Carbon and the Molecular Diversity of Life
by Dr. Ty C.M. Hoffman

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Life requires organic macromolecules that did not exist on early earth. However, conditions on early earth were much different than they are today, and those conditions could have eventually caused the creation of the organic building blocks of life out of simpler particles that were present. The famous Miller-Urey experiment demonstrated that setting up an apparatus that mimics conditions on early earth does produce organic compounds from inorganic ones that were present in the early atmosphere.

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Organic chemistry is the branch of chemistry dealing with organic compounds. An organic compound contains carbon atoms and other atoms, usually hydrogen and often oxygen, nitrogen, sulfur, phosphorous, and others. Pure carbon (like graphite or diamond) are not considered to be organic, and neither are some simple carbon-containing compounds like carbon dioxide. So much attention is devoted to carbon, because carbon is the smallest atom with tetravalence. Being tetravalent means being able to form four covalent bonds. Carbon is tetravalent, because it needs four more electrons to fill its valence shell. By forming four covalent bonds, carbon gets credit for four additional shared electrons, and this stabilizes the atom. Carbon can form any combination of four bonds: four single bonds, two double bonds, or a single bond and a triple bond. Therefore, carbon is extremely versatile with respect to compound formation, and millions of organic compounds have already been produced. One group of organic compounds, called hydrocarbons (shown in this slide), contain only carbon and hydrogen. They make excellent fuels.

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The valence of an atom is not the same as the number of valence electrons that atom has. The number of valence electrons in simply the number of electrons in that atom's outermost shell. The valence is the number of additional electrons that are required to fill that outermost shell. For instance, the outermost shell of nitrogen is the second shell (or level), which contains four orbitals ($2s$, $2p_x$, $2p_y$, and $2p_z$). The shell can hold a maximum of eight electrons (two per orbital). There are already five electrons in nitrogen's outer shell, so its number of valence electrons is five. It takes three more to fill that outer shell, so the valence of nitrogen is three. The valence indicates how many covalent bonds that atom will make to gain stability. For some atoms (like hydrogen and carbon), the number of valence electrons is coincidentally the same number as the valence, simply because the outer shell for that atom is exactly half filled.

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Urea is an example of an organic compound produced by organisms (including humans). It is a byproduct of the breakdown of proteins, all of which contain nitrogen. Urea is excreted by the kidneys. Gout results from an abnormally high level of urea in the blood.

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In any organic compound, we refer to the carbon atoms collectively as the carbon skeleton. An organic compound can therefore be viewed as a carbon skeleton to which other atoms are attached. All hydrocarbons contain only carbon and hydrogen, but hydrocarbons can be classified into different groups based on various criteria.

- Hydrocarbons can be classified according to the number of carbons in the skeleton. For instance, both hexane and hexene have six carbons.
- Hydrocarbons can be classified according to the shape of that carbon skeleton. Some skeletons are arranged linearly; others include branches.
- Hydrocarbons can be classified according to the presence or absence of double or triple bonds. A hydrocarbon with only single bonds is an alkane; one with at least one double bond is an alkene; and one with at least one triple bond is an alkyne.
- Hydrocarbons can be classified according to the presence or absence of rings in the carbon skeleton.

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A fat is a type of lipid, and lipids make up one of the four classes of organic macromolecules that organisms produce. A fat (also called a triglyceride) includes three long tails called fatty acids. Each fatty acid is a hydrocarbon chain. Since hydrocarbons in general make excellent fuels (like gasoline, kerosene, etc.), fats make excellent fuels for organisms, and organisms store their excess energy (obtained in food) as fat for use as fuel later on.

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It is possible for two molecules to contain exactly the same number and types of atoms but with different arrangements of those atoms. Such molecules are called isomers. A pair of isomers have the same chemical formula, but different chemical properties. There are three major classes of isomers:

- Structural isomers differ only in the shape of the carbon skeleton.
- Geometric isomers include a double bond, which disallows swiveling. This leads to two possibilities: the *cis* configuration, in which two substituents (connected atoms) appear on the same side of the double bond; and the *trans* configuration, in which two substituents appear on opposite sides of the double bond.
- Enantiomers (or stereoisomers) result when a central carbon atom is singly bonded to four different atoms. This leads to two possibilities that are mirror images of each other, like the two hands of a human. Enantiomers therefore exhibit handedness, or chirality.

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Many drugs are examples of enantiomers, so there is a left-handed version and a right-handed version. Either version can be chemically produced with equal ease; however, only one version will be effective, because a drug operates as a signal molecule. A signal molecule must temporarily bind to a protein acting as a receptor molecule. This requires the signal to be the correct shape for the receptor. A left-handed signal will not fit into a right-handed receptor, and vice-versa.

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L-dopa is an example of an endogenous enantiomer. Our cells produce L-dopa, which can then be converted into various molecules (like dopamine or norepinephrine) that act as signals within the body. D-dopa can be manufactured chemically, but it is biologically inactive, because it has the wrong chirality.

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Cholesterol is a compound made by animals. The molecule includes four rings. Cholesterol is a precursor molecule, because it can be modified to form various other compounds, including the steroid hormones, estradiol and testosterone. Estradiol (an estrogen) and testosterone have quite different effects on the body, despite having a very similar overall structure, because these two molecules contain different functional groups. A functional group is a small group of atoms attached to the carbon skeleton and arranged in a certain way. There are different types of functional groups, and the different functional groups give the molecules to which they belong different chemical properties and therefore different functions.

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Functional groups are categorized by the specific types and arrangement of atoms in each functional group. Functional groups do not occur as complete molecules; rather they are connected to a carbon skeleton, and a functional group is therefore just part of a molecule. This is revealed by the structural notation for any given functional group, which includes a line either connected to nothing or connected to the letter, R. "R" stands for residue, and it refers to the rest of the molecule.

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One example of a molecule with a phosphate group is an important biological molecule called adenosine triphosphate (ATP). There is a lot of energy stored in the bonds between the different phosphate groups in ATP. When one of those bonds is broken (cleaving off the terminal phosphate), energy is released, and some of that energy can be used by a cell to do some work.