Solutions: Crash Course Chemistry #27

Crash Course: Chemistry
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=====Introduction (00:00)=====

I want you to think, just for a second about breathing. But don't just think about the fact that you are breathing. Think about all the variables that have to be just so in order to create the air- and to make the air breathable.

So you need oxygen in the air but also if the air was just oxygen, you would die. The oxygen has to be mixed with nitrogen and other gases, and the whole concoction has to be at the right pressure and temperature in order to deliver the amount of O_2 that you need. The air that you are breathing is a solution. Also, not to belabor the point, but you are also kind of a solution as well,
albeit a sentioned one.

A solution, you'll recall back when we were doing my dirty laundry, is a mixture in which the particles of a solute are dissolved in the particles of a solvent. So, what's the solvent in air? Well, whatever there's more of. So, nitrogen is the solvent and oxygen, carbon dioxide, argon, and a bunch of other gases are dissolved in it.

All solutions have the qualities that they do because of the same three properties;

1. Molecular Structure
2. Pressure
3. Temperature

These are the factors that effect a substances solubility, the amount of solute that will dissolve per volume of solvent. Whether we're talking about the air that we breathe, the water that fish breathe, the bubbles in Coca-Cola, or the toxin in the tissues of the Japanese puffer fish, what usually matters most about a solution is how much solute is in it.

[Intro music]

=====Molarity, Molality, and Mass Percent (01:21)=====

Often, in the lab we use placeholders like 'dilute' and 'concentrated' when talking about solutions. But those are vague terms, and we should generally be as precise as possible. Here are a few ways to do that.

We could describe a solution by its molarity - the number of moles of solute per liter of solution; its molality - the number of moles of solute per kilogram of solvent; or its mass percent. The mass percent of a solution is the mass of the solute divided by the mass of the solution all multiplied by 100.

So, when a can of your average soft drink has about 33 grams of sugar and a total mass of 355 grams: divide the mass of the solute by the mass of the whole thing times 100 and the mass percent of sugar in the solution is 9.2%.

Easy-peasy there, but the more interesting question here is ‘why?’ Why can you even dissolve so much sugar in a can of soda and what about all that carbon dioxide gas? What’s happening here? How does the stuff go in the stuff and where does it go and what’s actually happening at the molecular level?

=====Polar and Nonpolar Solutes and Solvents (02:21)=====

Well, the first thing to keep in mind is that not every solvent can dissolve every solute. Gas molecules don’t interact that strongly, so gases pretty much always dissolve in each other. But, liquid solvents have a ton of molecular interaction. So the structure of the individual molecules determines whether a substance will dissolve- and how well it will dissolve.

Polarity is, of course, the biggest bit of this. For a substance to dissolve, it needs to interact favorably with the solvent. This only happens if they have similar polarities which allows them to form cool, in-solution structures, spacing the solute particles out evenly.

Topic change! Say you’re on a first date- at a sushi restaurant, and you wanna be all cool and nonchalant and “I’ll tangle if death if death wants me to.” So you order the puffer fish, otherwise known as Fugu. Fugu contains a poison called tetrodotoxin, and even in the hands of chefs who know what they’re doing, it makes your lips go numb just to taste a bit. If the chef makes a mistake and you eat the wrong part of the fish, the tetrodotoxin will mess with your nervous system and cause paralysis, suffocation, maybe some death.

Why? Well, in part because of its polarity. And yours. Tetrodotoxin is covered on its surface with polar alcohol and Amin groups. So, it dissolves easily in polar solvents like water. And who’s made mostly of water? So, if you watch Crash Course Biology, you know all about sodium channels, the tunnels on the outside of nerve cells that allow them to communicate with each other. Well, tetrodotoxin is really good at binding to those channels, messing up your nervous system, and killing you. Because it’s so polar, and your body’s just one big aqueous solution, tetrodotoxin has free reign to just jump on every sodium pump you got.

=====Coke = Burps (04:00)=====

Now, onto the next attribute that affects solubility. Let’s assume you’ve survived your first course of your meal and you order a soda-pop. To get all those bubbles that make carbonated beverages so refreshing and tingly, carbon dioxide must be dissolved in the water. But how do you shove a gas into a liquid? A gas gets dissolved into a solution the same way David Bowie and Freddy Mercury collaborate.

sings Under pressure. *snaps* What? As previously noted, I am old! It’s not just the pressure outside of the solvent, it’s the partial pressure of the solute.

Quick review: partial pressure is the portion of pressure caused by the gas we’re interested in. In this case, carbon dioxide. Gas molecules, as long as they have kinetic energy, are going to want to escape the solution so they will be creating an upward pressure on the surrounding gas. And in order to keep the CO2 dissolved, the partial pressure of carbon dioxide and the gas outside the solution has to be equal to, or higher than the pressure of the carbon dioxide molecules pushing their way out of the solution.

That’s why soda bottles are nice and taut when you squeeze them. That little bit of gas up there is pressurized carbon dioxide. And, also why, when you open the can a huge rush of carbon dioxide molecules bubble out of the soda. Because the normal partial pressure of CO2 in the atmosphere isn’t enough to keep it from escaping. So, to get the carbon dioxide in there, all you need to do is dramatically increase the pressure of CO2 outside the liquid. And this is what’s done in soda manufacturing plants. In fact, if you have a SodaStream, you can do it right in your own home.

=====Henry's Law (05:15)=====

Now it’s easy to calculate this change in pressure thanks to William Henry, a friend of John Dalton of Dalton’s Law of Partial Pressures. According to Henry’s Law, the concentration of a dissolved gas equals the partial pressure above the solution multiplied by a constant that expresses the solubility of the gas in that solution. And we can use Henry’s Law to figure out how much carbon dioxide is dissolved in our can of soda. The pressure of CO2 in a can is 5.0 atmospheres and you can look up the solubility of CO2 in an aqueous solution.

3.4 times 10 to the negative 2 moles per liter atmosphere. So the concentration of dissolved CO2 in 0.17 moles per liter. Now, there are 355 milliliters or 0.355 liters of cola in a can. How much volume would that CO2 take up at normal atmospheric conditions? Whip out your trusty ideal gas law and we find that atmospheric pressure and 298 kelvins or room temperature, 0.060 moles of carbon dioxide will expand to about 1 and a half liters. That's a lot of burps, something else to keep in mind on date night.

Finally, in addition to polarity an pressure, it's temperature that affects solubility in the most complicated, and therefore interesting ways. When we're dealing with solid solutes and liquid solvents, their total solubility generally goes up as temperature increases. This is a fact that you already know if you've tried to put a bunch of sugar into your iced coffee. The solubility of gases, on the other hand, is the exact opposite because colder molecules have less kinetic energy and are less likely to escape the surface of the liquid. So, the upward pressure they exert is lower than it would be in a hot liquid. That's why it's safer and cleaner to open a can of soda-pop when it's cold rather than when it's hot. While this phenomenon might result in a bit of mess in your house, it's a much bigger deal for fish, who need oxygen dissolved in water to , like, breathe. At 4 degrees Celsius the solubility of oxygen in water is about double that of what it is at 25 degrees Celsius. Trout, here in Montana, are highly evolved to that nice, oxygen rich water. But summer heat waves can cause the amount of oxygen in the water to drop dramatically, and cold-water fish can get pretty unhappy. Also, a little dead. Fortunately for Fugu, it's a tropical fish, so it's perfectly evolved for 25 degree water.

=====Summary (07:23)=====

And unfortunately for all of us, that brings us the end of this episode of Crash Course Chemistry. If you've been paying attention today, you learned that solutions can be described in terms of molarity, molality, or mass percent; that polar solvents tend to dissolve polar solutes, and nonpolar solvents tend to dissolve nonpolar solutes; you also learned about Henry's Law which states that the concentration of dissolved gas equals the partial pressure of that gas above the solution multiplied by a constant; and that there are a lot of burps in every single can of coke.

=====Credits (07:53)=====

This episode of Crash Course Chemistry was written by Kim Krieger, the script was edited by Blake de Pastino and myself, and our chemistry consultant was Edi Gonzalez. It was filmed, edited, and directed by Nicholas Jenkins. Our script supervisor was Katherine Green and our sound designer is Michael Aranda. And, of course, our graphics team is Thought Café.