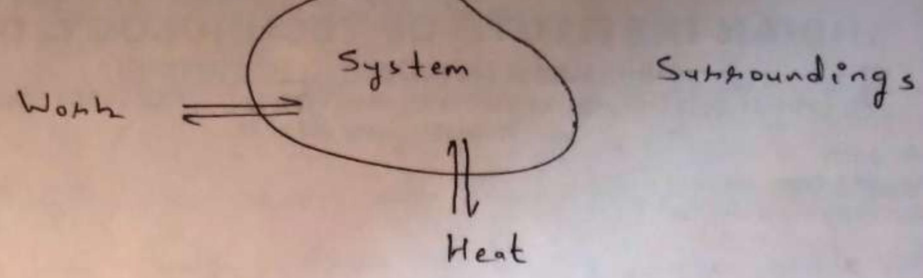
Work and Heat Transfer



A closed system and its surroundings can interact in two ways:

(i) By work transfer

(ii) By heat transfer

Work transfer

- The term "work" was first used in the scientific sense by Coriolis in 1829.
- Work has many different faces – electrical work, chemical work, mechanical work, and so on.

1. Push-Pull work

In mechanics the action of a force on a moving body is defined as work. This is the basic definition of work, that was introduced and properly defined by Newton.

$$W = F \cdot x$$

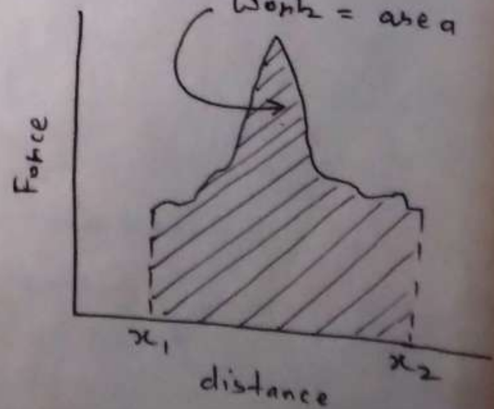
Work done

Force applied to object

distance object moves while this force is applied

Or more generally

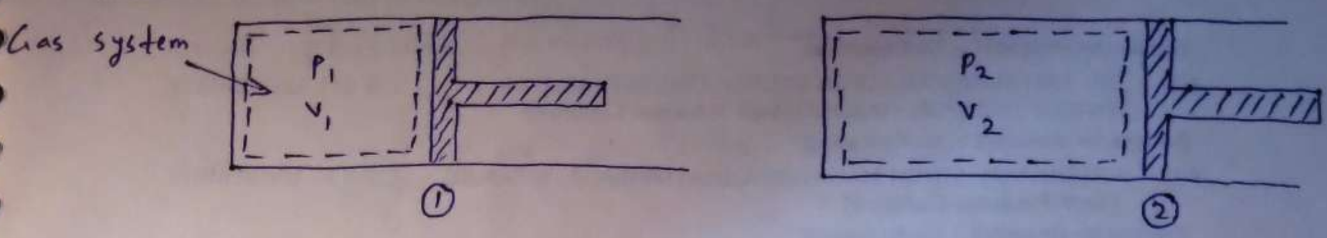
$$W = \int_{x_1}^{x_2} F \cdot dx$$



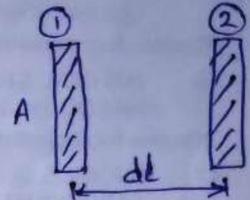
Unit = N·m

= J (Joule)

2. P.dV work or Displacement work



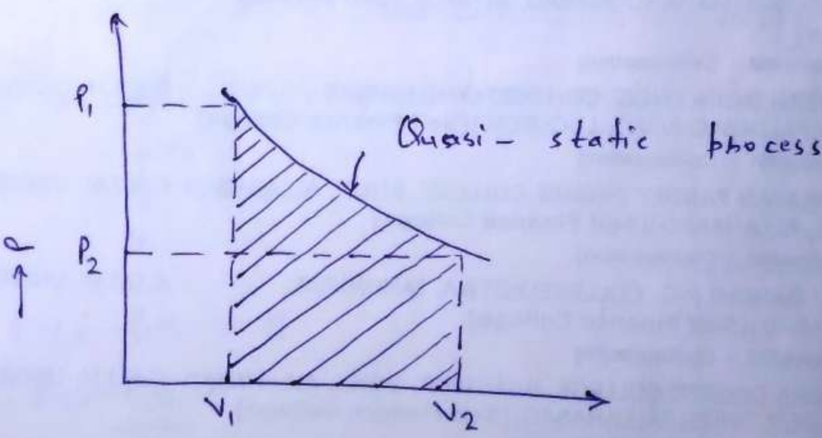
When the piston moves out from position 1 to position 2 with the volume changing from V_1 to V_2, the work done by the system will be



$$dW = F \times dl$$
$$= P.\,A.\,dl$$
$$= P.\,dv$$

$$W_{1-2} = \int_{V_1}^{V_2} P.\,dv$$

$$\text{Unit} = Pa.\,m^3 = \frac{N}{m^2}.\,m^3 = J$$



The piston moves infinitely slow so that every state passed through is an equilibrium state. The integration $\int P\,dv$ is performed only on a quasi-static path.

* The above equation tells the work done by the gas in the cylinder, but where does this work go?

→ Some goes into pushing back the atmosphere.

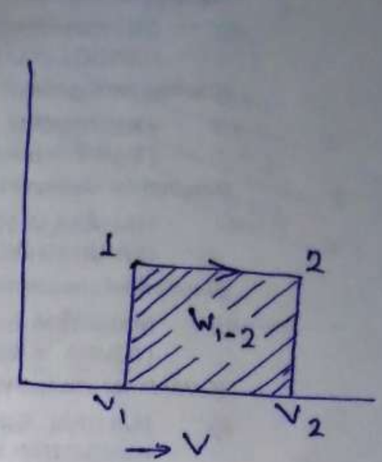
→ Some may go into pushing the shaft back.

→ Some goes into friction and generation of heat.

P. dV work in various quasi-static processes

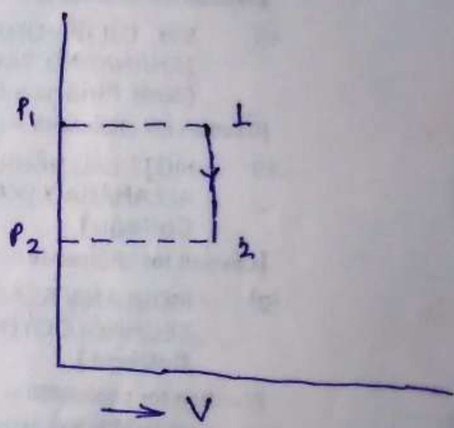
(a) Constant pressure process (Isobaric process)

$$W_{1-2} = \int_{V_1}^{V_2} P.\,dV = P(V_2 - V_1)$$



(b) Constant volume process (Isochoric process)

$$W_{1-2} = \int P.\,dV = 0$$



(c) Process in which $PV = C$

$$W_{1-2} = \int_{V_1}^{V_2} P.\,dV$$

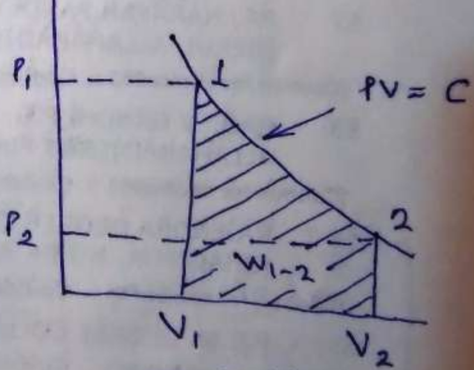
$$PV = P_1V_1 = C$$

$$P = \frac{P_1V_1}{V}$$

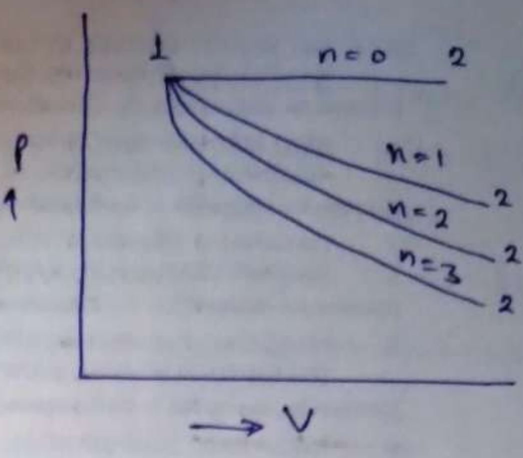
$$W_{1-2} = P_1V_1 \int_{V_1}^{V_2} \frac{dV}{V}$$

$$= P_1V_1 \ln \frac{V_2}{V_1}$$

$$= P_1V_1 \ln \frac{P_1}{P_2}$$



(d) Process in which $PV^n = C$, where n is a constant



$$PV^n = P_1V_1^n = P_2V_2^n = C$$

$$P = \frac{P_1V_1^n}{V^n}$$

$$W_{1-2} = \int_{V_1}^{V_2} P.dV$$

$$= \int_{V_1}^{V_2} \frac{P_1V_1^n}{V^n}.dV$$

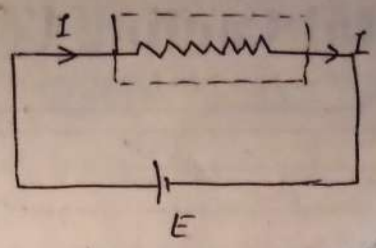
$$= (P_1V_1^n)\left[\frac{V^{-n+1}}{-n+1}\right]_{V_1}^{V_2}$$

$$= \frac{P_1V_1^n}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$$= \frac{P_2V_2^n . V_2^{1-n} - P_1V_1^n . V_1^{1-n}}{1-n}$$

$$= \frac{P_1V_1 - P_2V_2}{n-1} = \frac{P_1V_1}{n-1}\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}\right]$$

3. <u>Electrical work</u>



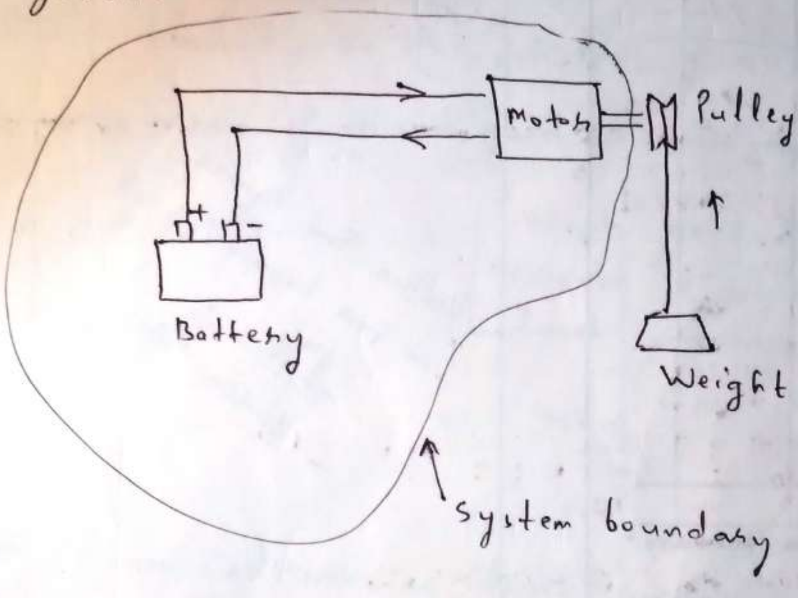
I = Current flow, Amp.

E = Voltage potential

τ = Time, seconds

C = Charge, coulombs

When a current flows through a resistor, work is transferred into the system.



e.g. The electric current can drive a motor, the motor can drive a pulley and the pulley can raise a weight.

The electrical work is -

$$W = \int_1^2 E I . d\tau$$

$$= \int_1^2 E . dC$$

dC = charge crossing a boundary during time $d\tau$

4. Surface tension work

Have you ever seen an insect struggling to free itself from the surface of water? Its problem is that it has to create new surface to take its place as it leaves. To create surface requires doing work, and this is measured by the surface tension of the liquid.

(The surface tension, on the surface of a liquid, acts to make the surface area of the liquid a minimum.)

$$\sigma = \text{surface tension} = \begin{bmatrix} \text{Work needed to} \\ \text{create a unit of} \\ \text{fresh surface} \end{bmatrix}$$

$$= \frac{N \cdot m}{m^2} = \frac{N}{m}$$

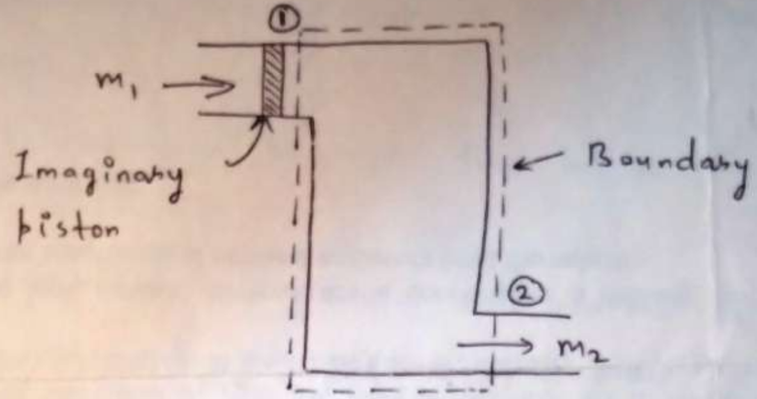
The work done in creating fresh surface of area A,

$$W = \int_0^A \sigma \cdot dA$$

$$\text{unit} = \frac{N}{m} \cdot m^2 = J$$

(5) Flow work

- Flow work is significant only in a flow process or an open system.
- Flow work is analogous to displacement work.



The work done at point 1

$$dW_{flow} = P.\,dV$$
$$= P.\,v.\,dm$$

$$\rho = \boxed{\frac{1}{v} = \frac{dm}{dV}}$$

$$dV = v.\,dm$$

Specific volume

Volume of fluid element entering the system

Flow work at inlet,

$$\left(dW_{flow}\right)_{in} = P_1 v_1 .\, dm_1$$

Flow work at outlet,

$$\left(dW_{flow}\right)_{out} = P_2 v_2 .\, dm_2$$

The flow work per unit mass $dW_{flow} = Pv$

Heat Transfer

Heat is defined as the form of energy that is transferred across a boundary by virtue of a temperature difference.

It is a boundary phenomenon, since it occurs only at the boundary of a system.

- The heat transfer between two bodies in direct contact is called conduction.
- The heat transfer between two bodies separated by empty space or gases through electromagnetic waves is called radiation.
- A third method of heat transfer is convection which refers to the transfer of heat between a wall and a fluid system in motion.
- The unit of heat in S.I. units is Joule.
- The rate of heat transfer is given in KW or W.

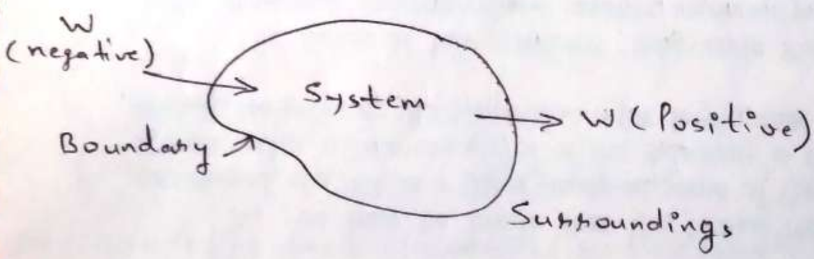


Fig: Direction of work transfer

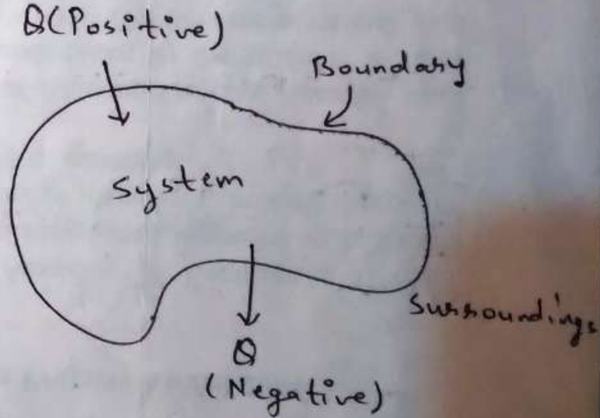


Fig: Direction of heat transfer

Work Transfer and Heat Transfer - Point Function or Path Function

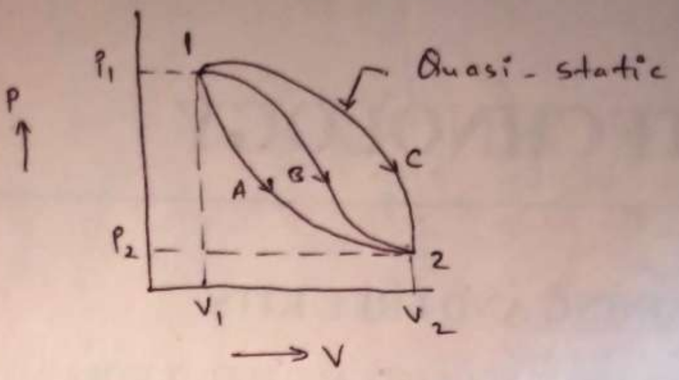


Fig: Work - a path function

It is possible to take a system from state 1 to state 2 along many quasi-static paths, like A, B, or C. Since the area under each curve represents the work for each process, the amount of work involved in each case is different as it is not a function of the end states of the process, instead, it depends on the path the system follows in going from state 1 to state 2. For this reason, work is called a path function and $đW$ is an inexact differential.

When the change in a thermodynamic property is independent of the path, and depends only on the initial and final states of the system, it is known as the point function. The differentials of point functions are exact/perfect and their integration is simple

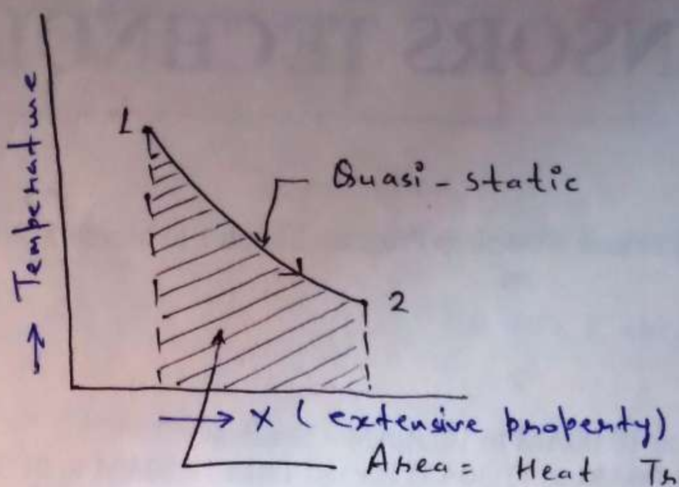
$$\int_{V_1}^{V_2} dV = V_2 - V_1$$

The change in volume thus depends only on the end states of the system irrespective of the path the system follows.

While, work done in a quasi-static process b/w two states 1 & 2 depends on the path followed.

$$\int_1^2 đW \neq W_2 - W_1$$

$$\text{but } \int_1^2 đW = W_{1-2} = \int_1^2 P.\,dV$$



$$Q_{1-2} = \int_1^2 T \cdot dX$$

Fig: Heat Transfer - a path function

Heat transfer is a path function, i.e., the amount of heat transferred when a system changes from a state 1 to a state 2 depends on the path the system follows. Therefore, $đQ$ is an inexact differential.

$$\int_1^2 đQ \neq Q_2 - Q_1$$

But

$$\int_1^2 đQ = Q_{1-2}$$