

Thermodynamics - I

Lecture 22

Entropy: T- s Diagram and T - ds Relation (Ch-7)

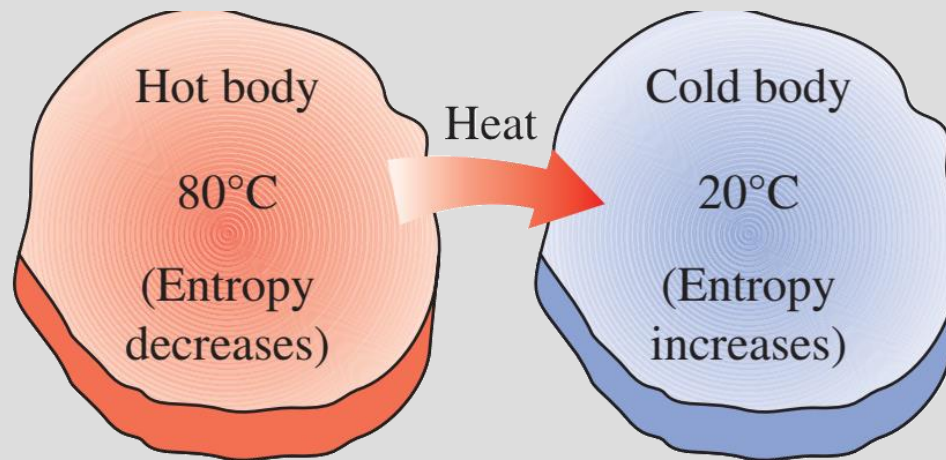
Entropy Change of Steam/ Real Gases for
(i) Constant Volume Process (ii) Constant Pressure Process

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Entropy

The Entropy is a measure of the amount of energy in a system that is no longer available to effect changes in that system. That energy becomes unavailable not by leaving the system but by becoming irretrievably disordered.

Law of increase of Entropy: Entropy of the universe is increasing all the time

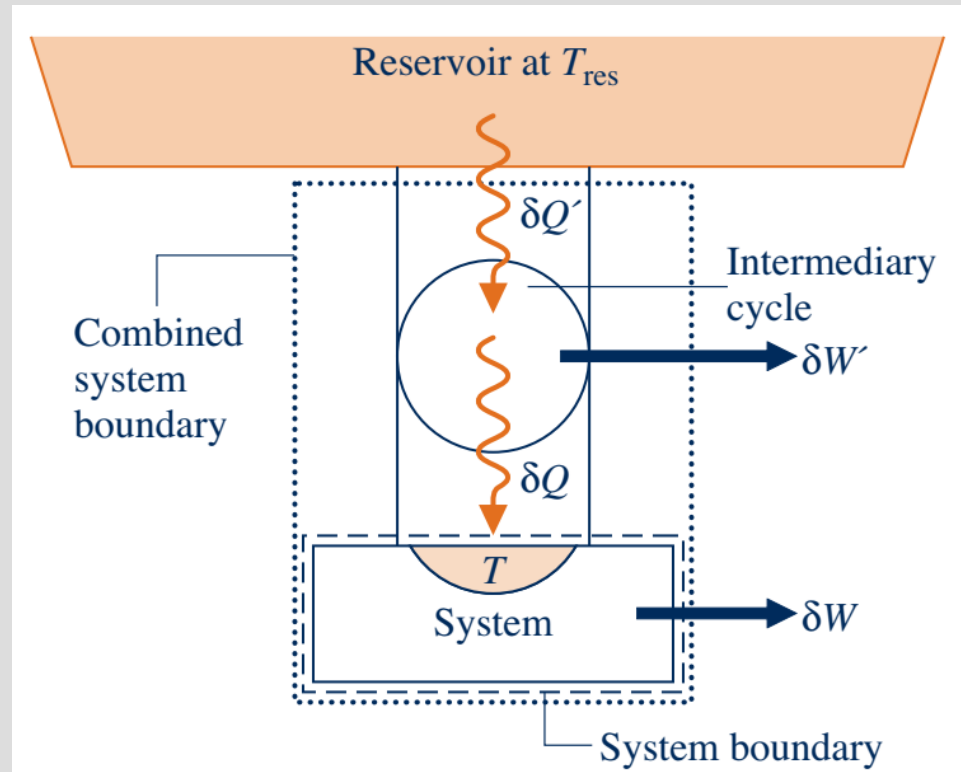


Clausius Inequality

A corollary of the second law known as the **Clausius inequality** is introduced that is applicable to any cycle without regard for the body, or bodies, from which the cycle receives energy by heat transfer or to which the cycle rejects energy by heat transfer.

The **Clausius inequality** states that for any thermodynamic cycle

$$\oint \left(\frac{\delta Q}{T} \right)_b \leq 0$$



Clausius Inequality

The symbol \oint indicates that the integral is to be performed over all parts of the boundary and over the entire cycle.

The equality and inequality have the same interpretation as in the Kelvin–Planck statement:

The equality applies when there are no internal irreversibilities as the system executes the cycle, and the inequality applies when internal irreversibilities are present.

The **Clausius inequality** states that for any thermodynamic cycle

$$\oint \left(\frac{\delta Q}{T} \right)_b = -\sigma_{\text{cycle}}$$

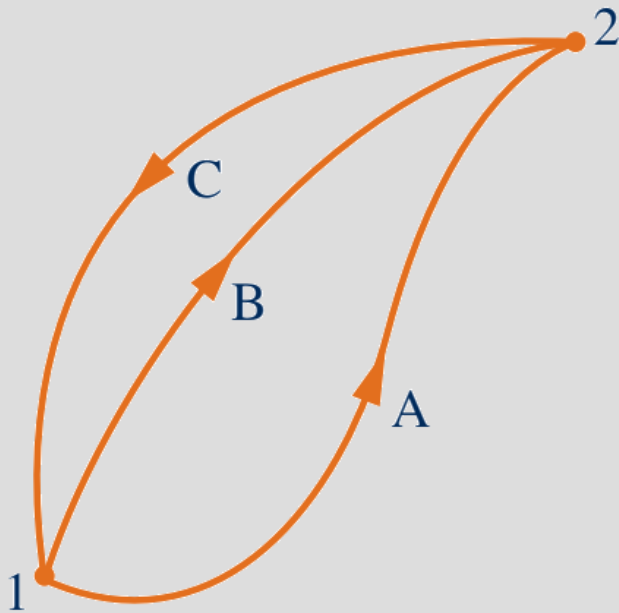
$\sigma_{\text{cycle}} = 0$ no irreversibilities present within the system

$\sigma_{\text{cycle}} > 0$ irreversibilities present within the system

$\sigma_{\text{cycle}} < 0$ impossible

Entropy – A Property

A quantity is a property if, and only if, its change in value between two states is independent of the process.



$$\left(\int_1^2 \frac{\delta Q}{T} \right)_A + \left(\int_2^1 \frac{\delta Q}{T} \right)_C = -\oint_{\text{cycle}}^0$$

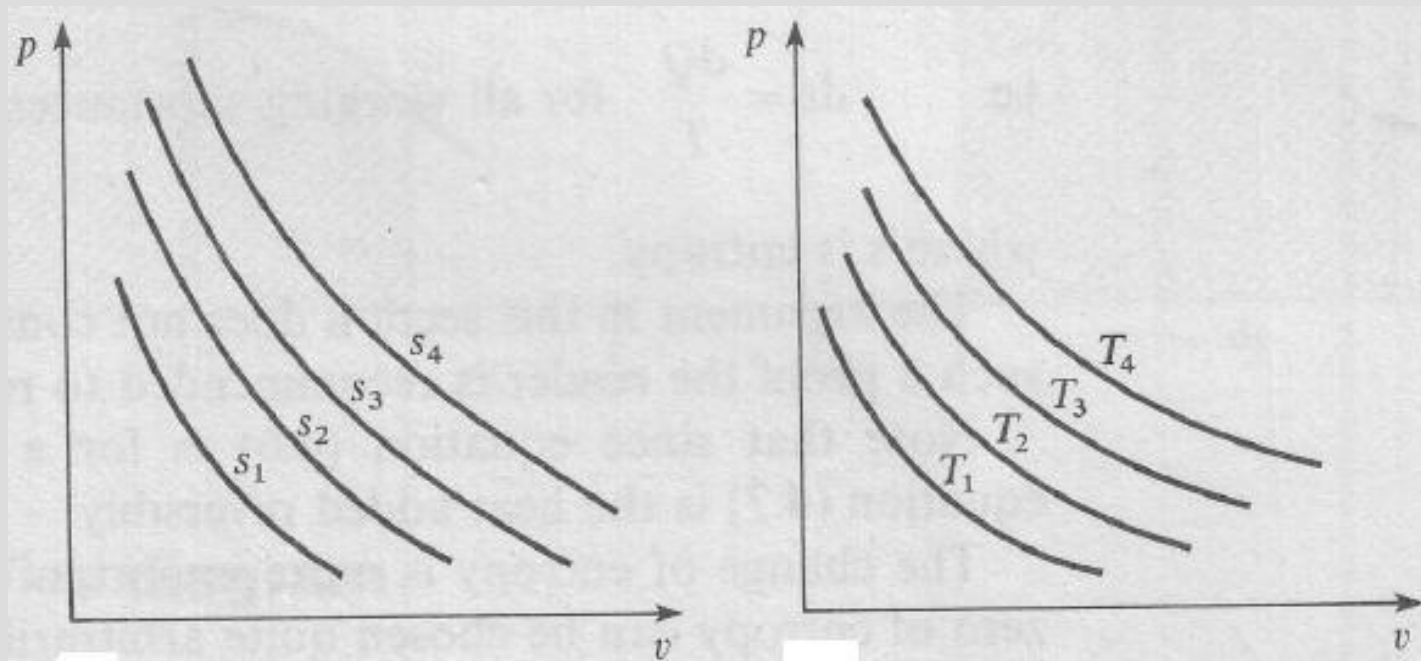
$$\left(\int_1^2 \frac{\delta Q}{T} \right)_B + \left(\int_2^1 \frac{\delta Q}{T} \right)_C = -\oint_{\text{cycle}}^0$$

$$\left(\int_1^2 \frac{\delta Q}{T} \right)_A = \left(\int_1^2 \frac{\delta Q}{T} \right)_B$$

Since A and B are arbitrary, it follows that the integral of dQ/T has the same value for any internally reversible process between the two states

Entropy – A Property

One of the characteristics of a property of a system is that there is one unique line which represents a value of the property on a diagram of properties



A series of constant entropy and temperature lines on P - v Diagram

Entropy Change

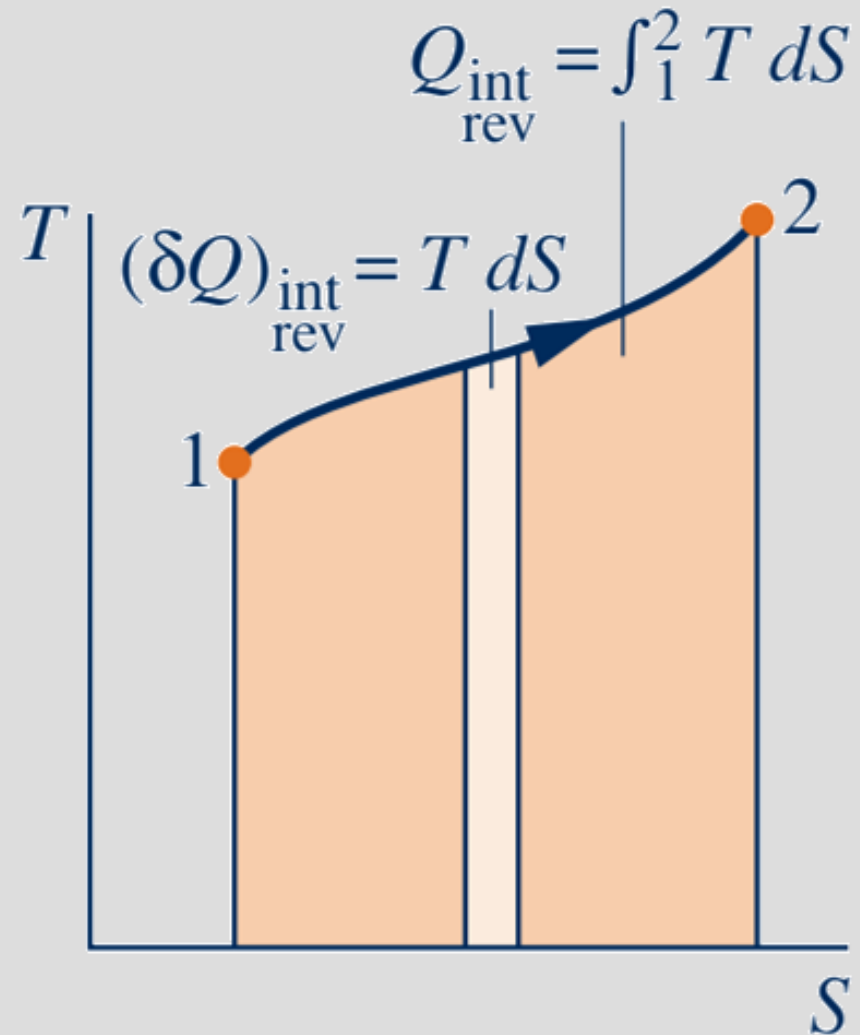
The change in entropy (Δs) is equal to change in heat (dQ) divided by the absolute Temperature (T) at which heat change occurs in the system.

$$ds = \frac{dQ}{T} \quad dQ = Tds \quad Q = \int_1^2 Tds$$

Analogous to $W = \int_1^2 p dv$

The **SI unit for entropy** is J/K.

However, in this book it is convenient to work in terms of kJ/K.



$$S_2 - S_1 = \left(\int_1^2 \frac{\delta Q}{T} \right)_{\text{int rev}}$$

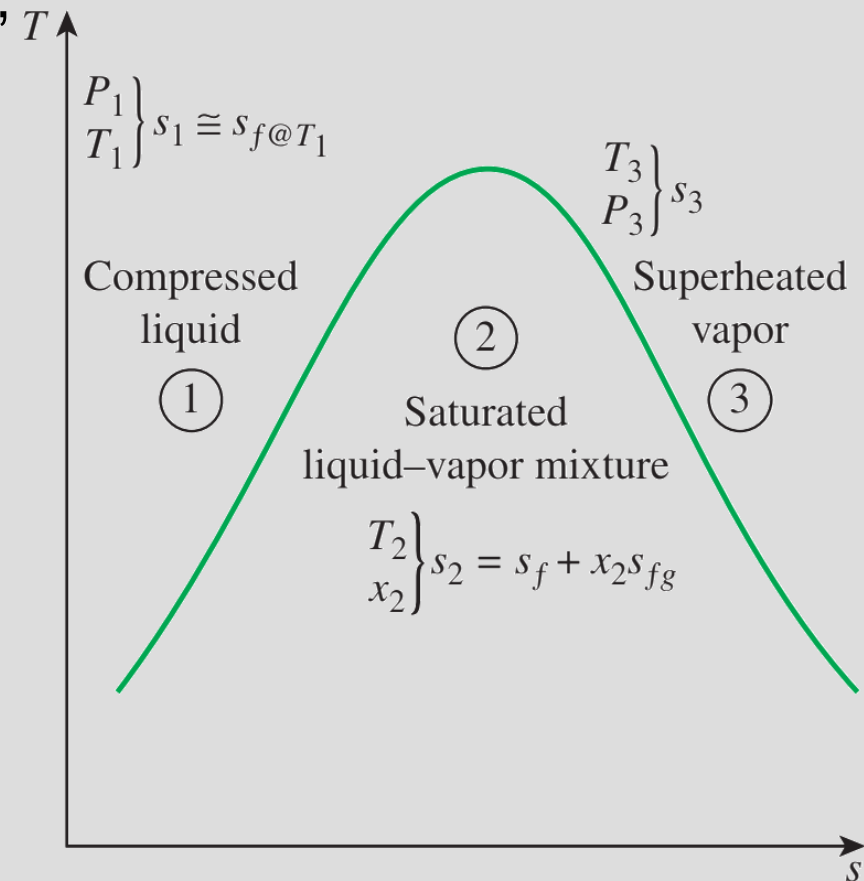
$$S_y = S_x + \left(\int_x^y \frac{\delta Q}{T} \right)_{\text{int rev}}$$

Retrieving Entropy Data

Vapor/Liquid Data: In compressed liquid and superheated vapor regions, it can be obtained directly from tables at the fixed state

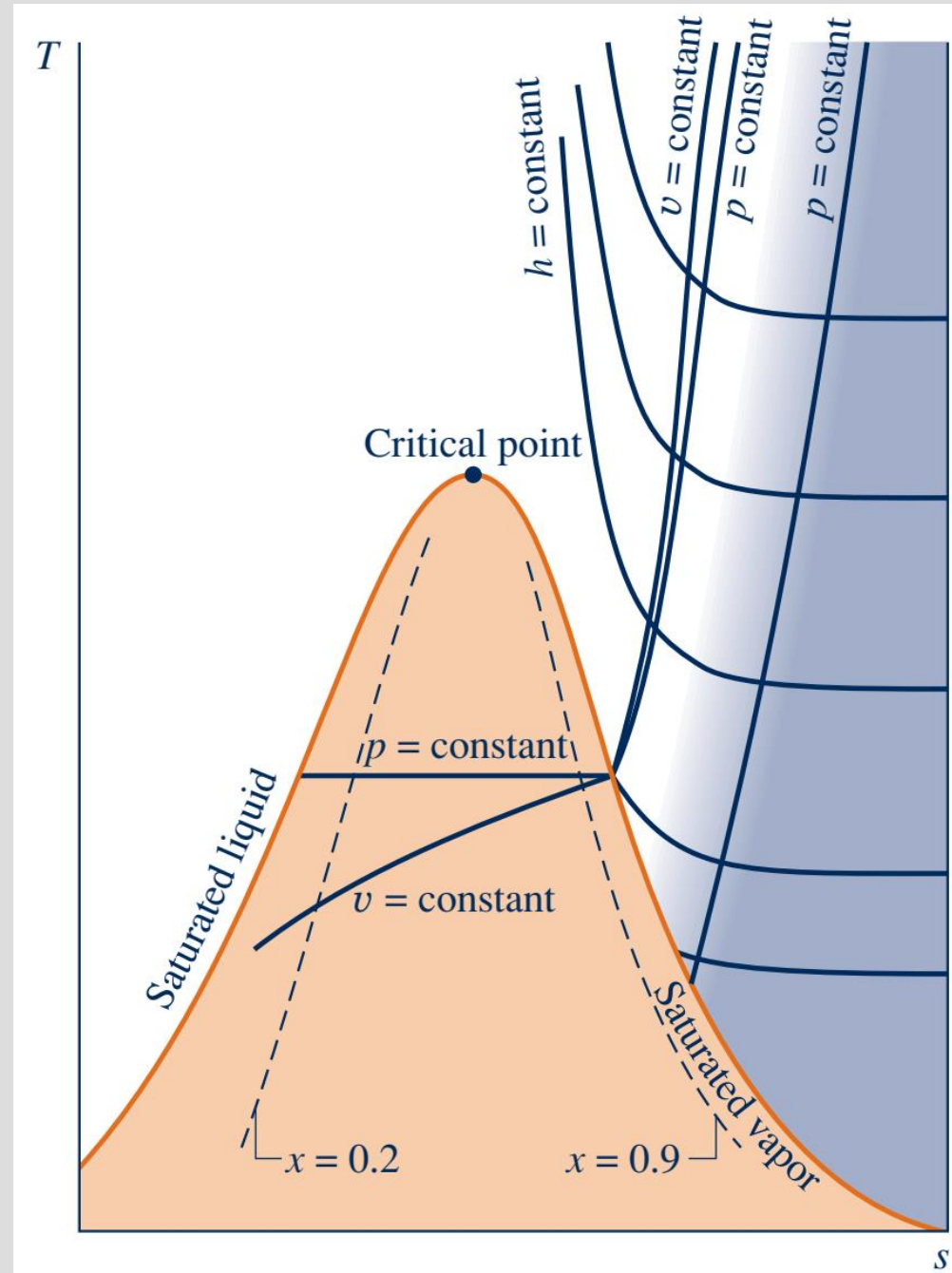
Saturation Data: In saturated - mixture region, it is determined by

$$\begin{aligned}s &= (1 - x)s_f + xs_g \\ &= s_f + x(s_g - s_f)\end{aligned}$$

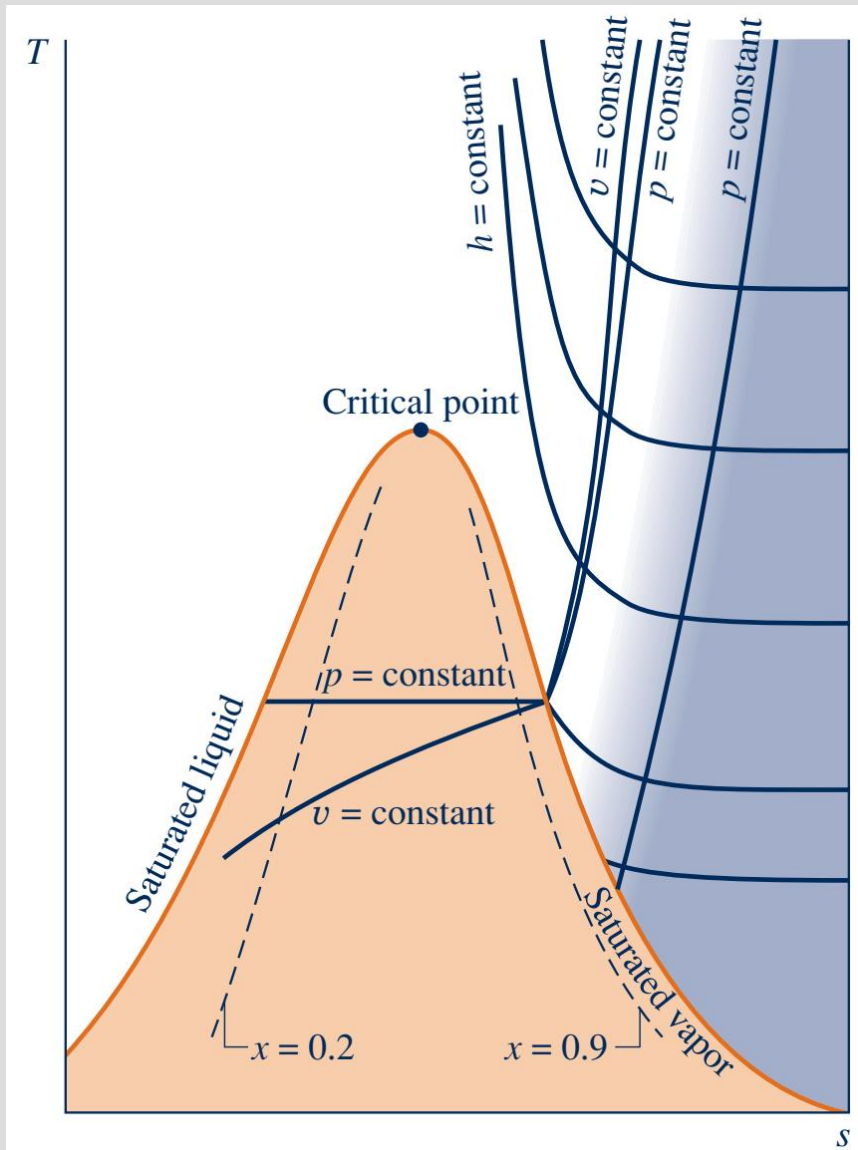


T - s Diagram

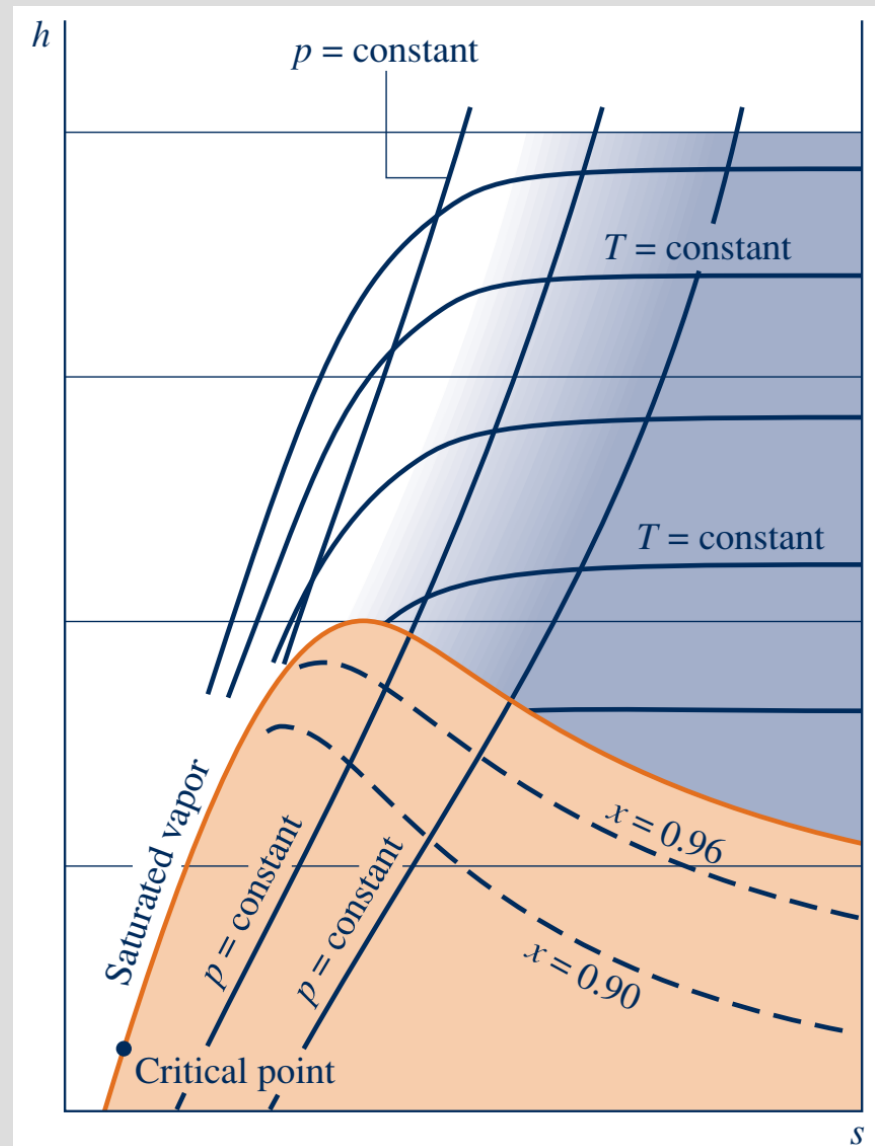
- **Constant - volume lines** are steeper than the **constant - pressure lines** in superheated region.
- **Constant - pressure lines** almost coincide with the saturated liquid line in compressed liquid region
- **Constant - pressure lines** are parallel to **constant - temp lines** in mixture region



T - s Diagram



Temperature–entropy diagram.



Enthalpy–entropy diagram.

Introducing the T - dS Equations

The T dS equations are developed by considering a pure, simple compressible system undergoing an internally reversible process.

$$(\delta Q)_{\text{int rev}} = dU + (\delta W)_{\text{int rev}}$$

$$(\delta W)_{\text{int rev}} = p dV$$

$$(\delta Q)_{\text{int rev}} = T dS$$

first $T dS$ equation

$$T dS = dU + p dV$$

$$H = U + pV.$$

$$dH = dU + d(pV) = dU + p dV + V dp$$

second $T dS$ equation

$$T dS = dH - V dp$$

$$T ds = du + p dv$$

$$T ds = dh - v dp$$

$$T d\bar{s} = d\bar{u} + p d\bar{v}$$

$$T d\bar{s} = d\bar{h} - \bar{v} dp$$

Entropy Change of an Incompressible Substance

In terms of specific heat,

$$du = c(T)dT,$$

$$ds = \frac{c(T)dT}{T} + \frac{pdv}{T} \overset{0}{=} \frac{c(T)dT}{T}$$

$$s_2 - s_1 = \int_{T_1}^{T_2} \frac{c(T)}{T} dT$$

$$s_2 - s_1 = c \ln \frac{T_2}{T_1} \quad (\text{incompressible, constant } c)$$

$$T ds = du + p dv$$

$$T ds = dh - v dp$$

$$T d\bar{s} = d\bar{u} + p d\bar{v}$$

$$T d\bar{s} = d\bar{h} - \bar{v} dp$$

Entropy Change of an Ideal Gas

For an ideal gas, $du = c_v(T) dT$, $dh = c_p(T) dT$, and $pv = RT$.

$$ds = \frac{du}{T} + \frac{p}{T} dv$$

$$ds = \frac{dh}{T} - \frac{v}{T} dp$$

$$ds = c_v(T) \frac{dT}{T} + R \frac{dv}{v}$$

$$ds = c_p(T) \frac{dT}{T} - R \frac{dp}{p}$$

$$s(T_2, v_2) - s(T_1, v_1) = \int_{T_1}^{T_2} c_v(T) \frac{dT}{T} + R \ln \frac{v_2}{v_1}$$

$$s(T_2, p_2) - s(T_1, p_1) = \int_{T_1}^{T_2} c_p(T) \frac{dT}{T} - R \ln \frac{p_2}{p_1}$$