You've heard this before, but it bears repeating. Carbon is the element of life. So much so that when we explore other planets the first thing we look for is compounds that contain carbon. In fact, there was a time when we thought carbon compounds could only be produced by living things. So early chemists called them, as we still do today organic compounds.

Scientists back then considered biological molecules to be almost mystical in origin. Until, 1828 when German chemist Friedrich Wöhler discovered that urea a component of urine could be synthesized simply by heating ammonium cyanate, an inorganic compound. That proved biological molecules were just chemicals that could be created and manipulated in the lab.

Suddenly a new branch of chemistry was born, organic chemistry. It's like my favorite chemistry. So what is it about carbon though, that makes it so special? Well, a lot of things. Like silicon, which we talked about a few weeks ago.. carbon is in group 14 on the periodic table, and like all of the elements in that group, it has 4 valence electrons. In carbon those 4 electrons can bond to other atoms in a really promiscuous number of configurations to form all kinds of structures. Which is why carbon is to biology, which silicon is to geology. Just as silicon forms the basis, not only for sand, but also most of the rocks on earth, carbon is the foundation of most biological molecules. Really all biological molecules.. right? Yup. The simplest organic molecules are pure hydrocarbons containing only carbon and hydrogen. Hydro-carbon. They are where we're going to start our six week exploration of organic chemistry.

And they're a good place to start, partly because they play by the most straight forward rules. When all carbons in a pure hydrocarbon are bound to the maximum number of atoms, 4 atoms each, so that there are no double or triple bonds anywhere; these compounds are considered to be full or saturated. That means that all the carbons have 4 bonds, either with other carbon atoms or with hydrogen atoms, in which case the hydrogens are bound to one carbon. No questions, no exceptions. These are the simple rules that govern some of the world's most useful, or at least, used compounds. The hydrocarbons that we use as diesel fuel, gasoline, methane, propane. You're gonna learn what these and other compounds look like, what they're names mean, and how they take part in the reactions that fuel our lives. Welcome to organic chemistry!

The fully saturated hydrocarbons I just described are usually called by the much simpler name, alkanes. The simplest of the alkanes is one you've heard of before, methane, or CH_4, the main compound in natural gas. The next simplest alkane contains two carbons side by side, each one of them in bonded to three hydrogen atoms. This is ethane, C_2H_6. Another gas, and it's mostly used in the production of plastics.

If we add another carbon and enough hydrogens to fill all those spaces we get our next alkane: propane, C_3H_8. Also a gas at room temperature and normal atmospheric pressure, propane is a common fuel for cooking, heating, and vehicles, as well as a propellant for everything from aerosol cans to paintball guns. And we could do this all day, adding carbons to the chain and giving each compound a name, but that would be pretty boring.

Things get more interesting, though, with the next alkane, butane, C_4H_{10}, because there are two different forms of it. The first is what you'd expect: just a chain of carbons with hydrogens stuck wherever they're needed to make each carbon have four bonds. This is called normal butane or n-butane. But you can also arrange the four carbons differently by making a chain of three and then branching the fourth one off the center of the chain. This is called isobutane or i-butane. And even though it has the same chemical formula as n-butane, its structure gives it different properties. For example, n-butane boils at -0.5 degrees Celsius while isobutane boils at -11.7 degrees Celsius.

These different structures for compounds that have the same molecular formula are called isomers. As you add more and more carbon atoms to the molecule, there are more and more ways that you can arrange them. So the number of atoms is butane only allows for two isomers, n-butane and isobutane. But pentane, C_5H_{12}, has three possible isomers and C_6H_{14}, known as hexane, has five. Again, I could do this all day. But looking at this table of the number of possible isomers you could see that that escalated quickly.

The take away here is that molecules that have the same mass and number of atoms can form different structures. And as their structure changes, their properties also change. As a general rule, the larger and more complex alkanes are, the more densely their molecules can pack together, which means that they tend to be liquid or solid instead of gaseous at room temperature. So alkanes with five to eighteen chains of carbon atoms like octane and gasoline are liquids at room temperature and those with more than eighteen carbon atoms like paraffin or other waxes are solids.

Now you're probably picking up on a lot of words that you've heard before, even outside of chemistry class: octane, propane, methane, paraffin, and so on. You can chalk that up to the enormous popularity of these compounds in our daily lives. Like I said, hydrocarbons are super useful because of the types of reactions they can take part in, which I will explain more in a bit.

But first, I think it's high time you know what these names actually mean. Much like the general language of chemistry that we talked about months ago, organic nomenclature has its own system of prefixes, suffixes, and numbers that tell you what's in the compound being named. Now you gotta know the prefixes because they indicate how many carbon atoms are present.

Here's one that I know you've heard before: meth. Meth- in a name always indicates a molecule or branch containing one carbon atom. So the difference between amphetamines doctors prescribe and methamphetamines that are sold on the streets is that methamphetamine has a methyl group, CH_3 with one carbon. where amphetamine just has a single hydrogen atom. Hopefully, that's helpful to you. Don't do drugs.

Eth- in a name means two carbon atoms. Prop- means three. But- means four. From there, most of the prefixes will be familiar from geometry class and you can review them in tables and learn them. I'm not gonna go through them all.

There are a few naming rules that are specific to alkanes. First, alkanes are always named based on the longest possible continuous chain in their structure. For example, even though this looks like a five carbon chain intersecting with a six carbon chain, it actually contains an eight carbon chain if you look at it close enough. So this is considered an octane with two carbon chain attached to one of its carbon atoms.

When shorter carbon chains are attached to longer ones like this, they're still named using the same prefixes but we stuff a little -yl onto the end to show that they're just attachments. Since this attachment has two carbons, we call it an ethyl group. And the attachment with just one carbon that turns amphetamine into methamphetamine, that's the methyl group.

Attachments are also given a number to show you where along the chain they're attached. The long chain is always numbered carbon by carbon in the direction that gives the attachments the lowest numbers possible. So, if we number the chain the right way, the ethyl group will end up at position four. But if you do it the wrong way, it's in position five. Low numbers win so it's numbered from left to right in this case. So when we put it all together, this compound is called 4 ethyl octane. And congratulations! You just named an organic compound.

Now particularly astute and studious students would have noticed something here. Earlier, I introduced you to isobutane, a compound with four carbons that are not all in a chain. They call that isobutane and it is an isomer of butane, but according to these all important rules of nomenclature, it's not actually any sort of butane at all. Its longest carbon chain is just three carbons long, so it's propane with one methyl group sticking off of it. If we wanted to give a technical name for it, isobutane would be 2-methylpropane. Though, since the second carbon is the only place where the methyl group can go without the molecule once again becoming butane, properly proper chemists just drop the two and call it methylpropane.

Now suppose you have more than one of the same size group attached to the same chain, like two methyl groups on the same alkane. In this case, you put a number for both of them and then prefixes like di- and tri- are used to indicate multiple attachments. So for instance, if an octane chain has methyl groups attached with second and fifth carbons, it's called 2,5 dimethyloctane.

On the other hand, if you have attachments of different lengths, you just name and number each one separately, being sure to list them in alphabetical order. The structure we just used had a methyl group on it and an ethyl group on its fifth, it would be 5-ethyl-2-methyloctane. This is super useful for several reasons. One, because there are trillions of ways that organic compounds can come together. But also because you can work backwards from a name and build a structural formula from it.

Let's try that out. We're gonna build 2-ethyl-3,5-dimethylnonane. Start with the prefix non- indicates nine carbons. Then, add an ethyl group, a two carbon chain on number four and then methyl groups just one carbon on carbons three and five. Our final step is to add enough hydrogen atoms to give every carbon atom four bonds. And now, the molecule is complete. It's like a puzzle that we got to make.

Of course these compounds don't exist in isolation. Like any other compound, they can undergo a whole variety of reactions. But there are three types of alkane reactions that are important enough for us to cover right now right here.

The first is the kind that made alkane the most common fuel for combustion or burning. You'll note here that I'm saying burning, a common misperception even among chemistry students is that combustion somehow equals explosion. While that would definitely make things more interesting, also more dangerous, those two things are not synonymous. Combustion is the type of reaction that powers your car and your propane grill, even candles among other alkane fuels.

The general reaction for combustion requires a hydrocarbon, oxygen, and a source of heat energy. In this example, we're using methane, but it works the same for any pure hydrocarbon. The only thing that changes is the coefficients. The products of a complete combustion
of a pure hydrocarbon are always carbon dioxide and water vapor, just those two things.

The next major reaction that alkanes experience is halogenation, when halogen atoms like fluorine or chlorine are substituted for one or more hydrogen atoms in the alkane. For example, the rather well-known compound chloroform is more correctly called trichloromethane. It's a molecule of methane that is reacted with a chlorine gas, resulting in three of the hydrogen atoms being replaced with chlorine atoms.

The final reaction type is dehydrogenation, and it, somewhat obviously, is the removal of hydrogen atoms for alkanes. For example, ethane can be dehydrogenated by this reaction, and as you can see, the result is that the carbon atoms are no longer saturated with hydrogen, thus, requiring the formation of double or triple bonds to give the atoms the four bonds that they need. Hydrocarbons that contain double or triple bonds have their own specific groups with different rules, reactions, and properties than alkanes. And those are the topic of next week's episode.

For now though, thank you for watching this episode of Crash Course Chemistry. If you were listening, you learned about some of the different classifications of organic compounds, the structure and properties of the simplest alkanes. You also learned about isomers and why they're important, how to name an alkane based on its structure, and how to build an alkane structure from its name. And finally, you learned a few important types of chemical reactions that alkanes experience: combustion, halogenation, and dehyrdogenation.

This episode was written by Edi Gonzalez, it was edited by Blake de Pastino and our chemistry consultant is Dr. Heiko Langner. It was filmed, edited, and directed by Nicholas Jenkins. The script supervisor was Caitlin Hofmeister. And Michael Aranda is our sound designer. Our graphics team, as always, is Thought Cafe.