

Thermodynamics and Metabolism

There are 3 laws to thermodynamics, and like all things, life does not violate them. Interestingly, there is so much you can do with the laws and life—to explain the microbial world.

1st Law:

Energy can neither be created nor destroyed.

A function of this law, enthalpy, ΔH is the equivalent to the heat added to or subtracted from a system as a result of a chemical process at constant pressure.

When a system evolves heat-- ΔH is negative, exothermic; when the system absorbs heat, ΔH is positive, endothermic.

ΔH is one of many terms that describe a system, a cell, at steady state. Enthalpy is a state function. At STP (25°C and 1 atm), ΔH is termed ΔH° . For microbes, this is good, because most of the time we're talking about STP—unless you're in the extreme world, then you have to take numbers into account.

Enthalpies are given as the heat of reaction necessary to form one mole of substance from its elementary components, the enthalpy of formation at STP. Appendix 2 and 3 useful, an example on pg. 67.

2nd Law:

Entropy—for any spontaneous process, there is an increase in entropy in the universe. S , describes the state of a system too, the entropy, and it is a state function.

$$\Delta S_{\text{total}} = \Delta S_{\text{surroundings}} + \Delta S_{\text{system}}$$

Which can lead to the derivation (pg. 68) of a third state function, Gibbs Free Energy:

$$\Delta G = \Delta H - T\Delta S \quad \text{or at standard state,} \quad \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

If ΔG for a reaction is negative, the reaction is spontaneous, and it is an exergonic reaction.

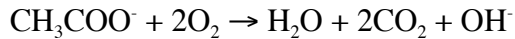
If ΔG for a reaction is positive, the reaction is not-spontaneous, and it is an endergonic reaction (it is written in the other direction).

If $\Delta G = 0$, the reaction is at equilibrium.

In Geo-micro-biology, ΔG is very important. Driving force for mineralization reactions depends on ΔG . The more negative the ΔG , the more likely it is to occur.

ΔG helps to explain the microbial world, predict what is possible, and explain what is observed.

ΔG Example—the oxidation of acetate by oxygen:



$$\Delta G^{\circ\prime} = [\Delta G_f^{\circ} \text{ products}] - [\Delta G_f^{\circ} \text{ reactants}]$$

$$[(-237.17 (\text{H}_2\text{O})) + 2(-394.4 (\text{CO}_2)) + (-197.2 (\text{OH}^-))] - [(-369.4 (\text{CH}_3\text{COO}^-))]$$

$$\Delta G^{\circ} = -853.76 \text{ kJ / mol}$$

To sustain growth, organisms need to utilize reactions with substantially negative ΔG values (above). The threshold of growth is generally considered to be that needed to product ATP. Under standard conditions the production of ATP from ADP has a $\Delta G = -32 \text{ kJ / mol}$. In reality, about $\Delta G = -70 \text{ kJ / mol}$ is more like it—because concentrations of reactants varies widely (ATP, ADP, P, etc.) and some energy is lost as heat.

Basic Cell Biochemistry

Microbes are really amazing biochemical machines. They can exploit the smallest amounts of anything—and successfully make a living on it. We have to think about individual electrons, and individual atoms as being of use. Like all finely engineered things, nothing is wasted!

Enzymes are critical to the process. They have had eons to evolve their atomic specialization.

Energy is derived from a series of linked oxidation-reduction reactions to pass electrons down a transfer chain.

Light drives energy gaining oxidation-reduction reactions in photosynthesis, and in the absence of light, energy can be gained by electron transfer from electron donors such as carbon and electron acceptors such as oxygen (respiration).

But also, there are proteorhodopsins—molecules that can capture light energy and use as an electron donor—without photosynthesis.

Main electron carriers in a cell— NAD^+ / NADH used most often in catabolic pathways (breakdown of organic and inorganic compounds that leads to the production of energy).

And NADP^+ / NADPH used in anabolic pathways (synthesis of cell constituents from simpler molecules and requiring energy).

Proton Motive Force

There is a continuous transfer of protons from one side of a cell plasma membrane to the other—from the cytoplasm to the periplasm in G^- cells or to the cell wall region in G^+ cells.

It is possible because there is an asymmetric arrangement of carrier enzymes. Some carriers like flavoproteins and ubiquinones acquire or transfer H_2 , while iron-sulfur complexes only carry electrons.

When a carrier can only accept electrons, protons are released as ions, external to the plasma membrane. A net accumulation of protons happens, outside the cell. Plasma membrane is normally impermeable to protons (and OH^-)