Doing Solids: Crash Course Chemistry #33

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

Hank Green: When you say the word 'chemicals', most people think 'chemicals bad' or 'chemicals dangerous', those people say things like 'I don't give my kids food with chemicals in it' or 'that factory puts chemicals in the water'. Sometimes these people are thinking of liquid chemicals that are, for example, sprayed on crops or gaseous chemicals that come out of smokestacks or exhaust pipes, but those people probably don't think of chemicals as solids.

To them, solids like this table here or my computer or aardvarks, that's just stuff. But it's vital to recognize that, as I've said before, almost everything you interact with on a daily basis is chemicals, except for like, light. And with the exception of air, the vast majority of the matter that you interact with is in the form of solids, like I'm interacting with my clothes right now, which is good, otherwise this would be, this would be an inappropriate episode.

But solids are a lot more diverse than what we might think of as just hard or strong or stuffy. Stuff-like. Stuffish. Stuffable. Stuff the Magic Dragon. Many metals, for example, are almost infinitely moldable under the right conditions. Meanwhile, rocks aren't moldable at all, their lack of flexibility causes them to shatter or crumble under sufficient force. Then there are solids that we think of as being softer, like rubber and clay and Styrofoam, all of which are soft for different reasons, and behave in very different ways. None of this is random.

=====Amorphous and Crystalline Solids (01:20)=====

Like all matter, solids get their characteristics from the arrangement of their electrons, their chemical bonds, and their intermolecular forces. There are two main classes of solids, crystalline and amorphous. The atoms in molecules in crystalline solids are arranged in an orderly, predictable way. Amorphous literally means 'without shape', and amorphous solids, unsurprisingly, don't have a definite shape because their atoms and molecules are arranged randomly.

And just within these two classes, solids can exhibit a pretty amazing variety of characteristics and behaviors. So you may just surprise yourself by learning something new about materials that you thought you knew inside and out, and even better than that, you can explain it to some of those people who don't even know what chemicals really are.

(CrashCourse Intro plays)

The category of amorphous solids includes things that you might expect, like foams and gels and colloids, like mayonnaise, rubber, waxes, and some biological tissues such as fat. They also include some things that you might not expect, like coal, the things silicon panels use in semiconductors, and even glass. That's right, despite what you may have heard, glass is not a liquid, I don't know who made that up. In chemistry, amorphous doesn't mean soft or even flexible, although many amorphous solids are both of those things. Instead, the classification is all about the fact that their atomic structure is disordered, or random.

Amorphous solids do however have a couple of macroscopic properties in common. First, it is important to understand that because the particles in an amorphous solid are arranged randomly, the strength of the bonds holding them together are also random. That's what causes amorphous solids to melt gradually, like this glass tube. As the material is heated, the weaker intermolecular bonds break first, then the stronger ones break as the energy threshold is broken by heat. So amorphous solids don't have the sharp discrete melting points of things like ice, which melts exactly at 0, instead, they melt over a range of temperatures, as the heat energy increases.

Amorphous solids also respond to stress very differently than crystalline solids. Because the arrangement of crystalline solids is so orderly, they're often very easy to break along a plane that falls between adjacent molecules, and when they break, they tend to do it along straight lines, the way cutting a diamond creates perfectly smooth facets. But with many amorphous solids, it's hard to find a plane like that, no matter how you attack it, you'll usually run into molecules that are sitting right in the middle of that plane, resisting the break. And even hard amorphous solids that do break under pressure rarely do it along straight lines, that's why broken glass ends up in crazy random shapes. And why coal looks like a random rock, not like a nice orderly crystal.

=====Types of Crystalline Solids (03:53)=====

We have a name for this, amorphous solids are isotropic. Meaning that they respond to stress in the same way in every direction. No matter which direction you poke a piece of clay, or hit a piece of glass, it's resistance to breakage will always be similar. But crystalline solids are anisotropic, they break differently depending on which plane you hit.

Speaking of diamonds, you probably think of 'crystalline' as things that look sorta like that. But there are actually three different types of crystalline solids, and they cover a huge array of materials, some of them pretty surprising. Those types are based on composition. They can be molecular, ionic, or atomic.

Molecular solids are made up of covalent compounds that form an orderly crystalline structure as they solidify, while their molecules remain unchanged. Examples include things like water ice, dry ice - which is just frozen CO2, and sugar. Because the molecules are held together by weak Van de Waals forces, they break down pretty easily. For that reason, these solids generally tend to be soft with fairly low melting points.

Ionic solids are basically the solid forms of things we think of as ionic compounds like sodium chloride - or table salt, calcium carbonate - which is chalk and limestone, and magnesium sulfate - otherwise known as Epsom salt. Because they are made of ions, they are often soluble in water and other polar solvents, but they have very high melting points. So table salt would be gone in no time if I put it in water, but if I applied heat directly to it, it wouldn't melt until the temperature reached 800 and 1 degree Celsius.

=====Types of Crystalline Atomic Solids (05:17)=====

Atomic solids, as the name suggests, are made up of individual atoms, not molecules at all. Sounds simple, well there are actually three types of atomic solids too: network solids, group 18 solids, and metals.

Network solids are so interesting and important that we're going to cover them in a separate lesson. I won't get in to it now except to say that the atoms basically form a rigid crystal structure. A diamond, for example, is just a big crystal made of carbon atoms. So you can think of diamonds, and other network solids, as really giant molecules.

Group 18 solids meanwhile are the solid phase materials of the noble gases - Group 18 on the periodic table. Since noble gases have little interest interacting, even among themselves, it's very hard to cool and pressurize them enough to make them form a liquid and even more so to make them solidify. So when they do crystallize, the atoms are held together by weak little Van de Waals forces, not stable at all to say the least, so they don't tend to stick around for long. Because of this, they're really rare, and not something that you'll, like, ever encounter unless you go on to study them specifically.

=====Properties Depend on Bond Types (06:17)=====

But metals, you know metals they're everywhere. You're probably looking at me on a device made of metal. You probably have metal in your pocket. You might have metal in your teeth. And yeah, you probably don't think of metals as crystals, but remember the key is that their atoms are arranged in an orderly way. The atoms, in fact, form several different arrangements in order to best take advantage of the space and the structure.

These structures are called closest packing arrangements. To picture how it works, think of metal atoms as spheres and consider how they can pack together in the most efficient ways possible. Like imagine if you have to fill the box with as many ping pong as you can, the atoms stack just like the ping pong balls would.

In spite of their orderly arrangement though, most metals are quite malleable. Meaning that they can be pounded in to various shapes, and ductile, meaning that they can be stretched out in to wires. Both of these characteristics result from the nature of their atoms and the bonds between them.

The atoms in metals are large. So large, that the valence electrons aren't held very strongly by the nucleus. This gives them much more freedom to move around than the electrons on most elements. So instead of belonging to a single atom, they form a kind of sea of electrons, wandering from one nucleus to another. These freely moving electrons are in fact the main reason that metals can conduct heat and electricity so easily. It's actually more accurate to say that the electrons form large, somewhat unstable, orbitals around collections of atoms. The nuclei are tightly bonded together by the electrons that are all around them, making the metal structure extremely strong. But the bonds are uniquely flexible, allowing the kinds of deformations that we're accustomed to from metals.

Despite the crazy array of solids that classify as crystalline, they do all have certain things in common. And as usual, most of their common characteristics are related to their bonds. Since all the bonds in a crystal are the same length, their all equally strong. Which means they can be broken by the same amount of energy, and their melting points are very specific temperatures, not broad ranges. Crystalline solids are also generally more brittle than amorphous ones, and as I mentioned, respond to force differently in different directions.

It's kind of crazy to think that all of the different things that we think of as solids are actually so different from each other. All of the Volvos, and reusable shopping bags, and kid's bicycle helmets, are all from a diverse array of chemicals called solids.

=====Summary & Credits (08:20)=====
Thank you for watching this episode of CrashCourse Chemistry. If you've paid attention, you've learned the difference between amorphous and crystalline solids. You've learned that crystalline solids can be made up of molecules, ions, or atoms. And that the ones made of atoms, can be networks, noble gases, or metals. You also learned some of the properties of solids in each of those categories, and you learned that in every case the properties of the solid are much more related to the bonds between the particles than to the identity of the particles themselves.

This episode was written by Edi González. It was edited by Blake de Pastino and the chemistry consultant was Dr. Heiko Langner. It was filmed, edited, and directed by Nicholas Jenkins. And the script supervisor was Michael Aranda, who is also our sound designer and our graphics team. As always is thought cafe.