Chapter 9

Organic Chemistry

For produce to be certified as "organic", it must (among other things) not use industrially-produced fertilizers or pesticides. That's why these tomatoes look nearly inedible.

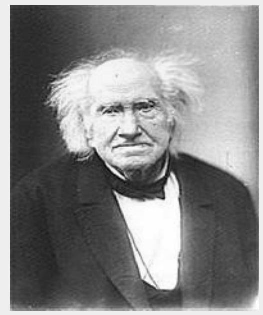
9.1: What Is Organic Chemistry

If you've ever taken antibiotics, eaten food, or been alive, you've taken advantage of organic chemistry. You see, like the demons that live within our souls, we are always in the presence of organic compounds.

Organic compounds are chemical compounds that contain carbon and hydrogen. They frequently also contain other elements, but it's the carbon and hydrogen part that makes these compounds organic. Not surprisingly, **organic chemistry** studies the reactions involving organic compounds.

Why "Organic"?

Back in the old days, people used to think that compounds that came from living things (i.e. "organisms") had a special life force associated with them. Not coincidentally, these compounds all contained carbon and hydrogen. Between 1816 and 1818, chemists Michel Chevreul and Friedrich Wöhler demonstated that these compounds were just plain ol' chemicals and didn't have any magical life force. Wöhler always gets credit for this, though, so if you see the ghost of Chevreul, act cool about it.



In his later life, Chevreul was known to yell at children "to get off my lawn."

What's So Special About Carbon, Anyway?

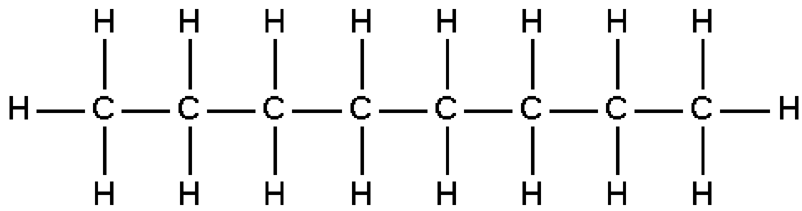
Since all organic compounds are based on carbon, it stands to reason that carbon must be special in some way or another. What may *not* be obvious, however, is how it's special. Fortunately, you're reading a book with a chapter about organic chemistry, which means that I'm going to tell you this information below:

- **Carbon has several different allotropes**: **Allotropes** looks like a big word, but it's just a fancy way of saying that carbon occurs in several different forms:

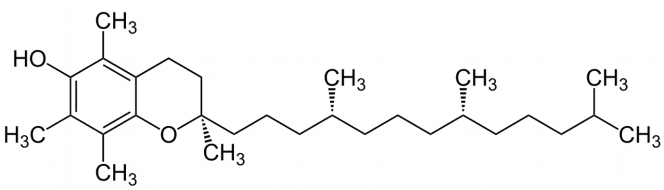
Allotrope	Structure	Other interesting information
Graphite	Flat sheets of carbon atoms.	These flat sheets slide around one another easily, which makes it slippery. It's also the black stuff in pencils, so there's that.[1]
Diamond	3-D solid in which all atoms are covalently bonded.	Diamond is one of the strongest materials in the world. Pretty, too!
Fullerenes	Graphite rolled into tubes or balls	This is a very wide class of compounds and have various biomedical uses (with more to come!)

1 *It's called "pencil lead" because back in the old days people thought that graphite was a form of lead. They were wrong.* Dead wrong.

- **Carbon can form long chains in molecules**: Most elements may form small chains, but carbon is unusual because it can be present in long chains in chemical compounds. Octane, for example, contains of eight carbon atoms in a chain:



- **Carbon can form branched chains and rings**: Just as carbon atoms can form straight chains, these chains can also be branched or arranged into rings:



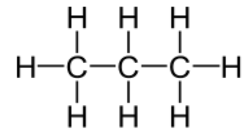
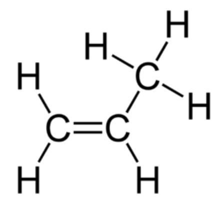
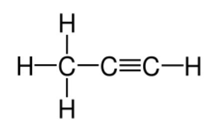
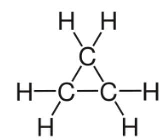
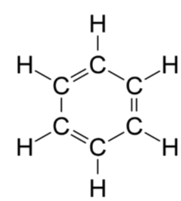
Vitamin E shows the versatility of carbon chemistry, with branched chains, ring structures, and the presence of elements other than carbon and hydrogen.

- **Carbon bonds with almost everything**: Just as the above structure shows, carbon bonds readily with oxygen, nitrogen, phosphorus, sulfur, the halogens, and just about everything else. This wide variety of bonding means that carbon exists in compounds that can do just about anything.

Section 8.2: Types Of Organic Compounds

Carbon's ability to bond in so many different ways means that there are a lot of different types of compounds that you need to be familiar with. Sorry 'bout that.

- **Hydrocarbons**: Hydrocarbons are compounds that contain only carbon and hydrogen. However, this definition really downplays the vast variety of hydrocarbons that can exist. To make our lives simpler, we won't memorize all of the possible compounds that are out there. However, we will make a table to describe the general classes of hydrocarbons. But we'll put the table on the next page because it won't fit on this one.

Name	Description	Example
Alkane	A hydrocarbon that contains only C-C single bonds. These are also called “saturated hydrocarbons”, as mentioned in chapter 7.	 propane
Alkene	A hydrocarbon that contains at least one C-C double bond. Alkenes (and any other organic molecules with C-C multiple bonds) are called “unsaturated hydrocarbons.”	 propene[2]
Alkyne	A hydrocarbon that contains at least one C-C triple bond. Also called an “unsaturated hydrocarbon.”	 propyne
Cyclic hydrocarbon	A hydrocarbon in which the carbon atoms are arranged in a circle. Cycloalkanes have all C-C single bonds, while cycloalkenes have at least one C-C double bond and cycloalkynes have at least one C-C triple bond.	 cyclopropane
Aromatic hydrocarbon	A hydrocarbon in which there are alternating C-C and C=C bonds. This alternating structure makes aromatic hydrocarbons exceptionally stable. Benzene (C_6H_6) is the basis for most aromatic hydrocarbons.[3]	 benzene

- **Other types of organic molecules**: There are a huge number of other organic molecules, but I'm not going to discuss them. Let's be honest, you won't need to know what they are because you're not going to do any serious organic chemistry for a while. If you keep doing science, somebody will tell you about them, but until then, just chill.

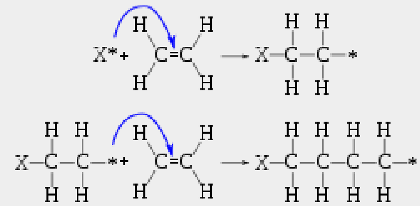
2 *Common name: Propylene. Though there is a systematic way of naming organic compounds, there are still a lot of nonsystematic names in use. Fortunately, we're not going to worry about that.*

3 *The definition of “aromatic” is a little more complicated than this. Hückel's rule states that only molecules with (4n+2) carbon atoms are aromatic, while molecules with (2n) carbon atoms are antiaromatic.*

Let's Polymerize!

Let's say you've got two molecules of ethylene (C_2H_4). Put them together and you'll get a larger molecule. Now, add another ethylene to it to make an even larger molecule. Keep at it and eventually you'll get a really, really long molecule. In this example, ethylene is a monomer and polyethylene is the polymer formed when you put them all together.

There are lots of different polymers out there. Some occur naturally (starches, cellulose) while others are manmade (nylon, Teflon, polyethylene).



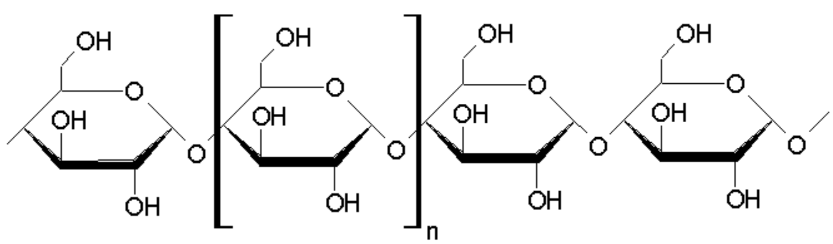
The formation of polyethylene from ethylene.

Polyethylene rope

8.3: Biochemistry

Because carbon is so versatile at forming compounds, it's not surprising that living things are just chock full of organic compounds. In fact, you may have heard of the following:[4]

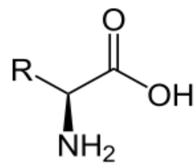
- **Carbohydrates**: Carbohydrates (also known as sugars or saccharides) are compounds that contain rings of carbon, hydrogen, and oxygen. Monosaccharides (also known as simple sugars) contain only one of these ring units, while polysaccharides (called complex carbohydrates) are polymers that contain long chains of sugar monomers. The term **starch** refers specifically to carbohydrates made from glucose monomers.



This is a depiction of a carbohydrate named amylose, and shows how a long starch can be made from D-glucose monomers.

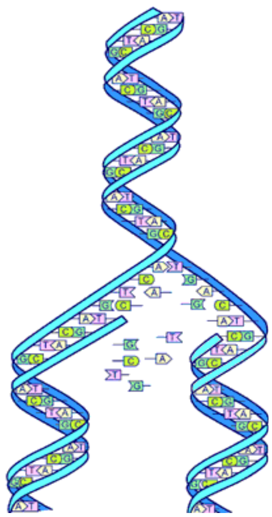
4 *Then again, maybe you haven't.*

- **Amino acids**: Amino acids are compounds that contain both an amino group (-NH_2) and an acid group (-COOH). When put together, amino acids make up the proteins in living things.



This is the generalized form of an amino acid. Check it out.

- **Nucleic acids**: Nucleic acids are very long polymers that are made of monomers called nucleotides. Examples of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).



DNA is a very large molecule that carries the information that the body needs for growth, development, reproduction, and metabolic functioning. One of the coolest things about DNA molecules is that it consists of two strands that are held together via an intermolecular force called hydrogen bonding. During DNA replication, each strand can be used to grow a whole new strand of DNA.

DNA: Macromolecular Madness!

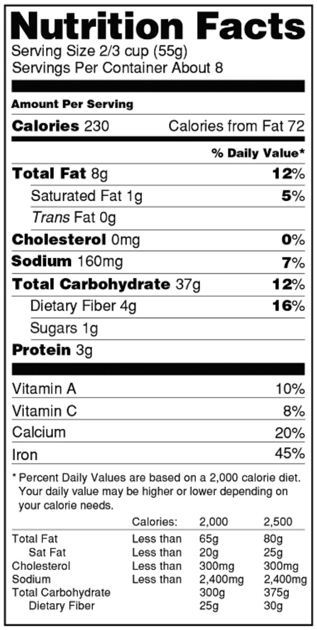
Many biochemical compounds such as DNA are referred to as being macromolecules because they're so huge. How big? Well, recall that water has a molar mass of 18.0 g/mol.[5] *The molar mass of DNA is about 86 billion g/mol, which means that one mole of DNA molecules is roughly equal to the weight of 47,000 cars.*

DNA molecules are so big that you can actually see them. Gross.

5 *I had to make some assumptions here to come up with the right answer. These assumptions are that we're using human DNA, that the average mass of a base pair unit is 660 g/mol, there are three billion base pairs in the human genome, and that all 23 chromosomes have DNA molecules of the same size. Though these are a lot of assumptions to make, they can at least give you an idea of how fantastically huge DNA molecules are.*

Food Biochemistry

You've probably seen food labeling that indicates the many things that are present in the stuff you eat. Since this is a textbook and you're supposed to learn useful things, it seems reasonable to talk about this.



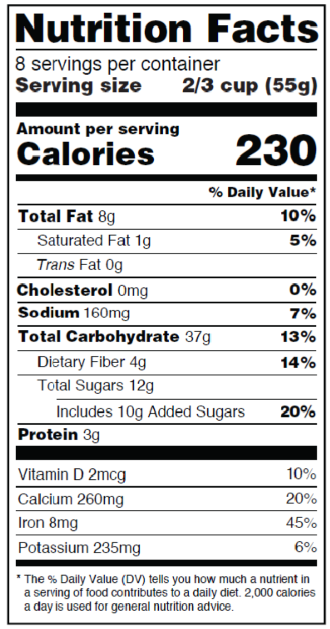
Nutrition Facts

Serving Size 2/3 cup (55g)
Servings Per Container About 8

Amount Per Serving	
Calories 230	Calories from Fat 72
	% Daily Value*
Total Fat 8g	**12%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**12%**
Dietary Fiber 4g	**16%**
Sugars 1g	
Protein 3g	
Vitamin A	10%
Vitamin C	8%
Calcium	20%
Iron	45%

* Percent Daily Values are based on a 2,000 calorie diet. Your daily value may be higher or lower depending on your calorie needs.

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g



Nutrition Facts

8 servings per container
Serving size 2/3 cup (55g)

Amount per serving	
Calories	**230**
	% Daily Value*
Total Fat 8g	**10%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**13%**
Dietary Fiber 4g	**14%**
Total Sugars 12g	
Includes 10g Added Sugars	**20%**
Protein 3g	
Vitamin D 2mcg	10%
Calcium 260mg	20%
Iron 8mg	45%
Potassium 235mg	6%

* The % Daily Value (DV) tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Current U.S. food labeling (left) and labeling that will go into effect by 2018 (right)

- **Calories**: Calories are a measure of how much energy a food contains. Foods with higher calorie counts give the consumer higher quantities of energy to use for metabolic processes, growth and body maintenance, or storage as fat.
- **Fat**: Fats are long organic molecules with an acidic end and an oily end. *Saturated fats* have no multiple C-C bonds and are thought to make people unhealthy. *Trans fats* contain C-C double bonds with a particular shape and are also believed to be unhealthy. Both types, however, taste good.
- **Cholesterol**: A large organic molecule that is used in the formation of cell membranes in the body. The bad news is that cholesterol can cause plaques that block blood vessels and make you die. The good news is that the amount of cholesterol in your diet doesn't seem to have much to do with the amount in your blood.
- **Sodium**: Sodium is used for a lot of different stuff in the body (I won't go into all of it, but you can Google it). It is thought that a high sodium intake can cause kidney problems and high blood pressure.[6]
- **Total carbohydrate**: These are the same carbohydrates we talked about a couple of pages ago. **Dietary fiber** is not metabolized in the body and passes straight through.[7] **Sugars** refer to simple sugars.
- **Protein**: Proteins are polymers of amino acids. When consumed, they are broken back down into amino acids to be made into proteins in the body.
- **Various nutrients**: This tells you how much of each nutrient is present.

6 *There's actually very little evidence for this, but people think it anyway.*
7 *“Bulk-forming laxatives” such as Metamucil consist mostly of fiber.*

Food Biochemistry (The Useful Version)

On the preceding page, we talked about the official biochemistry stuff having to do with food labels. However, given that this is a really important topic and that there was a lot of science talk that might have made it harder to understand, I figured that I'd write it out in a way that makes it a little more useful:

Ingredient	Where it's found	Why You Should Worry
Calories	It's in all food items.	The more calories you eat, the fatter you get.
Fat	It's the greasy stuff in meats, cheese, and processed foods	It tastes good and fills you up, but can make you fat.
Saturated and trans fat	These are types of fat	They probably make you die faster than unsaturated fats.
Cholesterol	Meats, oils, eggs, fast food	You probably shouldn't. Though blood cholesterol can be dangerous, dietary cholesterol doesn't have much to do with it.
Sodium	Anything salted, processed foods.	It's not clear that sodium levels now considered higher than normal are really dangerous. However, *extremely* high levels (higher than you'd ever normally get in food) can cause health problems.
Carbohydrates	Grains, sugars	Not inherently a big deal, but they don't fill you up much, either (with the exception of fiber).
Dietary fiber	Whole grains, fruits, nuts, beans, anything in grandma's house	They don't have any calories and fill you up a lot. But they also make you poop.
Sugars	Anything sweet or processed	It makes stuff taste good, but isn't good for you.
Added sugars	Anything processed	Pretty much just consists of sugars that are crammed into food to make you eat more of it. Chemically, they're the same as other sugars.
Protein	Meats, dairy, beans	Filling and relatively low calorie, but kind of expensive.
Nutrients	Everything	If you don't eat these, you'll die after a while. However, it's nearly impossible to eat so few of these that you'll die, so don't worry too much.

Other Miscellaneous Biochemical Processes

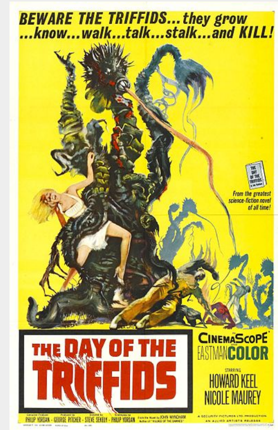
There are literally thousands of biochemical processes that take place. However, the following are some of the processes that somebody may actually expect you to learn about one day. Please keep in mind that this is by no means a comprehensive discussion of any of these reactions.

- **Photosynthesis**: In photosynthesis, water and carbon dioxide are converted into glucose via the process $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$.   The energy that causes this to occur comes from sunlight, which is why plants can't be left in a closet for months at a time. You'll also note that oxygen is formed, making photosynthesis important for creatures that like to breathe.

Did You Know?

When a plant grows, where does all of the matter come from? If you guessed "from the soil", you've made a reasonable guess. After all, the only solid matter the plant comes into contact with is the soil.

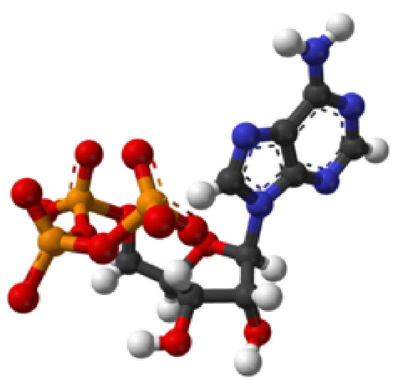
Unfortunately, this is also wrong. The stuff in plant matter comes from water absorbed through the roots and carbon dioxide absorbed through the air. Though there are very small quantities of nutrients in the soil that the plant needs, they account for almost none of the plant's mass.



The Day of the Triffids *is a documentary recounting the horrors of a September, 1964 plant uprising.*

- **Cellular respiration**: Cellular respiration occurs when the body breaks up glucose to make carbon dioxide and water via the reaction $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$. The energy given off by this exothermic reaction is the energy that living things use to live.

- **Other important reactions**: For some reason, biochemists like to use a lot of abbreviations for their little reactions. Things like ATP, NAD, and G6P are involved in biochemistry, and I don't really know what any of them mean. Most textbooks at least mention them, but only because school boards feel like you should memorize them for some reason or another. Since you and I both know that you have no intention of learning about these things at this point and that nobody will notice if you don't, let's just drop the whole matter.



Wikipedia says that this is the structure of ATP. Since neither of us has any way of knowing whether this is true, let's just pretend that you learned something from looking at this figure.

The Main Ideas In Chapter 9:

- Organic compounds are compounds that contain carbon and hydrogen. And maybe other stuff, too.
- There are a ton of different organic compounds because carbon can form long chains.
- There are different types of organic compounds that you should probably memorize.
- Biochemistry is the study of reactions that take place in living things. It's mostly organic chemistry, too.
- There are a different types of biochemical compounds that you should probably memorize.
- Food labels can tell you what's in food. Which is kind of the point.
- There are many different types of biochemical reaction, but nobody will notice if you actually learn any of them until at least high school, if not later.

Image Credits:

- Chevreul: Nadar [Public domain], via Wikimedia Commons.
- Octane: By User Magnus Manske on en.wikipedia (from rozeta) [Public domain], via Wikimedia Commons.
- Vitamin E: By Jü (Own work) [Public domain], via Wikimedia Commons.
- Propane: By NEUROtiker ⇌ (Own work) [Public domain], via Wikimedia Commons.
- Propene: By Benjah-bmm27 (Own work) [Public domain], via Wikimedia Commons.
- Propyne: By Renate90 (Own work) [Public domain], via Wikimedia Commons.
- Cyclopropane: By Holger87 (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons.
- Benzene: By Leyo (Own work), via Wikimedia Commons. Though this work has been licensed under the GNU Free Documentation License 1.2, chemical structures are generally considered to be common property and in the public domain. Make of that what you will.
- Formation of polyethylene: By Cdang (Own work) [Public domain], via Wikimedia Commons.
- Amylose: By TenOfAllTrades (Own work) [Public domain], via Wikimedia Commons.
- General nucleic acid: By NEUROtiker (Own work) [Public domain], via Wikimedia Commons.
- DNA replication: By US Department of Energy (DOE Human Genome project) [Public domain], via Wikimedia Commons.
- DNA: CSIRO [CC BY 3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons. By the way, this is onion DNA. I didn't want you to think that this is what it looks like when scientists make huge mutant people or anything. I'm sure that looks different than this.
- Food labels: By U.S. Food and Drug Administration [Public domain], via Wikimedia Commons.
- Triffids: Reynold Brown [Public domain], via Wikimedia Commons.
- ATP: By Ben Mills (Own work) [Public domain], via Wikimedia Commons.