance in our lives, in this case it's not always a desirable thing. In fact, most chemists make their living using tricks to prevent chemical equilibrium, to knock it out of whack, maximizing the concentrations of the chemicals they want to produce at the expense of the balance that nature usually seeks.

For example, consider the Haber process for making ammonia from nitrogen in the air. When we discussed it as a redox reaction a few weeks ago, we described it as a one way, complete reaction because that's all we needed to understand right then. But I was lying to you. Sorry, I'd rather you hear it from me than out on the streets- turns out, the reaction really exists as an equilibrium. As nitrogen and hydrogen react to form ammonia, the concentration of those gases drops, making them less likely to collide and keep reacting, so the rate of the forward reaction slows down. At the same time, the concentration of ammonia rises. More ammonia molecules are available to break up into the reactant gases, and surprise, the rate of the reverse reaction speeds up. Eventually, those processes reach a point where they happen at the same rate. At that point, there's no discernible change in the concentration of any gas. Nitrogen and hydrogen keep combining to form ammonia, while ammonia keeps breaking down into nitrogen and hydrogen at the same time. Notice that I did not say that the reaction stops. The reaction basically never stops, it's just that we don't notice any changes at that point, because everything that happens in one direction is perfectly balanced out by what happens in the other direction.

That's why reactants like this are written with a double arrow, indicating that the process runs both directions. Like if I stand on a balanced board, I never stop moving. I just shift my body back and forth to compensate for the motion of the board. When it moves left, I move right and vice versa, and by doing that, I'm able to stay upright, hopefully. But sometimes there is, if you will, a disturbance in the force, and as any good Jedi knows, those things must be put right.

Chemical equilibria can be disturbed by changes in the concentration of one or more substances or by changes in temperature or pressure. We describe these changes based on which way they force the equilibrium. We say a change shifts the reaction to the right if it tends to make more products form and to the left if it tends to make more reactants form. This was all summarized nicely by a French chemist named Henry Louis Le Châtelier who was born in Paris in 1850. Today, we call call his summary Le Châtelier's Principle, and it says that if stress is placed on a system that is at equilibrium the system will proceed in a direction that minimizes the stress. That can happen in several ways. For starters, changing the concentration of any substance in a reaction causes it to proceed in whatever direction restores the former balance. For example, once the Haber reaction is at equilibrium if you were to add more nitrogen gas to the mix the existing hydrogen would have more nitrogen to react with. Thus, it would begin forming more ammonia, sending the reaction noticeably to the right until the reaction balances itself again. Removing some of the ammonia would have the same effect. There would be less ammonia available to break down, so the formation of the ammonia would temporarily exceed the formation of nitrogen and hydrogen, and the reaction would again shift to the right until the balance is restored.

Now here's an ironic side of irony served up for you. In 1901, Le Châtelier tried to invent a process for fixing nitrogen to make ammonia from nitrogen and hydrogen. But he gave up the effort after the experiment caused a huge explosion that killed one of his lab assistants. 8 years later, the German chemist, Fritz Haber, probably the closest the world ever got to a literal evil genius, did just what Le Châtelier was trying to do. And in contrast to Le Châtelier's despair at the death of his assistant, Haber had no problem at all with the fact that his procedure now known as the Haber Process was used to make chemical explosives which killed hundreds of thousands of people in World Wars One and Two. But just to prove that there aren't clear winners or losers in science the Haber Process also saved uncounted millions of lives because the ability to fix nitrogen has made chemical fertilizers possible and basically revolutionized modern agriculture. Haber was awarded the 1918 Nobel Prize for his discovery but thirty years later he was considered by many to be a war criminal and spent his last years as an object of shame to his family and hatred for many others. Le Châtelier, meanwhile despite his great contributions to our understanding of equilibrium, considered his failure to find an efficient method for making ammonia to be the greatest blunder of his scientific career.

One of the key achievements that Haber made was figuring out a way to continuously remove ammonia as it was being produced. This allowed the forward reaction to keep going faster than the reverse reaction. Basically preventing the process from reaching a state of equilibrium. But changing concentrations is only one part or actually one third of the story.

There's also pressure to consider. When you look at the equation for the Haber Process, for example, you can see that four moles of gas react to form two moles of gas. So the forward reaction decreases the volume while the reverse reaction increases it. This is important. Increasing the pressure will then put more stress on the high volume reactants than the low volume products so the reaction shifts to the right, producing more ammonia than it does at low pressure. And indeed, the industrial Haber Process is done at two hundred atmospheres of pressure. Decreasing the pressure, meanwhile, has the opposite effect. The reaction precedes in the direction that raises the pressure back to where it was before. In this case that's the break-down of ammonia. Toward the left where there are four moles of gas. Solids and liquids aren't affected by pressure as much so the more gasses that are present in the reaction, the greater effect any pressure change will have.

The third and final way to affect the position of equilibrium is with temperature changes. It gets a bit complicated up in here but basically the thing to keep in mind is that endothermic reactions, which consume heat, are favored if heat is added so higher temperatures tend to feed endothermic reactions. And by the same token, exothermic reactions, which release heat fair better at low temperatures. And since exothermic reactions produce heat, that heat tends to favor the reverse endothermic reactions. So if heat is added to reaction, it forces the reaction back to the left. But if heat is removed by cooling the reaction mixture, the reaction will proceed to the right. Now, you may be wondering since battling equilibrium is what most chemists do for a living, how they work out the specifics of it. How do they determine how much of each substance is present or how much they need to add or what the temperature or pressure should be when everything is constantly changing. You probably won't be surprised to learn that there is math we can do to answer those questions. We'll get into the numbers in our next lesson. But right now, let's have some fun.

I've been talking about the Haber Process because it's a simple reaction, it's an important reaction. And because it's one of the main reactions that Le Châtelier studied. But it's not very interesting to watch. A much more interesting reaction involves two different ions of cobalt that reach equilibrium in an endothermic reaction. As you can see, one of the ions is pink in aqueous solution and the other is blue. One stress I can put on this system is the addition of hydrochloric acid. This increases the chloride ion concentration and pushes the reaction to the right, the blue side. And if I add water, the reaction is pushed right back to the left, pink. Cool, right? I can also stress the reaction by changing its temperature. If I raise the temperature, it's like adding a reactant so the reaction will proceed to the right. You use it up and turn blue again. You can probably guess by now that if I lower the temperature it's like taking away some reactants so the reaction proceeds to the left and turns pink. We could make these colors go back and forth all day by making changes to the reaction but I think you're getting the idea.

Equilibrium isn't about staying the same all the time, it's just about keeping your balance as your circumstances change. And now it is time for me to go get a nice Greek salad to help balance out the corn dogs that I may or may not have eaten this weekend. But first thank you for watching this episode of Crash Course Chemistry. If you paid attention, you learnt that equilibrium is just a fancy word for balance which is a thing that chemical reactions need just as much as we do. And that the way they achieve balance is to compensate for change, not just to stop completely. You also learned and saw that chemical equilibrium can be affected by the concentration of substances, their temperatures, and if they're gasses, their pressure. Finally, you learned about Le Châtelier's principle of chemical equilibrium and about his failed attempt to do what Fritz Haber eventually did. Invent an efficient process to produce ammonia. This episode of Crash Course Chemistry was written by Edi Gonzales. This script was edited by Blake de Pastino. And our chemistry consultant was Dr. Heiko Langner. It was filmed, edited, and directed by Nicholas Jenkins. Our script supervisor, Katherine Green. And our sound designer is Michael Aranda. And of course, our graphic team is Thought Cafe.