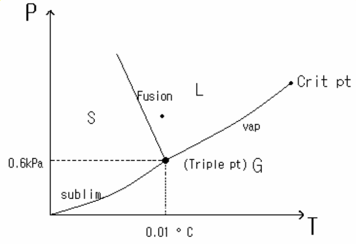
Chapter 3. Properties of Pure Substances and Equations of state

- Properties of Pure Substance

  Phase diagram

  Along these lines, two phases are in equilibrium



p–T diagram for water

- Triple pt at 0.01 °C, 0.6113 kPa
  (where 10^5 Pa = 1 atm and 0.006 x 10^5 Pa)
  - the state in which all 3 phases may be present in equilibrium.
- Sublimation line.......(both Vapor & Sol exist in equilibrium)
- Vaporization line.... (both Vapor & Liquid exist in equilibrium)
- Fusion line ....(both Solid & Liquid exist in equilibrium)

- Beyond Critical point, no distinct changes from L to V.

- Pure substance
  - one that has a homogeneous and invariable chemical composition.
  - ex) liquid water + steam
    liquid water + ice
    Air (at room temperature)

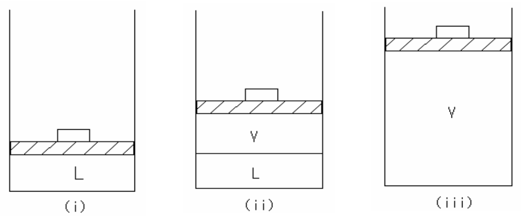
- Mixture
  - Air at low temperature (decomposes)
  - ex) liquid nitrogen + liquid oxygen
    (i.e. decomposed composition of Air)

- Phase equilibrium in a pure substance

  Consider a system, 1kg of water contained in the piston–cylinder arrangement;

  Water

  @p = p_0 = 1 atm = 0.1MPa



(*)

Fix p, increase T from 20°C to 100°C
At (ii), both phases (L+V) co–exist.

- Saturation (shown in step (ii) in the previous cartoon

  When two phases are in equilibrium, like in (ii).
  ex) L + V, S + L, S + V

  - Saturation liquid : Liquid that exists at the saturation temperature and pressure

  - Sub–cooled liquid : Temperature is lower than the saturation temperature for the given p.
  - Compressed liquid : Pressure is greater than the saturation pressure for the given temperature.

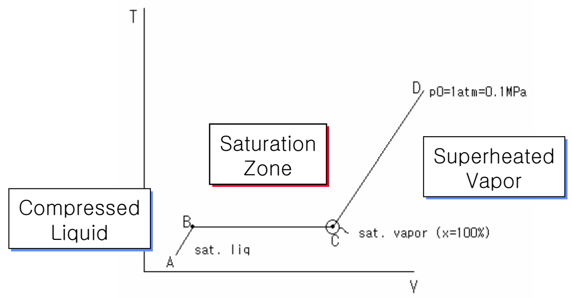
  NOTE: Sub–cooled Liquid = Compressed Liquid
  (Shown left of the steam dome on T–Vol Diagram)

- In (ii), if the $m_{vap} = 0.2kg$ and $m_{liq} = 0.8kg$, we define

  Quality (x) ≡ Ratio of the mass of vapor to the total mass
  = 0.2 or 20% = *x*

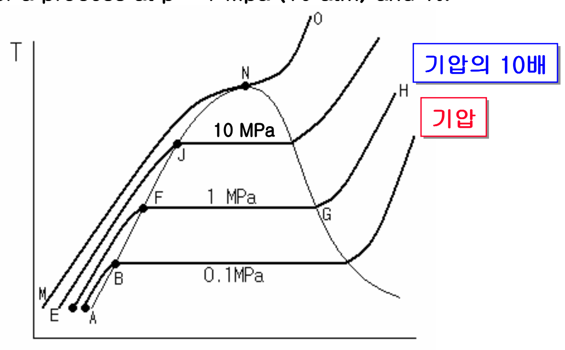
  - Saturated vapor = a substance exists as vapor at the saturation temperature
  - Superheated vapor = vapor is at a temperature greater than the saturation temperature. (대부분의 기체)
    (Shown on the right outer end of the steam dome on P-V)

- Let's plot T-V diagram that represents process shown in (*).



State	(A)	Initial state at T_0, P_0
	(B)	Saturated liquid state (T_{sat} 99.6°C)
	(A-B)	L is heated to T_{sat}
	(C)	Saturated vapor state
	(B-C)	L, V co-existing at constant T, and p (boiling)
	(C-D)	Steam(Vapor) is superheated at constant p

- Now consider a process at p = 1 Mpa (10 atm) and T_0.

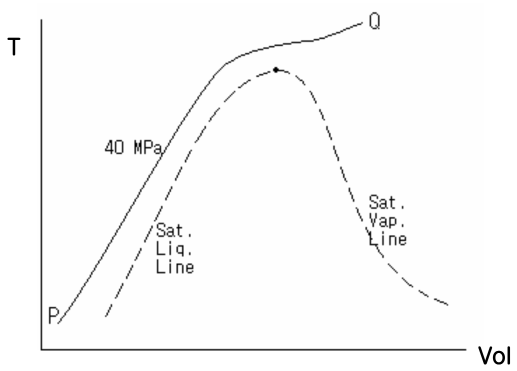


T_B = 99.6°C
T_F = 179.9°C (Sat. Liquid)
Sat. vapor state (G)
Superheated vapor (G-H)

- Draw p = 10 Mpa case, T_J = 311.1°C
- At a pressure of 22.09 Mpa (MNO) there is no constant temperature vaporization region or No co-existence region found.
- N is a point of inflection with zero slope. → "Critical point"
- Critical Point ≡ the saturated-liquid and saturated-vapor states are the same. P_{crit}, T_{crit}, V_{crit}.
- For some critical point data,

	T_{crit} (°C)	P_{crit} (Mpa)	v_{crit} (m³/kg)
Water	374.14	22.09	0.003155
Carbon Dioxide	31.05	7.39	0.002143
Oxygen	-118.35	5.08	0.002438
Hydrogen	-239.85	1.3	0.032192

- If p ~ 40 Mpa

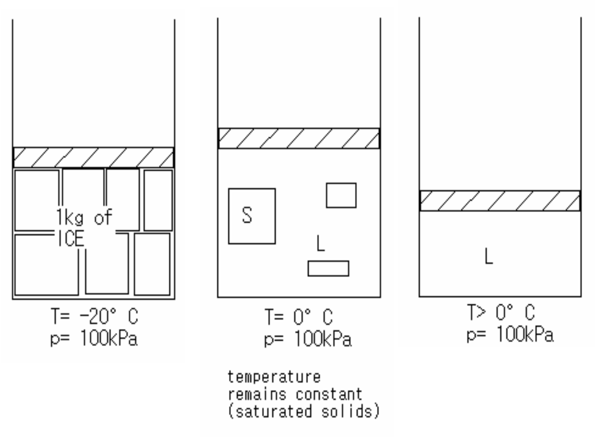


If p > p_{crit}, for water at 40MPa, 20°C is heated in constant p process in a cylinder as shown in (*), there will never be 2 phases present and state (ii) will never exist.

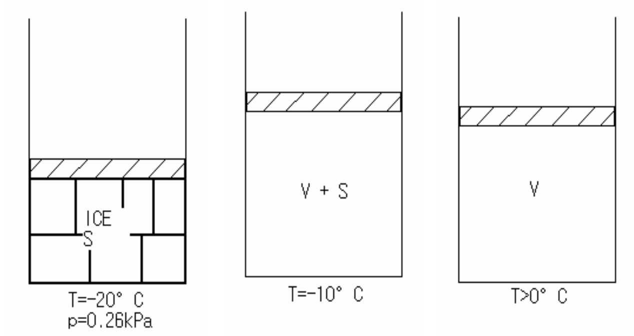
→ only superheated vapor exists at p > p_{crit}.

- Another experiment ------------------------(**) for water

Adding HEAT

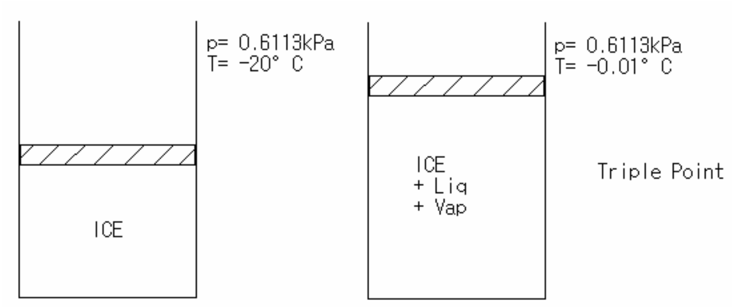


- Another example----------------(***)
  T = −20°C
  P = 0.26kPa (S → Vapor) Sublimation (승화)

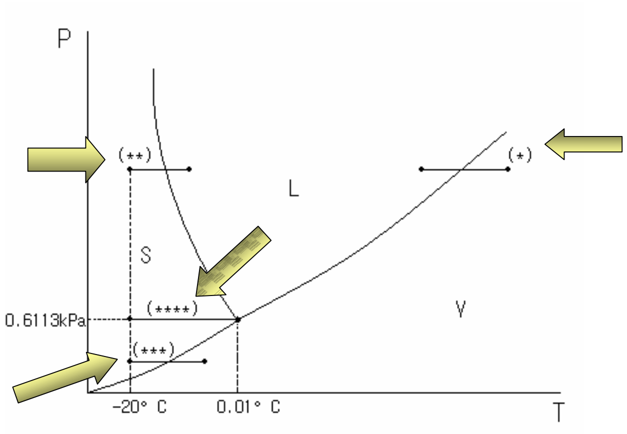


Aside	S → L	fusion (melt) 융해
	L → V	evaporate 증발
	S → V	sublimation 승화

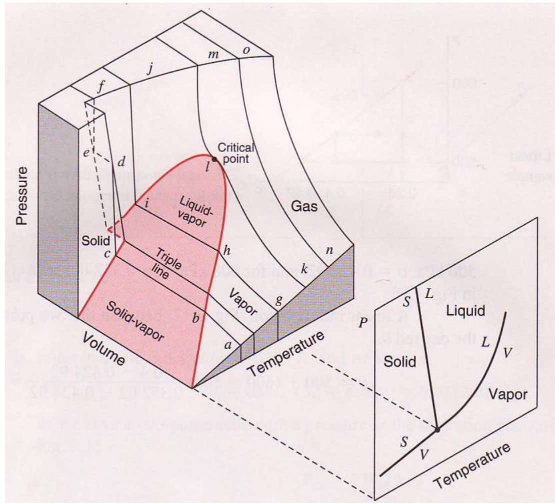
- Another Example--------------------------(****)



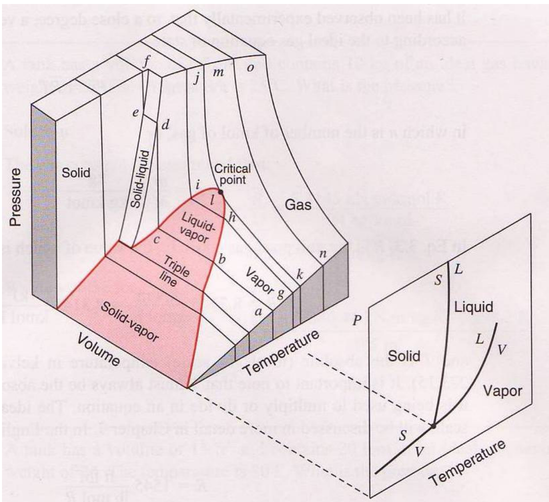
- Describe all 4 processes on P–T curve (Constant–p processes)



These are the lines of phase equilibrium.



P–Vol.–T surface for a substance that expands on freezing
(such as WATER!)



P–Vol.–T surface for a substance that contracts on freezing