The Molecular Logic of Life

Living organisms are composed of lifeless molecules. When these molecules are isolated and examined individually, they conform to all the physical and chemical laws that describe the behavior of inanimate matter. Yet living organisms possess extraordinary attributes not exhibited by any random collection of molecules. In this chapter, we first consider the properties of living organisms that distinguish them from other collections of matter, and then we describe a set of principles that characterize all living organisms. Some of the principles in the molecular logic of life;

- All living organisms build molecules from the same kinds of monomeric subunits.
- The structure of a macromolecule determines its specific biological function.
- Each genus and species is defined by its distinctive set of macromolecules.

These principles underlie the organization of organisms and their cells.

The Chemical Unity of Diverse Living Organisms

What distinguishes living organisms from inanimate objects? First is their degree of chemical complexity and organization. Thousands of different molecules make up a cell’s intricate internal structures. By contrast, inanimate matter—clay, sand, rocks, seawater—usually consists of mixtures of relatively simple chemical compounds.

Second, living organisms extract, transform, and use energy from their environment, usually in the form of chemical nutrients or sunlight. This energy enables organisms to build and maintain their intricate structures and to do mechanical, chemical, osmotic, and other types of work. Inanimate matter does not use energy in a systematic, dynamic way to maintain structure or to do work; rather, it tends to decay toward a more disordered state, to come to equilibrium with its surroundings.

The third attribute of living organisms is the capacity for precise self-replication and self-assembly, a property that is the quintessence of the living state. A single bacterial cell placed in a sterile nutrient medium can give rise to a billion identical "daughter" cells in 24 hours. Each of the cells contains thousands of different molecules, some extremely complex; yet each bacterium is a faithful copy of the original, its construction directed entirely from information contained within the genetic material of the original cell.

Although the ability to self-replicate has no true analog in the nonliving world, there is an instructive analogy in the growth of crystals in saturated solutions. Crystallization produces more material identical in lattice structure to the original "seed" crystal. Crystals are much less complex than the simplest living organisms, and their structure is static, not dynamic as are living cells. Nevertheless, the ability of crystals to "reproduce" themselves led the physicist Erwin Schrödinger to propose in his famous essay "***What Is Life?***" that the genetic material of cells must have some of the properties of a crystal. Schrödinger's 1944 notion (years before our modern understanding of gene structure) describes rather accurately some of the properties of deoxyribonucleic acid, the material of genes.

Each component of a living organism has a specific function. This is true not only of macroscopic structures, such as leaves and stems or hearts and lungs, but also of microscopic intracellular structures such as the nucleus or chloroplast and of individual chemical compounds. The interplay among the chemical components of a living organism is dynamic; changes in one component cause coordinating or compensating changes in another, with the whole ensemble displaying a character beyond that of its individual constituents. The collection of molecules carries out a program, the end result of which is reproduction of the program and self-perpetuation of that collection of molecules; in short, life.

Biochemistry: Explains Diversity of Life

If living organisms are composed of molecules that are intrinsically inanimate, how do these molecules confer the remarkable combination of characteristics we call life? How can a living organism be more than the sum of its inanimate parts? Philosophers once answered that living organisms are endowed with a mysterious and divine life force, but this doctrine, called vitalism, has been firmly rejected by modern science. The study of biochemistry shows how the collections of inanimate molecules that constitute living organisms interact to maintain and perpetuate life animated solely by the chemical laws that govern the nonliving universe.

Living organisms are enormously diverse. In appearance and function, birds and beasts, trees, grasses, and microscopic organisms differ greatly. Yet, biochemical research has revealed that all organisms are remarkably alike at the cellular and chemical levels. Biochemistry describes in molecular terms the structures, mechanisms, and chemical processes shared by all organisms, and provides organizing principles that underlie life in all of its diverse forms, principles refer as **the molecular logic of life.** Although biochemistry provides important insights and practical applications in medicine, agriculture, nutrition, and industry, its ultimate concern is with the wonder of life itself.

Despite the fundamental unity of life, very few generalizations about living organisms are absolutely correct for every organism under every condition. The range of habitats in which organisms live, from hot springs to Arctic tundra, from animal intestines to college dormitories, is matched by a correspondingly wide range of specific biochemical adaptations, achieved within a common chemical framework. For the sake of clarity, we will sometimes risk certain generalizations, which, though not perfect, remain useful; we will also frequently point out the exceptions that illuminate scientific generalizations.

Macromolecules Construction from Simple Compounds

Most of the molecular constituents of living systems are composed of carbon atoms covalently joined with other carbon atoms and with hydrogen, oxygen, or nitrogen. The special bonding properties of carbon permit the formation of a great variety of molecules. Organic compounds of molecular weight (also called relative molecular mass, M_r) 1 less than about 500, such as amino acids, nucleotides, and monosaccharides, serve as monomeric subunits of macromolecules: proteins, nucleic acids, and polysaccharides. A single protein molecule may have 1,000 or more amino acids, and deoxyribonucleic acid has millions of nucleotides.

Each cell of the bacterium Escherichia coli (E. coli) contains several thousand kinds of organic compounds, including a thousand different proteins, a similar number of different nucleic acid molecules, and hundreds of types of carbohydrates and lipids. In humans there may be tens of thousands of different proteins, as well as many types of polysaccharides (chains of simple sugars), a variety of lipids, and many other compounds of lower molecular weight.

To purify and to characterize thoroughly all of these molecules would be an insuperable task were it not for the fact that each class of macromolecules (proteins, nucleic acids, polysaccharides) is composed of a small, common set of monomeric subunits. Deoxyribonucleic acids (DNA) are constructed from only four different kinds of simple monomeric subunits, the deoxyribonucleotides.

Ribonucleic acids (RNA) are composed of just four types of ribonucleotides. Proteins are composed of 20 different kinds of amino acids. The eight nucleotides from which all nucleic acids are built and the 20 different amino acids from which all proteins are built are identical in all living organisms. The specific sequence of monomeric subunits together with their arrangement in space shapes macromolecules for their particular biological functions as genes, catalysts, hormones, and so on.

Most of the monomeric subunits from which all macromolecules are constructed serve more than one function in living cells. Nucleotides serve not only as subunits of nucleic acids but also as energy-carrying molecules. Amino acids are subunits of protein molecules and are also precursors of hormones, neurotransmitters, pigments, and many other kinds of biomolecules.