7.1: Green Biochemistry

Biochemistry is the science of chemical processes that occur in living organisms.[1] By its nature biochemistry is a green chemical and biological science. This is because over eons of evolution organisms have evolved that carry out biochemical processes sustainably. Because the enzymes that carry out biochemical processes can only function under mild conditions, particularly of temperature, biochemical processes take place under safe conditions, avoiding the high temperatures, high pressures, and corrosive and reactive chemicals that often characterize synthetic chemical operations. Therefore, it is appropriate to refer to **green biochemistry**.

The ability of organisms to carry out chemical processes is truly amazing, even more so when one considers that many of them occur in single-celled organisms. Photosynthetic cyanobacteria consisting of individual cells less than a micrometer (μm) in size can make all the complex biochemicals they need to exist and reproduce using sunlight for energy and simple inorganic substances such as CO_2, K^+ ion, NO_3^- ion and HPO_4^{2-} ion for raw materials. Beginning soon after conditions on Earth became hospitable to life, these photosynthetic bacteria produced the oxygen that now composes about 20% of Earth's atmosphere. Fossilized stromatolites (bodies of sedimentary materials bound together by films produced by microorganisms) produced by cyanobacteria have been demonstrated dating back 2.8 billion years, and this remarkable microorganism that converts atmospheric carbon dioxide to biomass and atmospheric N_2 to chemically fixed N may have been on Earth as long as 3.5 billion years ago.

It is fascinating to view single live cells of animal-like protozoa through an optical microscope. An ameba appears as a body of cellular protoplasm and moves by oozing about like a living blob of jelly. Examination of *Euglena* protozoa may show a cell several μm in size with many features including a cell nucleus that serves to direct metabolism and reproduction, green chloroplasts for photosynthetic production of biomass, a red eye-spot sensitive to light, a mouth-like contractile vacuole by which the cell expels excess water, and a thin tail-like structure(flagella) that moves rapidly and propels the cell. More detailed examination by electron microscope of such cells and those that make up more complex organisms reveals many more cell parts that are involved with biochemical function.

At least a rudimentary knowledge of biochemistry is needed to understand green chemistry, environmental chemistry, and sustainability science and technology. One reason is the ability of organisms to synthesize a vast variety of substances. The most obvious of these is biomass made by the photosynthetic fixation of carbon dioxide and that forms the basis of nature's food webs.Organisms make many of the materials upon which humans rely. In addition to food, one such material is the lignocellulose that composes most of plant biomass such as wood used for construction, paper-making, and fuel. Very complex molecules are made by organisms, for example, human insulin produced by genetically engineered organisms. Organisms make materials under very mild conditions compared to those used in the anthrosphere. An important example is chemically fixed nitrogen from the atmosphere which is produced synthetically in the anthrosphere as ammonia (NH_3) at high temperatures and pressures whereas *Rhizobium* bacteria attached to the roots of soybeans and other legume plants fix nitrogen in the mild conditions of the soil environment. Increasingly as supplies of petroleum and other non-renewable raw materials become more scarce, humans are turning to microorganisms and plants to make essential materials.

Another major reason for considering biochemistry as part of green chemistry and sustainability is the protection of organisms from products and processes in the anthrosphere. It is essential to know the potential toxic effects of various materials, a subject addressed by **toxicological chemistry**.[2] One of the fundamental goals of green chemistry is to minimize the production and use of products that may have adverse environmental effects. Sustainability of the entire planet requires that humans not disperse into the environment substances that may undergo bioaccumulation and be toxic to humans and other organisms.

Biochemical processes not only are profoundly influenced by chemical species in the environment, they largely determine the nature of these species, their degradation, and even their syntheses, particularly in the aquatic and soil environments. The study of such phenomena forms the basis of **environmental biochemistry.**

This chapter is designed to give an overview of biochemistry and how it relates to green chemistry and sustainability science and technology. A glance at the structural formulas of some of the biochemicals shown in this chapter gives a hint of the complexity of biochemistry. This chapter is designed to provide a basic understanding of this complex science with enough detail for it to be meaningful but to avoid overwhelming the reader. It begins with an overview of the four major classes of biochemicals— proteins, carbohydrates, lipids, and nucleic acids. Many of the compounds in these classes are polymers with molecular masses of the order of a million or even larger. Proteins and nucleic acids consist of macromolecules, lipids are usually relatively small molecules, carbohydrates range from small sugar molecules to high-molar-mass macromolecules such as those in cellulose.

The behavior of a substance in a biological system depends to a large extent upon whether the substance is hydrophilic ("water-loving") or hydrophobic ("water-hating"). Some important toxic substances are hydrophobic, a characteristic that enables them to traverse cell membranes readily and to bioaccumulate in lipid (fat) tissue. Many hydrocarbons and organohalide compounds synthesized from hydrocarbons are hydrophobic. Part of the detoxification process carried on by living organisms is to render such molecules hydrophilic, therefore water-soluble and readily eliminated from the body.
