In thermodynamic, we transfer energy from a hot reservoir to a cold reservoir. During this process we use part of the energy to do work. But once the energy is gone from a hot to a cold reservoir, part of that energy is no longer available to do work.

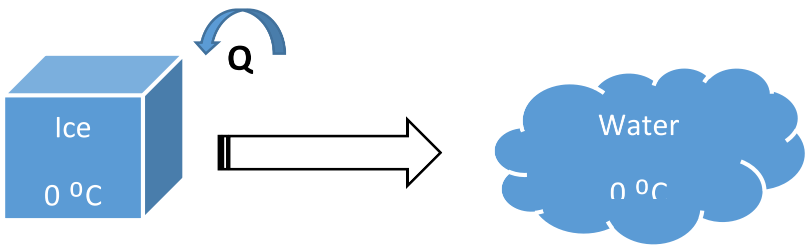
Entropy (S): It is a measure of the amount of energy unavailable to do work.

$$\Delta S = \int_{t_1}^{t_2} \frac{dQ}{dt} \; (\frac{J}{K})$$

In the case of small temperature difference, this equation can be approximated to

$$\Delta S = \frac{Q}{T_{ave}} \; (\frac{J}{K})$$

It is also defined as a measure of disorder (العشوائية). For example, if we put a cube (1kg) of ice under the sun light, it will melt. Ice is more order state because the atoms are organized in 3D pattern while water is less ordered state.



$\Delta S = +ive$

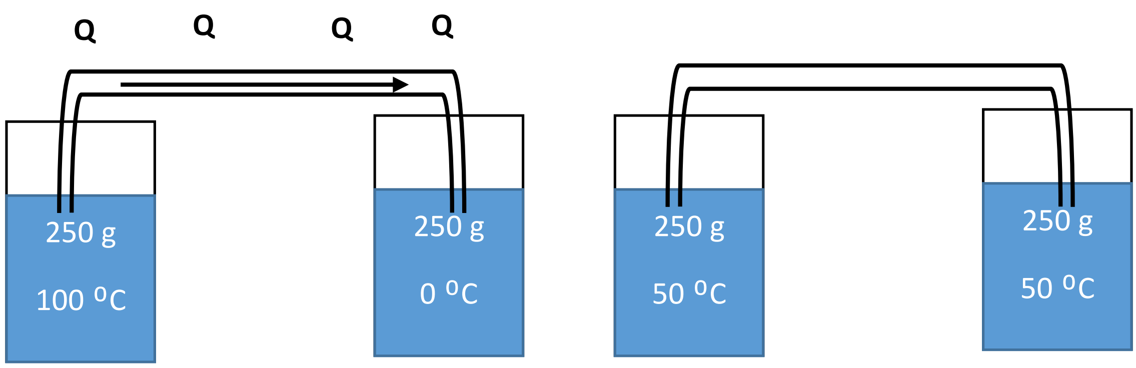
More ordered state

Less ordered state

Thus

$$\Delta S = \frac{Q}{T_{ave}} = \frac{m\ x\ L_{hf}}{T_{ave}} = \frac{1\ x\ 333000}{273} = \quad 1220\ (\frac{J}{K})$$

Ex₁) Heat exchanges from a hot cup of water at 100 ^{0}C to a cold cup of water at 0 ^{0}C through a heat conductor. Since both cups have the same amount of water (250g), the final will settle at 50 ^{0}C. Calculate the change in entropy (ΔS) during the heat exchange.



Before heat exchange

After heat exchange

Ex₂) 1 kg of water initially at 0 ^{0}C is heated up to 100 ^{0}C from an external source. Calculate the change in entropy.

Property diagrams

Diagrams that are used for visualizing the second law aspects of processes and cycles.

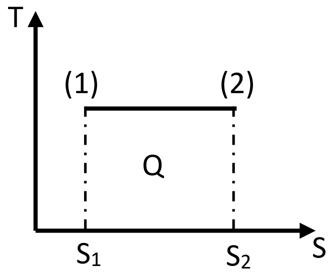
T-S diagram

It is a diagram that shows the relationship between the temperature (vertical axis) and the entropy (horizontal axis).

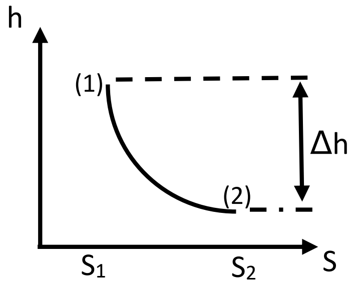
$$Q = \int_{S_1}^{S_2} T\, ds$$

The area under the process curve on a T-S diagram

represents heat transfer during a reversible process.



h -S diagram



Another diagram commonly used in engineering is the enthalpy-entropy diagram. This is quite valuable in the analysis of steady-flow devices such as turbines, compressors and nozzles.

If we consider the h-s diagram of a turbine, the vertical distance between the inlet and the exit states *Δh* is a measure of the work output of the turbine, and the horizontal distance *Δs* is a measure of the irreversibility associated with the process.

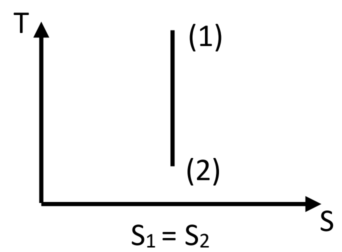
Isentropic Processes

The entropy of a fixed mass can be changed by **heat transfer** and **irreversibility**.

Isentropic Processes is an adiabatic and reversible process.

It is a process during which the entropy remains constant.

I.e. For isentropic process: $\Delta S = 0$, $Q = 0$

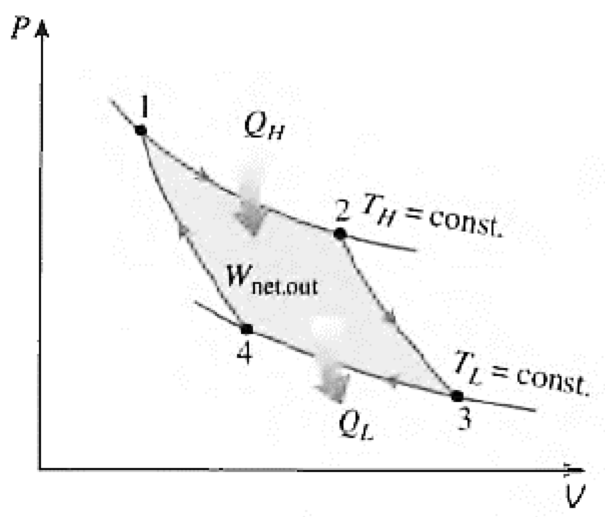


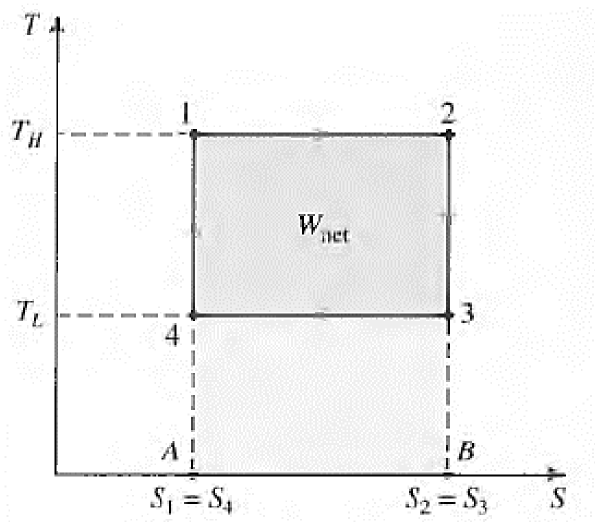
Ex) Steam enters an adiabatic turbine at 5 MPa and 450°C and leaves at a pressure of 1.4 MPa. Determine the work output of the turbine per unit mass of steam assuming that the process is reversible.

The *T-S* Diagram of Carnot Cycle

Carnot cycle is made up of two reversible isothermal (T = constant) processes and two isentropic (S = constant) processes. These four processes form a rectangle on a T-S diagram.

The Carnot cycle on ***P-V and T-S*** diagrams are shown below. They indicate the areas that represent the heat supplied Q_H, heat rejected Q_L and the net output work W_{out}.





$$\eta = \frac{W_{net}}{Q_H}$$

$$W_{net} = Q_H - Q_L$$

$$\eta = \frac{Q_H - Q_L}{Q_H}$$

On a T-S diagram, the area under the process curve represents the heat transfer for that process.

$$\eta_c = \frac{T_H x(S_2 - S_1) - T_L x(S_2 - S_1)}{T_H x(S_2 - S_1)} = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$$

Entropy change of ideal gases in process

The differential form of the 1st Law of Thermodynamics for a closed system (fixed mass) containing an ideal gas can be expressed as

$$\delta q - \delta w = du$$

$$\delta q = du + \delta w$$

$$T\, ds = C_v\, dt + P dv$$

$$ds = C_v \frac{dt}{T} + \frac{P}{T} dv$$

$$ds = C_v \frac{dt}{T} + R \frac{dv}{V}$$

Integrating both sides

$$\int_{S1}^{S2} ds = C_v \int_{t1}^{t2} \frac{dt}{T} + R \int_{v1}^{v2} \frac{dv}{V}$$

$$s_2 - s_1 = C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \quad (\frac{J}{kg.k})$$

But:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \rightarrow \frac{T_2}{T_1} = \frac{P_2 V_2}{P_1 V_1}$$

$$s_2 - s_1 = C_v \ln \frac{P_2 V_2}{P_1 V_1} + R \ln \frac{V_2}{V_1}$$

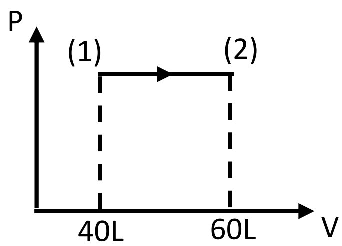
$$s_2 - s_1 = C_v \ln(\frac{P_2}{P_1} . \frac{V_2}{V_1}) + R \ln \frac{V_2}{V_1}$$

$$s_2 - s_1 = C_v \ln\left(\frac{P_2}{P_1}\right) + C_v\, ln(\frac{V_2}{V_1}) + R \ln \frac{V_2}{V_1}$$

$$s_2 - s_1 = C_v \ln\left(\frac{P_2}{P_1}\right) + \ln(\frac{V_2}{V_1})\ (R + C_v)$$

$$s_2 - s_1 = C_v \ln\left(\frac{P_2}{P_1}\right) + Cp \ln(\frac{V_2}{V_1}) \quad (\frac{J}{kg.k})$$

Ex) Calculate the change in the entropy during the constant pressure process shown below:



Cv = 5/2 Ru