Thermal Engineering

Work and Energy

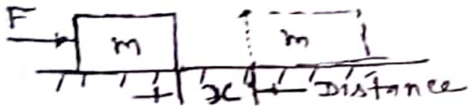
A closed system and its surroundings can interact in two ways.

ⓐ By work transfer and ⓑ By heat transfer

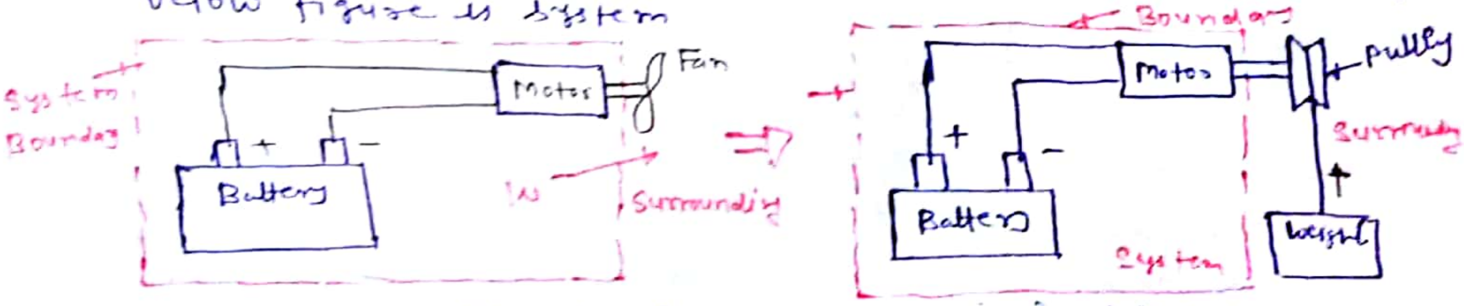
These may be called energy interactions and these bring about changes in the properties of the system. Thermodynamics mainly studies these energy interactions and the associated property changes of the system.

Work Transfer → Work is one of the basic modes of energy transfer. In mechanics, work is defined as the product of the force and displacement in the direction of the force. The action of a force through a distance (or torque through an angle) is called mechanical work. The product of the force and distance moved parallel to the force is the magnitude of mechanical work.

Mechanical work $= (F \times x)$ N-m (Joule)

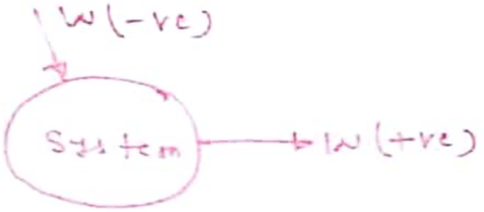


In Thermodynamics, work is said to be done by a system if the sole effect on things external to the system can be reduced to the raising of a weight. The weight may not ~~not~~ actually be raised, but the net effect external to the system would be the raising of a weight. Let us consider the battery and the motor in below figure is system



The motor is driving the fan. The system is doing work upon the surroundings. When the fan is replaced by pulley and a weight, the weight may be raised with the pulley driven by the motor. The sole effect on things external to the system is then the raising of a weight.

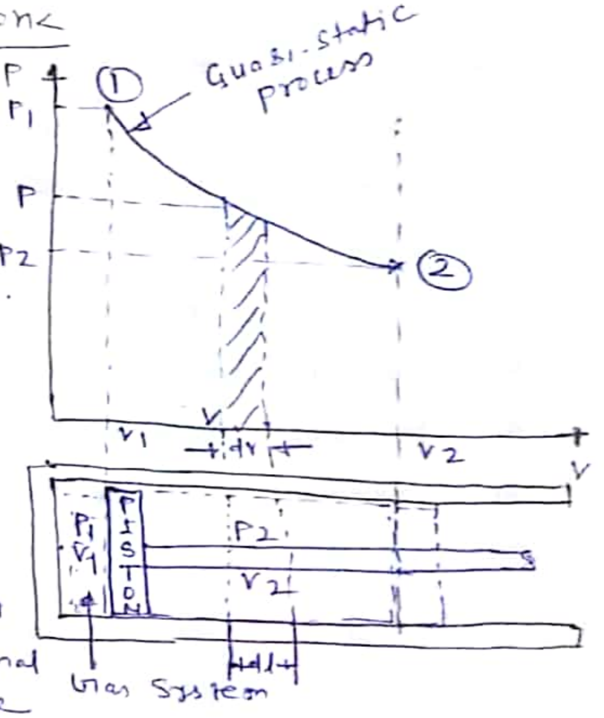
When work is done by a system, it is taken to be positive and when work is done on a system, it is taken to be negative.



The unit of work is Nm or Joule.

The rate at which work is done by or upon, the system is known as power. Power = $\frac{\text{Work done}}{\text{Time}} = \frac{N\text{-}m}{Sec}$ or J/Sec or Watt

PdV – Work or Displacement work



Let the gas in the cylinder be a system having initially the pressure P_1 and Volume V_1. The Piston is the only boundary which moves due to gas Pressure [Deformable closed system]. Let the piston move out to a new final state 2 where pressure is P_2 and volume is V_2.

At an intermediate point in the travel of the piston, let the pressure be P and the volume V.

Let area of cross section of Piston = A

When the piston moves an infinitesimal (very very small) distance dl, the Force acting on the piston

$F = A \times P$

Infinitesimal amount of work done by the gas on the piston

dW = Force × piston Displacement = $F \times dl = P \times A \times dl$

$dW = PdV$ where $dV = A \times dl$ - Infinitesimal increase in volume.

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

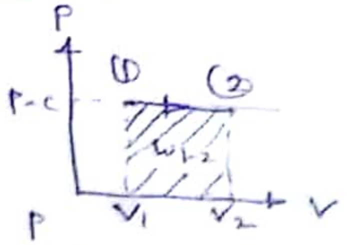
$$W_{1-2} = \int_1^2 dW = \int_1^2 PdV$$

Note → Area under PV-diagram indicates work done

PdV – Work in Various Quasi-static Processes

ⓐ Constant pressure process →

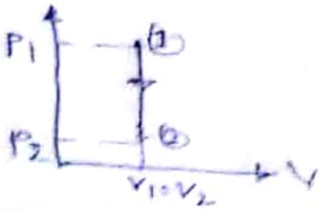
$$W_{1-2} = \int_{V_1}^{V_2} PdV = P\int_{V_1}^{V_2} = P[V_2 - V_1]$$



ⓑ Constant Volume process →

$$W_{1-2} = \int_{V_1}^{V_2} PdV = P[V_2 - V_1] = P \times 0 = 0$$

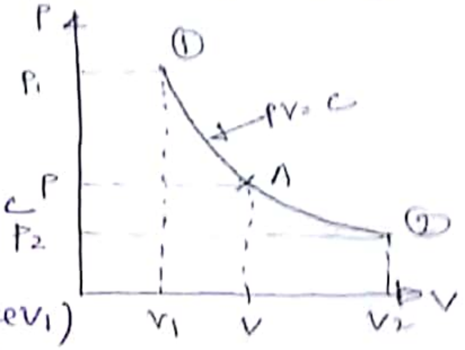
$\because V_1 = V_2$



© Constant Temperature process (Isothermal process)

In this prorcess, $PV = C$

$\therefore P_1V_1 = PV = P_2V_2 = C \quad \therefore P = \frac{P_1V_1}{V}$



$$w_{1-2} = \int_1^2 P\,dV = \int_1^2 \frac{P_1V_1}{V}\,dV = P_1V_1 \int_1^2 \frac{dV}{V} \quad \because P_1V_1 = C$$

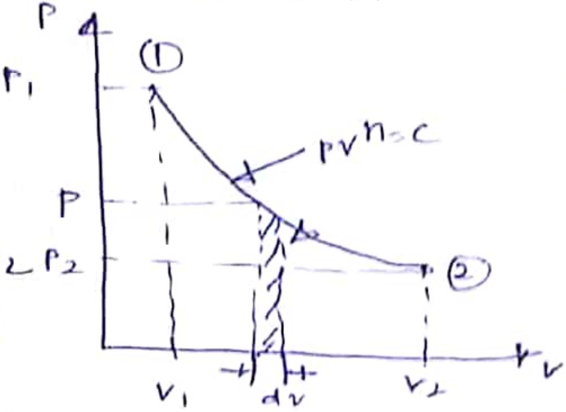
$$w_{1-2} = P_1V_1 \left[\log_e\right]_{V_1}^{V_2} = P_1V_1(\log_e V_2 - \log_e V_1)$$

$$\boxed{w_{1-2} = P_1V_1 \log_e \frac{V_2}{V_1} = P_1V_1 \log_e \frac{P_1}{P_2}} \quad \left[\because P_1V_1 = P_2V_2 \Rightarrow \frac{V_2}{V_1} = \frac{P_1}{P_2}\right]$$

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

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

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



$$w_{1-2} = \int_1^2 P\,dV = \int_{V_1}^{V_2} \frac{P_1V_1^n}{V^n}\,dV$$

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

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

$$= \frac{1}{1-n}\left[(P_2V_2^n)(V_2)^{-n+1} - (P_1V_1^n)(V_1^{-n+1})\right] \quad \because P_1V_1^n = P_2V_2^n$$

$$= \frac{1}{1-n}\left[P_2V_2 - P_1V_1\right] = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{P_1V_1 - P_2V_2}{n-1}$$

$$\boxed{W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}}$$

Heat Transfer → Energy transfer by virtue of temperature difference is called heat transfer. Heat transfer is also a boundary phenomenon.

Difference between Heat and Work

① Heat transfer is the energy interaction due to temperature difference only while work is not.

② Heat is thermal energy transfer while work is mechanical energy transfer across the system boundary.

③ Heat is low grade energy while work is high grade energy.

Different Form of Stored Energy

The symbol 'E' refers to the total energy stored in a system. Basically there are two modes in which energy may be in a system

ⓐ Macroscopic energy mode ⓑ Microscopic energy mode.

The macroscopic energy mode includes the macroscopic kinetic energy and potential energy of a system.

Let fluid element of mass 'm' having velocity 'v', Then~~macrosc~~ macroscopic kinetic energy $E_K = \frac{1}{2}mv^2$

If the elevation of the fluid element from the arbitrary datum is Z, then the macroscopic potential energy $E_P = mgZ$.

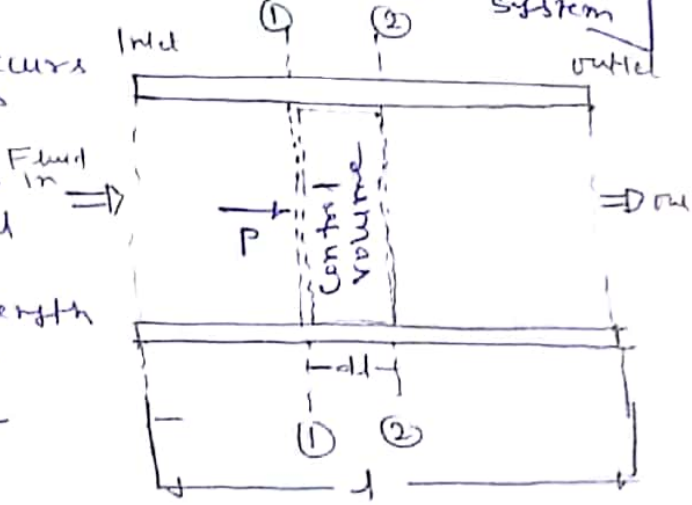
The microscopic energy mode refers to the energy stored in the molecular and atomic structure of the system, which is called the molecular internal energy or simply internal energy (U).

In an ideal gas, there are no intermolecular forces of attraction and repulsion, and internal energy depends on temperature i.e $U = f(T)$

Other form of energy which can also be possessed by a system are magnetic energy, electrical energy and surface tension energy. In the absence of these forms, the total energy E of a system is given by

$$E = \underbrace{E_K + E_P}_{\text{Macro}} + \underbrace{U}_{\text{Micro.}}$$

In the absence of motion and gravity $E = U$ [for closed system]



Flow work + The flow work occurs in a flow process and represents the energy transferred across the system boundary to make the fluid flow across the control volume

Area of control volume is A and length is dl and applied pressure is P

Volume of fluid in control volume

$= dV = A\,dl.$

Let P be the pressure applied to move the fluid inside the control volume (Inside section 1-1 and 2-2) to outside the control volume i.e outside the section ②-②.

The work done to move fluid inside the control volume to outside of control volume (i.e outside the section ②-②)

$= dW_{flow} = P \times dV$, where dV is volume inside the control volume.

So flow work to move fluid inside the pipe ($V=Al$) between inlet and outlet of pipe to outside of the outlet of pipe $= \int_{\text{Inlet}}^{\text{outlet}} dw_{\text{flow}} = \int_0^V P\,dV = PV$

$$\boxed{W_{Flow} = PV}$$

Enthalpy → It is defined as sum of internal energy and flow work. &

$h = u + Pv$ → unit (J/kg) for unit mass

It is an intensive property of the system

$H = U + PV$ → J for m kg of mass.

Entropy → It is defined as the quantitative measure of disorder or randomness of a system. The second law of thermodynamics states that the entropy of any isolated system always increases.

entropy is defined as $dS = \frac{dQ}{T}$

Entropy is also defined as the measure of a system's thermal energy per unit ~~time~~ temperature that is unavailable for doing useful work. Because work is obtained from ordered molecular motion, the amount of entropy is also a measure of the molecular disorder, or randomness, of a system.