Polar & Non-Polar Molecules: Crash Course Chemistry #23

Crash Course: Chemistry
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Molecules! So many of them in their infinite and beautiful variety, but while that variety is great, it can also be pretty dang overwhelming. And so, in order to help this complicated chemical world make a little more sense, we classify and we categorize. It's our nature as humans, and it's extremely useful.

One of the most important of those classifications is whether a molecule is polar or non-polar. It's a kind of symmetry, not just of the molecule, but of the charge. It's pretty easy to see when you just look at an atom. You got polar [on screen: H_2O] and non-polar [Cl_2], polar [HCl], non-polar [CH_4], polar [a polar bear], non-polar [a creature with two polar bear heads opposite each other...]. I'm gonna take sides right now. I'm on team polar. I think polar molecules are way more interesting, despite their wonky, off-balance selves. Non-polar molecules are useful, and their symmetry has a kind of beauty, but polar in my humble opinion is where it's at.

[intro music]

All right. Now here are two very different types of chemicals. Right here I have a stick of butter, and then in this bowl, that's just normal water. So I'm just gonna go ahead and squeeze this butter, which if you're wondering is both a terrible and wonderful feeling. And then I'm going to [laughs] just drop that. Now I'm going to attempt to wash that butter off my hand. But that is just not hap... that's just, it's not going anywhere, ever. Ever. It's just beading up on me. Why? Because water is a polar molecule, and the various chemicals that make up butter are non-polar, and water wants nothing to do with that. *groans*

=====Polar Molecules (1:33)=====

So. What makes a molecule polar? Well, two things. First, asymmetrical electron distribution around the molecule. You can't have a polar molecule made up entirely of the same element because those atoms will all have the same electronegativity, and thus the electron distribution will be completely symmetrical.

Electronegativity is usually thought of as how much an element wants electrons around it, but I think it's more about how much electrons want to be near that element. If electrons were 13-year-old girls, fluorine would be Niall Horan. They'll do anything just to be near it. Why? Some simple periodic trends. Electronegativity increases from left to right because there are more protons in the atoms, and more protons means more boys in the band. Meanwhile, it decreases as you move from top to bottom because as the crowd of electrons gets bigger, they start to shield each other from the effects of the protons. What I'm trying to say is that electrons are hipsters. If a bunch of other electrons are into that thing, they're less interested.

Now there are a number of other factors here, but just like the relationship between tweens and their latest boy band fixation, it's complicated and weird and you probably don't want to think too much about it. But in this nice little map, you can see that the trend is pretty clear. The upper-right is where all the superstars of electro-fame are. Oxygen, nitrogen, fluorine, chlorine, and bromine are basically the One Direction of the periodic table.

So for polarity to occur in a molecule, you have to have two different elements at a minimum, and the difference between their electronegativities has to be 0.5 or greater. If that's the case, the outer electrons spend enough extra time around the element that's more electronegative that chemists label the molecule polar. The result is a partially negative charge on the more electronegative part of the molecule and a partially positive charge on the less electronegative side. Now in extreme cases, like if the electronegativity is greater than 1.6, then we end up with two ions in the same molecule. This isn't what we're talking about here when we talk about polar molecules. We're talking about differences between 0.5 and 1.6.

Another requirement for polarity: you gotta have geometrical asymmetry. CO_2 here has the charge asymmetry locked up, but because the molecule is linear, in a straight line, it's a kind of symmetrical asymmetry. The same thing does for CH_4 with its tetrahedron of weakly electronegative hydrogens around a more strongly electronegative carbon. These molecules have polar bonds, but the molecules themselves are not polar because the symmetry of the bonds cancels out the asymmetry of the charges.

=====Dipole Moments (3:49)=====

In order for a molecule to be polar, there has to be a dipole moment, a separation of the charge around the molecule into a more positive area and a more negative area. Lots of molecules are asymmetrical in both electronegativity and geometry. Those are our polar molecules, the asymmetrical beauties of chemistry. Look at 'em all! They're so quirky and weird!

We've also got a system for indicating where their charges are. We draw an arrow with a plus sign at the tail pointing toward the negative side of the molecule. A little lowercase delta plus ($?^+$) or delta minus ($?^-$) by the individual atoms signify a partial positive pr partial negative charge. Liquids made up of polar molecules are really good at dissolving solids that are composed of polar or ionic compounds. Ionic solids are basically just polarity taken to the extreme, so far that instead of having a partial positive and partial negative dipole moment, the electrons have completely transferred, creating two charged ions.

=====Like Dissolves Like (4:41)=====

Now I assume we've all heard that like dissolves like, so the easiest way to figure out if a liquid is polar or non-polar is just to dump it in some water. But the why of this phenomenon is usually just totally glossed over. What's actually happening to those molecules? It seems like they're all just bigots, terrified of anything a little bit different than themselves. But this is chemistry, so there must be some fundamental reason. And if it's fundamental, it probably has something to do with decreasing the energy of the system.

And indeed it does. Those partial positive and partial negative charges of water? They're at their lowest energy state when they're lining up together, positive to negative, into a kind of liquid crystal. There's an arrangement there. It flows, of course, but the oxygen sides are always doing their best to orient themselves toward the hydrogen sides of other molecules. You can even see the effects of that attraction as the surface tension that allows me to pour more than 100 milliliters of water into a 100 mil container. The strength of that surface tension depends on the intermolecular forces that pull molecules of a liquid together. These attractive, also called cohesive, forces pull the surface molecules inward. And what you see when you look at this pile of water is the result of those cohesive forces, minimized surface area in the water in this beaker.

When you pit a bit of oil into that mix, the water totally freaks out. Oils have notoriously non-polar molecules, so suddenly there's this mass of uncharged gunk interfering with the nice, orderly arrangement of polar water molecules. But if you take a closer look, the processes are very similar to those between water and air. Water does everything it can to minimize its surface area and kind of expels the oil droplets. Rather than the water disliking the oil, it actually just likes itself much more, so it won't mix with the oil.

Now if you put polar stuff in, water is all about that, and those polar water molecules just go after whatever other partial charges they can find. Or, in the case of many ionic solids, the partial negative charges on the oxygen side all gang up on the positive ions while the partial positives on the hydrogen side surround the negative ions, breaking the crystals apart and dissolving them into freely moving ions. In some cases we can actually witness these interactions in unexpected ways. Mix 50 milliliters of water with 50 mils of alcohol and what the heck? There's less than 100 mils of liquid! The arrangement of water mixed with alcohol is actually more structured, and thus more dense, resulting in a smaller volume.

=====Hydrogen Bonding (7:06)=====

The polarity of water also results in a phenomenon that makes life possible: hydrogen bonding. The partially negative oxygen and positive hydrogen atoms in a water molecules are not 100% faithful to each other. They engage in additional kind of loose relationships with other neighboring hydrogen and oxygen atoms. These loose, somewhat fleeting relationships are called hydrogen bonds.

In ice, 100% of O and H atoms are involved in hydrogen bonding. The most energetically favorable spatial arrangement of these bonds actually pushes the water molecules apart a bit, resulting in the volume of ice being 10% larger than the volume of water, which is really weird for solids and liquids. When ice melts, there are still about 80% of Os and Hs engaged in hydrogen bonding, creating ice-like clusters that keep the volume of the cold water relatively high. With rising temperatures, these clusters disappear, while the volume of the truly liquid water rises resulting in a major characteristic of water, having its highest density at 4 °C. And yes, that's why ice floats on lakes in the winter and why the bottom of frozen lakes tends to be about 4 °C. And also why hockey was invented. And why soda bottles explode when you leave them in the freezer.

But hydrogen bonds are also why taking a warm bath is so great, why steam engines changed the world, and why temperatures on our planet are so constant when compared to other cosmic temperature fluctuations. It takes a lot of energy to change the temperature of water because each little temperature change is associated with breaking or forming lots of hydrogen bonds, and they absorb or give off a lot of heat. In fact, the specific heat capacity of water is about five times that of common rocks.

And amazingly, we haven't even finished talking about how useful these partial charges are. They also allow water to dissolve pretty much anything that's even partially non-polar, which includes sugars, proteins, ions, and tons of inorganic chemicals. Water and its useful little dipole moment can dissolve more compounds than any other chemical on Earth. Frankly, it's amazing that it doesn't dissolve us from the inside out.

=====Hybrid Molecules (9:07)=====

Which brings me to one last little polarity tidbit, the hybrid molecule. There are lots of different molecules, like the surfactants in soap, for example, that have both polar and non-polar areas. Dish soap is thus able to dissolve the fatty parts of my butter catastrophe here, and then stick the polar sides out, allowing the whole mess to get washed away by Avogadro's numbers of polar water molecules that I'm sticking on my hand right now. Oh yeah. That's better, but not... I'm gonna have to go to the bathroom to get this all the way fixed up. So, be right back.

Likewise, the fatty acids that make up your cell membranes have polar heads, which keeps them interacting with the aqueous environment of out bodies, but non-polar tails, which prevent the cells from being just dissolved by the water around them. Pretty dang elegant if you ask me.

=====Conclusion/Credits (9:54)=====
Thanks for watching this episode of Crash Course Chemistry. If you were paying attention, you learned that a molecule needs to have both charge asymmetry and geometric asymmetry to be non-polar, that charge asymmetry is caused by a difference in electronegativities, and that I am totally team polar. You also learned how to notate a dipole moment or charge separation of a molecule, the actual physical mechanism behind "like dissolves like", and why water is just so dang good at fostering life on this planet.

This episode was written by me and edited by Blake de Pastino. Our chemistry consultants are Dr. Heiko Langner and Edi Gonzalez. It was filmed, edited, and directed by Nicholas Jenkins. Michael Aranda is our script supervisor and sound designer, and our graphics team is Thought Café.