

Thermodynamics = Study of energy transformations

First Law of Thermodynamics = Energy can be transferred and transformed, but it cannot be created or destroyed (energy of the universe is constant) aka Conservation of Energy.

Second Law of Thermodynamics = Every energy transfer or transformation makes the universe more disordered (every process increases the entropy of the universe). aka Entropy is always increasing.

Entropy = Quantitative measure of disorder that is proportional to randomness (designated by the letter S).

Third Law of Thermodynamics = The entropy of any pure crystalline substance at absolute zero is equal to zero. (i.e., A perfect crystal with no heat has perfect order)

Closed system = Collection of matter under study which is isolated from its surroundings.

Open system = System in which energy can be transferred between the system and its surroundings.

The entropy of a system may decrease, but the entropy of the system plus its surroundings must always increase. Highly ordered living organisms do not violate the second law because they are open systems. For example, animals:

! Maintain highly ordered structure at the expense of increased entropy of their surroundings.

! Take in complex high energy molecules as food and extract chemical energy to create and maintain order.

! Return to the surroundings simpler low energy molecules (CO₂ and H₂O) and heat.

Energy can be transformed, but part of it is dissipated as heat which is largely unavailable to do work. Heat energy can perform work if there is a heat gradient resulting in heat flow from warmer to cooler.

✓ **Combining the first and second laws; the quantity of energy in the universe is constant, but its *quality* is not.**

Energy = Capacity to do work.

Kinetic energy = Energy in the process of doing work (energy of motion).

Examples:

! Heat (thermal energy) is kinetic energy expressed in random movement of molecules.

! Light energy from the sun is kinetic energy which powers photosynthesis.

Potential energy = Energy that matter possesses because of its location or arrangement (energy of position). For example:

! In the earth's gravitational field, an object on a hill or water behind a dam have potential energy.

! Chemical energy is potential energy stored in molecules because of the arrangement of nuclei and electrons in its atoms.

Energy can be transformed from one form to another. For example:

! Kinetic energy of sunlight can be transformed into the potential energy of chemical bonds during photosynthesis.

! Potential energy in the chemical bonds of gasoline can be transformed into kinetic mechanical energy which pushes the pistons of an engine.

Exergonic reaction = A reaction that proceeds with a net loss of free energy.

Endergonic reaction = An energy-requiring reaction that proceeds with a net gain of free energy; a reaction that absorbs free energy from its surroundings.

Metabolism = Totality of an organism's chemical processes.

Catabolic pathways = Metabolic pathways which release energy by breaking down complex molecules to simpler compounds. (e.g., Cellular respiration which degrades glucose to carbon dioxide and water; provides energy for cellular work.)

Anabolic pathways = Metabolic pathways which consume energy to build complicated molecules from simpler ones. (e.g., Photosynthesis which synthesizes glucose from CO₂ and H₂O; any synthesis of a macromolecule from its monomers.)

Free Energy: A Criterion For Spontaneous Change

Not all of a system's energy is available to do work. The amount of energy that is available to do work is described by the concept of free energy. Free energy (G) is related to the system's total energy (H) and its entropy (S) in the following way:

$$\mathbf{G = H - TS}$$

where: G = Gibbs free energy (energy available to do work)
H = enthalpy or total energy
T = temperature in °K
S = entropy

Free energy (G) = Portion of a system's energy available to do work; is the difference between the total energy (enthalpy) and the energy not available for doing work (TS).

The maximum amount of useable energy that can be harvested from a particular reaction is the system's free energy change from the initial to the final state. This change in free energy (ΔG) is given by the Gibbs-Helmholtz equation at constant temperature and pressure:

$$\mathbf{\Delta G = \Delta H - T \Delta S}$$

where: ΔG = change in free energy
 ΔH = change in total energy (enthalpy)
 ΔS = change in entropy
T = absolute temperature in °K (°C + 273)

Significance of Free Energy:

- ! Indicates the maximum amount of a system's energy which is available to do work.
- ! Indicates whether a reaction will occur spontaneously or not.

Metabolic Disequilibrium: Since many metabolic reactions are reversible, they have the potential to reach equilibrium.

- ! At equilibrium, $\Delta G = 0$, so the system can do **NO** work.
- ! **Metabolic disequilibrium is a necessity of life; a cell at equilibrium is dead.**
- ! For example, during cellular respiration a steady supply of high energy reactants such as glucose and removal of low energy products such as CO₂ and H₂O, maintain the disequilibrium necessary for respiration to proceed.