Biological Systems & Thermodynamics

Abstract

Thermodynamics deals with the study of heat flow through different systems in different conditions. Biological thermodynamics deals with energy transductions within living organisms. Thermodynamics plays an important role in studying the functioning of different chemical processes that take place within these systems.

Technical Point of View

Energy Transformation

Energy transformation taking place within our systems are determined with the help of thermodynamics. Sun is the most important form of energy for living organisms and the formula that determines the wavelength and frequency for this energy is given by:

$$E = \frac{hc}{\lambda} = h\nu$$

Hess Law and Calorimeter

Hess law states that the heat entering and leaving a reaction is equal. This is the basis for the calorimeter which is used to determine amount of heat in a chemical reaction. As the heat enters a biological system in oxidized form the production is estimated using calorimeter in kilojoules.

Gibbs Free Energy

Gibbs law in thermodynamics develops an inter relation with biological reactions. It states that energy and entropy change simultaneously. It can be used to determine a reaction occurring spontaneously. For example, the reaction between glucose and fructose to sucrose occurs spontaneously with *+5.5 k mole/cal*. If the energy is negative, then it won't occur spontaneously.

Experimental Point of View

Bioengineering Of Thermodynamics of Cells

Cells are complex thermodynamics systems. They are regarded as complex engines to run different thermo-electrical-chemical processes. Different thermo-biochemical behaviors occur between health and disease states. The heat is dissipated into the environment which can be a new approach to study the behavior of cells and control their behavior. The total entropy of the closed biological system dissipating heat in disease state is given by:

$$dS = d_i S + d_e S$$

The analysis of this new approach concludes that cell behaviors are based on the ion fluxes across the cell membranes.

Separation of Time Scales in Thermo-Biological Systems

For thinking about the processes in the living world one the constraint is the assumption of fixed temperature, and this is equivalent to imposing the constant mean energy. This assumption is mostly true because the temperature changes are very slow in nearly all biological systems. On the other hand, if we want to consider the disposition of DNA molecule on a surface then we consider very rapid heat changes. This application of time scale change can simplify many tasks if the temperature is constant.

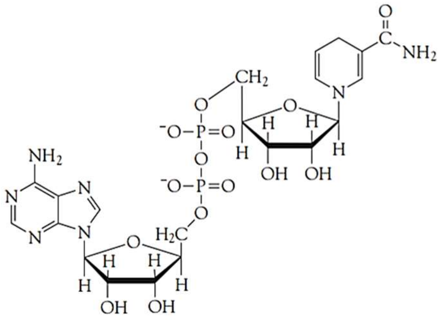
Thermodynamic Models of Binding

One of the important aspect of thermodynamics is its usefulness in the study of biological binding reactions. By determining the binding energies and molecular enthalpy of chemical reactions within the organisms it can be determined about the prediction od binding of molecules in the bio-chemical reactions as well. Thermodynamics can be used to predict he feasibility of the chemical reactions.

Computational Point of View

Energy Conservation in Living Organisms

The processes taking place inside the biological systems such as metabolism and catabolism are either endothermic or exothermic.



3 NADH

The above shows a highly exothermic reaction. Thermodynamics is used in computational aspect of calculation of enthalpies of reactions.

Numerical Example

Problem Statement

Exhalation of air during breathing requires work because air must be pushed out from the lungs against atmospheric pressure. Consider the work of exhaling 0.50 L (5.0 x 10^4 m3) of air, a typical value for a healthy adult, through a tube into the bottom of the apparatus and against an atmospheric pressure of 1.00 atm (101 kPa). The exhaled air lifts the piston so the change in volume is V = 5.0 x 10^4 m3 and the external pressure is p_{ex} = 101 kPa.

Solution

The work of exhaling is given by:

$$
\begin{aligned}
w &= -p_{ex} \nabla V \\
&= -(1.01 \times 10^5\ Pa) \times (5.0 \times 10^{-4} m^3) \\
&= -51\ Pa\ m^3 \\
&= \boldsymbol{-51\ J}
\end{aligned}
$$

Where we have considered 1 Pa m^3 = 1 J.

ATP Cycle and Reaction Coupling

The most significant application of thermodynamics is around ATP and energy consumption rate which is an important parameter for modelling energy demands for cell growth.

The hydrolysis of ATP through water mediated breakdown Is also studied under thermo-biological reactions.

$$\mathrm{ATP} + \mathrm{H_2O} \leftrightharpoons \mathrm{ADP} + \mathrm{P}_i + \mathrm{energy}$$

Reaction coupling is given by:

$$
\begin{array}{ll}
\mathrm{A} \leftrightharpoons \mathrm{B} & \Delta G = X \\
+\,\mathrm{B} \leftrightharpoons \mathrm{C} + \mathrm{D} & \Delta G = Y \\
\hline
\mathrm{A} \leftrightharpoons \mathrm{C} + \mathrm{D} & \Delta G = X + Y
\end{array}
$$

Applications

Other applications of thermodynamics in biological systems include:

- Metabolism and Catabolism
- Sweating from Body
- Changes in Cell behavior during diseases due to temperature
- Travelling of energy in oxidized form throughout the body

These are some of the many applications of thermodynamics in biological systems.

Conclusion

Thermodynamics plays a vital role in determining the physical processes going on within the living bodies. From heat of enthalpies to physical binding of molecules everything can be predicted with the help of thermodynamics. Moreover, with the help of thermodynamics different physical applications are made such as calorimeter which are used in different places. In a nutshell everything involves thermodynamics.