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Biophysics

An Introduction

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“Nothing is more practical than a good theory…..”

L. Boltzmann

Content

Introduction

Thermodynamics is the branch of physics that deals with the concepts of heat flow and temperature change in a system and the inter-conversion of heat and other forms of energy. Thermodynamics is governed by four laws. However, let's understand the Thermodynamic system.

1- The Thermodynamic System

1. *A thermodynamics system is a study of the behavior of gases, it is a macroscopic science. It deals with bulk systems and does not go into the molecular constitution of matter*.
2. For a *thermodynamic system*, we can say that a system *is in an equilibrium state if the macroscopic variables that characterize the system do not change in time*.
3. Either if a gas inside a closed system which is completely insulated from its surrounding, with some fixed values of P, V, T, m does not change with time can be considered to be in thermal equilibrium.

2- Fundamentals of Thermodynamics

Thermodynamics is defined as the branch of science which deals with the study of different forms of energy along with their conversion. It is indeed an *important branch* of science *because it provides an explanation of the macroscopic properties of matter in terms of the microscopic concept of matter*. Unlike Kinetics, which deals with the rate of reaction, *Thermodynamics is concerned with only the initial and final states of the system undergoing the changes*. It is to be noted that, the laws of thermodynamics are applicable for only those systems that are in equilibrium.

There are three fundamental laws of thermodynamics. But before discussing them in detail, there are some important terms that will be used during our discussion of Thermodynamics.

A- System

A specified part of the universe that is under observation is called the system.

Types of Systems

1. *Open system: A system that can exchange matter as well as energy with the surroundings is called an open system.*
2. *Closed System: A system that can exchange energy but not matter with its surroundings is called a closed system.*
3. *Isolated System: A system that can neither exchange matter nor energy with the surroundings is called an isolated system.*

B- Surroundings

The remaining portion of the universe which is not a part of the system is called the surroundings.

C-Macroscopic Properties of a System

These are the properties of any system which arise from the bulk behavior of matter. These properties can be classified into two types:

1. *Extensive Properties*: The properties of the system whose value depends upon the amount or size of substance present in the system. For example, mass, volume, molar properties (molar volume, molar heat capacity, etc.), surface area, internal energy, entropy, free energy, heat capacity, Force, etc.
2. *Intensive Properties: The properties of the system whose value is independent of the amount or size of substance present in the system. For example, temperature, pressure, viscosity, surface tension, dielectric constant, specific heat capacity, vapor pressure, refractive index, etc.*

D-State Variable

The measurable properties required to describe the state of the system are the state variables. For example, temperature, pressure, volume, composition, etc.

E-State Functions

It is a property of the system whose value depends only upon the state of the system and is independent of the path or manner by which the state is reached. The change in the value of these properties depends only upon the initial and final states of the system and not on the path by which the change from initial to the final state is brought about. *For example – pressure, volume, temperature, internal energy, entropy.*

F- Isothermal Process

Defined as a process where a change in pressure or volume does not affect temperature. Hence., *the temperature in this process, remains constant*.

G- Adiabatic Process

A process in which the system does not exchange any heat with the surroundings. This implies that no heat leaves or enters the system.

H- Isobaric Process

Defined as a process where the pressure of the system remains constant.

I-Isochoric Process

When the volume of a system remains constant regardless of the change in pressure or temperature then that process is known as the isochoric process.

J- Reversible Process

A process in which the direction may be reversed at any stage by merely a small change in a variable like a temperature, pressure, etc.

K- Irreversible process

A process that is not reversible is called an irreversible process. All-natural processes are irreversible.

L- Cyclic Process

A process in which the system undergoes a series of changes and ultimately returns to its original state.

3- Entropy (S)

The entropy (S) can be defined as the degree of randomness or disorder of the system. So, entropy CORRELATES with randomness or disorder. A system with more possible microstates will have more disorder and more entropy.

A microstate is simply one arrangement in which all particles in a system can exist. The number of possible microstates is typically greater when there are more particles present

4- Thermodynamics Laws

A-Zeroth law: *states that if two bodies are individually in equilibrium with a separate third body, then the first two bodies are also in thermal equilibrium with each other.* This means that if system A is in thermal equilibrium with system C and system B is also in equilibrium with system C, then system A and B are also in thermal equilibrium.

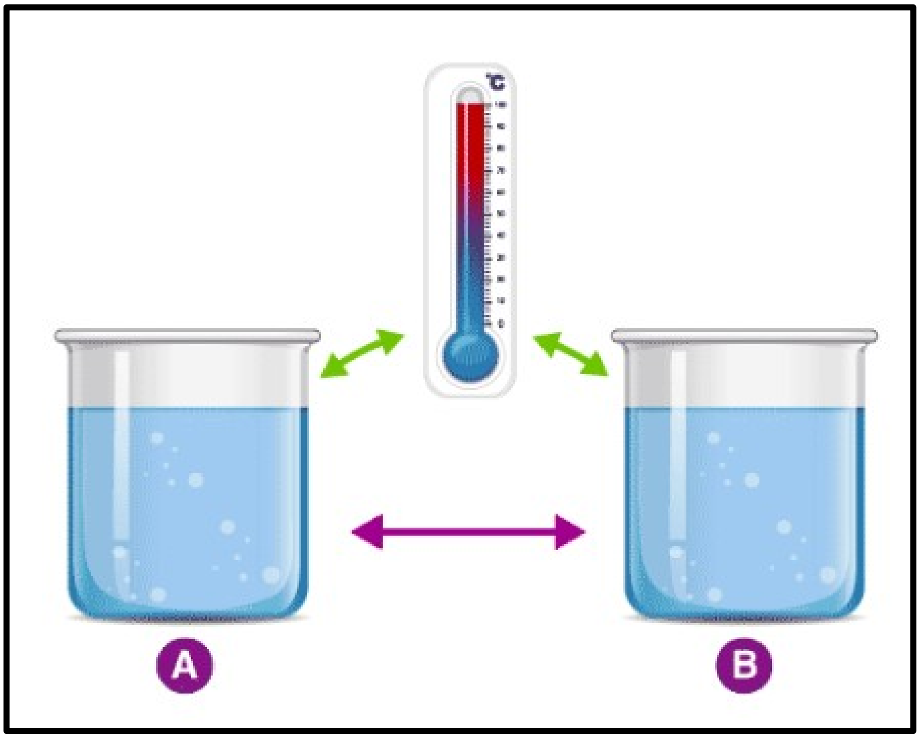

Figure 8.1: An example demonstrating

the Zeroth Law

-This law establishes the concept of temperature and the idea that temperature is a fundamental property that determines the direction of heat transfer.

B- First law: states that *energy cannot be created nor destroyed, only converted from one form to another.* This means that the total energy of an isolated system remains constant over time. It forms the basis for understanding energy transfer in various systems, from engines to living organisms.

$$\Delta U = Q - W$$

where (ΔU) is the change in internal energy, (Q) is the heat added to the system, and (W) is the work done by the system.

- This law is a statement of the conservation of energy and is often expressed as "*the total energy of an isolated system remains constant*."

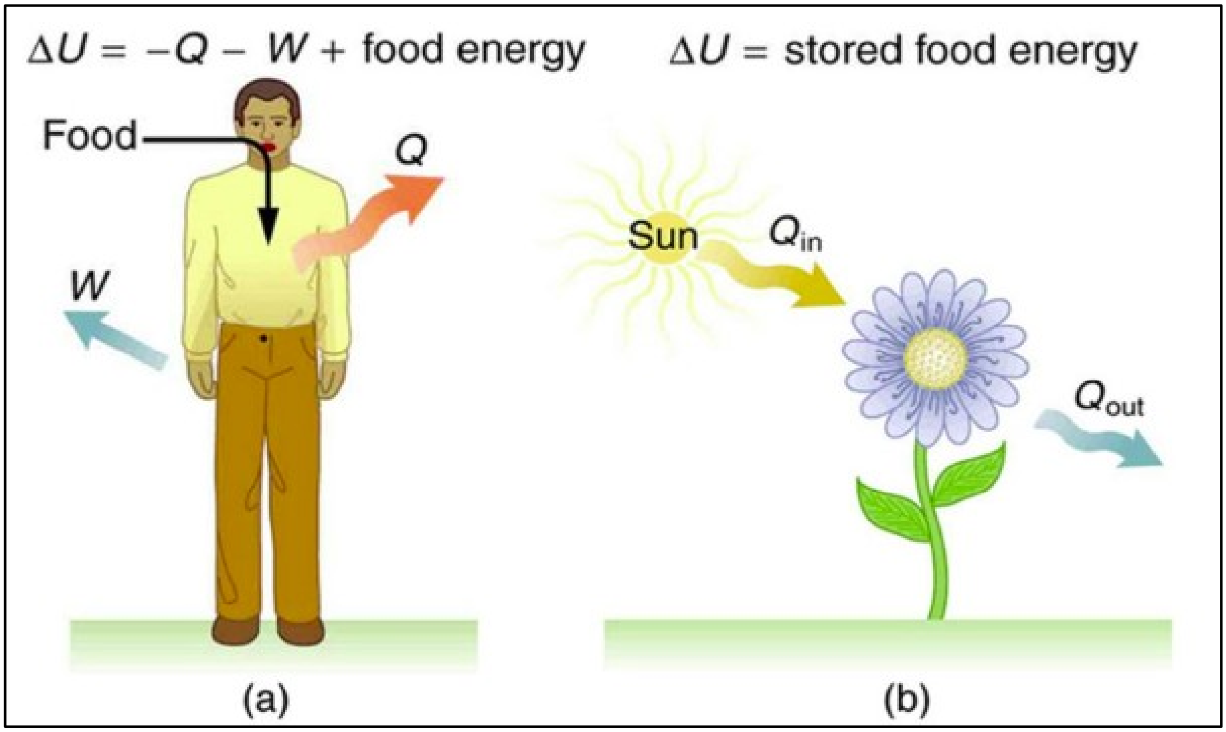

Figure 8.2: (a) The first law of thermodynamics applied to metabolism. Heat transferred out of the body (Q) and work done by the body (W) remove internal energy, while food intake replaces it. (Food intake may be considered as work done on the body.) (b) Plants convert part of the radiant heat transfer in sunlight to stored chemical energy, a process called photosynthesis.

C- Second law: *In a closed system, natural processes tend to increase the overall entropy (measure of disorder) of the system.*

$$dS \geq \frac{dQ}{T}$$

Where (dS) is the change in entropy, (δQ) is the heat added reversibly, and (T) is the absolute temperature.

- The second law implies the existence of a state function called entropy, which increases in the direction of spontaneous change.

D-Third law: *As the temperature of a system approaches absolute zero, the entropy of the system approaches a minimum value.*

$$S = k_B ln\Omega$$

Where (S) represent the entropy, (k_B) ≡Boltzmann constant= $1.38064 * 10^{-23}\ Joul/K$, and (Ω) the total number of microstates that are consistent with the system's macroscopic configuration.

- This law helps to define the behavior of systems as they approach absolute zero and provides a reference point for the determination of entropy values.

These laws form the foundation of classical thermodynamics, providing the framework for understanding energy transfer, work, and the behavior of systems in various conditions.