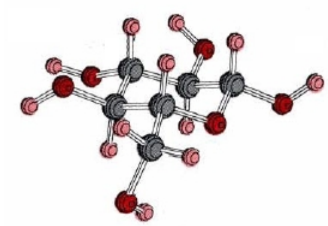
20.1: Prelude to Biochemistry

Most of us have little difficulty distinguishing living organisms from inanimate matter. The former are capable of reproducing nearly exact copies of themselves; they can appropriate both matter and energy from their surroundings, moving, growing, and repairing damage caused by external factors; and groups of them evolve and adapt in response to long-term environmental changes. On a macroscopic scale the differences are sufficiently striking that early philosophers and scientists postulated the existence of a vital force without which living organisms would be inanimate. It was thought that organic compounds could only be manufactured in living organisms, and chemistry was divided into the subfields of inorganic and organic on this basis.



This subdivision persists today, but the definition of organic has changed in response to the discovery of numerous ways to make organic compounds from inorganic starting materials. As seen in the sections on organic compounds, organic chemistry now means "chemistry of compounds containing carbon." No restriction is placed on the origin of the compounds, and hundreds of thousands of organic compounds which are foreign to all living systems have been produced in laboratories around the world. Indeed, concern about the effects of some of these synthetic substances on the environment has led to yet another definition of organic. The general public now takes it to mean "free of substances produced as a result of human activities."

Just as the division between organic and inorganic chemistry has become more arbitrary with the advance of knowledge, the distinction between life and nonlife has also blurred. Living organisms are made up of atoms and molecules which follow the same chemical principles as any other set of atoms and molecules. Yet there is a difference-these atoms, molecules, and even groups of molecules are organized to a much greater degree than in any of the cases we have discussed. Above a certain level of complexity a collection of chemicals begins to exhibit most of the behavior patterns that we associate with life. A virus, for example, may consist of fewer than 100 associated large molecules. It is the structures of these molecules and the ways in which they are associated that determine a virus' behavior and make it appear to be on the threshold of life.

Biochemistry is the study of chemical elements found in living systems, and how these elements combine to form molecules and collections of molecules which carry out the biological functions and behaviors that we associate with life. Our treatment must of necessity be brief, but even if it were not, the complexity of biochemical systems would insure that it would be incomplete. Much of modern chemistry, both inorganic and organic, involves the extension to complex biological systems of principles and facts gleaned from studies of more general chemical behavior.

More than 99 percent of the atoms in most living organisms are H, O, N, or C. These are the smallest atoms which can form one, two, three, and four covalent bonds, respectively, and they are especially suited to make up the more than 10^{11} different, but often related, kinds of molecules estimated to exist in the biosphere. Each such molecule has a specific function to perform in a specific organism, and its molecular structure is very important in determining how that function is carried out.

Many biological molecules are formed by condensation polymerization from small building-block molecules. Reversal of such condensations (hydrolysis) breaks large molecules down into the building blocks again, allowing them to be used by another organism. Examples of condensation reactions are the formation of lipids from fatty acids and glycerol, the formation of cellulose and starch from glucose, the formation of proteins from amino acids, and the formation of nucleic acids from ribose or deoxyribose, phosphate, and nitrogenous bases.

Lipids may be divided into two categories: nonpolar (hydrophobic) and polar (hydrophilic). Both types consist of long hydrocarbon chains, but polar lipids have electrically charged or hydrogen-bonding groups at one end. Lipid bilayers, in which the hydrophilic ends of polar lipids contact an aqueous phase while the hydrophobic tails intertwine, are important components of cell walls and other membranes. Nonpolar substances often dissolve in the hydrophobic portions of lipid tissue and may be concentrated along ecological food chains, a process referred to as bioamplification.

Carbohydrates provide a storehouse for solar energy absorbed during photosynthesis. Simple sugars usually contain five or six C atoms in a ring and a large number of OH groups. Disaccharides are formed from a condensation reaction between two simple sugars. Polysaccharides, such as cellulose and starch, are condensation polymers of simple sugars. Their structures and chemical reactivities are very dependent on the exact structure of the simple sugar from which they are made.

Fibrous proteins, in which polypeptide chains are arranged parallel to one another, are fundamental components of structural tissues such as tendons, hair, etc. Globular proteins, on the other hand, have compact, nearly spherical structures in which the polypeptide chain folds back on itself. Enzymes, antibodies, hormones, and hemoglobin are examples of globular proteins. Proteins are made by polymerization of 20 different amino acids. The order of amino acid side chains along the polymer backbone constitutes primary protein structure. Secondary structure involves hydrogen bonding to form α-helix or pleated-sheet structures. The intricate folding of the polypeptide chain in a globular protein is referred to as tertiary structure. Some proteins (hemoglobin, for example) have quaternary structure— several polypeptide chains are nested together.

Nucleic acids, such as DNA and RNA and formed from nitrogenous bases, sugars and phosphate, constitute a blueprint and a mechanism for synthesizing useful proteins. Codons, each consisting of a sequence of three nitrogenous bases along a nucleic acid polymer chain, indicate which amino acid goes where. DNA also has secondary structure, the double helix. When cells divide, the double-stranded DNA molecule can replicate itself, and complementary base pairing insures that each new cell will contain identical DNA. During protein synthesis, information is transcribed from DNA to mRNA and then translated from the mRNA code into a protein. In the translation process, tRNA molecules bonded to specific amino acids, base pair their anticodon sequence with a codon sequence on the mRNA. The ribosome, itself constituted of RNA and protein performs the catalytic activity of synthesizing the protein. In this way the primary protein structure is determined, and secondary and higher order structures then follow directly.
