Thermodynamics

1st Law of thermodynamics :

The first Law of thermodynamics states that "the amount of heat given to a system is equal to the sum of the increase in the internal energy of the system and the external work done."

Mathmatically, $dQ = dU + dW$ ——— ①

Let, the quantity of heat supplied to a system be dQ.

The amount of external work done be dW and the increase in internal energy of the molecules, dU.

The term U represents the internal energy of a gas due to molecular agitation as well as due to the forces inter molecular attraction. then, $dQ = dU + dW$.

Eqn ① is known as 1st Law of thermodynamics.

we must remember that Q is considered positive when heat enters the system and it is considered negative when heat is rejected by the system. W is positive when work is done by the system and negative when work is done on the system.

We know at constant pressure 'P' amount of work done when the volume increases from V_1 to V_2 is:

$$dW = P(V_2 - V_1) = PdV$$

Then eqn (1) becomes:

$$dQ = dU + PdV \quad \text{——— (2)}$$

——— o ———

At atmospheric pressure 1.00 gm of water having volume of 1.00 cm^3, becomes 1671 cm^3 of steam when boiled. The heat of vaporization of water is 539 cal/gm at 1 atm. Find the change of internal energy of the system during this process.

Here, $m = 1.00$ gm.

So, heat absorbed by the system is, $Q = mL_v = 1 \text{ gm} \times 539 \text{ cal/gm}$

$= 539$ cal.

Work done is,

$$W = P(V_f - V_i) = (1.013 \times 10^5 \text{ nt/m}^2) \times (1671 - 1) \times 10^{-6} \text{ m}^3$$

$$= 1.013 \times 10^5 \times 1670 \times 10^{-6} \text{ nt-m}$$

$$= 169.5 \text{ Joules}.$$

Since 1 cal = 4.186 Joules, then $W = 169.5 / 4.186$

$= 41$ cal.

From 1st Law, we have,

$$dU = U_f - U_i = Q - W$$

$$= 539 - 41$$

$$= 498 \text{ cal}.$$

here, dU is +ve means that internal energy will increase during this process.

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Definitions:

Mechanical Equivalent of Heat:

The exact relationship between mechanical work and heat was established by Drs. Joule. Whenever mechanical work is converted into heat or heat into mechanical work, one is equivalent to the other. This is the principle of equivalence. If W is the quantity of work done, Q the amount of heat supplied, then, $W \propto Q$

$W = JQ$.

Where, J is a constant, known as the mechanical equivalent of heat. value of J is 4.186×10^7 ergs/cal or 4.186 Joules/cal or 1 Joule $= 10^7$ ergs.

Reversible Process:

A reversible process is one which can be retraced in the opposite direction so that the working substance passes through exactly the same states in all respects as in the direct process.

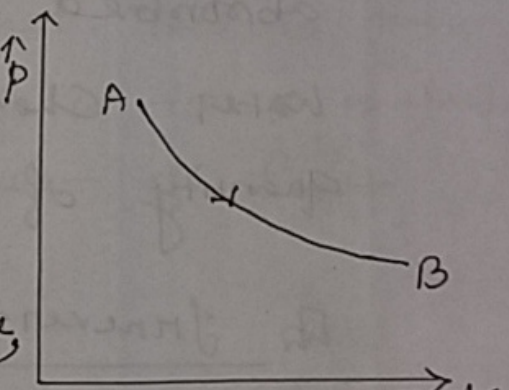
A given mass of ice changes to water when a certain amount of heat is absorbed by it, and the same mass of water changes to ice when the same quantity of heat is removed from it.

Irreversible Process:

An irreversible process is one which can not retraced in the opposite direction by reversing the controlling factors. All changes which occur suddenly like explossin, Joule – Thomson expansion etc. are irreversible, process.

Isothermal Process:

If a system is perfectly conducting to the surroundings and temperature is constant throughout the process, it is called an isothermal process. Consider a working substance at a certain pressure and temperature and having a volume represented by the point A as shown in fig below:



As the pressure is decreased, work is done by the working substance at the cost of its internal energy, so there should be fall in temperature, But as the system is perfectly conducting to the surroundings, it absorbs heat from the surroundings and maintains a constant temperature. Thus from A to B the temperature remains constant. The curve AB is called the isothermal curve or isothermal.

$$dQ = dU + dW$$
$$= 0$$
$$dQ = dW$$

Adiabatic Process:

During an adiabatic process, the working substance is perfectly insulated from the surroundings. It can neither give heat nor take heat from the surroundings. When work is done on the working substance, there is rise in temperature. because the external work done on the working substance increases its internal energy. When work is done by the working substance, it is done at the cost of its internal energy.

As the system is perfectly insulated from the surroundings, there is fall in temperature.

Thus, during an adiabatic process, the working substance is perfectly insulated from the surroundings. All along the process, there is change in temperature.

$$\boxed{\begin{aligned} dQ &= dU + dW \\ 0 &= dU + dW \\ dW &= -dU \end{aligned}}$$

Ex Determine the value of J, the mechanical equivalent of heat from the following data: 2000 Cal of heat are supplied to a system, the system does 3350 Joules of external work during that time. The increase in internal energy during the process is 5030 Joules.

Soln: Here total work done

= External work + Raise in internal energy

i.e $W = (3350 + 5030)$ Joules.

$= 8380$ Joules.

Here, $Q = 2000$ Cal.

We know, $W = JQ$

or, $J = W/Q$

$= 8380$ Joules $/ 2000$ Cal

$= 4.19$ Joules / Cal.