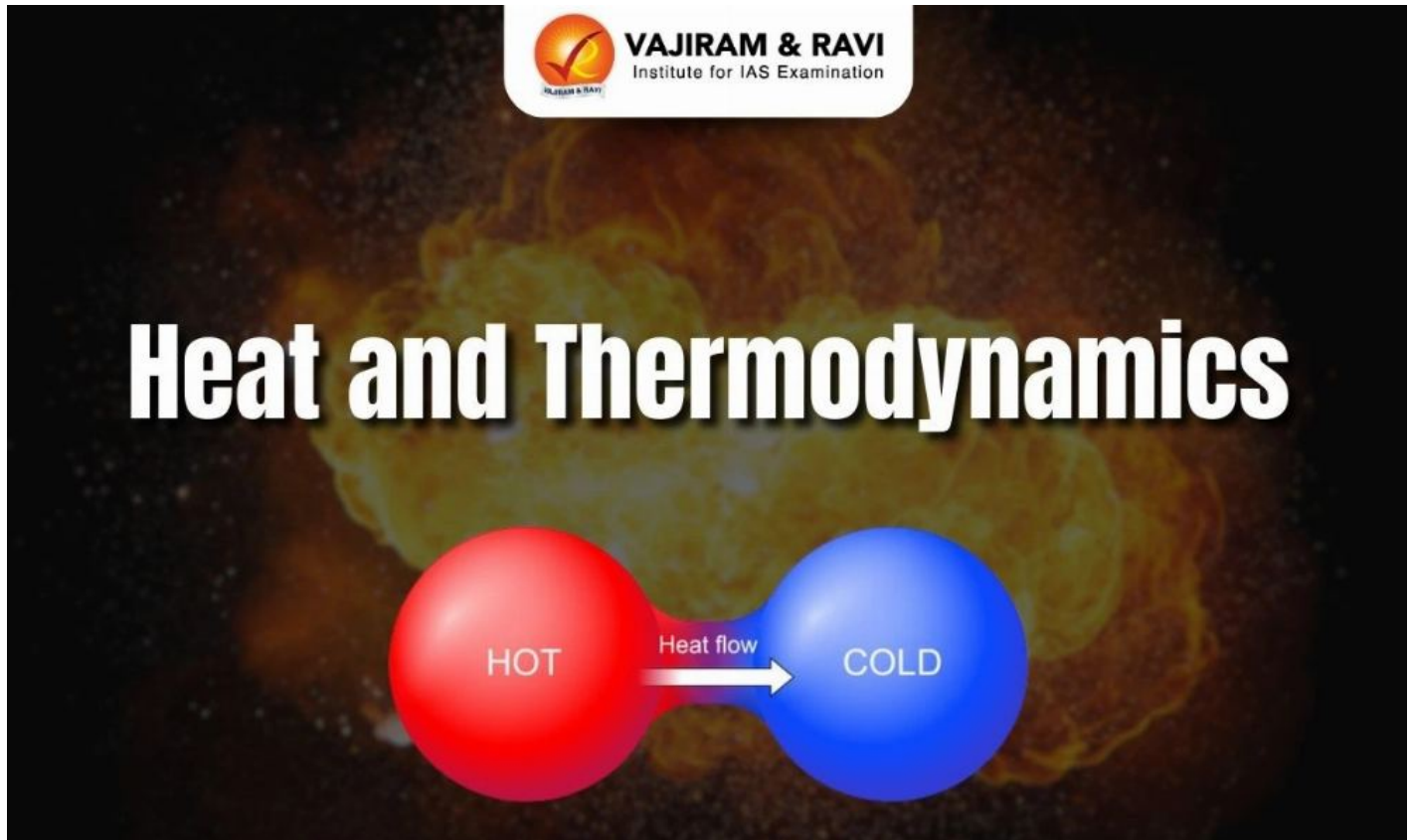


Heat and Thermodynamics, Laws, Applications, UPSC Notes

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Heat and Temperature are extremely significant in everyday life. All species can only operate effectively if their bodies are kept at a specific temperature. Life on Earth is conceivable because the Sun keeps its temperature constant. Temperature differences cause heat, a type of energy, to be transmitted across systems.

The Laws of Thermodynamics are fundamental concepts that investigate energy, its transport, and the principles that govern these processes. It is critical in comprehending a wide range of natural phenomena and practical applications.

Heat and Temperature

Heat and temperature are closely related concepts. Heat is the thermal energy that is transferred from a hotter system to the cooler when they are in contact. Temperature is the measure of the average kinetic energies of the molecules in a system.

- **Effect of heating:** Heat is also a function of the internal energy of a molecule. When a system is heated, the kinetic energy of the system is increased thereby increasing its temperature.

- Thus, **Heat is the cause and Temperature is its effect.**
- **Units:** Temperature has units of degrees Celsius or Kelvin and heat has units of energy, Joules.
- **Transfer of heat:** At the microscopic level, the molecules in each body are constantly in motion, colliding with each other. In every collision, kinetic energy can be transferred.
 - When the two systems (body) are in contact, heat is transferred through these molecular collisions, from the hotter system to the cooler one.
 - Thus, heat transfer results in a change of the system's temperature as long as it is not undergoing a phase change (between states of matter).
- **Heat capacity:** It tells us how much heat transfer (energy) is required to change the temperature of a body assuming no phase change.
 - The heat required for the unit rise in temperature (1 K) is called **specific heat capacity.**
- **Methods of heat transfer: Heat moves in three ways - conduction, convection, and radiation.**
- **Conduction is the movement of heat when the bodies are in contact. This occurs mainly in solids.**
- In liquids and gases, heat generally moves by **convection**. It is a movement of heat when there is mixing of hotter material with cooler material.
- In **radiation**, the heat is transferred through Electromagnetic waves thus, it does not require a medium (molecules) and can be transferred in a vacuum.

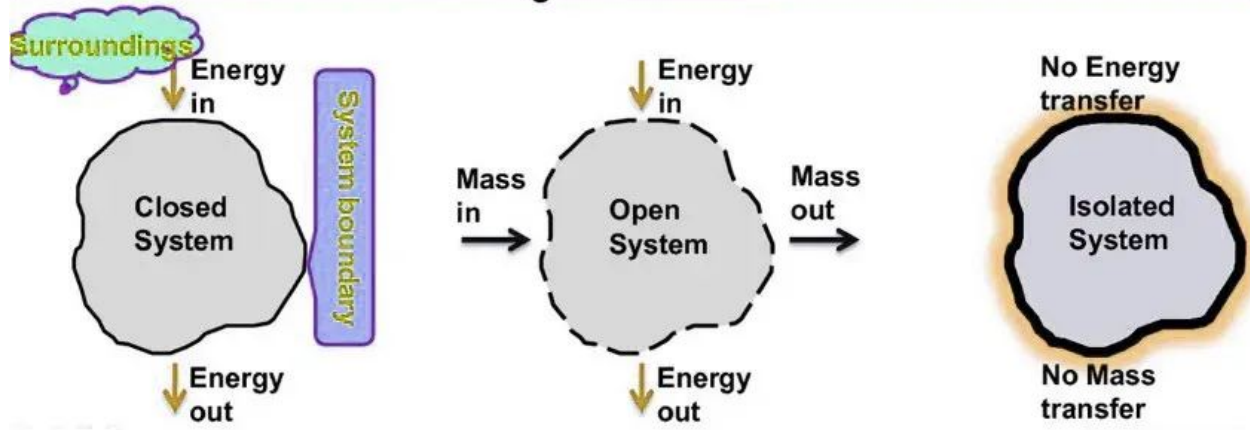
About Thermodynamics

Thermodynamics is a branch of physics that studies energy, its transformations, and how it affects matter. It encompasses **fundamental laws governing energy conservation, efficiency, entropy, and heat transfer, providing essential principles for understanding** natural phenomena, designing machines, and predicting system behaviour in engineering, chemistry, and environmental science.

Thermodynamics System

A thermodynamic system is a distinct portion of matter with a defined boundary on which we focus our attention. The system boundary can be physical or fictitious, fixed or malleable.

Types of Thermodynamic System



- **Types:** Systems are classified into three types:
 - **Isolated System** -An isolated system cannot exchange energy or mass with its surroundings. **The universe is thought to be an isolated system.**
 - **Closed System** - The flow of energy over the boundary of a closed system occurs but the transfer of mass does not. **Closed systems include refrigerators and gas compression in piston-cylinder assemblies.**
 - **Open System**- **Mass and energy can both be moved between the system** and its surroundings in an open system. An open system is exemplified by a steam turbine.

Thermodynamic Process

Isobaric process



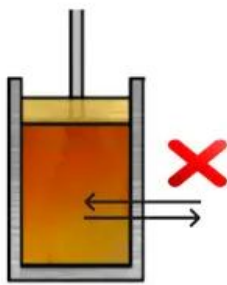
Thermodynamic process in which the **pressure remains constant** is known as *isobaric process*.

Isochoric process



Thermodynamic process in which the **volume remains constant** is called *isochoric process*.

Adiabatic process



Thermodynamic process in which there is **no heat transfer** involved is called *adiabatic process*.

Isothermal process



The process in which the **temperature remains constant** is known as *Isothermal process*.

Thermodynamic Equilibrium

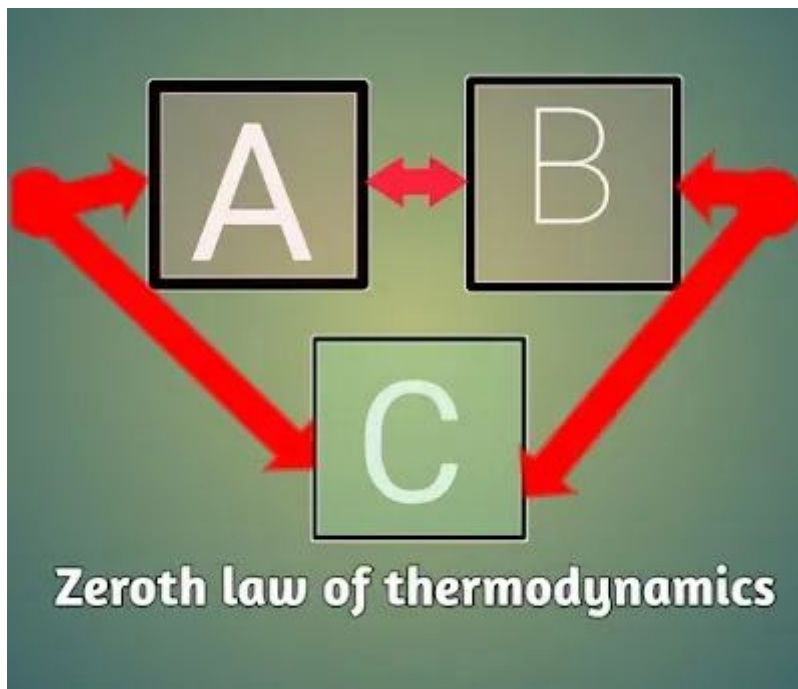
Equilibrium refers to a state of balance. Thermodynamics equilibrium represents a state where a system is in complete balance in terms of thermal, mechanical, and chemical factors. These include:

- **Thermal Equilibrium:** When there is **no net heat flow** within the system or between the system and its surroundings. This is a result of the Zeroth Law of Thermodynamics.
- **Mechanical Equilibrium:** When there is **no net force acting within it or on it**. This means there are no unbalanced forces within the system. It often means that the pressure is uniform throughout the system.
- **Chemical Equilibrium:** When the **chemical composition of a system does not change over time**, meaning that the rates of the forward and reverse chemical reactions are equal.

The Laws of Thermodynamics

The Laws of Thermodynamics are fundamental principles in physics that govern the principles of **energy conservation, efficiency, and entropy**, providing a framework for understanding physical processes in both natural and engineered systems.

Zeroth Law of Thermodynamics



First Law of Thermodynamics

It is based on the energy conservation principle.

- **Internal Energy, Heat and Work:**

- Internal energy, U is the sum of the kinetic and potential energies of the molecules. Heat and work are the modes of energy transfer that result in changes in the internal energy of a system.
- Heat is the energy transfer due to temperature differences between the system and the environment.
- Work is the energy transfer brought about by any means that do not involve temperature difference.

- **First Law of Thermodynamics:**

- It states that if energy (ΔQ) is supplied to the system, it goes in partly to increase the internal energy of the system (ΔU), and the rest in work done by the system (ΔW), that is, $\Delta Q = \Delta U + \Delta W$.
- It is fundamental in understanding processes in **engines, power plants, and even biological systems**.

Second Law of Thermodynamics

It states that the entropy of any isolated system **always increases over time and remains constant if the process is reversible**.

- **Entropy is a measure of disorder or randomness in a system.** The Second Law implies that **natural processes tend to move towards a state of maximum disorder or entropy**.
- It explains why certain processes are irreversible (like heat flow from hot to cold) and sets limits on the efficiency of heat engines.
- It's crucial in understanding not just mechanical systems, but also chemical reactions and cosmological phenomena.

Third Law of Thermodynamics

It states that the **entropy of a perfect crystal at absolute zero is exactly zero.**

- As the temperature approaches absolute zero, **the system becomes more ordered, and its entropy decreases.** The law implies that it's impossible to reach the temperature of absolute zero in a finite number of steps, as the entropy **would become constant and no further energy could be extracted.**
- **This law is significant in cryogenics and in understanding the quantum behaviour** of materials at very low temperatures.

Applications of Heat and Thermodynamics

The laws of thermodynamics have a wide range of applications in science and engineering, influencing everything **from industrial machines to natural processes.** A few of the applications are:

- **Applications of the Zeroth Law of Thermodynamics**

- **Thermometers and temperature measurement:** The Zeroth Law is the basis for the **physical concept of temperature.** It allows the use of thermometers for comparing temperatures. When a thermometer (the third system) is in thermal equilibrium with another system, their temperatures are equal.
- **Calibration of temperature scales:** This law is essential for calibrating temperature scales, ensuring consistency and accuracy in temperature measurements across different devices and environments.
- **Applications of the First Law of Thermodynamics (Law of Energy Conservation)**
- **Heat engines:** Internal combustion engines in cars and turbines in power plants operate on the principle that energy can be converted from one form (chemical or thermal) into mechanical work.
- **Refrigerators and Air conditioners:** **These devices work on the principle of energy transfer.** They remove heat from one area (the inside of a fridge or a room) and expel it into another (the outside environment), using work to transfer the energy.
- **Batteries and power systems:** The conversion of chemical energy into electrical energy in batteries and the conservation of energy in electrical grids.

- **Applications of the Second Law of Thermodynamics**

- **Heat transfer systems:** This law governs the natural flow of heat and is foundational in designing heat pumps, heaters, and radiators, ensuring heat transfer from hot to cold spaces.
- **Entropy and chemical reactions:** In chemistry, this law helps in predicting the direction of chemical reactions, as reactions tend to move towards increased entropy.
- **Efficiency of machines:** The Second Law sets the maximum theoretical efficiency for engines and other machines, influencing the design to minimise energy losses.
- **Applications of the Third Law of Thermodynamics**
- **Cryogenics and low-temperature physics:** The Third Law helps in reaching and measuring temperatures near absolute zero, crucial in cryogenics and superconductivity research.
- **Entropy calculations at absolute zero:** This law provides a reference point for calculating the absolute entropy of substances, important in thermodynamics and material science.
- **Superconductivity:** **Superconductors are materials that exhibit zero electrical resistance and the expulsion of magnetic fields when cooled below a certain critical temperature. The**

Third Law is critical in achieving these superconducting states.

- **Quantum computing:** The behaviour of materials and quantum states at temperatures approaching absolute zero is crucial in the field of quantum computing.

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