The Chemical Logic of Life and the Earth's Biosphere

Chemistry and the Environment

A Simple, One-Diagram Outline

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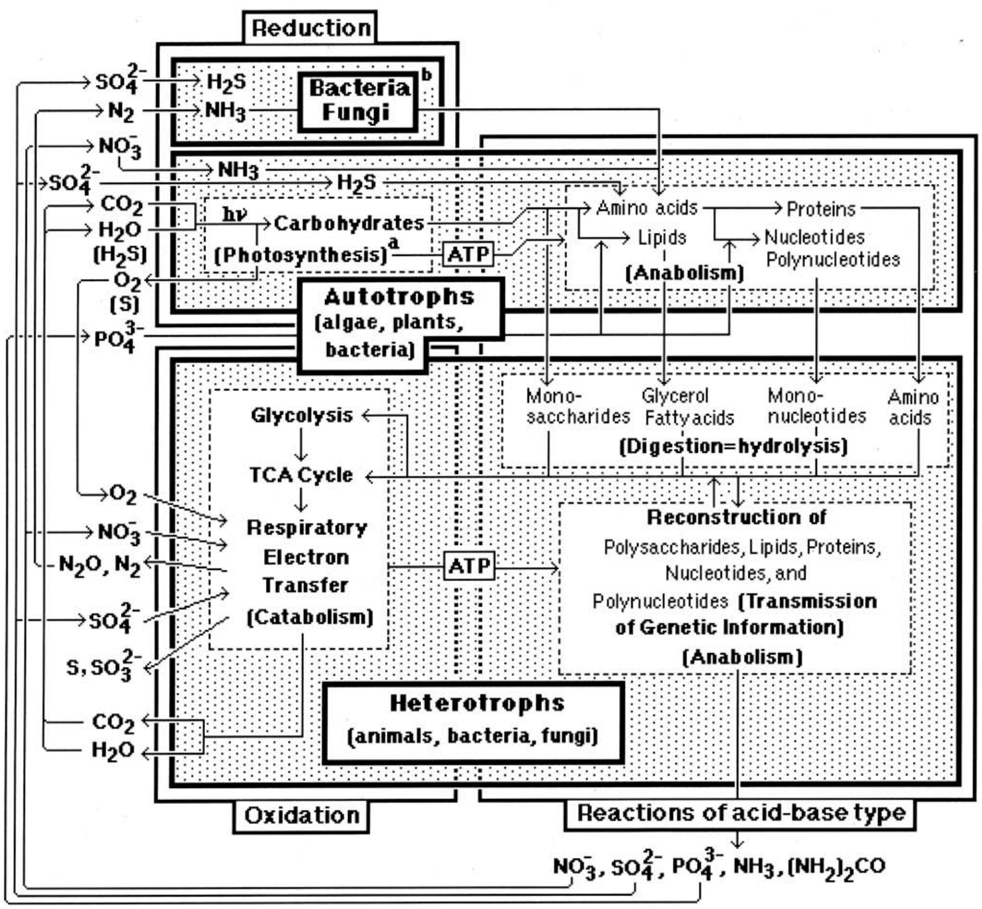
Biological science is diverse, embracing a wide range of subjects, including those on the following progressive list.

- ***ecology***, the study of the biosphere and its species
- ***biology***, the study of individual species (from monera to higher species)
- ***anatomy and physiology***, the studies of macrostructure and function
- ***cell biology***, the study of microstructure and function
- ***molecular biology and biochemistry***, the studies of the chemistry of living structures and processes.

Although the species are diverse, their biochemistry is rather universal. Thus, the most basic chemical principles of biochemical processes could be outlined easily and compactly. However, to the best of my knowledge, no such outline has been devised before now. This prompted me to furnish such a diagram. (See the figure.)



The chemical logic of life and the earth's biosphere. (a) Here *hν* represents sunlight. An alternative energy for carbohydrate production is chemical energy. (b) These organisms require the rest of the metabolic machinery, although this is not indicated here for the lack of a convenient way to incorporate it.

This diagram is intended to give a compact overall picture of the chemical logic of life and of the earth's biosphere. Obviously it is impossible to devise a perfectly complete diagram for such a complicated system because the biosphere consists of diverse species with different biochemistry.

The diagram deals with only the major events. They are much simplified for the sake of clarity and so that the diagram can be grasped readily. Thus, some rigor has been sacrificed. The diagram is self-explanatory, but some further comment may be helpful.

Types of Organisms

The organisms can be divided into two large categories: the autotrophs (e.g., most plants) and the heterotrophs (e.g., fungi). The autotrophs can produce carbohydrates from inorganic compounds (e.g., CO_2 and H_2O), whereas the heterotrophs rely on the autotrophs as their source of carbon compounds. The diagram indicates that the autotroph's biochemistry entails the synthesis of carbohydrates, the anabolismic processes, and to some extent, the respiratory processes.

Some bacteria (autotrophic or heterotrophic) and some fungi specialize in reducing N_2 to NH_3. They actually do need all the rest of the biochemical machinery. However, this is not shown on the diagram because it can not be conveniently incorporated.

The diagram applies mainly to aerobic organisms. The anaerobes lack either some parts or all parts of the TCA cycle and the respiratory electron-transfer processes. The ultimate electron acceptors in some anaerobic organisms are NO_3^-, SO_4^{2-}, and CO_2 (instead of O_2). Some anaerobes depend only on fermentation (glycolysis).

Types of Reactions

The other important distinction concerns the type of chemical reactions that are involved. All chemical reactions can be categorized essentially into one of two groups: oxidation–

reduction reactions and acid–base reactions. The chemical reaction types are indicated in the diagram by boldly outlined boxes.

Oxidation–Reduction Reactions

The oxidation–reduction reactions are placed on the left half of the diagram. They are involved in the production of energy as ATP or in the production of other energy-rich molecules, such as carbohydrates. The reactions represented on the right half of the diagram, particularly reactions involved in anabolism, consume ATP.

The reduction reactions are usually endothermic, and thus require energy input. Energy for carbohydrates and ATP production is supplied either by radiation from the sun (in the case of photoautotrophs) or by chemical energy (in the case of chemoautotrophs). Chemoautotrophs oxidize NH_3, Fe(II), H_2S, etc., and then use the energy obtained for carbohydrate synthesis. Carbon compounds produced by autotrophs are used later by heterotrophs in a series of oxidative reactions that produce ATP (catabolism). The reduction of N_2 and SO_4^{2-} requires ATP.

Acid–Base Reactions

The right half of the diagram represents mostly acid–base reactions. These reactions by definition involve heterolytic bond formation or cleavage, often catalyzed by acid–base catalysts. In the broadest sense, this includes Lewis acids and bases, such as Zn^{2+}, carboxylic acids, and the nitrogen on histidine, as well as H^+ and OH^-. Reactions of this category include the following processes.

- the formation of biologically important monomeric compounds, such as amino acids, lipids, and mononucleotides
- the formation of polymeric substances, such as polysaccharides, proteins, and polynucleotides
- the decomposition of complex compounds into smaller units

The reactions in the last category include the hydrolysis of lipids, nucleic acids, and proteins. They are characterized as “digestion”. The formation of polymeric substances involves condensation reactions, which are usually endothermic. The hydrolysis of ATP (exothermic) is usually coupled with these reactions, thus making the overall reaction spontaneous. All these reactions involve heterolytic bond cleavage and formation.

The so-called inorganic compounds are shown outside this system. These compounds are recycled, which is an important aspect of ecology. For example, O_2 is released from photoautotrophs and used by heterotrophs. The cycle of nitrogen and its compounds is mainly driven by N_2-fixing bacteria and fungi.