Substances and ideal gases

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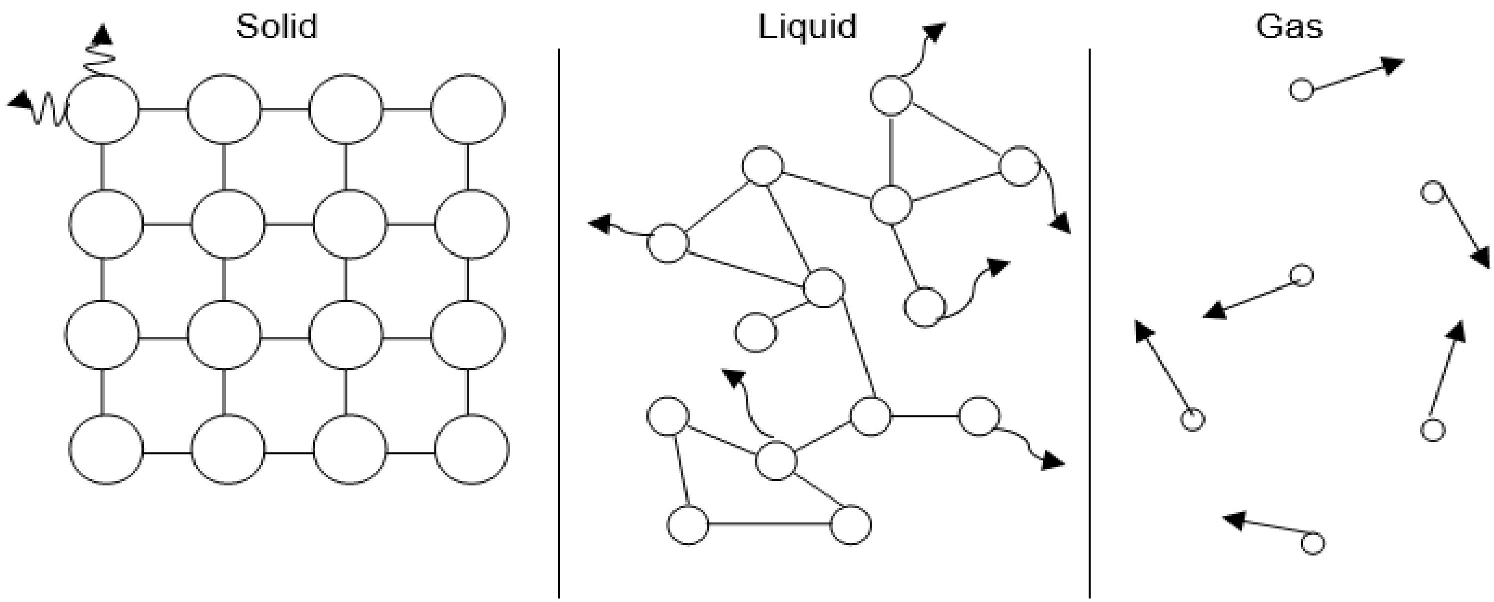
Content

- Phase and phase diagram
- Two phase region, dryness fraction (quality)
- Phase change, latent heat and sensible heat
- Steam (property) tables, linear interpolation
- Ideal gas equations (mass form and molar form) and approximations
- Mixture of gases
- Dalton’s model, partial pressure, partial volume

Substances

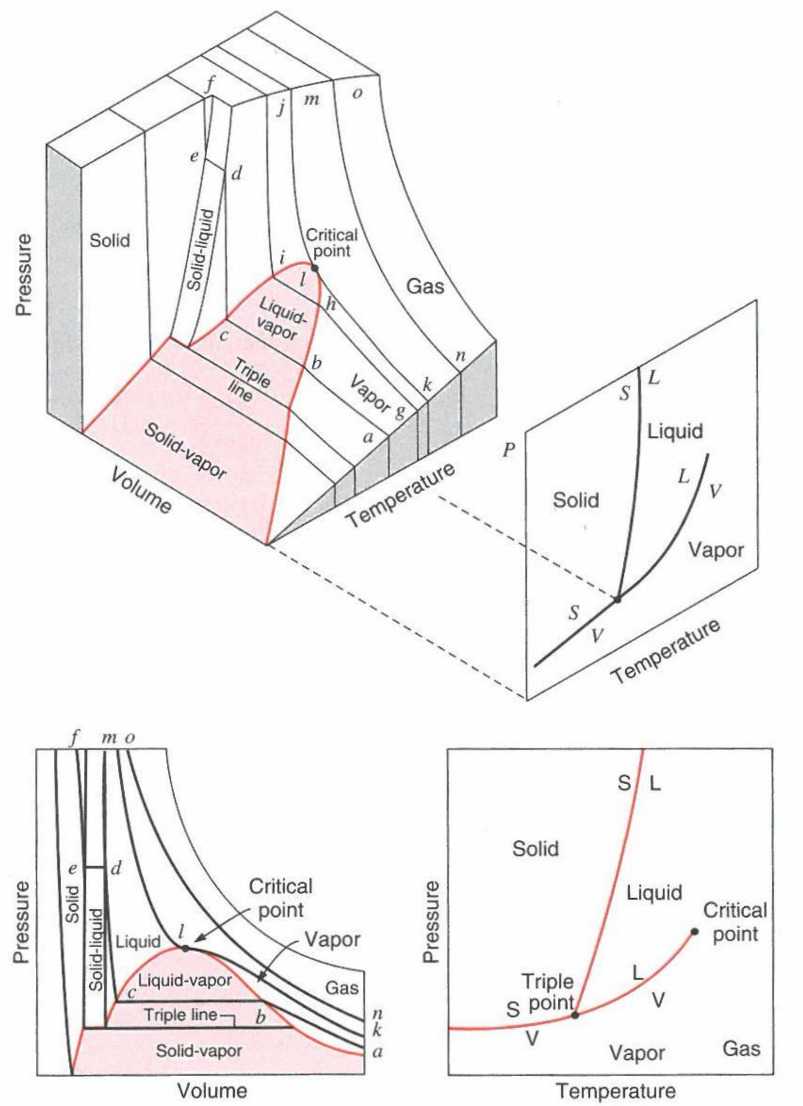
Phases

A **phase** is defined as a quantity of matter that is homogeneous throughout.

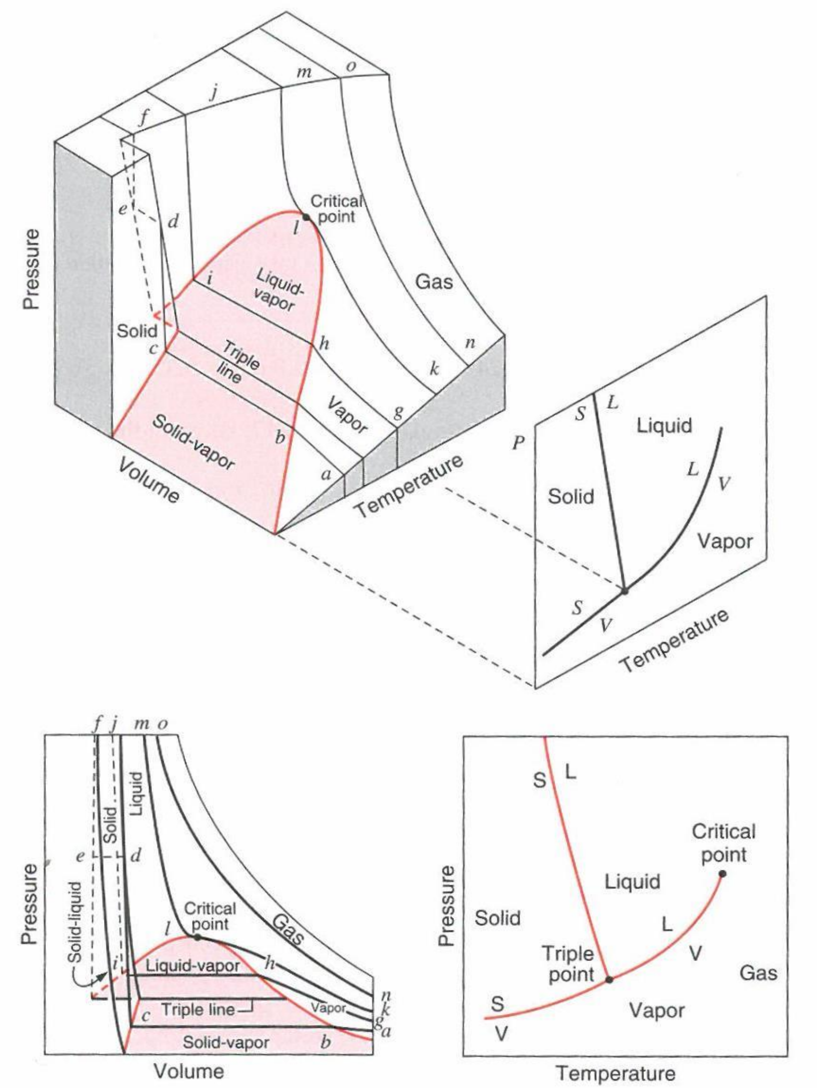


Substances

Phase diagram



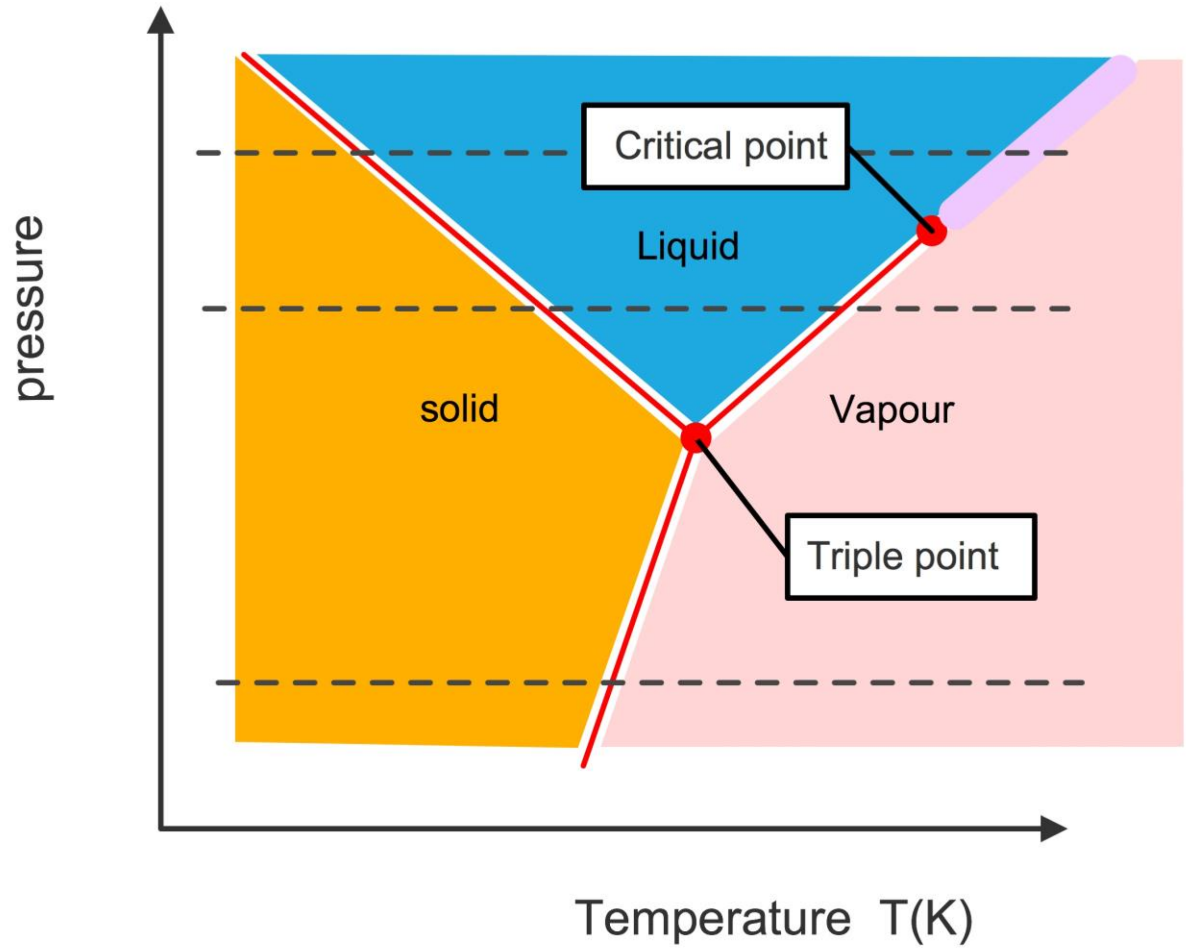
Phase diagram of a substance that contracts on freezing



Phase diagram of a substance that expands on freezing

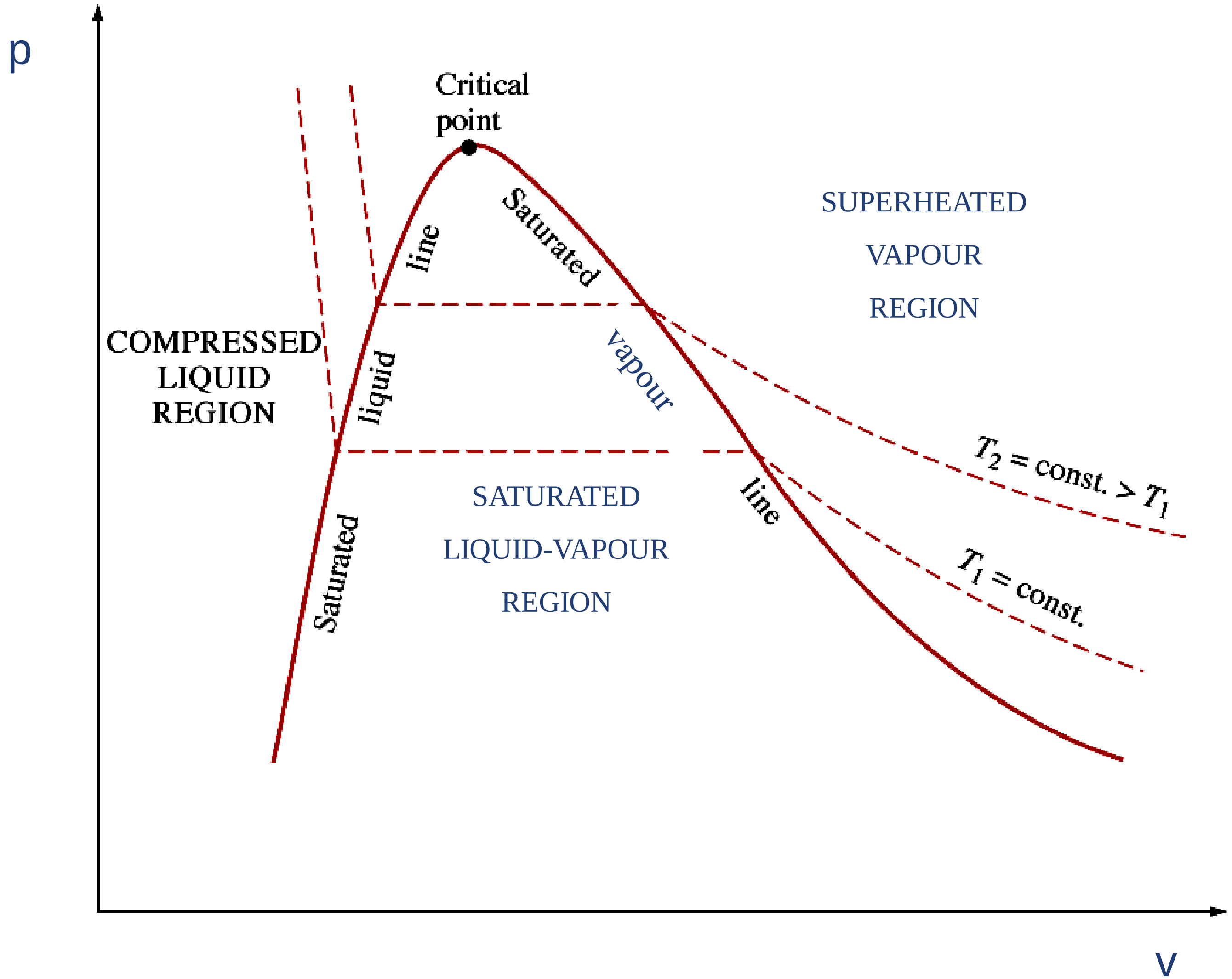
Substances

Phase diagram



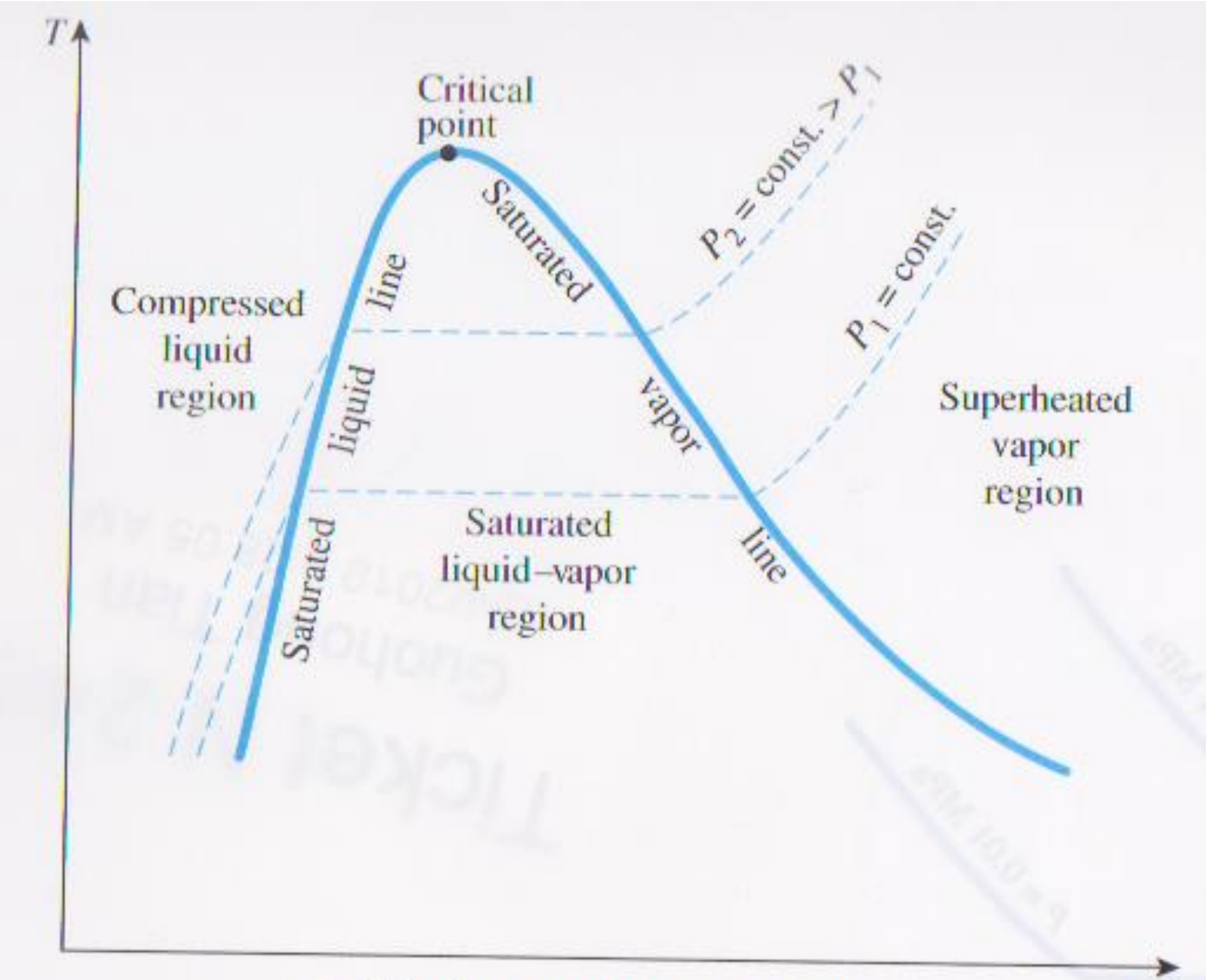
p-T diagram

p-v diagram of a pure substance and terminology



Substances

T-v diagram of a pure substance and terminology

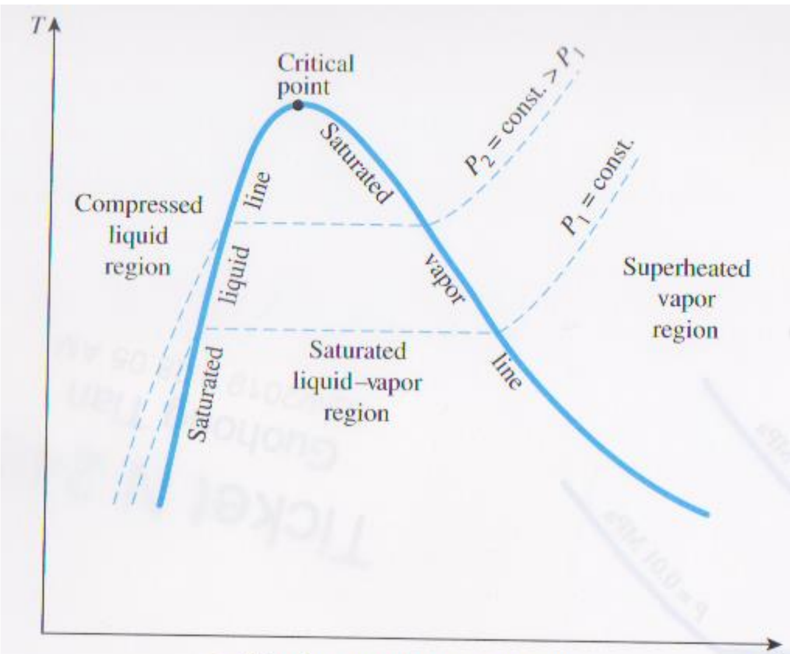


(a) T-v diagram of a pure substance

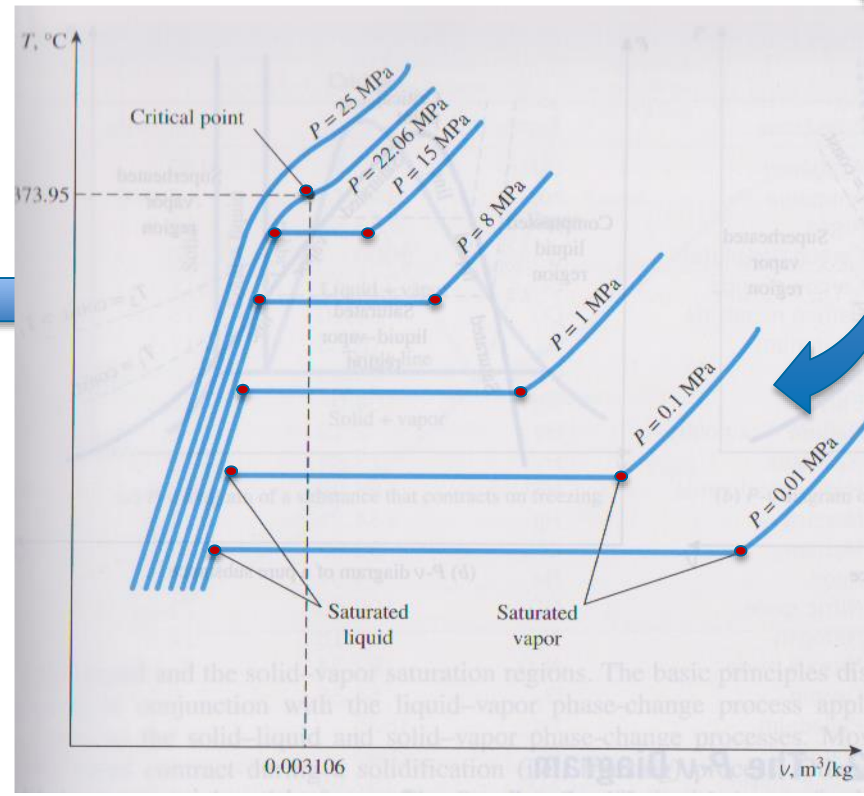
T-v diagram of a pure substance

@1bar

Temperature (°C)	-10	0	0	50	100	100	150
Specific volume (m^3/kg)	0.00106	0.00109	0.00100	0.00101	0.00104	1.673	1.912

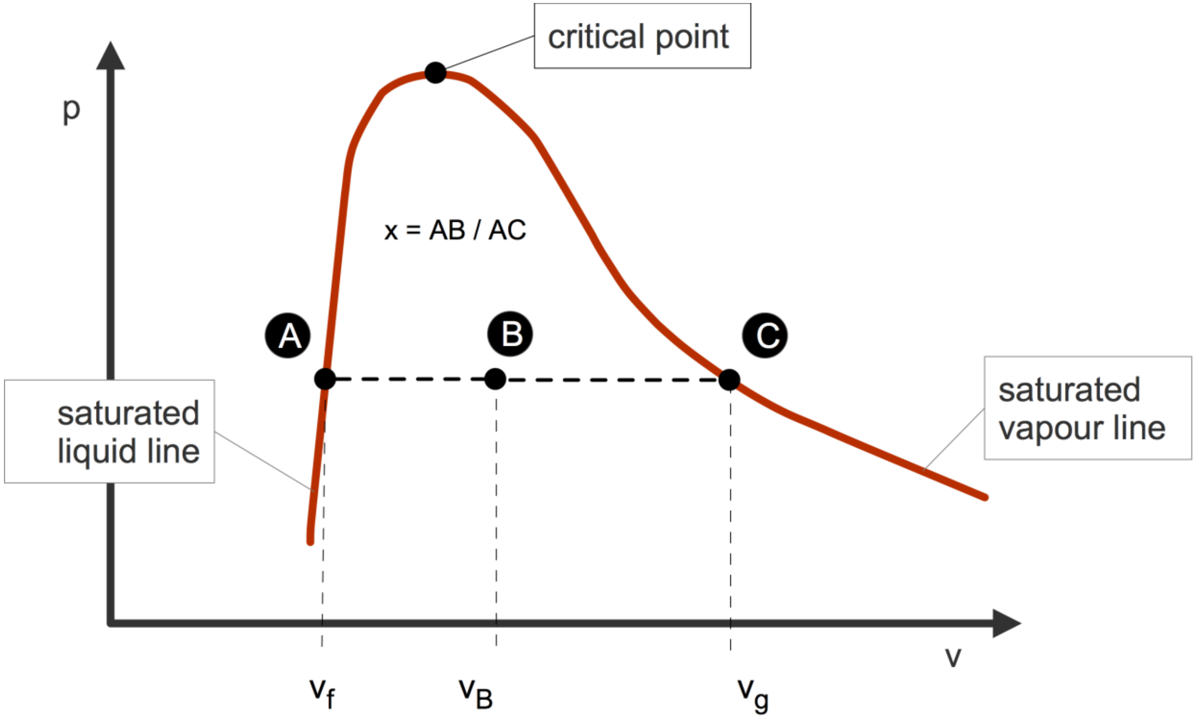


(a) T-v diagram of a pure substance



[Supercritical fluid video clip]

The two phase region

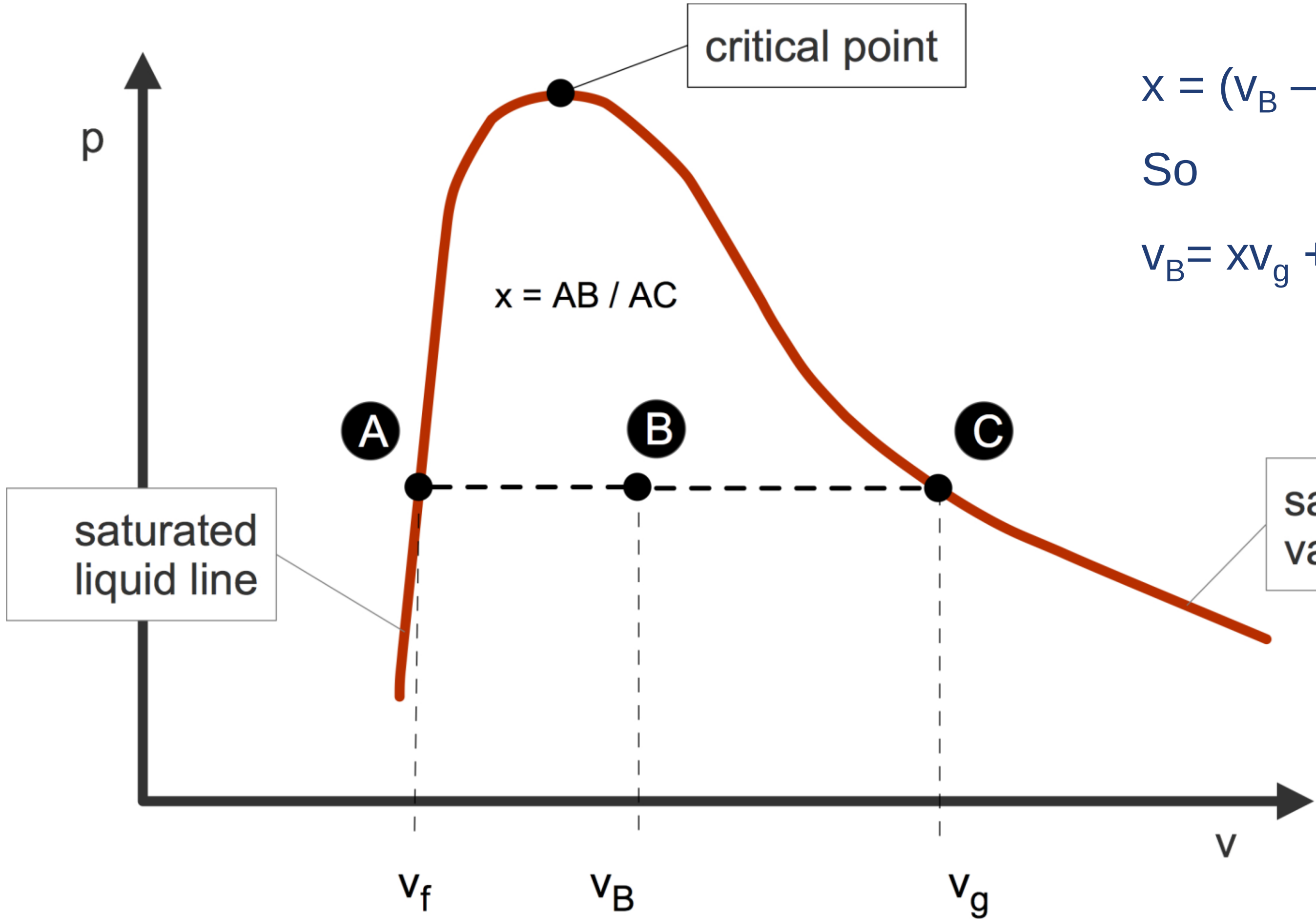


x = Quality or Dryness fraction

Relates to horizontal distances on p-v or T-v diagrams

$$\text{Dryness fraction } (x) = \frac{\text{mass of pure vapour in mixture}}{\text{mass of liquid and vapour}}$$

Dryness fraction



$x = (v_B – v_f)/(v_g – v_f)$

So

$v_B = xv_g + (1 – x)\ v_f$

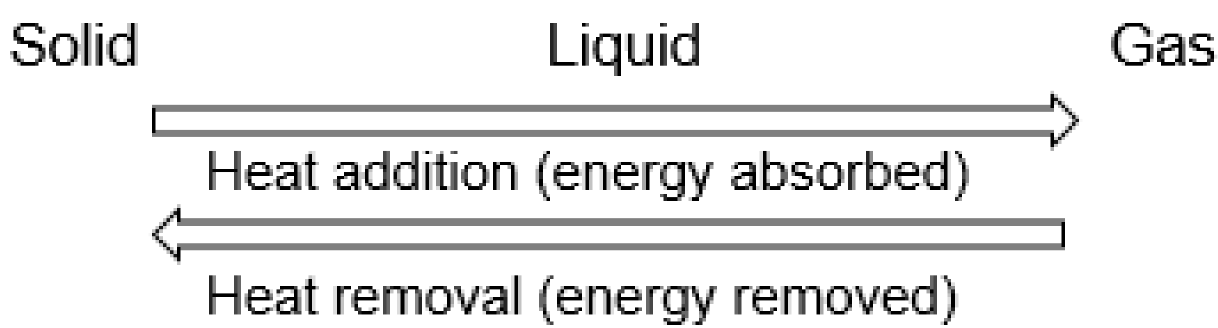
Similarly $h_B = xh_g + (1 – x)\ h_f$ Or $h_B = h_f + x\ h_{fg}$

In fact $\varphi_B = x\ \varphi_g + (1 – x)\ \varphi_f$ Or $\varphi_B = \varphi_f + x\ \varphi_{fg}$, where φ can be any specific properties

Phase change

During phase change, substance exists simultaneously in two phase at the same temperature. In this process the **temperature remains constant at constant pressure** until the process finishes.

Terminology:	**freeze** or **solidify**:	gas/vapour or liquid	→ solid
	melt or **fuse**:	solid	→ liquid
	sublimate:	solid	→ gas/vapour
	boil or **evaporate**:	liquid	→ gas/vapour
	condense or **liquefy**:	gas/vapour	→ liquid



Phase change

Latent heat and sensible heat

The energy transferred at constant temperature during change of phase is (specific) **latent heat**

$Q = m\lambda$ where λ (J/kg) is specific latent heat

The energy transferred in single phase resulting in temperature change is **sensible heat**.

$Q = mc\Delta T$ where c (J/kg K) is specific heat capacity

Latent heat λ has two components: changing molecular potential energy and specific work done by/against surroundings at constant pressure $p\Delta V$ due to change in volume when phase changes.

Ideal gas

Ideal gas equations

Boyle's Law

pV = constant, at constant temperature

Charle's (or Gay-Lussac's) Law

V/T = constant, at constant pressure

Combine:

$\boldsymbol{pV = mRT}$ where R (J/kg K) is a **constant for a specific gas**

Avogadro's Law

$\boldsymbol{pV = nR_0T}$ where n is the mole number and R_0 is the **universal constant** for all gases $R_0 = 8314$ (J/kmol K)

$M \equiv m/n$ therefore $R = R_0/M$

Ideal gas

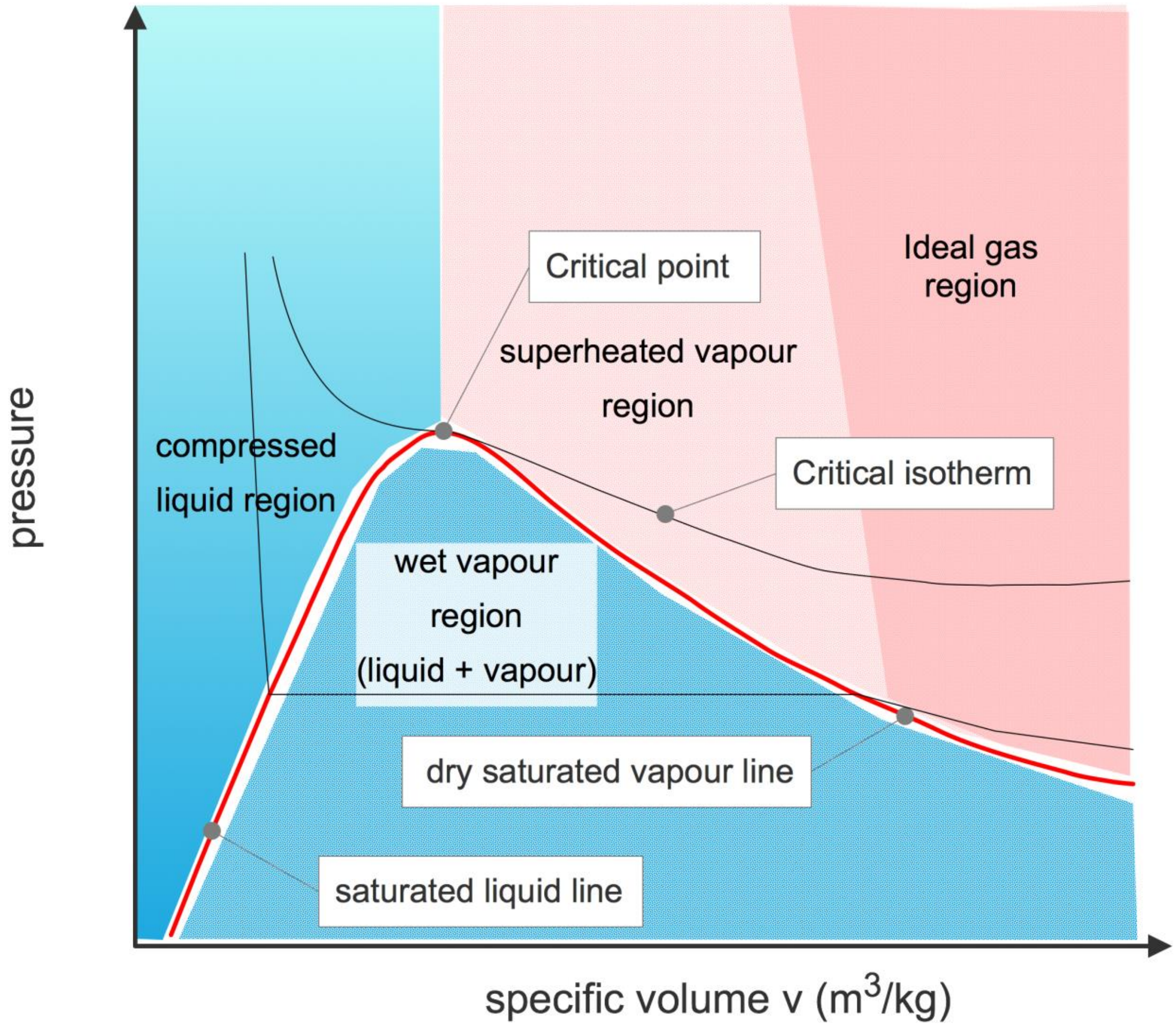
Ideal gas approximations

- All molecules are identical
- Sufficiently large numbers of molecules for statistics to be significant
- Molecular motion is continuous and random
- Law of Newtonian physics apply at molecular scale
- *Attractive forces between molecules are negligible
- *Any collisions between molecules and with walls of container are perfectly elastic
- *Molecules occupy negligible volume themselves

last three items imply that the ideal gas approximations are only valid when in the region of modest temperature and pressure of **gas phase**.

Ideal gas

Ideal gas approximation valid region



Mixture of gases

$$m_{tot} = m_1 + m_2 + \cdots + m_N = \sum m_i$$

$$n_{tot} = n_1 + n_2 + \cdots + n_N = \sum n_i$$

Mass fraction of component i: $$x_{mi} = \frac{m_i}{m_{tot}}$$

Mole fraction of component i: $$x_{ni} = \frac{n_i}{n_{tot}}$$

To calculate mass fraction from mole fraction

$$x_{mi} = \frac{n_i M_i}{m_{tot}} = \frac{n_i M_i}{\sum n_j M_j} = \frac{n_i M_i / n_{tot}}{\sum n_j M_j / n_{tot}} = \frac{x_{ni} M_i}{\sum x_{nj} M_j}$$

To calculate mole fraction from mass fraction

$$x_{ni} = \frac{m_i / M_i}{n_{tot}} = \frac{m_i / M_i}{\sum m_j / M_j} = \frac{m_i / (M_i m_{tot})}{\sum m_j / (M_j m_{tot})} = \frac{x_{mi} / M_i}{\sum x_{mj} / M_j}$$

Ideal gas

Mixture of ideal gases

The molar mass of the mixture becomes:

$$M_{mix} = \frac{m_{tot}}{n_{tot}} = \frac{\sum m_i}{n_{tot}} = \frac{\sum n_i M_i}{n_{tot}} = \sum x_{ni} M_i$$

Gibb's Law for extensive properties of any mixture (not just ideal gas)

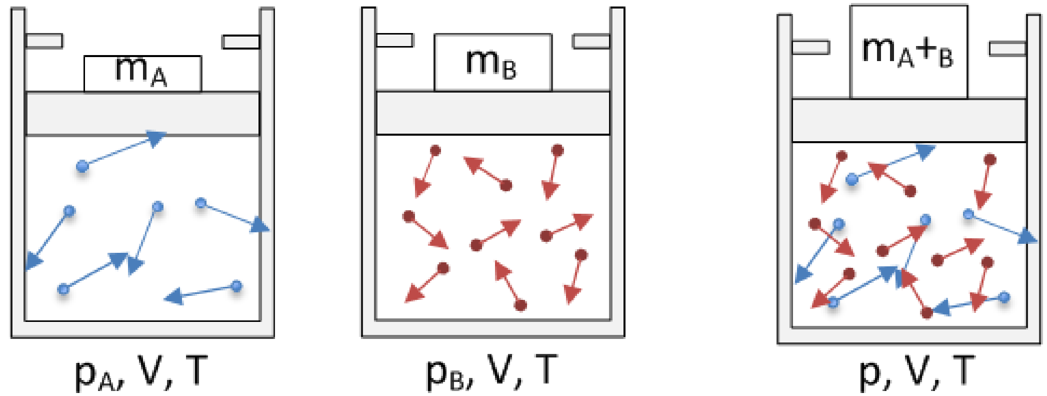
$\Phi_{tot} = \sum \Phi_i$ e.g. $\mathrm{U}_{tot} = \sum \mathrm{U}_i$ or $\mathrm{H}_{tot} = \sum \mathrm{H}_i$

Ideal gas

Dalton model

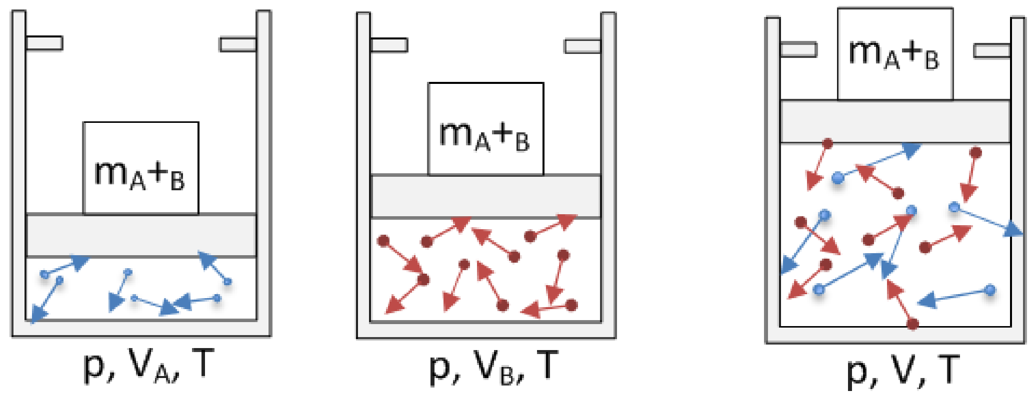
Partial pressure

$$p = p_A + p_B$$



partial volume

$$V = V_A + V_B$$



$$p_i V_{tot} = n_i R_0 T \quad \text{or} \quad p_{tot} V_i = n_i R_0 T$$

$$p_i = \frac{n_i R_0 T}{V_{tot}} = \frac{n_i}{n_{tot}} p_{tot} \quad \text{or} \quad V_i = \frac{n_i R_0 T}{P_{tot}} = \frac{n_i}{n_{tot}} V_{tot}$$

$$\boldsymbol{x_{pi} \equiv x_{ni} \equiv x_{Vi}}$$

Summary

- Phase and phase diagram (understanding and recognition)
- Two phase region, dryness fraction (quality) (understanding, calculation)
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- Steam (property) tables, linear interpolation (understanding, calculation)
- Ideal gas equations (mass form and molar form) and approximations (understanding and application)
- Mixture of gases (understanding and calculation)
- Dalton's model, partial pressure, partial volume (understanding and calculation)