



## Aromatics and Cyclic Compounds - Crash Course Chemistry #42

Crash Course: Chemistry

<https://youtube.com/watch?v=kXFEex-dABU>

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### ====Introduction=====

We've talked up carbon quite a bit here on Crash Course Chemistry, but we really haven't justified the lofty position I put it in. Just chains so far and while chains are good, they're not enough reason on their own for this high level of esteem.

But carbon atoms, they do more than just form chains. Sometimes, they form rings, or as chemists call them: cyclic structures, and if the rings have the right number and placement of double bonds they start acting weird and wonderful.

The compounds made from them are called aromatic, literally because they have aromas, they can smell amazing. Basil, vanilla, cloves, tarragon, lemon, cinnamon, when we smell these things, it's because aromatic compounds, compounds with carbon rings are binding to receptors in our noses that tell our brains "OMG tasty stuff nearby". Of course, moth-balls and modelling glue and lots of other stuff are also aromatic and don't smell so good... But if you've ever smelled an herb, taken medicine, worn clothes or enjoyed a meal, you probably owe that experience, at least in part, to aromatic hydrocarbons.

[(00:56) Crash Course opening & theme]

### ====Cyclic Organic Compounds & Naming Their Constituents===== (01:06)

But before we talk about aromatics, let's talk about the most basic cyclic structures, the cycloalkanes. You recognize the -alkane ending there, so there must be no double bonds, right? And you can't make a ring with one or two carbons, so the simplest cyclic hydrocarbon must be cyclopropane. But those tight bond angles of that triangular cyclopropane make it very fragile. This instability makes it highly reactive and it would much rather just be a straight chain. But as more carbons join into the ring cyclic structures get more stable.

Cyclobutane with its four carbon atoms is still fairly unstable and reactive, while in cyclopentane the bonds are even more stable because they form something close to those tetrahedral bond angles while the angles in cyclohexane are basically perfect for the tetrahedral orbitals to overlap without strain.

Cycloalkenes also start at three carbons and get increasingly stable as more are added though their double bonds make their molecules plainer instead of tetrahedral.

Finally, cycloalkynes do exist but they are crazy hard to form because the triple bond is linear so it hates bending into rings and that is why the simplest cycloalkyne has eight carbons. Of course these rings can have all sorts of things stringing off of them and their names work almost exactly the same way as straight chains do.

Example: This ring has five carbon atoms and a double bond, so it's a cyclopentene. It has two branches, an ethyl group and a methyl group. We list these in alphabetical order in the name. And we number the carbons in the ring so we get the lowest possible numbers on the branches and on the double bond. If we number counterclockwise from the beginning of the double bond, we get the branches at the two and five positions, but if we number clockwise from the double bond the branches are at the 1 and 3 positions. So, this must be 1-Ethyl-3-methylcyclopent-1-ene. But since it's only one double bond and it's in the first position the second one is often left out as being understood. So we simply call it 1-Ethyl-3-methylcyclopentene.

Incidentally all of the identifying parts of an organic molecule, the double and triple bonds, the carbon chains that branch off the main chain, those are called substituents because they substitute for hydrogen atoms.

### ====Aromatic Compounds=====

(03:02)

So far we've just been looking at the cyclic hydrocarbons, so what's up with the aromatics? How are they different? Well this is one of the times when carbon starts doing some of its spectacular dances. Cyclic hydrocarbons that contain resonant structures. Things are getting interesting, and by interesting, I mean--*what?*

### ====Resonance=====

(03:18)

Resonance occurs when electrons are distributed around the molecule in a way that makes it impossible to draw with a single Lewis structure. It's a limitation of our tools to represent this beauty and complexity of reality. In a resonance structure, the real world structure of a molecule is essentially an average of all the possible structures that we can draw.

The simplest aromatic hydrocarbon (and one of the most common) is benzene ( $C_6H_6$ ). It's the pungent compound that gives gasoline its strong sweet smell. It contains 3 double bonds, so that each carbon has a total of 4 bonds. We normally write this and other organic structures without the hydrogens in order to simplify things, and we often don't even write the c's for the carbons. Every corner is assumed to be a carbon atom, and since we know carbon needs four bonds it's easy to figure out where the hydrogens belong even when they are not written.

Here's the thing though. Those double bonds could just as easily be in these positions and they are in those positions--sort of.

Remember there are two types of bonds in double bonds. There's those sigma bonds that happen linearly, and then there's those p-orbitals that stick up above and below the plane of the molecule. Those p-orbitals in an aromatic compound all merge together in a ring that stretches above and below the whole molecule. It's a distribution of electrons that's like a donut on top of and below a molecule--it's extremely stable. Overall, the bonds are in both places so the actual structure is essentially an average of the two draw-able Lewis structures.

That's resonance, it's reality poking us in the nose and saying "oh you thought you were so clever with your Lewis structures, but in this situation, they are useless."

To show that the double bonds aren't in any specific place, we often just show the structure with a circle in the middle signifying that the double bonds are averaged in a ring throughout the benzene group. Technically the number of bonds between each pair of carbons is defined as 1.5. It's not a double bond, it's an one-and-a-half bond.

### ====Resonance=====

(05:00)

Now aromatics can have all sorts of substituents as well, and the naming system is pretty much the same as with other cyclics.

Another example: So this is a benzene with two methyl groups on it. As always, we number the rings so that the branches have the smallest possible numbers. In this case, if one of the methyl is in the 1 position, the other is in position 2. Note that the numbering can also be done like this, but it doesn't matter as long as the branches are at the lowest possible numbers. That makes this molecule 1, 2-dimethylbenzene. Now if you swap the methyls out for a couple of other slightly more complicated groups, then you get acetylsalicylic acid, or aspirin.

Aromatic rings can be used the other way around too, as



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substituents on dihydrocarbons. Consider this molecule, a hexane with a benzene ring attached to carbon number 2. When benzene is used as an attachment, we call it a phenyl group, so this is 2-phenylhexane (pronunciation: like GIF, both are correct). What's important is that it is not a benzyl group. *Why?*

Well, it was English genius Michael Faraday who first isolated benzene in 1825 from the gas used in lamps. In honor of this, his French contemporary chemist Auguste Laurent started calling the derivatives of benzene "phene," from the Greek "I eliminate." It's a lovely gesture, very sweet, but, like, seriously?

But just to make sure you're, like, good and solidly confused, benzyl groups do exist. They're a phenyl group joined by a methyl group instead of just directly. So now that we know where the word "phenyl" comes from, I'm bet you're just salivating with curiosity, wanting to know where "benzene" comes from, because, like, your desire to know things is stronger than any of your other desires, right? Yeah, I thought so. So here's how it happened.

Back in the 1400s when the spice trade drove the majority of the global economy, Arabic traders sold European traders a resin used in perfumes and medicine that they called "luban jawi" or "incense of Java." Of course, it didn't come from Java, it came from Sumatra, but the world was a big and complicated place so we can't really blame them for being a little bit confused. The "lu" was mistaken by the Italians for the definite article "la", and so it was dropped, making it "banjawa," and then the French called it "banjoin," and eventually the German and English made it "benzoin."

This is also, by the way, the same root as the name Bon Jovi (it's not...).

When we started doing some chemistry, we found that most of benzoin was composed of an acid which chemists named benzoic acid, or acid of benzoin. Then, a little chemistry knocked the acid off, creating what was clearly an alkene, so they named it benzene, because it was an alkene that was from the benzoin resin. History is hiding everywhere! And so is chemistry.

for the infinite variety of life on Earth.

So we'll leave you to jeans and basil pesto and aspirin now to appreciate them on a whole new level that simply was not possible just ten minutes ago.

### ====Credits and Thanks====

(09:06)

Meanwhile, thank you for watching this episode of Crash Course Chemistry. If you paid attention, you learned about the structure of cyclic organic compounds and how to name them and their substituents. You also learned what an aromatic compound is, what resonance is, and how to name aromatics and their substituents. And finally, you learned a few common reactions and uses for aromatic compounds.

This episode was written by Edi Gonzalez and myself. It was edited by Blake de Pastino and the chemistry consultant was Dr. Heiko Langner. It was filmed and edited then directed by Nicholas Jenkins. The script supervisor was Michael Aranda, who is also our sound designer. And the graphics team is Thought Cafe.

### ====Common Reactions & Uses==== (07:24)

Now benzoic acid is one of literally infinite possible benzene-based compounds. There's naphthalene, the main ingredient in mothballs. It's basically two benzene rings stuck together. And there's anthracene, with three benzenes, which is probably the dye that's making your blue jeans blue. And it can get crazy complicated all the way up to humic acid, a component of soil.

Now you might be wondering how something so complicated as that could ever even come into being. Like any organic compound, aromatics can undergo tons of reactions that produce all sorts of molecules. By far the simplest and most common are substitution reactions in which one substituent is substituted for another. Like one of the hydrogen atoms on a benzene might be changed to a propyl group, or that a halogen might come in and replace that propyl group with a bromine. These changes alter the compound, of course, but it may not be that major a change, like changing your shoes (unless you put on some really weird shoes).

Another fairly common reaction of aromatic hydrocarbons is coupling, the joining of two aromatic structures, and it basically works the same as a substitution reaction. The only difference is that the new substituent is another aromatic structure and it typically requires some kind of catalyst.

A final common reaction of aromatics is hydrogenation, which we talked about a little last week, the addition of hydrogen atoms to remove double bonds. Now of course getting rid of even a single double bond in a phenyl group always destroys the resonance, and thus it is no longer an aromatic compound after hydrogenation.

Now obviously we haven't covered all the possibilities here, but you can already see that organic molecules have the potential to become extremely large and complex, integrating straight chains, cyclic structures, and aromatic groups in the same molecule. This literally infinite variety is what makes organic compounds the basis