BIOCHEMISTRY IN PERSPECTIVE

The Extremophiles: Organisms That Make a Living in Hostile Environments

How can living organisms sustain life in very hostile environments? The *extremophiles*, the unique organisms that live in harsh or extreme environments, are classified according to the specific conditions to which they are adapted. Examples include thermophiles and hyperthermophiles (high temperature), acidophiles (low pH), piezophiles (high pressure), and halophiles (high salt concentration). Such organisms, many of which are archaeans, often thrive in habitats with several extreme conditions. For example, the hot water near hydrothermal vents is under very high pressure. As with all living organisms, the extremophiles require energy. Energy generation involves oxidation-reduction (redox) reactions (described in Chapter 8) in which free energy is released as electrons are transferred from an **electron donor** to an **electron acceptor**.

Briefly, there are three energy-generating mechanisms: photosynthesis, chemoorganotrophy, and chemolithotrophy. Photosynthesis (Chapter 13) is a process that converts light energy into chemical energy (ATP). Most photosynthetic organisms produce O_2 as a by-product. In certain microorganisms O_2 evolution does not occur. *Chemoorganotrophs* and *chemolithotrophs* generate ATP by oxidizing organic and inorganic compounds, respectively.

Chemotrophs have two possible mechanisms of synthesizing ATP: fermentation and respiration. **Fermentation** is a biochemical process in which energy capture occurs via the oxidation of organic molecules. ATP is synthesized from ADP by substrate-level phosphorylation, the direct transfer of a phosphate group from a phosphorylated organic molecule. Fermentation is inefficient because the product molecules released as waste are only partially oxidized. **Respiration** is a more sophisticated process in which a series of electron carrier molecules reversibly accept and donate electrons. The energy captured is used to create an electrochemical gradient that drives ATP synthesis. In **aerobic respiration**, the low-energy electrons that result from this process are donated to O_2. In **anaerobic respiration**, terminal electron acceptors other than O_2 are used. Examples of the latter include ferric iron (Fe^{3+}), nitrate (NO_3^-), or certain organic molecules. The following examples of energy-generating mechanisms used by selected extremophiles provide a hint of the diversity among these remarkable organisms.

Methanococcus janaschii is a hyperthermophile. It lives near hydrothermal vents at temperatures of 80°C or greater. It is also a piezophile. As its name suggests, this archaean is a methane (CH_4) producer. Under strictly anaerobic conditions, *M. jannaschii* obtains energy by converting CO_2 to CH_4 in a series of complex electron transfer reactions. The electron donor is hydrogen gas (H_2), a product of geochemical processes. The net reaction is

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Bacillus infernus (called the "bacillus from hell") is a thermophile that grows at 60°C. This halotolerant (0.6 M Na^+) bacterium was discovered 2700 m below the earth's surface. *B. infernus*, isolated in nutrient-deficient environments, has a very slow rate of reproduction. It derives energy from the fermentation of the sugar glucose or the anaerobic respiration of electron donors such as formate ($HCOO^-$) and lactate ($CH_3CHOHCOO^-$). Electron acceptors include manganese dioxide (MnO_2), ferric iron (Fe^{3+}), and nitrate (NO_3^{2-}).

Thiobacillus ferroxidans is an aerobic, acidophilic (pH 2–4) chemolithotroph that is commonly found in sulfate-containing acid drainage from coal mines. It derives energy from ferrous iron (Fe^{2+}) and reduced forms of sulfur such as H_2S and iron sulfide (FeS). The products of this process are Fe^{3+} and sulfuric acid. Acid drainage pollutes lakes and rivers and kills aquatic life.

SUMMARY: Extremophilic organisms utilize an array of oxidation-reduction reactions to generate the energy required to sustain life in hostile environments.