Department of Mining Engineering
-2nd-Class
College of Petroleum and Mining Engineering
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Thermodynamics
Lecture 4
Properties of Pure Substances

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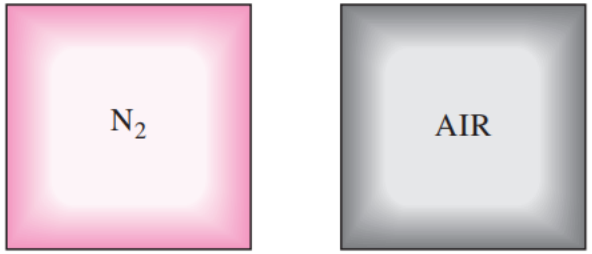
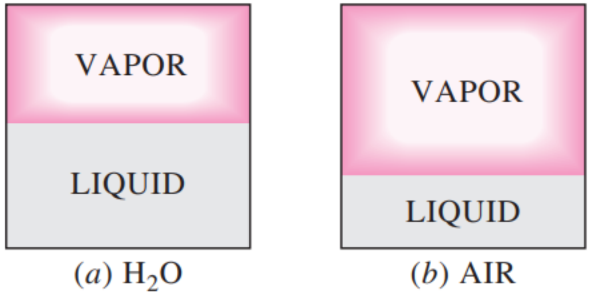
Properties of Pure Substances

❖ A substance that has a fixed chemical composition throughout is called a pure substance.

❖ Water, nitrogen, helium, and carbon dioxide, for example, are all pure substances.



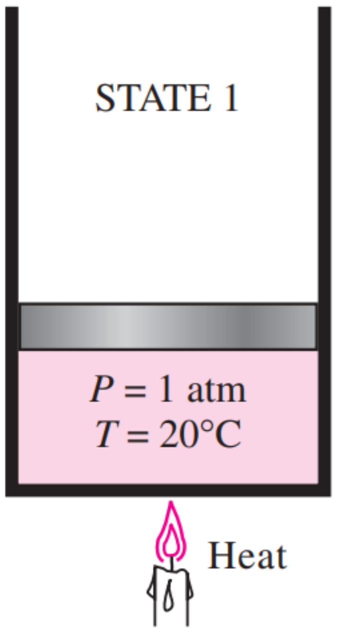
Nitrogen and gaseous air are pure substances.



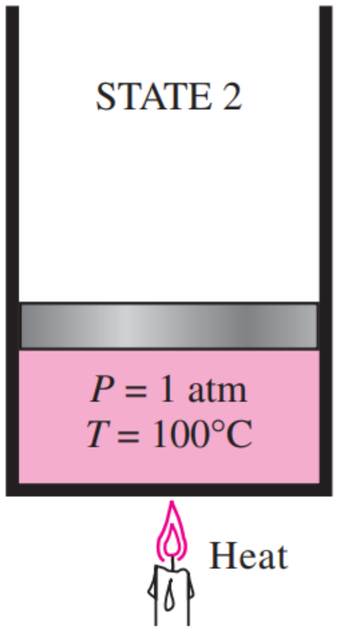
A mixture of liquid and gaseous water is a pure substance, but a mixture of liquid and gaseous air is not.

❖ Air, for example, is a mixture of several gases, but it is often considered to be a pure substance because it has a uniform chemical composition.

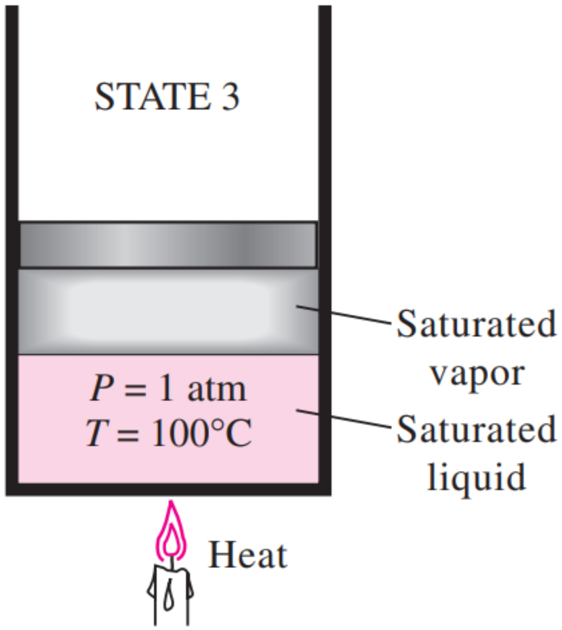
Vapor–Liquid–Solid-Phase Equilibrium in Pure Substances



At 1 atm and 20°C, water exists in the liquid phase (compressed liquid) or (subcooled liquid).

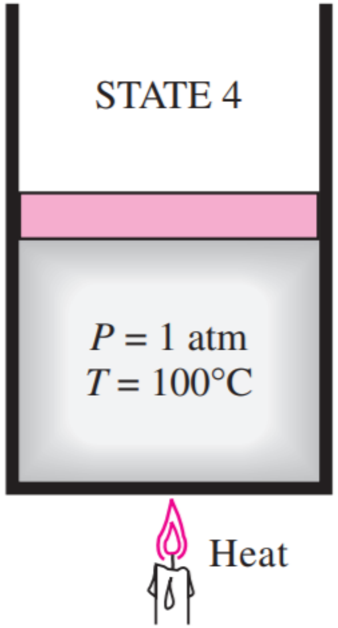


At 1 atm pressure and 100°C, water exists as a liquid that is ready to vaporize (saturated liquid).

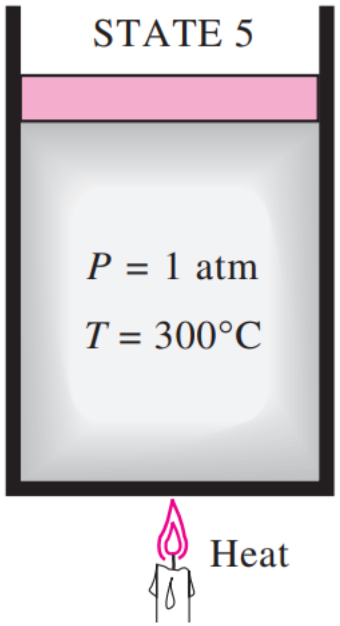


As more heat is transferred, part of the saturated liquid vaporizes (saturated liquid–vapor mixture).

Vapor–Liquid–Solid-Phase Equilibrium in Pure Substances

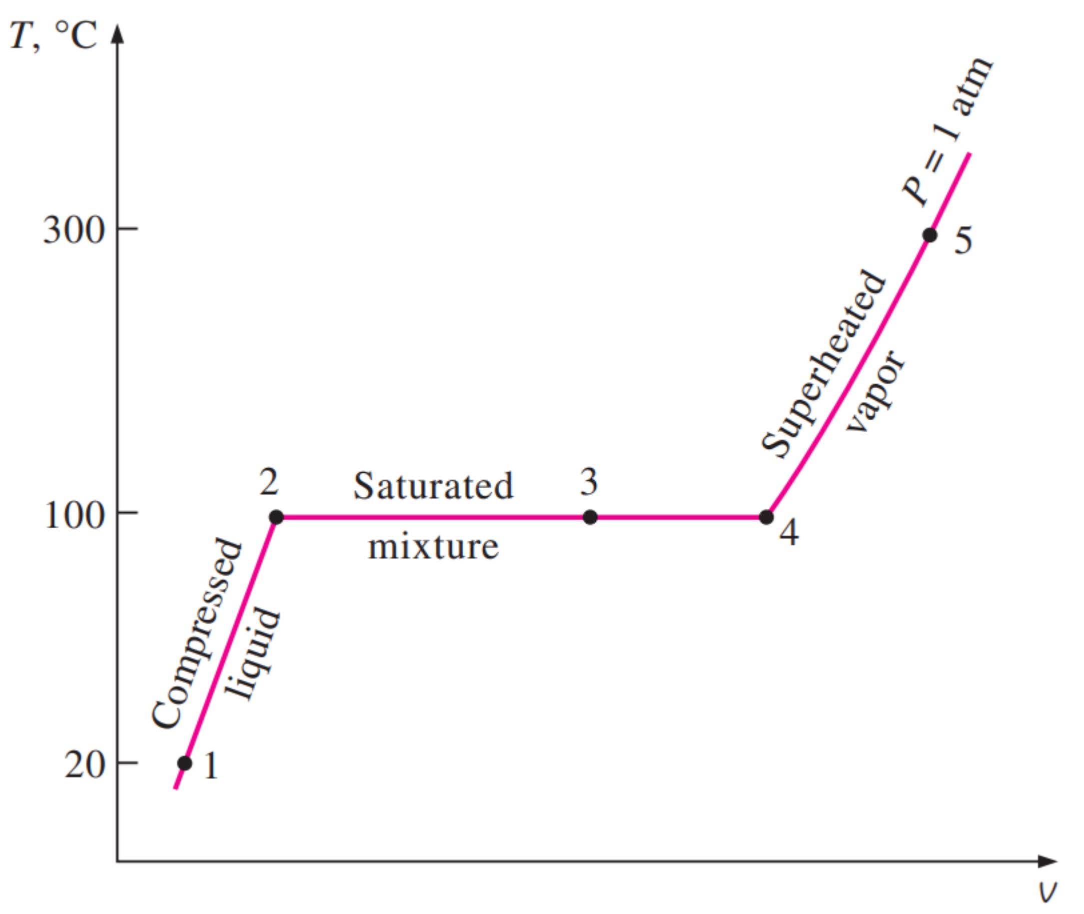


At 1 atm pressure, the temperature remains constant at 100°C until the last drop of liquid is vaporized (saturated vapor).

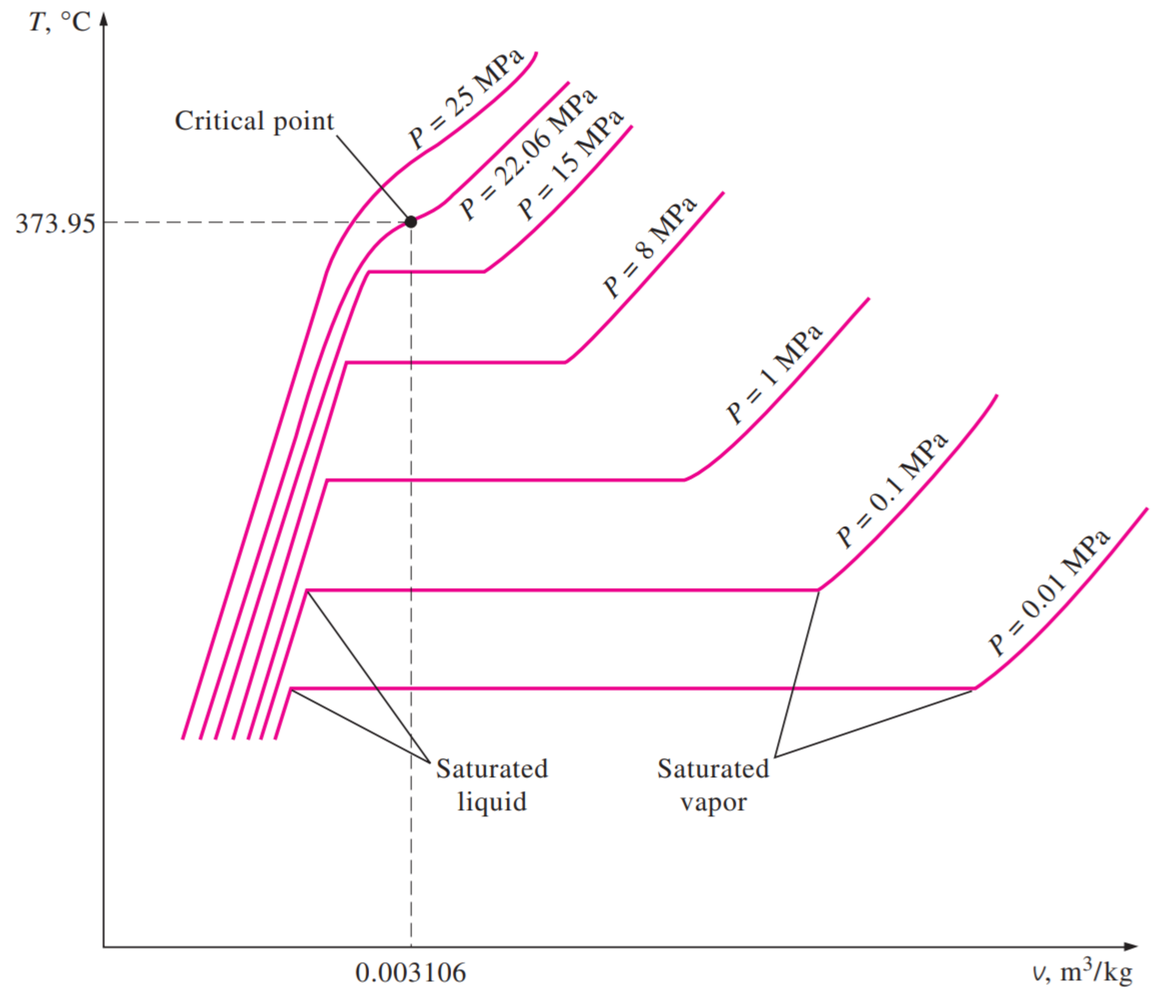


As more heat is transferred, the temperature of the vapor starts to rise (superheated vapor).

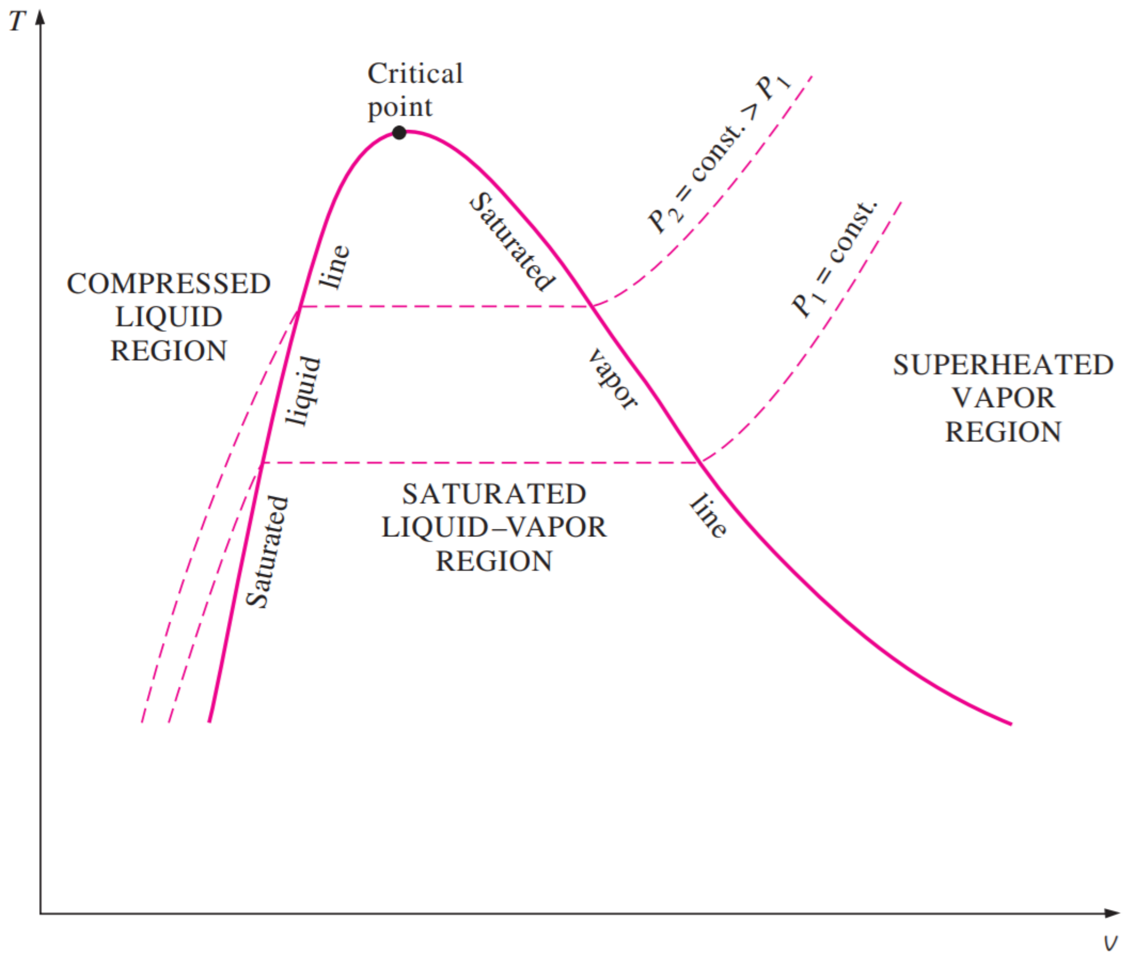
- Subcooled liquid or compressed liquid: a substance that exists in a liquid phase.
- Saturated liquid: a liquid that is about to vaporize.
- Saturated vapor: a vapor that is about to condense.
- Superheated vapor: a voper that is not about to condense.
- Saturated temperature: a temperature at which a pure substance changes phase.
- Saturated pressure: a pressure at which a pure substance changes phase.



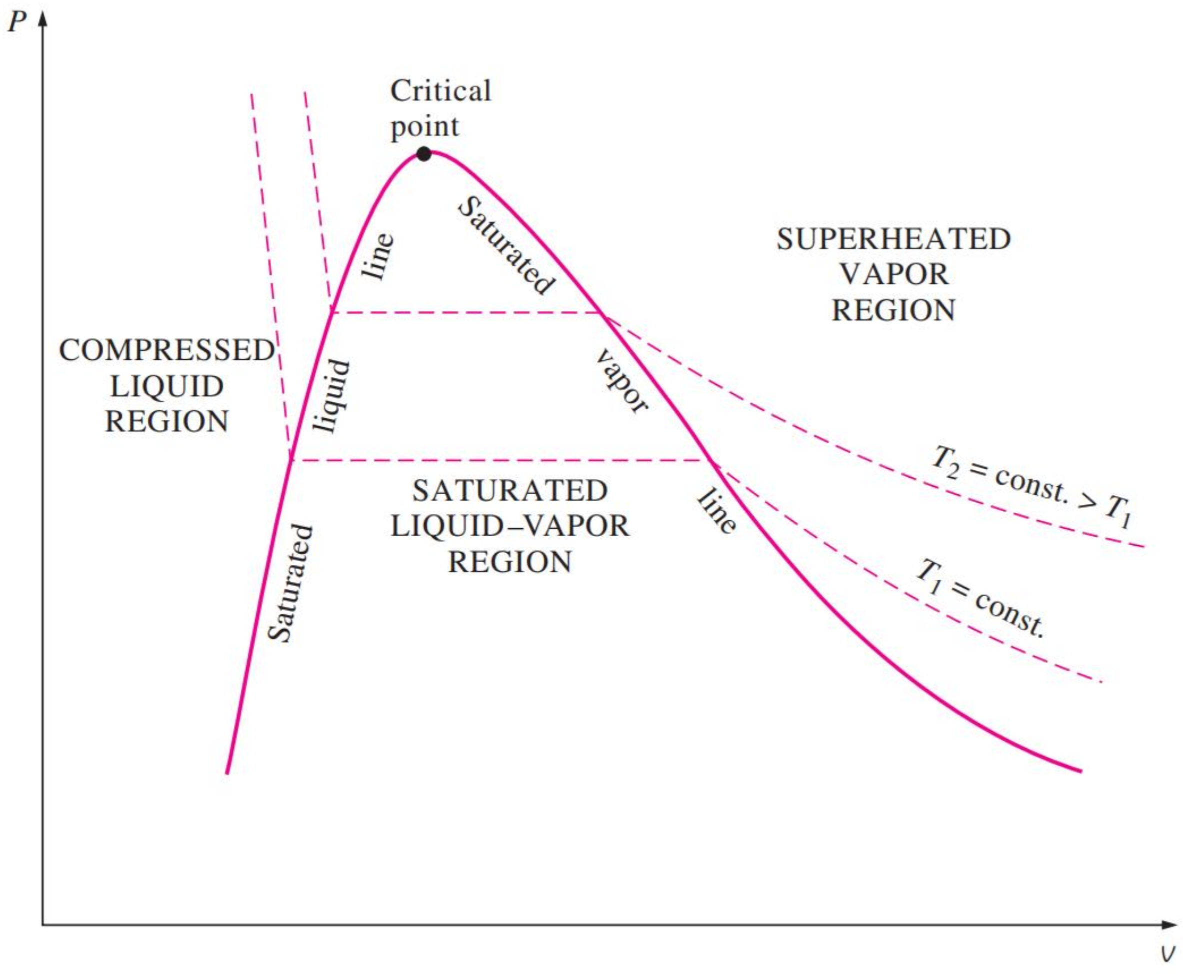
T-V diagram for the heating process of water at constant pressure.



T-V diagram of constant-pressure phase-change processes of a pure substance at various pressures (numerical values are for water).



T-V diagram of a pure substance.



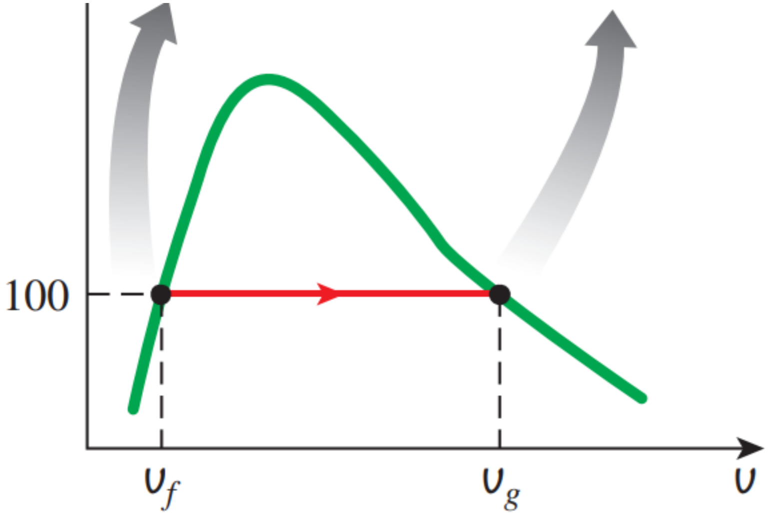
P-V diagram of a pure substance.

Saturated Liquid and Saturated Vapor States

υ_f = specific volume of saturated liquid

υ_g = specific volume of saturated vapor

υ_{fg} = difference between υ_g and υ_f (that is $\upsilon_{fg} = \upsilon_g - \upsilon_f$)



Temp. °C T	Sat. press. kPa P_{sat}	Specific volume m³/kg: Sat. liquid υ_f	Sat. vapor υ_g
85	57.868	0.001032	2.8261
90	70.183	0.001036	2.3593
95	84.609	0.001040	1.9808

Temperature → Temp. column; Corresponding saturation pressure → Sat. press. column; Specific volume of saturated liquid → υ_f column; Specific volume of saturated vapor → υ_g column.

Saturated Liquid–Vapor Mixture

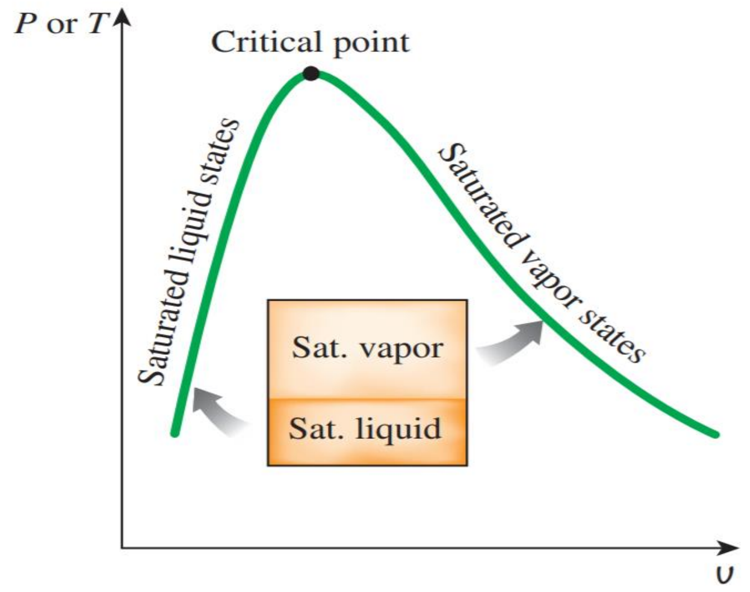
- During a vaporization process, a substance exists as part liquid and part vapor. That is, it is a mixture of saturated liquid and saturated vapor.

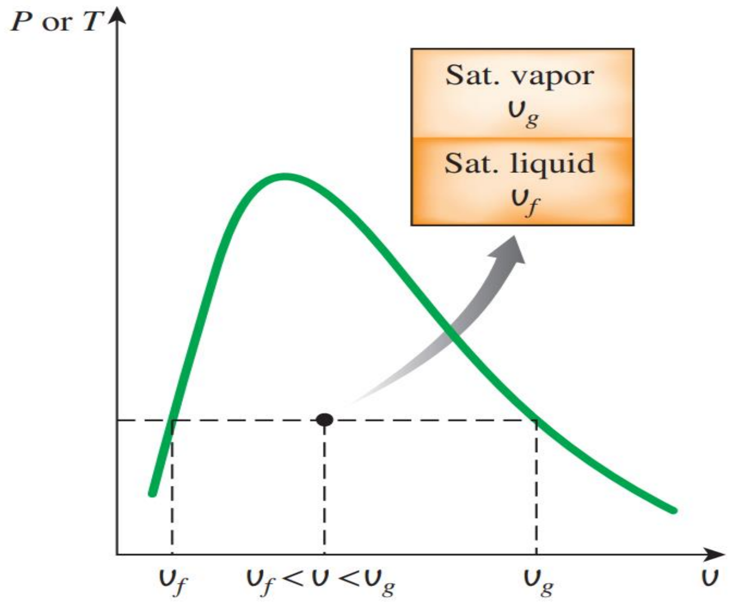
- The relative amounts of liquid and vapor phases in a saturated mixture are specified by the quality x.

- Dryness fraction (x): represents the ratio of dry mass of vapor to the total mass of the mixture.

$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$$

$$m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}} = m_f + m_g$$





Steam tables

Properties of wet substance

- Specific volume

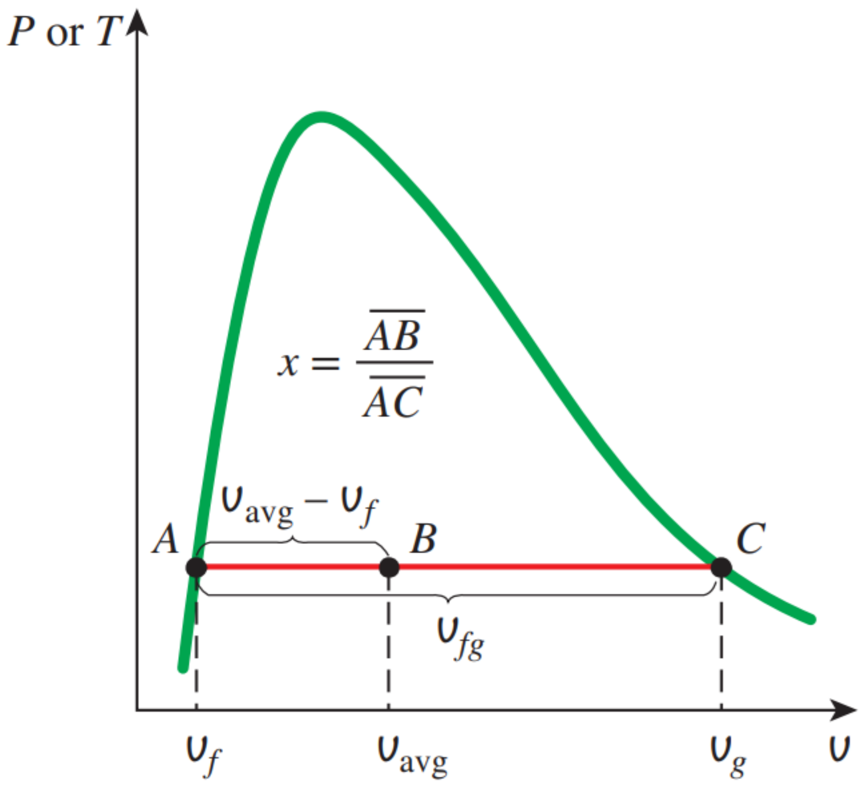
$$v = v_f + x(v_g - v_f),\ \ v_f\ is\ very\ small$$
$$\therefore v = xv_g$$

- Internal energy

$$u = u_f + x(u_g - u_f)$$

- Enthalpy

$$h = h_f + x(h_g - h_f)$$



Quality is related to the horizontal distances on P-v and T-v diagrams.

Superheated Vapor

In the region to the right of the saturated vapor line and at temperatures above the critical point temperature, a substance exists as superheated vapor.

- Compared to saturated vapor, superheated vapor is characterized by:

Lower pressures ($P < P_{sat}$ at a given T)

Higher temperatures ($T > T_{sat}$ at a given P)

Higher specific volumes ($\upsilon > \upsilon_g$ at a given P or T)

Higher internal energies ($u > u_g$ at a given P or T)

Higher enthalpies ($h > h_g$ at a given P or T)

T,°C	υ m^3/kg	u kJ/kg	h kJ/kg
	P = 0.1 MPa (99.61°C)		
Sat.	1.6941	2505.6	2675.0
100	1.6959	2506.2	2675.8
150	1.9367	2582.9	2776.6
⋮	⋮	⋮	⋮
1300	7.2605	4687.2	5413.3
	P = 0.5 MPa (151.83°C)		
Sat.	0.37483	2560.7	2748.1
200	0.42503	2643.3	2855.8
250	0.47443	2723.8	2961.0

A partial listing of Superheated Table.

Ex (1): Determine the internal energy for each of the following cases:

(a) P=20 bar and T=240°C.

(b) P= 10 bar and h= 2650 kJ/kg.

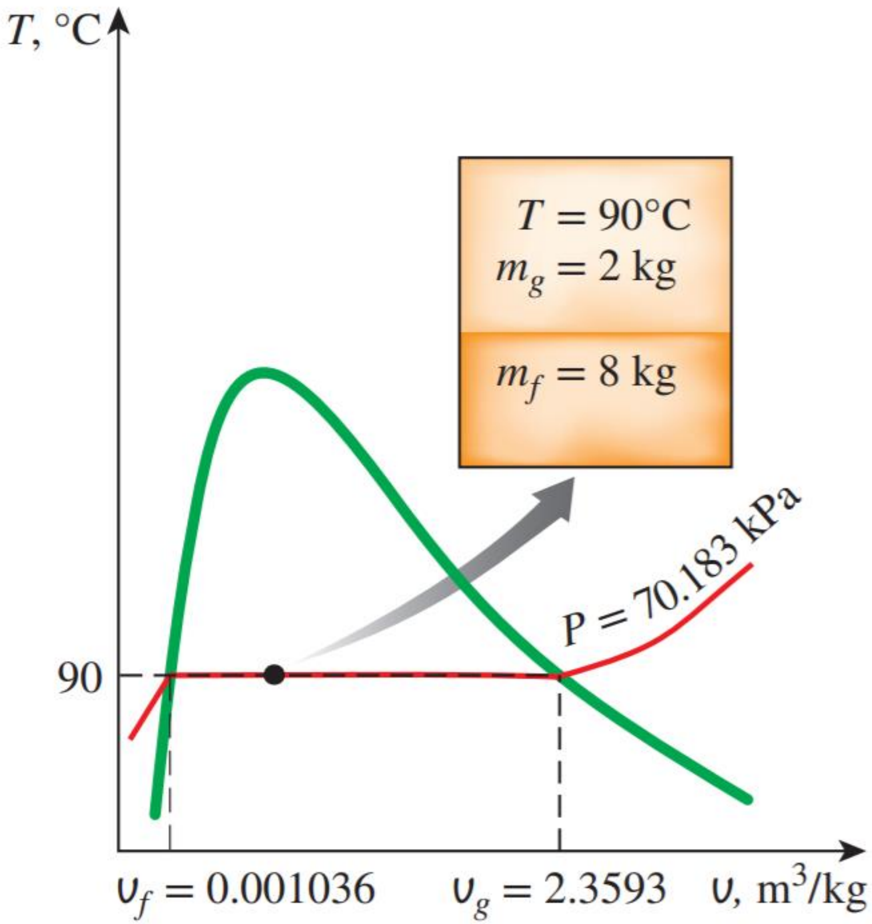
(c) P=5 bar and h= 3188 kJ/kg.

(d) P= 5 bar and h= 3150 kJ/kg.

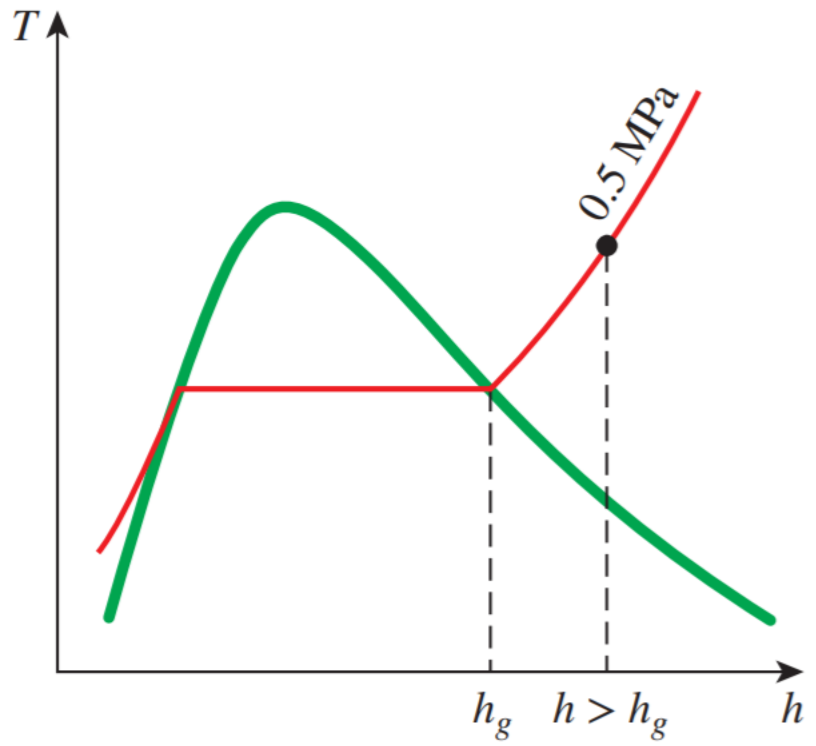
(e) P= 10bar and x=0.5.

(f) P=

Ex (2): A rigid tank contains 10 kg of water at 90°C. If 8 kg of the water is in the liquid form and the rest is in the vapor form, determine (a) the pressure in the tank and (b) the volume of the tank.



Ex (3): Determine the temperature of water at a state of P = 0.5 MPa and h = 2890 kJ/kg.



Ex (4): 1.5 kg of steam originally at 10 bar and temperature of 200 °C is expanded until the pressure becomes 3 bar with the dryness fraction of steam of 0.9. Determine the change in internal energy.

Thank you for listening