Heat and Thermodynamics

Thermodynamics: The branch of physical science that deals with the relations between heat and other forms of energy (such as mechanical, electrical, or chemical energy), and, by extension, of the relationships between all forms of energy.

Heat: Heat is simply the transfer of energy from a hot object to a colder object.

Temperature: Temperature is a measure of the ability of a substance, or more generally of any physical system, to transfer heat energy to another physical system.

Thermodynamic System: A thermodynamic system is a group of material and/or radiative contents. Its properties may be described by thermodynamic state variables such as temperature, entropy, internal energy, and pressure.

Surroundings or environment: Everything external to the matter or space, which is under thermodynamic study is called surroundings or environment.

Boundary: The boundary that separates the system and surrounding is called as system boundary. The system boundary may be fixed or moving.

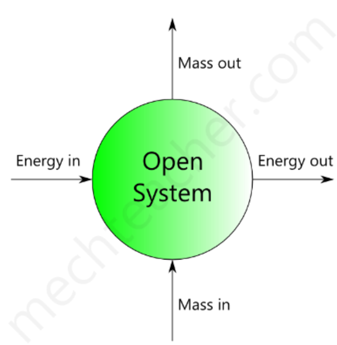
Types of Thermodynamic System:

Thermodynamic systems can be broadly classified into three types. They are:

1. Open System
2. Closed System
3. Isolated System

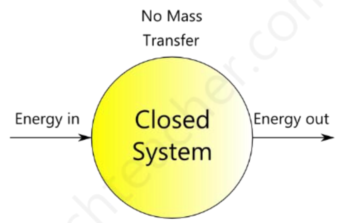
1. Open System:

An open system is a thermodynamic system which allows both mass and energy to flow in and out of it, across its boundary. The image below illustrates open system.



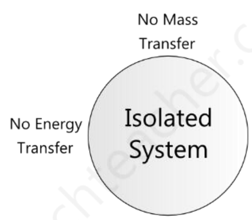
Example of open system: Water heated in an open container – Here, heat is the energy transferred, water is the mass transferred and container is the thermodynamic system. Both heat and water can pass in and out of the container.

2. Closed System:
A closed system allows only energy (heat and work) to pass in and out of it. It does not allow mass transfer across its boundary. The following image shows a closed system:



Example of closed system: Water heated in a closed vessel – Here only heat energy can pass in and out of the vessel.

3. Isolated System:
An isolated system does not interact with its surroundings. It does not allow both mass and energy transfer across its boundary. It is more restrictive. In reality, complete isolated systems do not exist. However, some systems behave like an isolated system for a finite period of time. The following image illustrates an isolated system:



Note: The entire universe is an isolated system. But the observable universe is an open system.

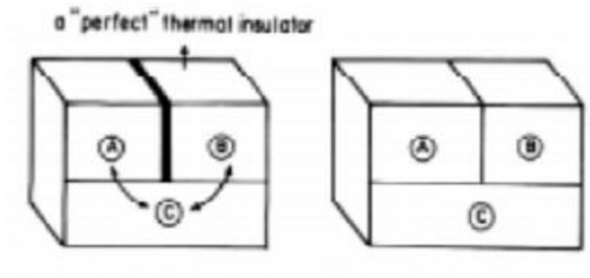
Example of isolated system: A good example for such a system is hot water in an insulated flask.

Internal Energy: Internal energy of a system is the total energy contained within the system.

Entropy: A thermodynamic quantity that is the measure of a system's thermal energy per unit temperature that is unavailable for doing useful work.

$$\oint \frac{dQ}{T} = 0$$

Zeroth law of thermodynamics: The zeroth law of thermodynamics states that if two thermodynamic systems are each in thermal equilibrium with a third one, then they are in thermal equilibrium with each other.



(i) (ii)

i) A and B are in thermal equilibrium with C
ii)A,B and C are in thermal equilibrium with each other

First law of Thermodynamics: When energy passes as work or heat into or out from a system, the system's internal energy changes in accord with the law of conservation of energy. Equivalently, machines that produce work with no energy input are impossible. The first law is often formulated as,

$$\Delta U = Q - W$$

It states that the change in the internal energy ΔU of a closed system is equal to the amount of heat Q supplied *to* the system, minus the amount of work W done *by* the system on its surroundings.

Application of First law of thermodynamics

1. Isolated system: It is a system that does not interact with the surroundings. In this case, there is no heat flow and the work done is zero. It means $\Delta Q = 0$ and $\Delta W = 0$. Hence $\Delta U = 0$. Therefore the internal energy of an isolated system remains constant.

2. A cyclic process: The process in which a system returns to its initial state after passing through various intermediate states is called a cyclic process. In this process, the change in internal energy is zero. i.e., $\Delta U = 0$. Hence from the first law of thermodynamics.

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

$$0 = \Delta Q - \Delta W$$

$$\Delta W = \Delta Q$$

Hence, in a cyclic process, the amount of heat given to a system is equal to the net work done by the system. This is the principle of heat engines whose purpose is to absorb heat and perform work in a cyclic process.

3. Boiling process: When a liquid is heated it absorbs heat and its temperature rises. After some time, a stage is reached, when it starts boiling and changes its phase from liquid to vapor. Due to this change of phase the volume increases and work are done. As the process involves work and heat, the first law of thermodynamics can be applied.

Consider the vaporization of mass m of a liquid at its boiling point T and pressure P. Let V1 be the volume of the liquid and V2 the volume of the vapor. The work done in the expansion is given by,

$$\Delta W = P\ \Delta V = P(V2 - V1)$$

If L is the latent heat of vaporization, the heat absorbed, $\Delta Q = mL$. If ΔU is the change in internal energy during the process, then,

$$\Delta Q = \Delta U + \Delta W;\ \Delta U = \Delta Q - \Delta W$$

$$\Delta W = mL - P(V2 - V1)$$

It is to be noted that as pressure remains constant during boiling it is an isobaric process.

4. Melting process: When the quantity of heat dQ is given to a solid at its melting point it is converted into a liquid. The temperature and pressure remain constant till the whole solid is completely converted into a liquid. The internal energy changes during melting.

If m is the mass and L is the specific latent heat of fusion of the solid, then, $dQ = mL$.

$dW = pdV = P(V2 - V1)$; where P is the pressure, V1 the volume of the solid and V2

is the volume of the liquid.

Therefore, $mL = dU + P(V2 - V1) = dU$ (since $dV = V2 - V1$ is negligible)

Second law of Thermodynamics: Second law of thermodynamics states that, the entropy of an isolated system always increases. Equivalently, machines that spontaneously convert thermal energy into mechanical work are possible.

Third law of thermodynamics: Third law of thermodynamics states that the entropy of a system approaches a constant value as the temperature approaches absolute zero. With the exception of non-crystalline solids (glasses) the entropy of a system at absolute zero is typically close to zero.

Thermal Conductivity: The thermal conductivity of a material is a measure of its ability to conduct heat. It is commonly denoted by K. The defining equation for thermal conductivity is $q = -K\nabla T$ where q is the heat flux, K is the thermal conductivity, and ∇T is the temperature gradient. This is known as Fourier's Law for heat conduction.

Heat Flux: Heat flux or thermal flux, sometimes also referred to as *heat flux density* or *heat flow rate intensity* is a flow of energy per unit of area per unit of time. In SI its units are watts per square metre ($W \cdot m^{-2}$). It has both a direction and a magnitude, and so it is a vector quantity.

Types of Thermodynamic Processes

Isobaric Process: An **isobaric process** is one where the pressure of the system (often a gas) stays constant. '**Iso**' means the same, and '**baric**' means pressure. Pressure is related to the amount of force that the molecules apply to the walls of the container.

Imagine that you have a gas inside a movable piston and you heat that gas up. By heating the gas up you make the molecules move faster, which would normally increase the pressure. But at the same time the piston expands, increasing the volume and giving the molecules more room to move. Since the walls of the container are now bigger, the pressure can stay the same even though the molecules are moving faster. That makes it an isobaric process.

Isochoric Process: An **isochoric process** is one where the volume of the system stays constant. Again, **'iso'** means the same and **'choric'** means volume. Volume is the amount of space the material takes up. So this would be like heating a gas in a solid, non-expandable container. The molecules would move faster and the pressure would increase, but the size of the container stays the same.

Isothermal Process: An isothermal process is one where the temperature of the system stays constant. Thermal relates to heat, which is in turn related to temperature. Temperature is the average heat (movement) energy of the molecules in a substance.

An example of an isothermal process would be if we took a gas held behind a movable piston and compressed that piston: the volume has decreased and the pressure behind the piston has increased, since the molecules have less space in which to move. When you compress a piston, you're doing work on the gas-so normally the molecules would gain energy and move faster and the temperature would increase. So the only way for an isothermal process to happen is if all that energy you put into compressing the gas comes out again, for example by putting a cold reservoir in contact with the piston.

Adiabatic Process: An adiabatic process occurs without transfer of heat or mass of substances between a thermodynamic system and its surroundings. In an adiabatic process, energy is transferred to the surroundings only as work.

An example of an adiabatic process is the vertical flow of air in the atmosphere; air expands and cools as it rises, and contracts and grows warmer as it descends. Another example is when an interstellar gas cloud expands or contracts. Adiabatic changes are usually accompanied by changes in temperature.

Heat: Heat is the transfer of kinetic energy from one medium or object to another, or from an energy source to a medium or object. Such energy transfer can occur in three ways: radiation, conduction, and convection.

Heat transfer processes:

Heat can be transferred from one place to another by three methods: conduction in solids, convection of fluids (liquids or gases), and radiation through anything that will allow radiation to pass. The method used to transfer heat is usually the one that is the most efficient. If there is a temperature difference in a system, heat will always move from higher to lower temperatures.

Conduction: Conduction is the mode of heat transfer from one atom to it's neighboring atom through molecular vibration in solids without the movement of molecules. For example, heat transfer within a metal or solids.

Convection: Convection is the mode of heat transfer by actual movement of molecules from hot place to cold place. For example, heat transfer in water.

Radiation: Radiation is the mode of heat transfer from one place to another due to electromagnetic waves. For example heat transfer from sun to earth.