Laws of Thermodynamics

Subject: Thermal Physics

Subject Code: BPHY-404

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Introduction

Thermodynamics is a branch of physics that deals with the study of energy, heat, and work, and how they interact with matter. It provides a framework for understanding the principles governing energy transformations and the behavior of systems at macroscopic scales.

Some key concepts and principles:

- **Basic Concepts**

System and Surroundings: A system is the part of the universe being studied, while the surroundings are everything outside the system.

Types of Systems:

Open System: Can exchange both energy and matter with its surroundings.

Closed System: Can exchange energy but not matter with its surroundings.

Isolated System: Cannot exchange energy or matter with its surroundings.

State and State Functions: Properties that define the state of a system, such as temperature, pressure, volume, and internal energy.

2. Laws of Thermodynamics

•**Zeroth Law**: If two systems are each in thermal equilibrium with a third system, they are in thermal equilibrium with each other. This law establishes the concept of temperature.

•**First Law**: Also known as the Law of Energy Conservation, it states that energy cannot be created or destroyed, only transferred or converted from one form to another. Mathematically, $\Delta U=Q-W\Delta U=Q-W$, where $\Delta U\Delta U$ is the change in internal energy, QQ is heat added to the system, and WW is work done by the system.

•**Second Law**: States that the total entropy of an isolated system can never decrease over time. It introduces the concept of entropy and explains the direction of spontaneous processes.

•**Third Law**: As the temperature of a system approaches absolute zero, the entropy of the system approaches a minimum value. This law implies that it is impossible to reach absolute zero in a finite number of steps.

3. Thermodynamic Processes

- **Isothermal Process**: Occurs at constant temperature.
- **Adiabatic Process**: Occurs without heat exchange.
- **Isobaric Process**: Occurs at constant pressure.
- **Isochoric Process**: Occurs at constant volume.

4. Thermodynamic Cycles

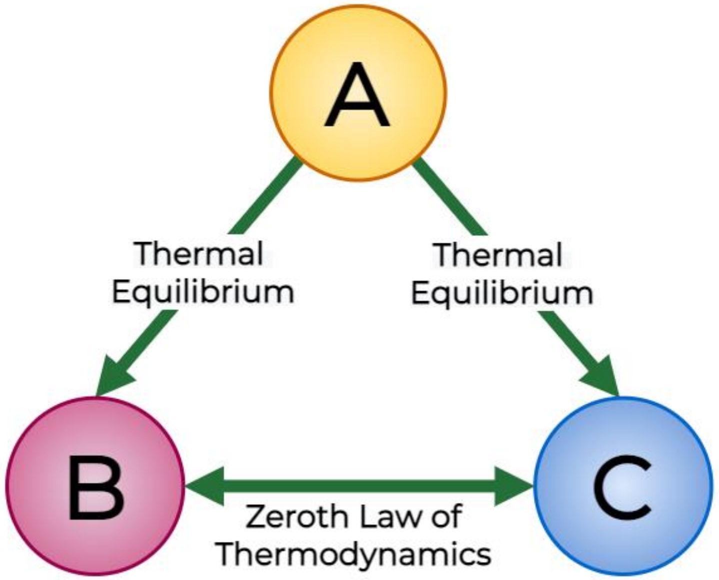
- **Carnot Cycle**: A theoretical cycle that is the most efficient possible.
- **Rankine Cycle**: Used in power plants.
- **Otto Cycle**: Used in internal combustion engines.
- **Refrigeration Cycle**: Used in refrigerators and air conditioners.

Zeroth Law of Thermodynamics

The Zeroth Law of Thermodynamics is a fundamental principle that establishes the concept of temperature and thermal equilibrium.

The Zeroth Law states that if two systems are each in thermal equilibrium with a third system, then they are in thermal equilibrium with each other. This can be expressed as:

- If system A is in thermal equilibrium with system C, and system B is in thermal equilibrium with system C, then system A and system B are in thermal equilibrium with each other.



Concept of Thermal Equilibrium

- **Thermal Equilibrium**: When two systems are in thermal equilibrium, there is no net flow of heat between them. This means they are at the same temperature.
- **Temperature**: The Zeroth Law allows us to define temperature as a property that determines whether systems are in thermal equilibrium.

Applications

- **Thermometers**: The Zeroth Law is the basis for the use of thermometers. A thermometer (system C) is brought into contact with another system (system A or B) to measure its temperature. If the thermometer is in thermal equilibrium with the system, it indicates the system's temperature.
- **Temperature Scales**: The law underpins the development of temperature scales, such as Celsius, Fahrenheit, and Kelvin.

First Law of Thermodynamics

The First Law of Thermodynamics, also known as the Law of Energy Conservation, is a fundamental principle that describes the relationship between heat, work, and internal energy in a system.

The First Law states that energy cannot be created or destroyed, only transferred or converted from one form to another. In other words, the total energy of an isolated system remains constant.

Mathematical Formulation

The First Law can be expressed mathematically as:

$\Delta U=Q-W\Delta U=Q-W$ where:

•$\Delta U\Delta U$ is the change in internal energy of the system.

•QQ is the heat added to the system.

•WW is the work done by the system.

Examples and Applications

- **Heating a Gas**: When heat is added to a gas in a closed container, the internal energy of the gas increases, which may result in an increase in temperature or pressure.
- **Piston in a Cylinder**: In an engine, when fuel combusts, it produces heat that increases the internal energy of the gas, causing it to expand and do work on the piston.
- **Refrigerators**: In a refrigerator, work is done by the compressor to remove heat from the interior and transfer it to the surroundings, keeping the inside cool.

Implications

- The First Law emphasizes the conservation of energy in all processes.
- It provides a framework for analyzing energy transfers and transformations in various systems, from simple mechanical systems to complex thermodynamic cycles.

Real-Life Example

Consider a steam engine:

- Heat energy from burning fuel is transferred to water, converting it into steam.
- The steam expands and does work on the piston, moving it.
- The internal energy of the steam decreases as it does work, but the total energy (heat added minus work done) remains constant.

Second Law of Thermodynamics

The Second Law states that the total entropy of an isolated system can never decrease over time. Entropy, often associated with disorder or randomness, tends to increase in natural processes.

Key Concepts

•**Entropy (S)**: A measure of the disorder or randomness in a system. Higher entropy means greater disorder.

•**Spontaneous Processes**: Processes that occur naturally without external intervention, typically resulting in an increase in entropy.

Statements of the Second Law

There are several ways to express the Second Law, including:

Clausius Statement: Heat cannot spontaneously flow from a colder body to a hotter body.

Kelvin-Planck Statement: It is impossible to convert all the heat from a heat source into work without any other effect (i.e., no engine can be 100% efficient).

Mathematical Formulation

For a reversible process, the change in entropy can be expressed as:

$$\Delta S=\mathrm{QrevT}\Delta S=TQ\mathrm{rev}$$

where:

•ΔS is the change in entropy.

•Qrev is the heat added or removed in a reversible process.

•T is the absolute temperature.

Examples and Applications

•**Heat Engines**: The Second Law explains why no heat engine can be perfectly efficient. Some energy is always lost as waste heat, increasing the entropy of the surroundings.

•**Refrigerators and Heat Pumps**: These devices transfer heat from a cooler to a warmer place, but they require work to do so, and the overall entropy of the system increases.

•**Natural Processes**: The melting of ice, the mixing of gases, and the diffusion of substances all occur spontaneously and result in an increase in entropy.

Implications

•The Second Law provides a direction for natural processes, indicating that they tend to move towards greater disorder.

•It sets limits on the efficiency of energy conversion systems, such as engines and refrigerators.

•It helps explain why certain processes are irreversible.

Real-Life Example

Consider a cup of hot coffee left in a room:

•The coffee will gradually cool down as heat flows from the coffee to the surrounding air.

•The entropy of the coffee decreases, but the entropy of the surrounding air increases by a greater amount, resulting in a net increase in the total entropy of the system.

Thanks