Properties of Substances

Presentation Outline

- Overview
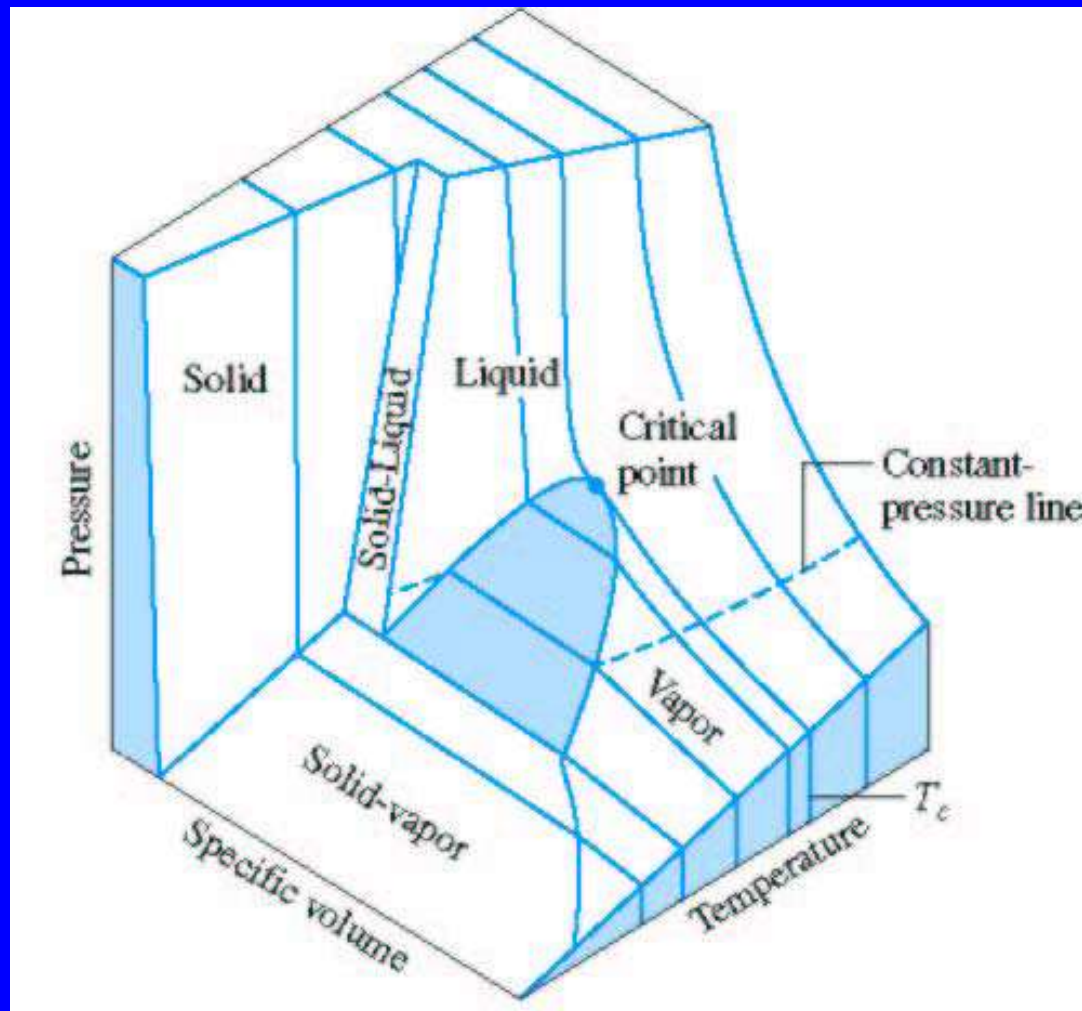- Property Diagrams
- Property Tables

Overview

- A *pure substance* is one of uniform and invariable chemical composition.

- For present analysis, a simple substance is taken as one for which if the values of two intensive properties are known, all the other properties can be found. E.g. $u = f(T, p)$

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Overview contd..

- A material can exist in the

  - ➢ Solid phase

  - ➢ Liquid phase

  - ➢ Vapour (or Gaseous) phase

  - ➢ A mixture of the above phases in equillibrium (e.g. melting, vaporization or sublimation)

- Through experiments it is known that temperature and specific volume can be considered as independent variables and pressure can be determined as a function of the two.
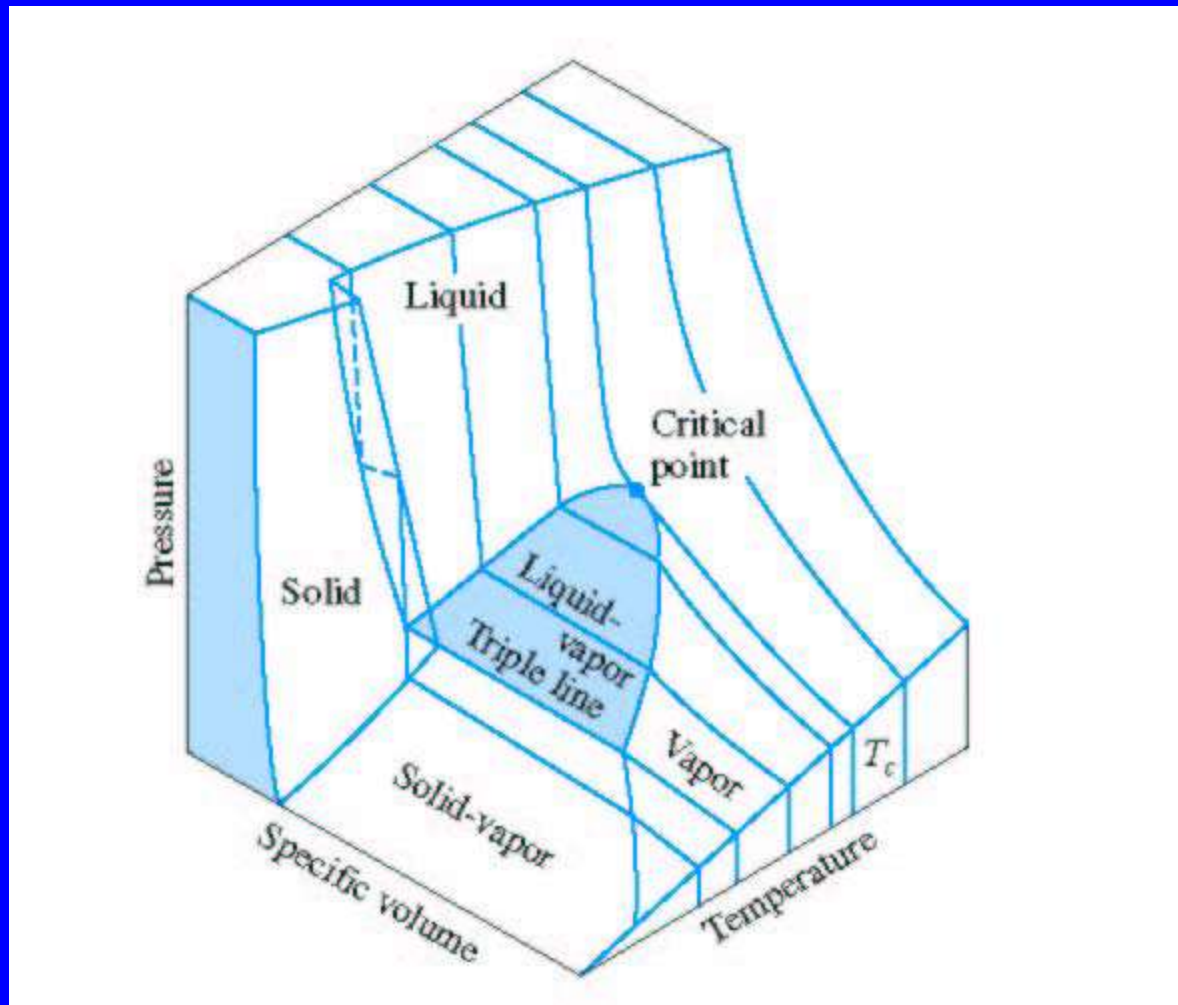
$$p = f(T, v)$$

p-v-T plot of a common metal

- This creates a p-v-T surface on the plot

p-v-T plot of water

- Note the step increase in specific volume (step decrease in density) when transferring from liquid to solid
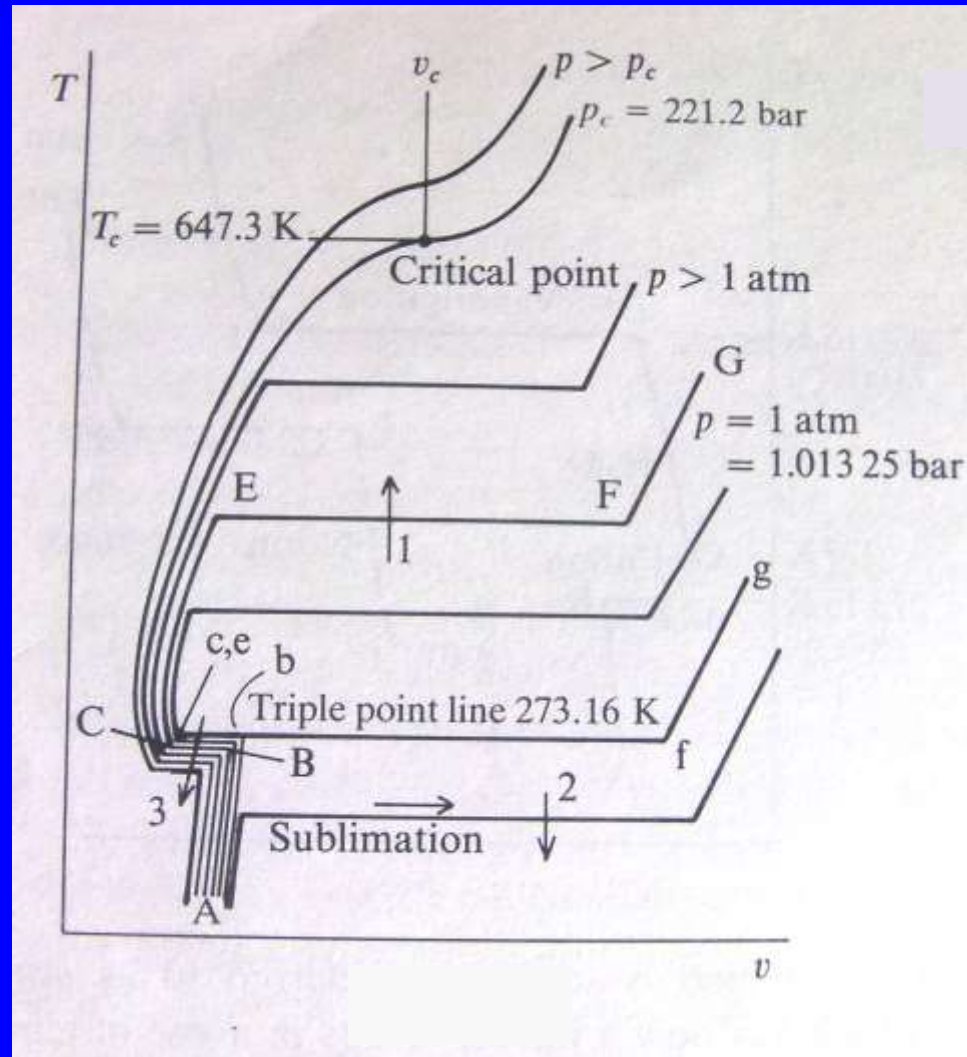
Property Diagrams

- 3-D surface plots are not very useful and rarely used.

- 2-D projections are more instructive from analytical point of view.

- Different standard property diagrams are used for obtaining relationships among different properties of substances.
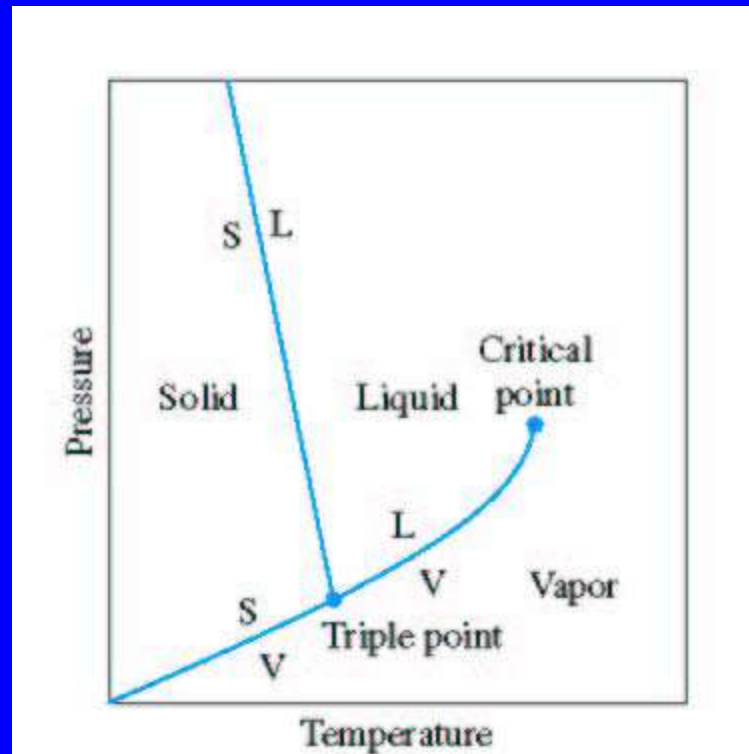
Property Diagrams contd..

- Common 2-D property diagrams include
  - ➤ Temperature vs. Specific Volume diagram (T-v diagram)
  - ➤ Pressure vs. Specific Volume diagram (p-v diagram)
  - ➤ Temperature vs. Specific Entropy diagram (T-s diagram)
  - ➤ Specific Enthalpy vs. Specific Entropy diagram (h-s diagram)
  - ➤ Pressure vs. Enthalpy diagram (p-h diagram)
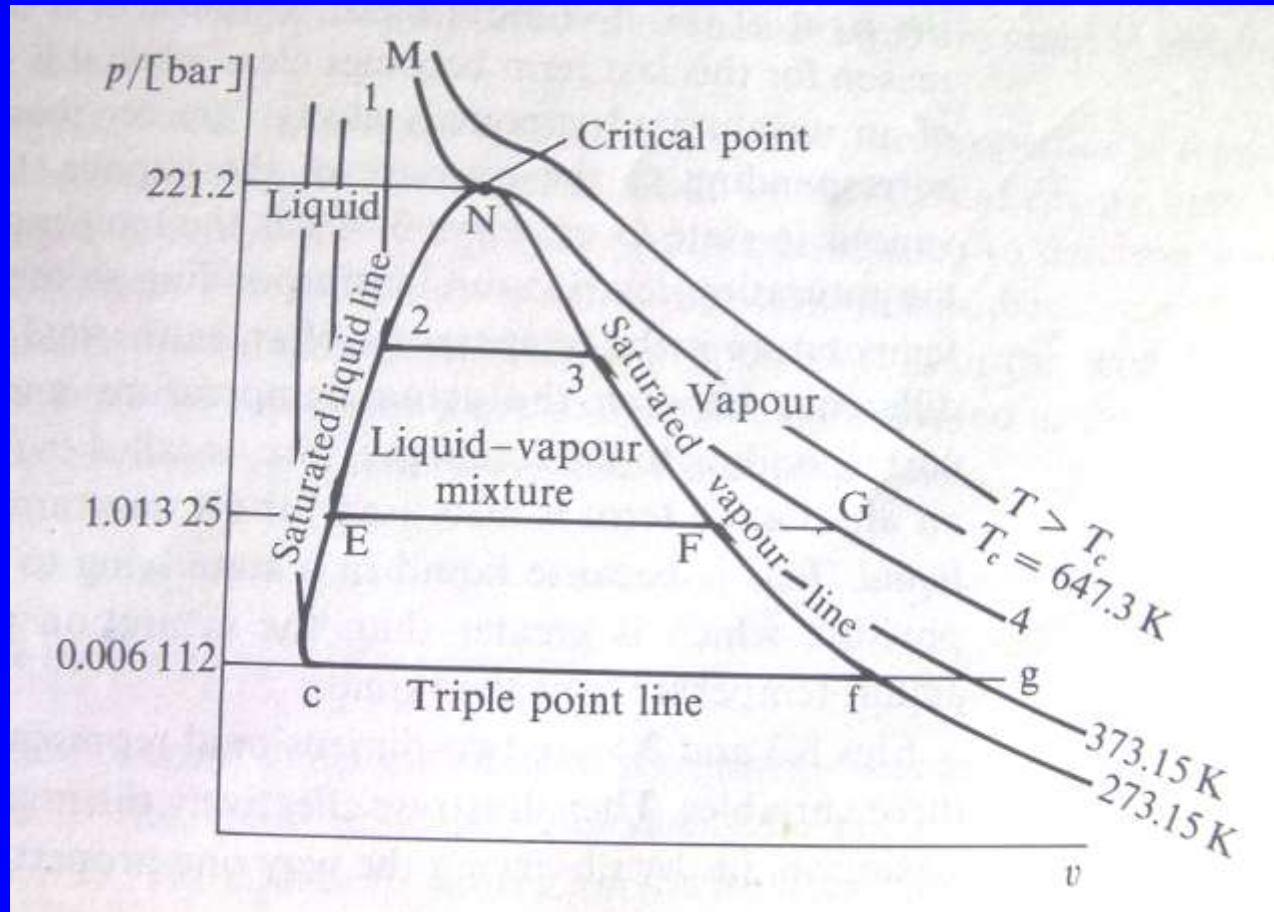
T-v diagram for water

p-T diagram for water

- Only single-phase regions observed
- Two-phase regions appear as lines (edge view)
- Triple point is represented on the edge view of the triple line where all three phases co-exist in equillibrium.
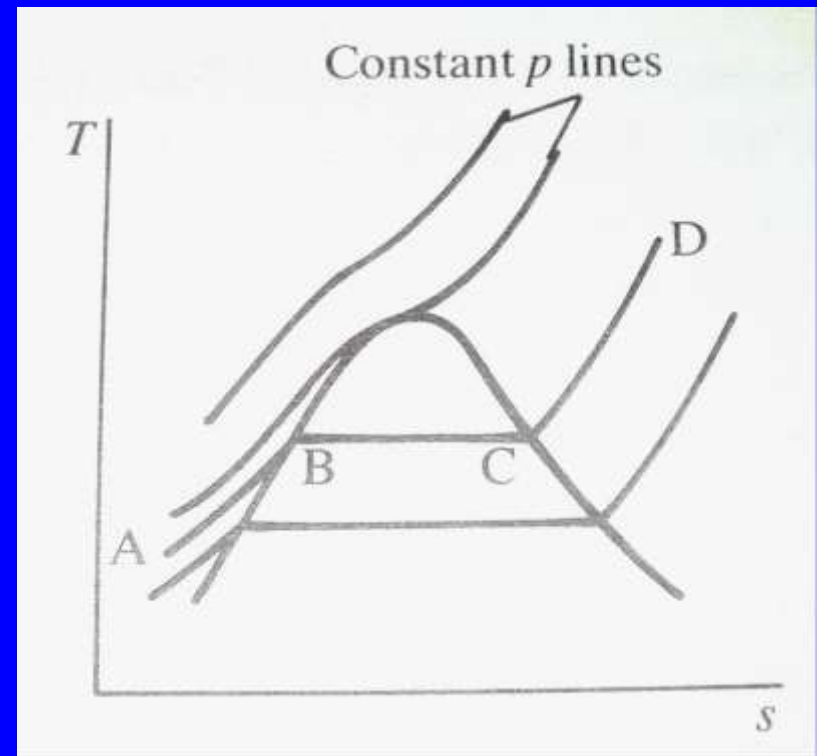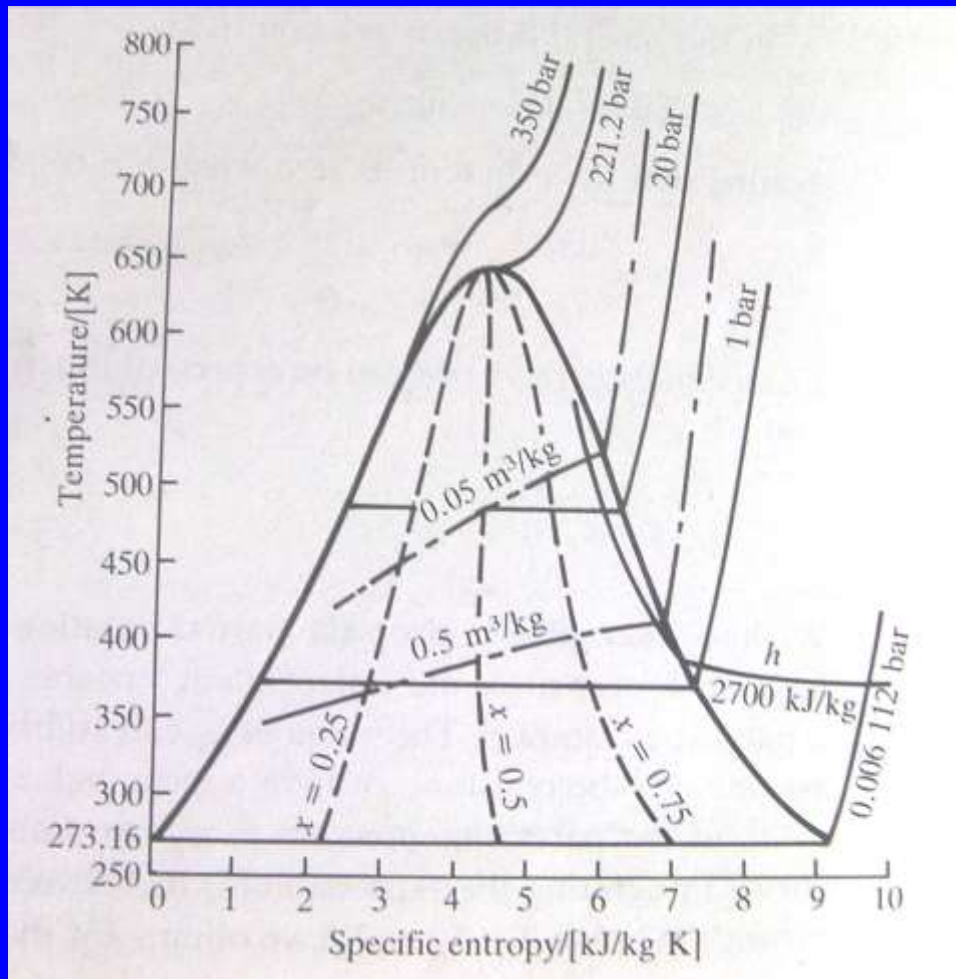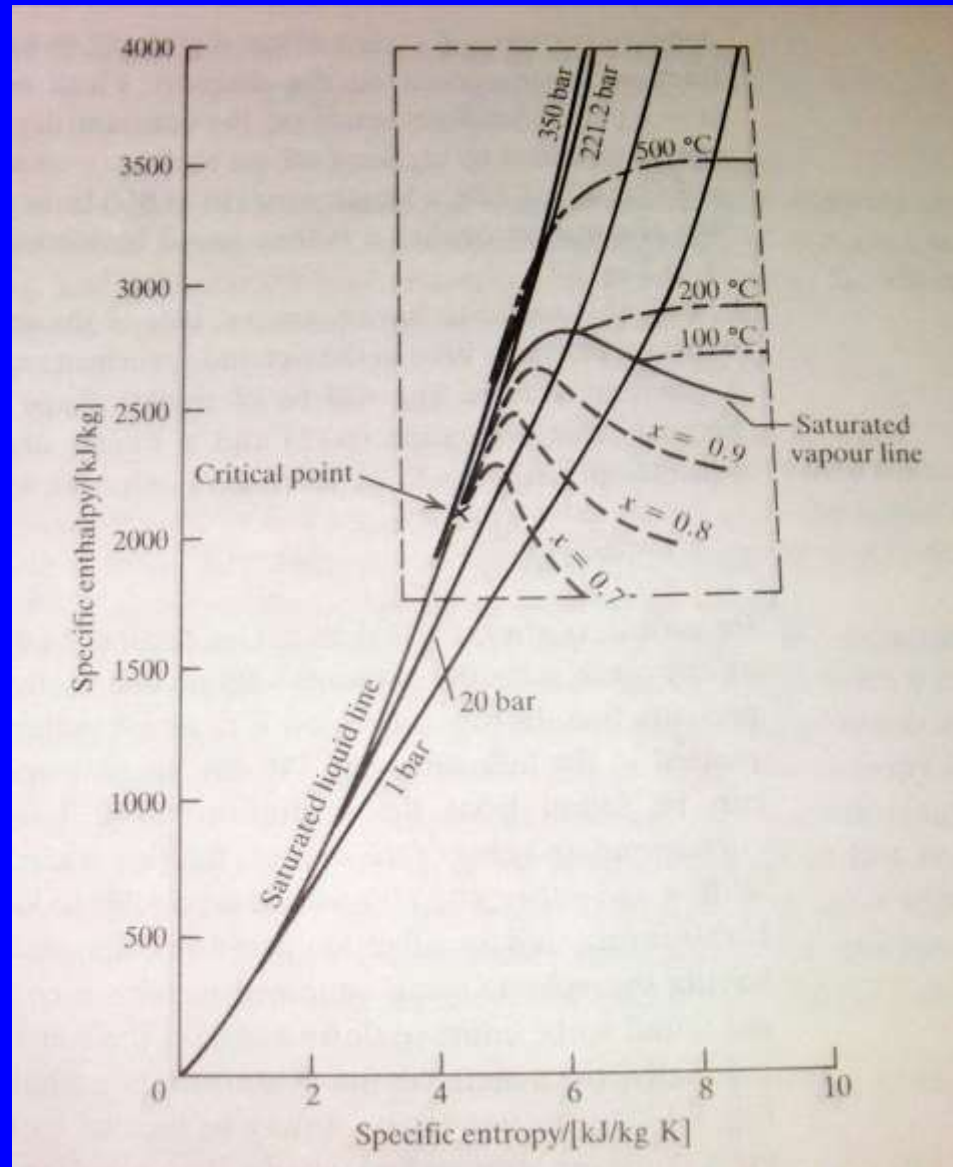
p-v diagram for water

p-v diagram for water contd..

▪ The dome-shaped two phase region is comprised of liquid and vapour, is called the saturation dome.

▪ Constant temperature lines shown are called isotherms.

▪ Above the critical point isobars and isotherms do not pass through the liquid-vapour region.

▪ The critical point defines the maximum pressure. i.e. Above the critical pressure liquid and vapour cannot co-exist in equllibrium.

▪ In single-phase regions, the state is fixed by any two of the properties p, v and T that are independent variables.

▪ In two-phase regions, p and T are not independent and the state cannot be fixed by p and T but can be explained by p and v or T and v.
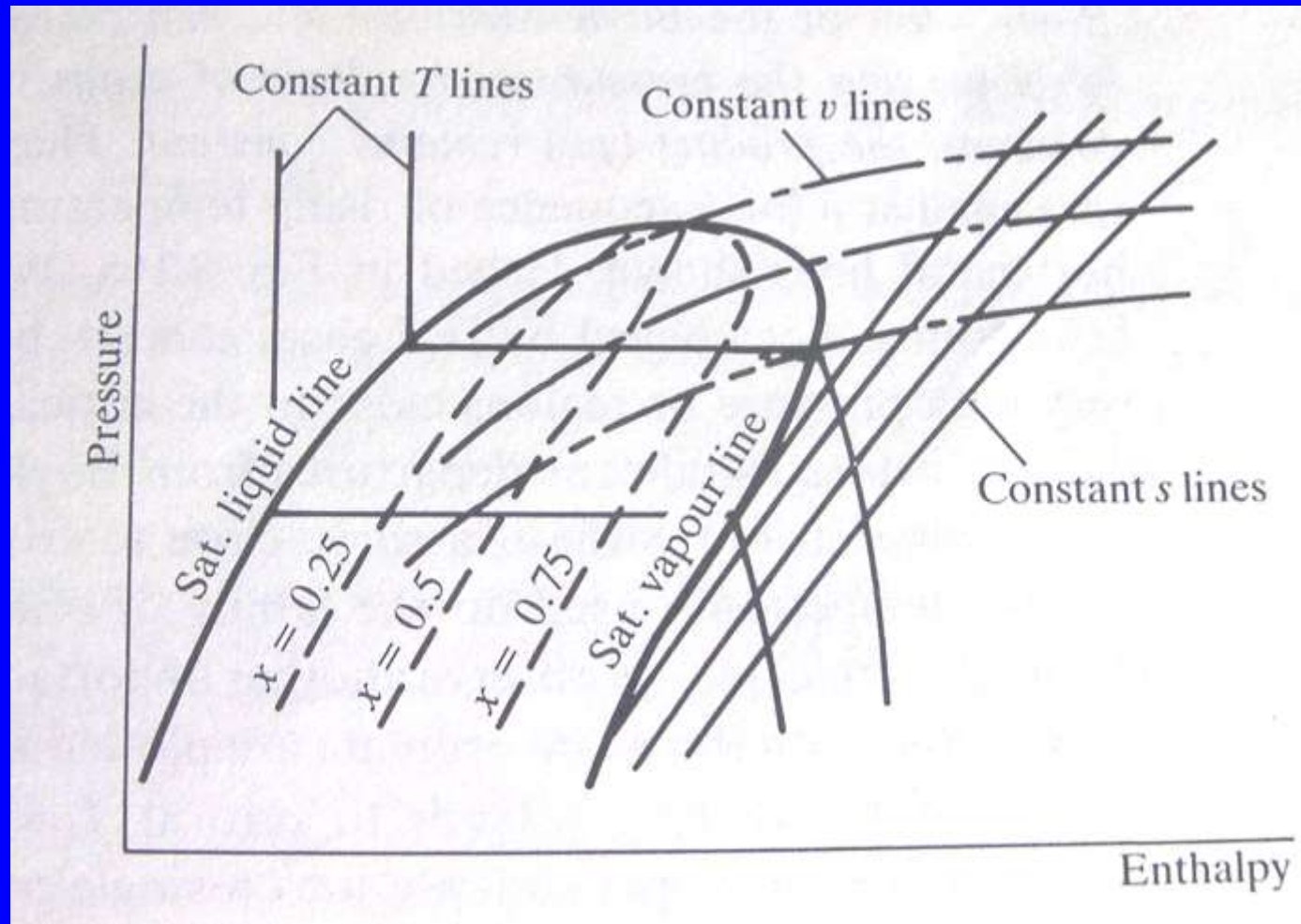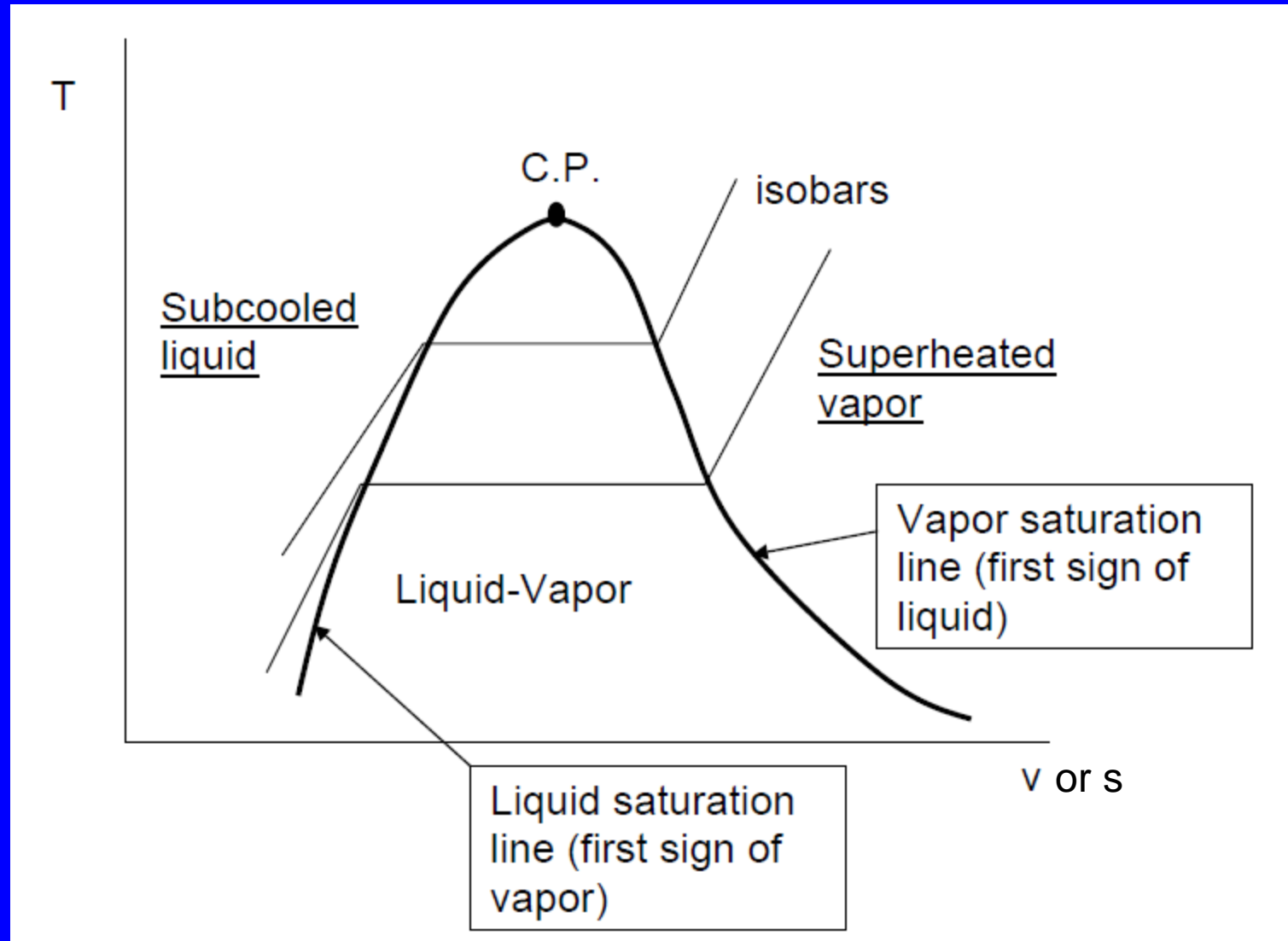
T- s diagram for water
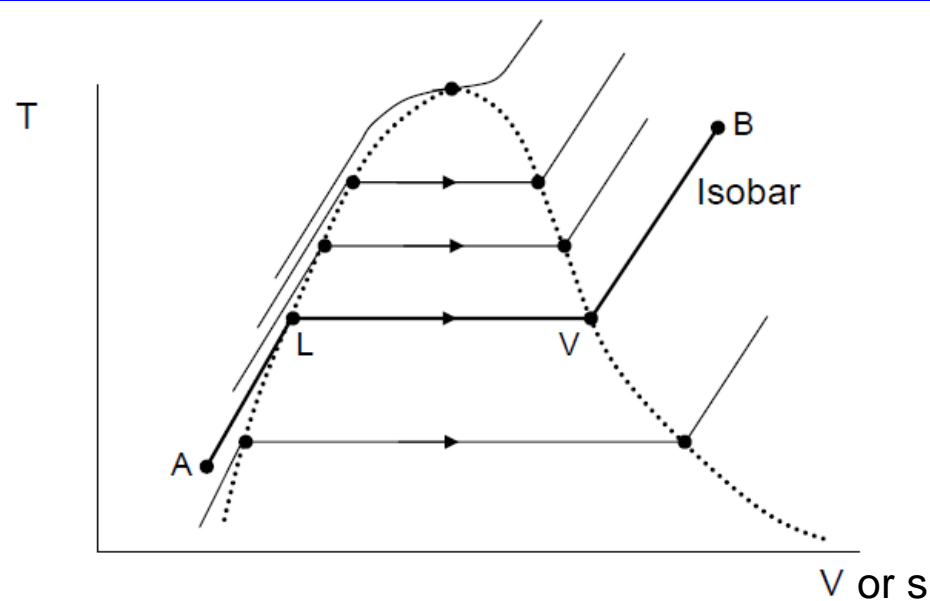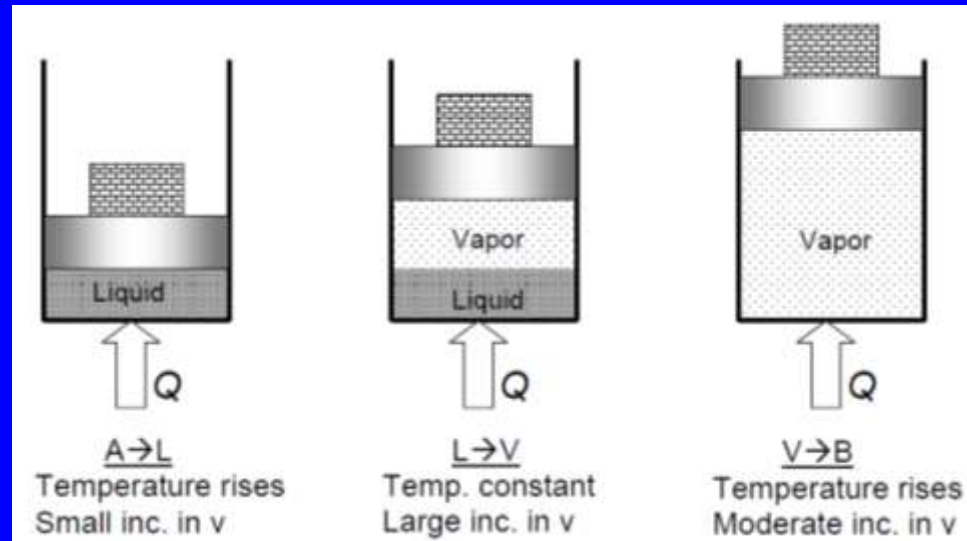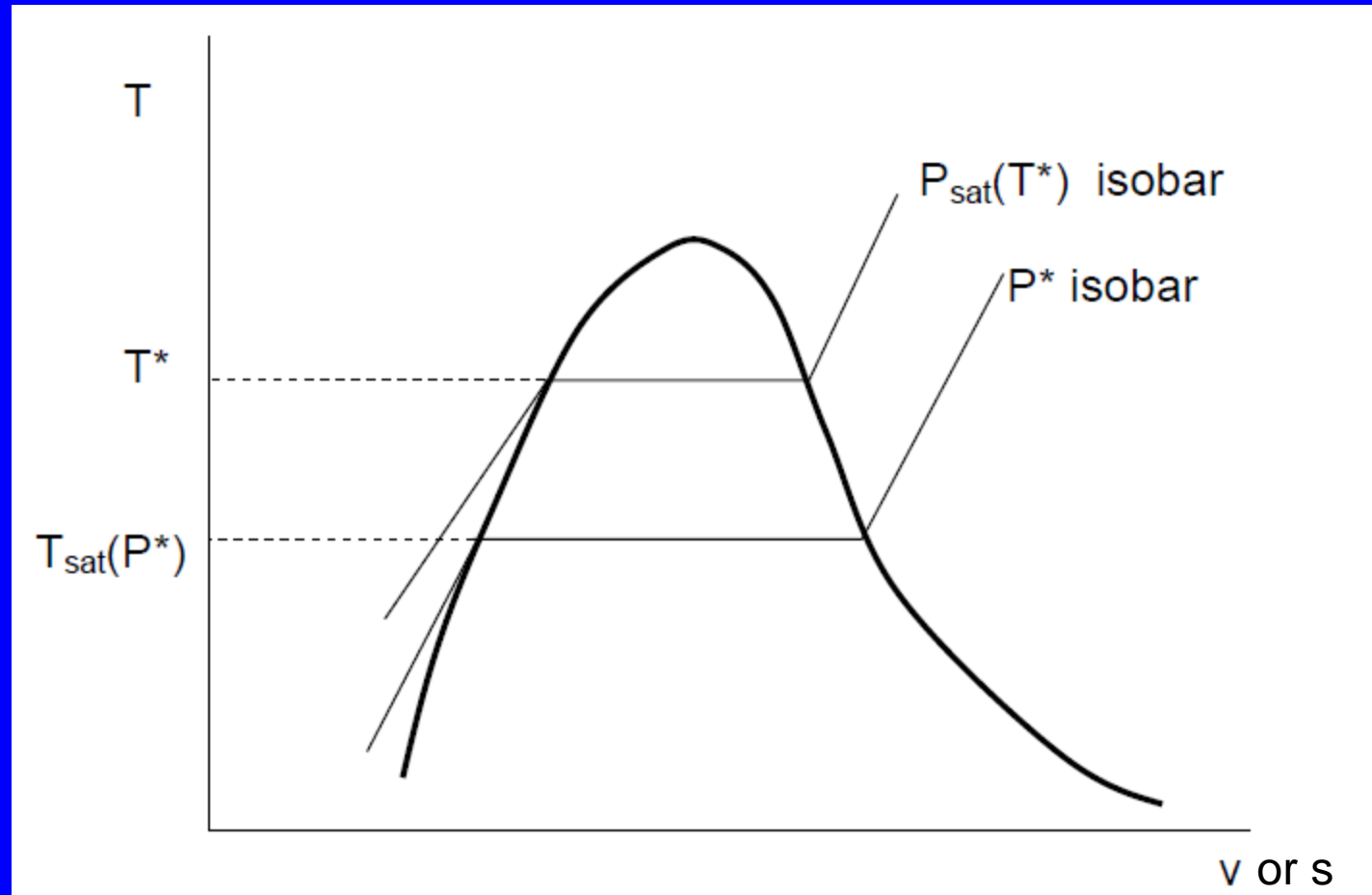
h-s diagram for water

p-h diagram for water

Characteristics of Saturation Dome

Consider the following constant pressure heating process
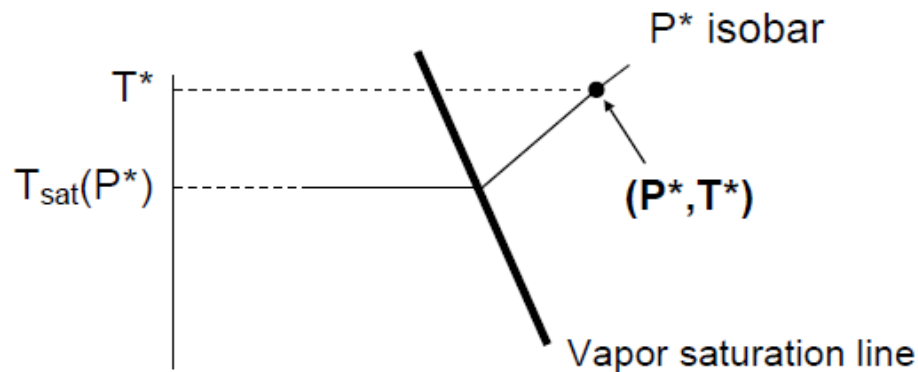
Saturation Pressure & Temperature

Saturation Pressure & Temperature

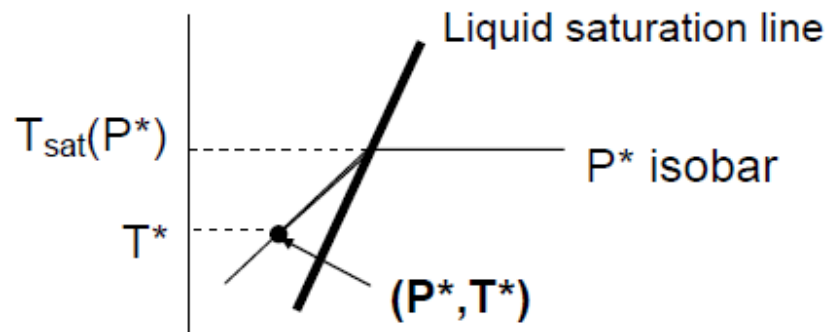- **Saturation Temperature:** Temperature of a liquid-vapour mixture in equilibrium at a pressure P*, denoted as T_{sat}(P*). This is the temperature where the P* isobar crosses vapour saturation line.

- **Saturation Pressure:** Pressure of a liquid-vapour mixture in equilibrium at a temperature T*, denoted as P_{sat}(T*). This is the pressure at which the T* isotherm crosses the liquid saturation line.

Saturation Pressure & Temperature contd..

Superheated Vapor: $T^* > T_{sat}(P^*)$
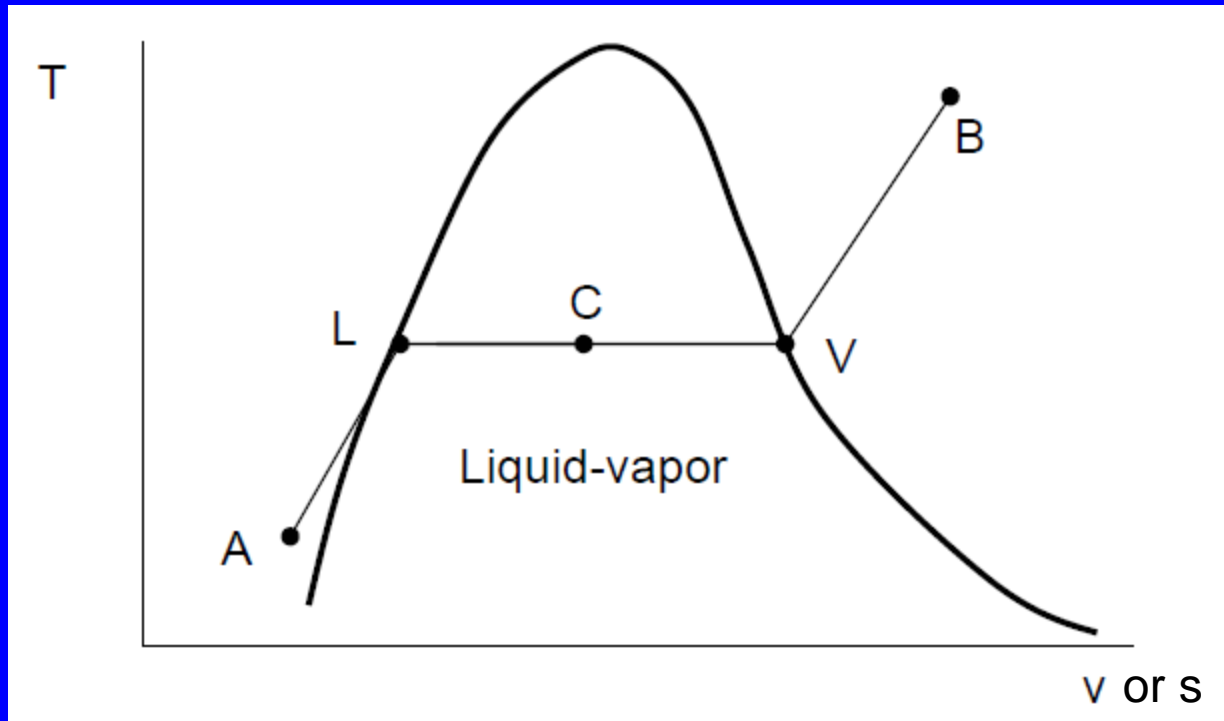

Subcooled liquid: $T^* < T_{sat}(P^*)$

Dryness Fraction (x)

- This gives an indication of the quality and characteristics of steam being utilized.

- It is defined as the ratio of the mass of vapour (m_v) to the total mass of a two-phase liquid-vapour mixture (m).
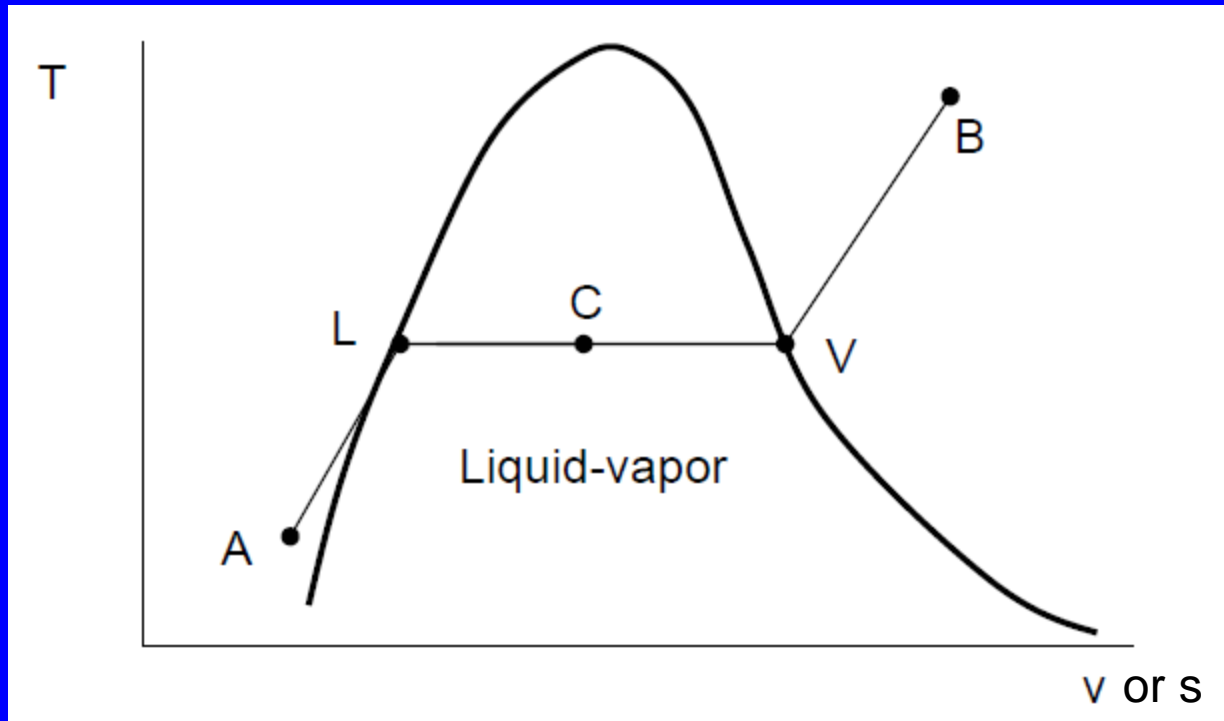
- Mass of liquid = m_l

Dryness Fraction $x = \dfrac{m_v}{m} = \dfrac{m_v}{m_v + m_l}$

Dryness Fraction contd..

- At point L, $x = 0$
- At point V, $x = 1$
- Between L and V, $0 < x < 1$
- Dryness Fraction may also be presented as a percentage ($0 \leq x \leq 100$)

Liquid – Vapour Properties

- Properties at point L are denoted by subscript f. (E.g. u_f, v_f, s_f, h_f etc.)

- Properties at point V are denoted by subscript g. (E.g. u_g, v_g, s_g, h_g etc.)

Liquid –Vapour Properties contd..

▪ Let us consider an intermediate point C and its corresponding properties are u, v, s and h.

▪ Then the following expressions will provide the properties of the two-phase fluid at C.

1. **Specific Internal Energy**

$$u = (1 - x)u_f + xu_g$$ or $$u = u_f + x(u_g - u_f)$$

If $$u_{fg} = u_g - u_f$$ then $$u = u_f + xu_{fg}$$

Liquid – Vapour Properties contd..

2. **Specific Volume** $v = (1-x)v_f + xv_g$

However v_f is very small compared with v_g.

Hence $v = xv_g$

3. **Specific Entropy**

$$s = (1-x)s_f + xs_g \quad \text{or} \quad s = s_f + x(s_g - s_f)$$

If $s_{fg} = s_g - s_f$ then $s = s_f + xs_{fg}$

Liquid – Vapour Properties contd..
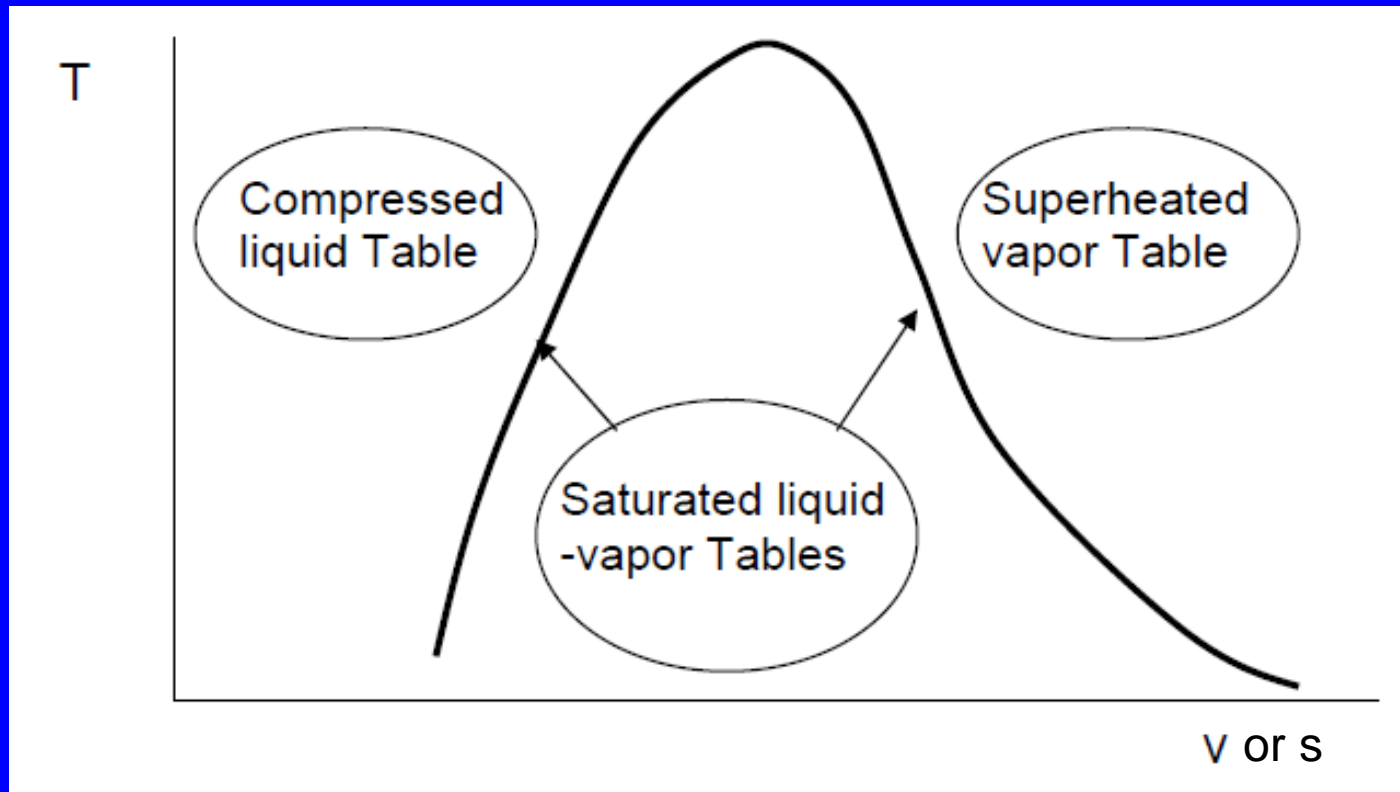
4. Specific Enthalpy

$$h = (1 - x)h_f + xh_g$$ or $$h = h_f + x(h_g - h_f)$$

If $$h_{fg} = h_g - h_f$$ then $$h = h_f + xh_{fg}$$

- Hence for any property α at C is given by

$$\alpha = (1 - x)\alpha_f + x\alpha_g$$ or $$\alpha = \alpha_f + x\alpha_{fg}$$

Use of Property Tables

- Appropriate Property Tables are used to define the relationships among different properties of fluids.

Properties of Superheated Steam

- For steam in the superheated region, temperature and pressure are independent properties.

- When the temperature and pressure are given for superheated steam then the state is defined and all the other properties can be found.