

Review of Separation Principles

An hour in the library could save you six weeks in the laboratory.

George Quarderer

Mixer and Splitter

Reactor

Flash

Distillation

Absorption

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Multicomponent Systems
Linear Balances

Mixer and Splitter
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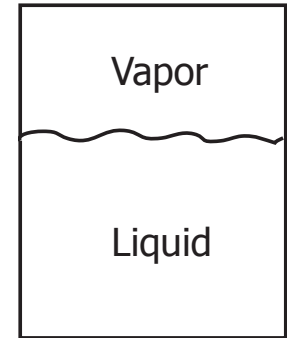
Multicomponent Systems
Linear Balances

Before we develop linear models for flash and distillation units, we will review some fundamental principles of separations that were covered in previous courses.

Vapor Liquid Equilibrium

1. Pure Substance

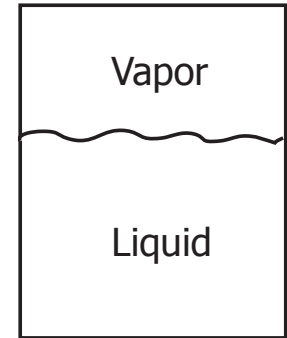
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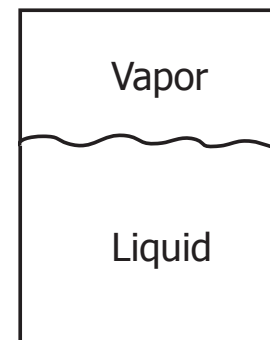
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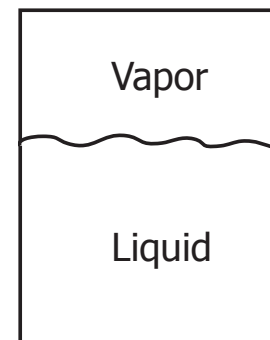
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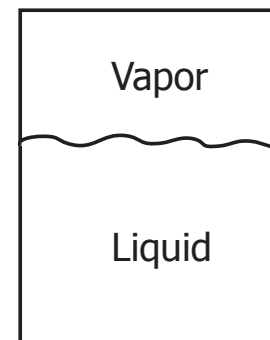
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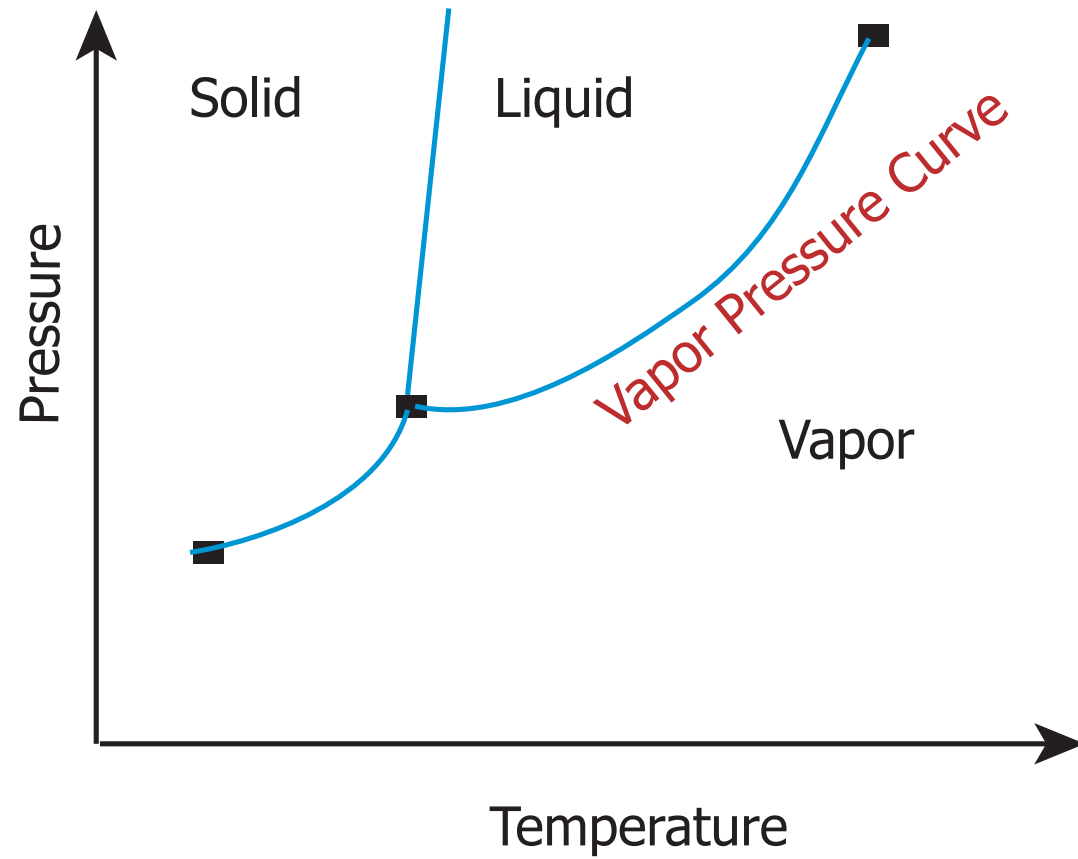


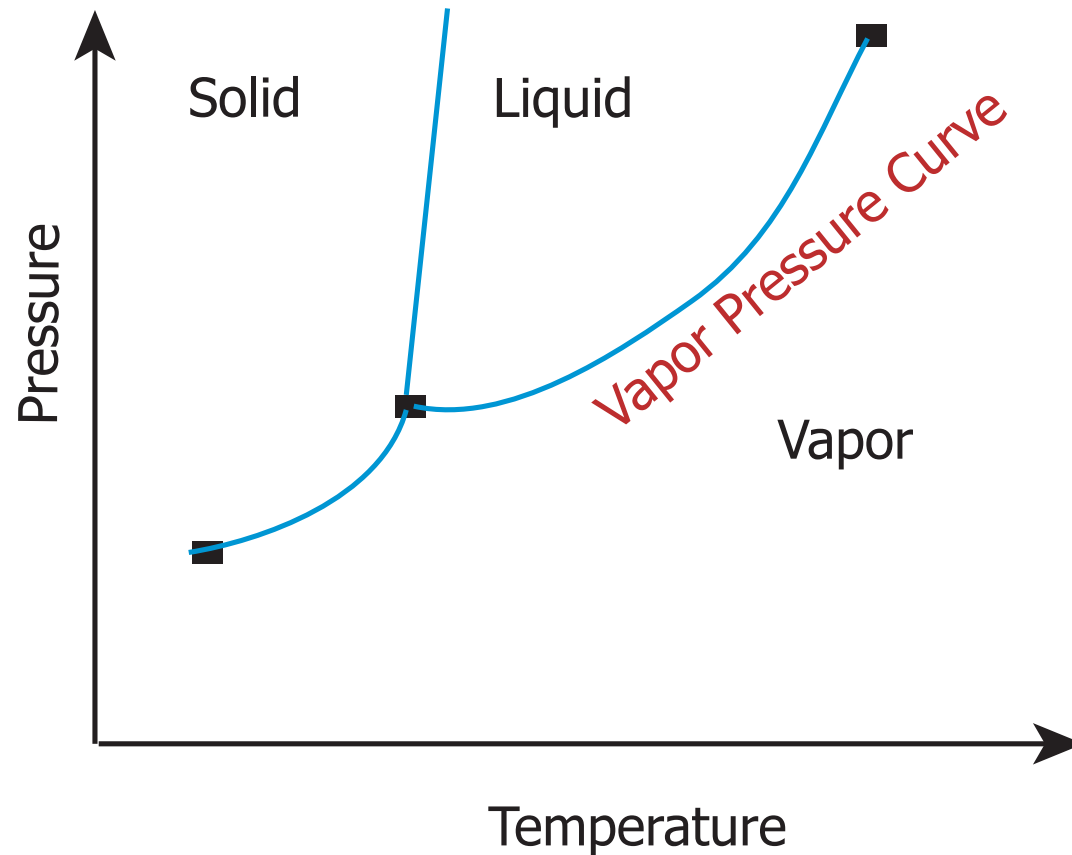
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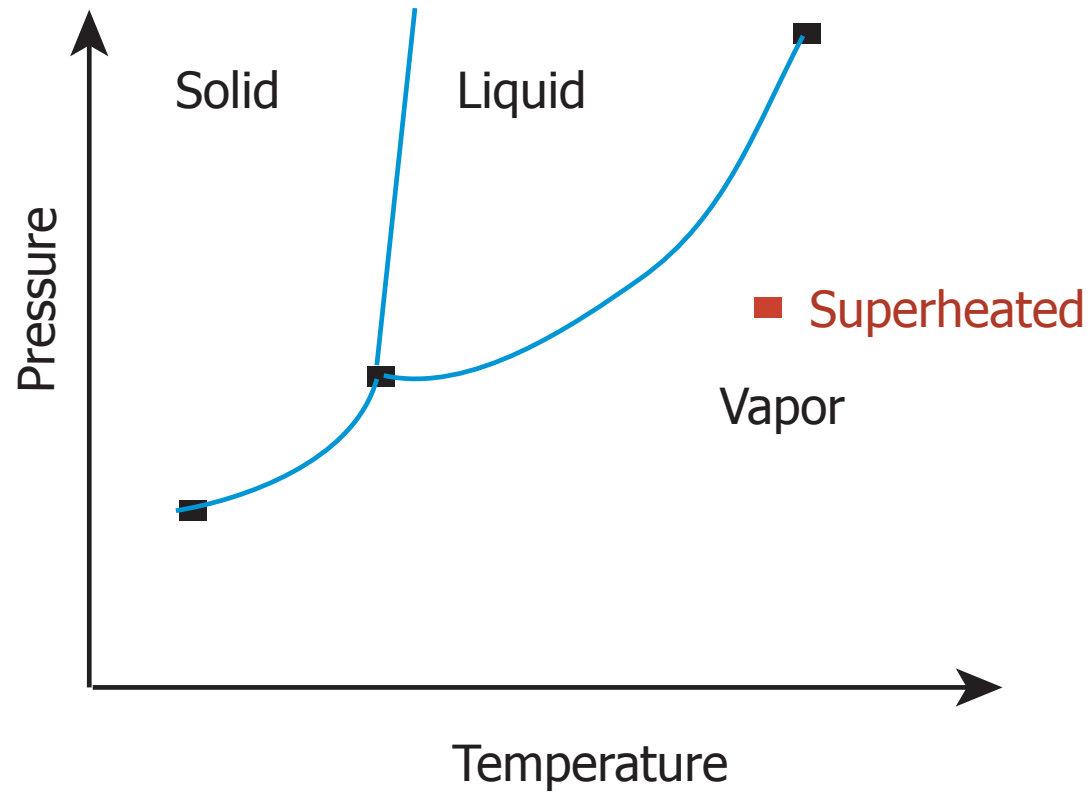
- When a pure liquid is placed in a sealed container, part of the liquid evaporates.
- At **equilibrium**, the pressure exerted by the vapor on the liquid is called the **vapor pressure** of the **liquid**.
- The value of the vapor pressure is **independent** of the amount of liquid in the container.
- Vapor pressure **increases** with temperature.
- The **boiling point** of a liquid is the temperature at which the vapor pressure equals the total pressure. At this point, liquid and vapor may co-exist in **any** proportion indefinitely.

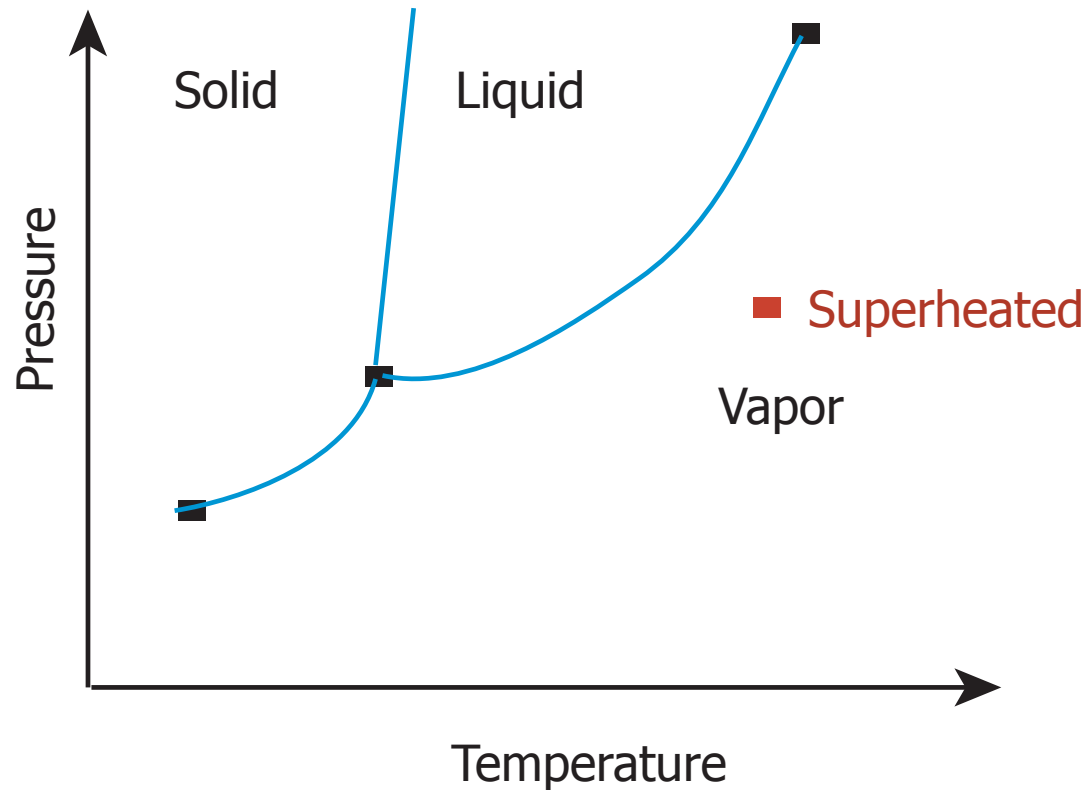




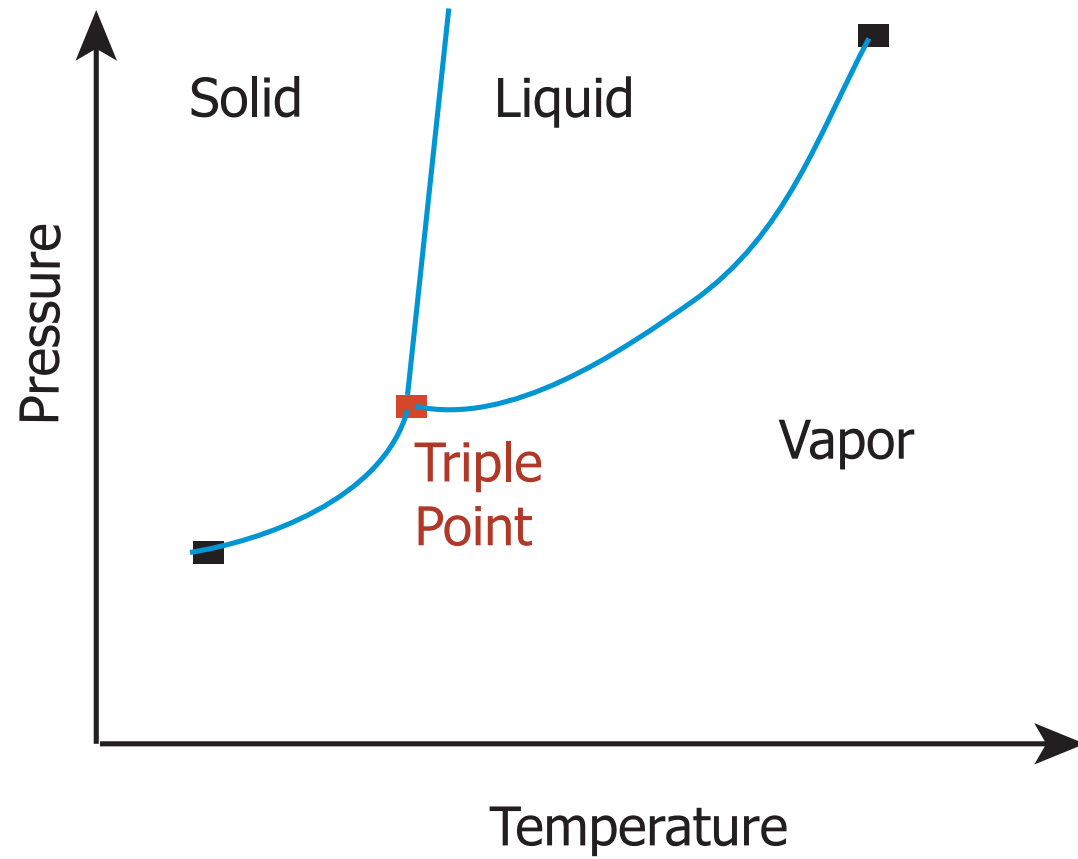


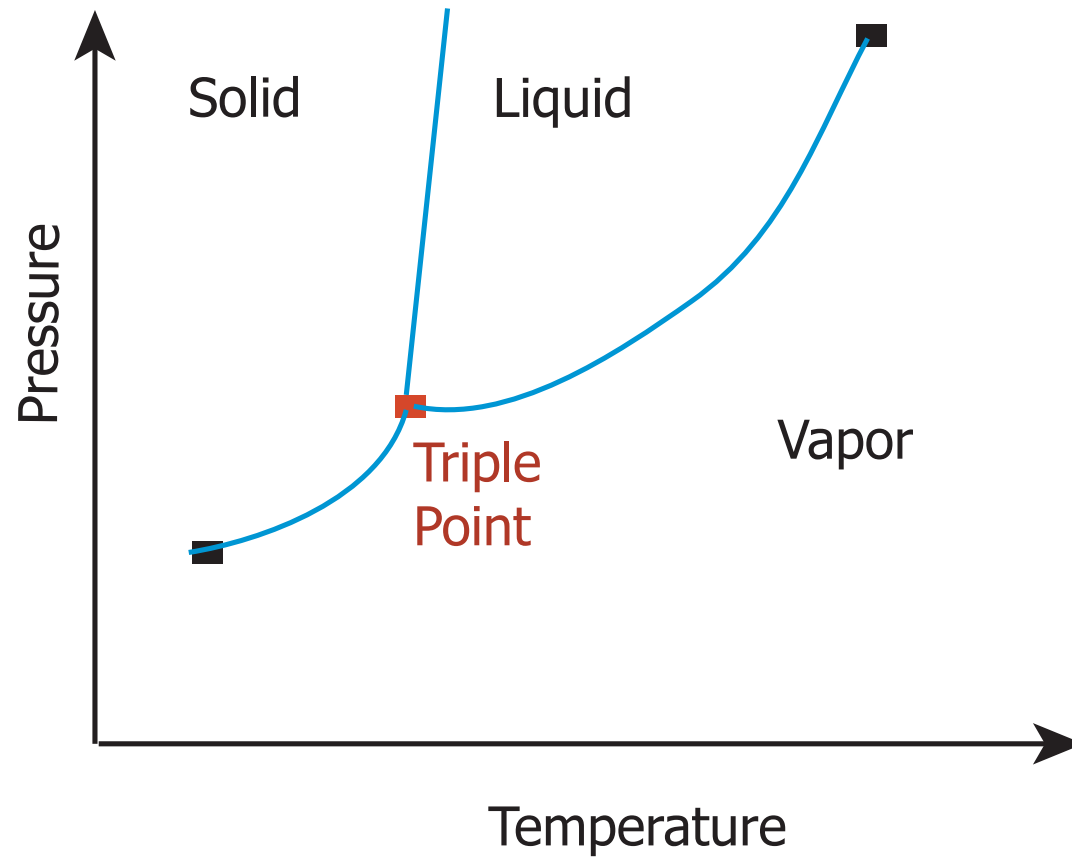
Liquid and vapor represented by points on the vapor pressure curve are called **saturated liquid** and **saturated vapor** respectively.



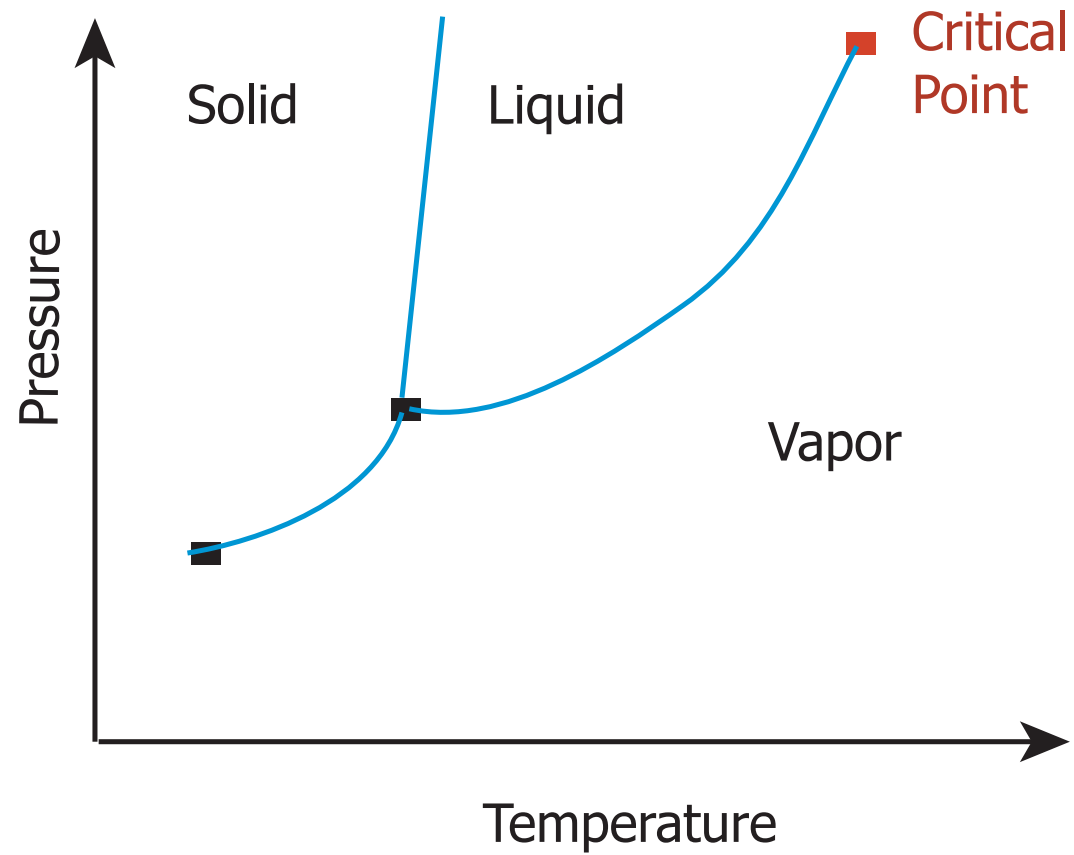


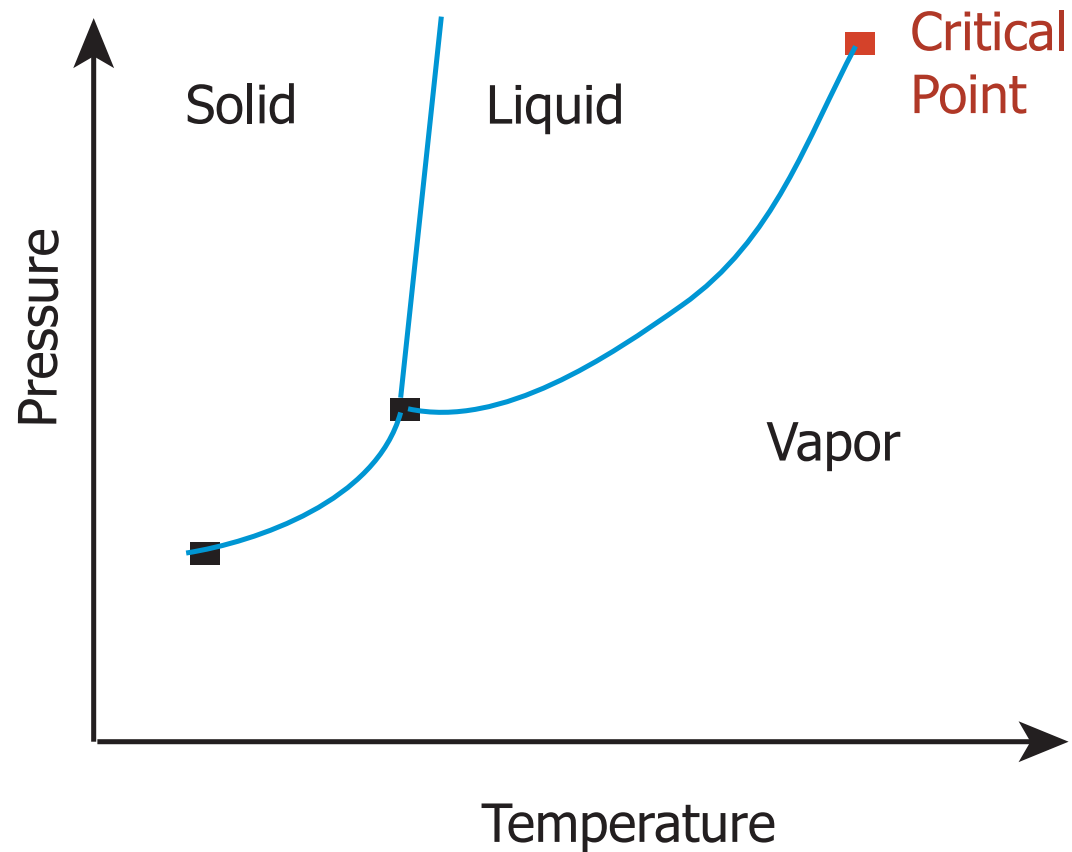
Vapor or gas at temperature above that corresponding to saturated is called **superheated**.



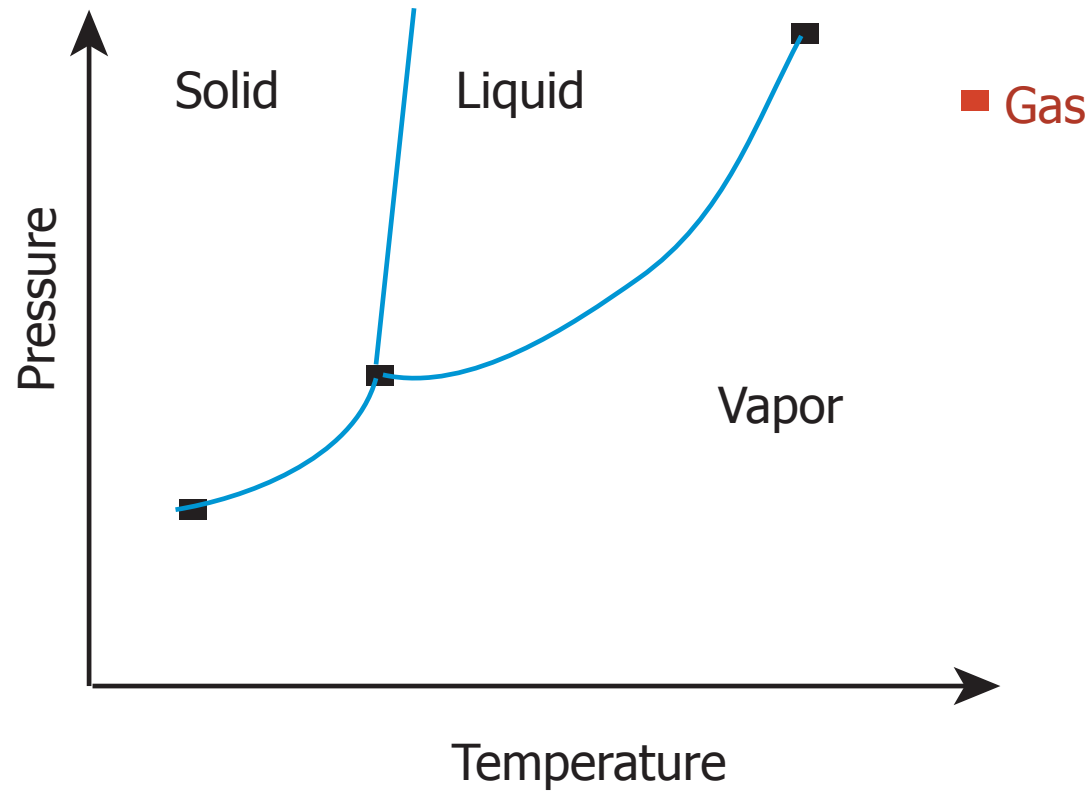


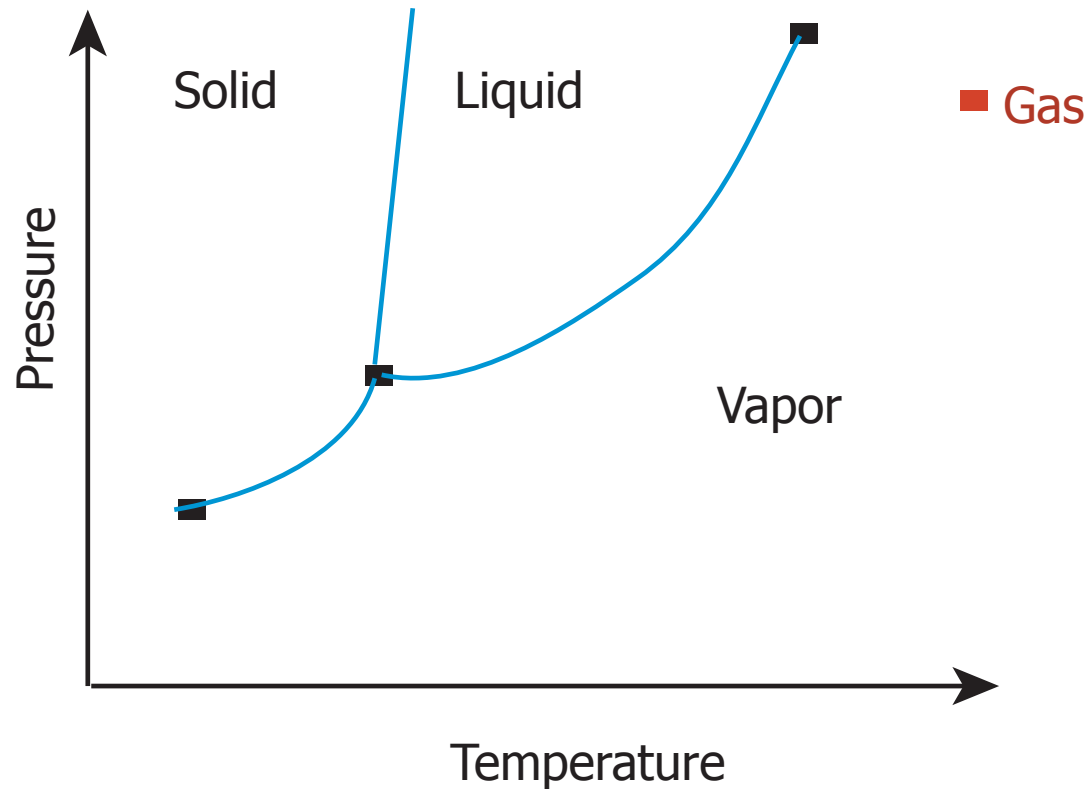
All three states **co-exist** at the **triple point**.





At the **critical point**, distinction between liquid and vapor disappears and all properties of the liquid, such as density, viscosity, refractive index etc. are **identical** to that of the vapor.





The substance at the temperature **above** the critical point is called a **gas** and it will not be **liquified** at this temperature regardless of how high the pressure might be imposed.

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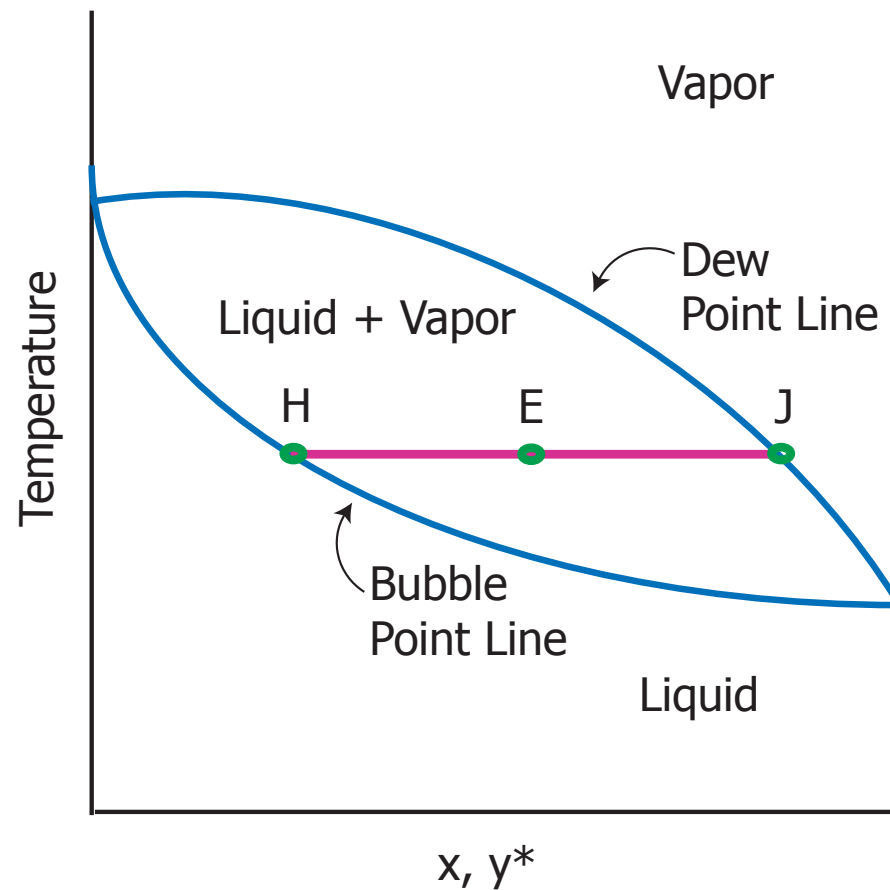
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- However, there is an additional variable, **concentration** (usually represented by mole fraction)

x : mole fraction of A in **liquid**

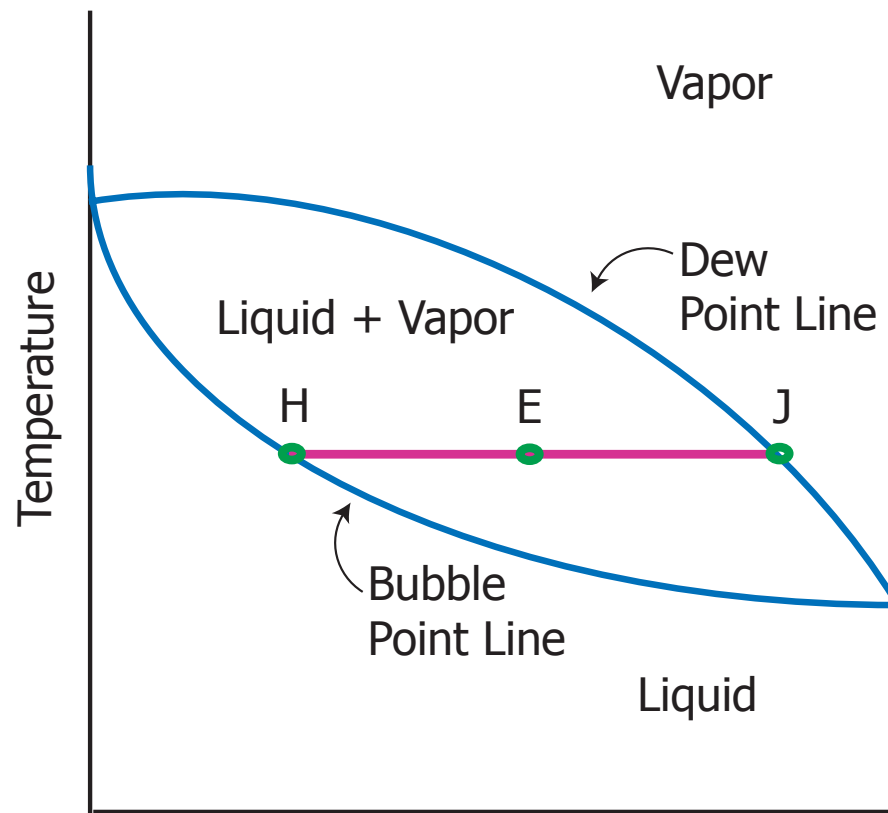
y^* : corresponding mole fraction of A in **vapor**

$(1 - x)$: mole fraction of B in liquid

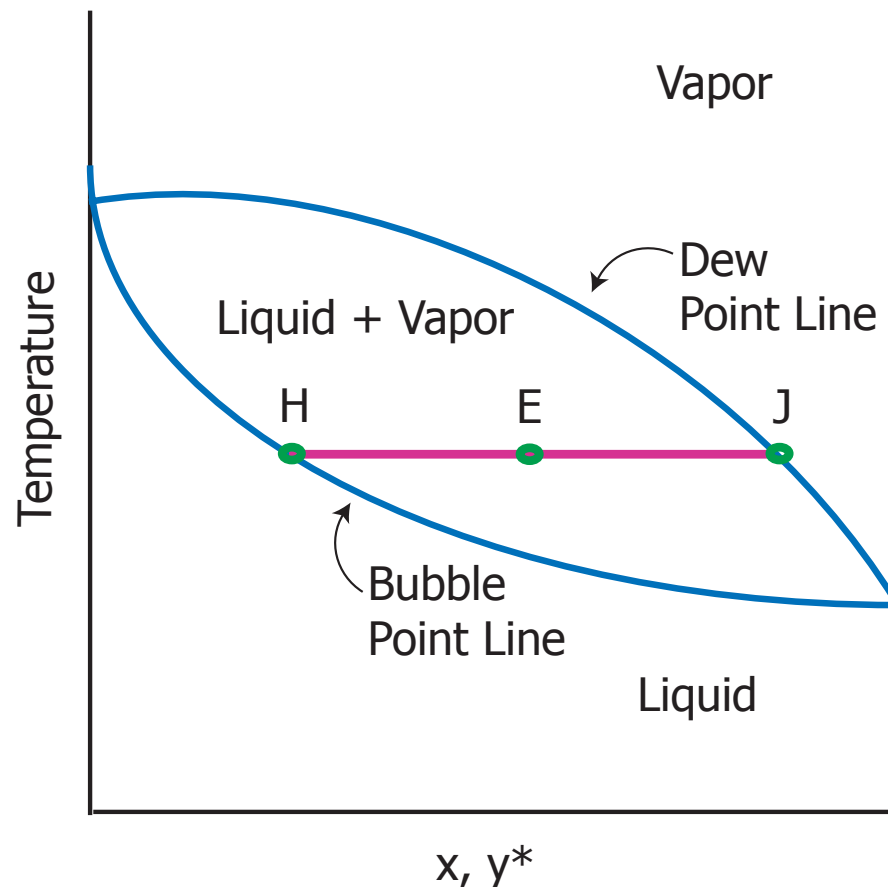
$(1 - y^*)$: corresponding mole fraction of A in vapor



- At point H , the mixture is a **saturated liquid**.

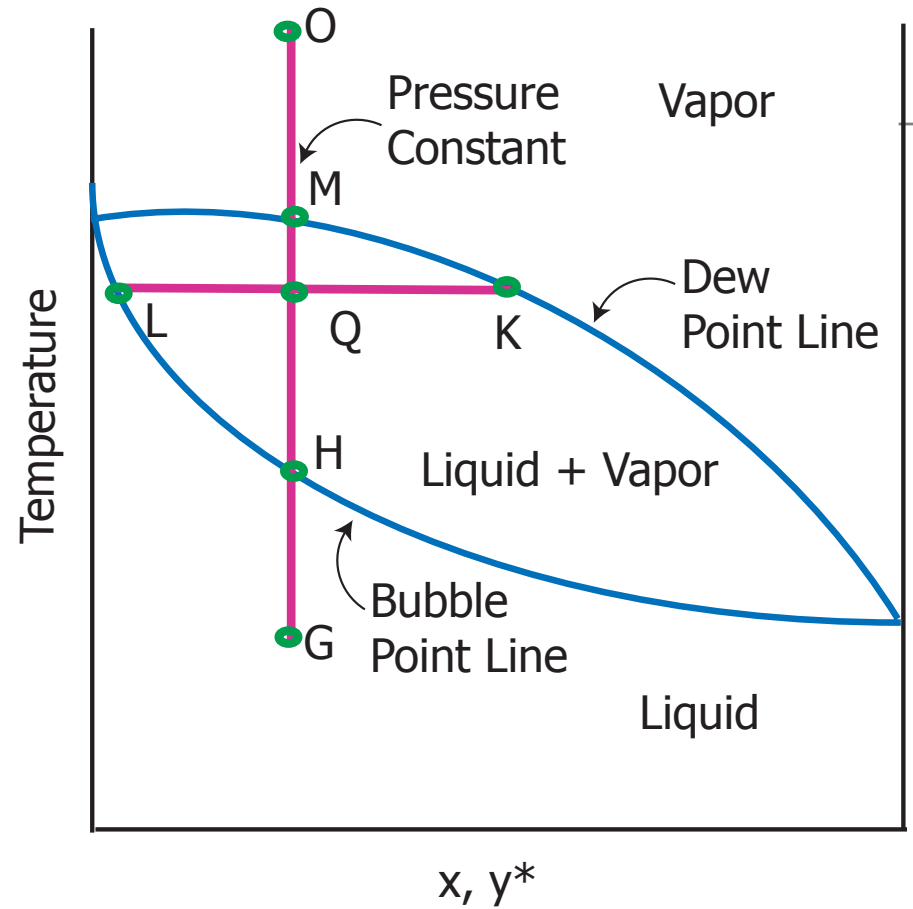


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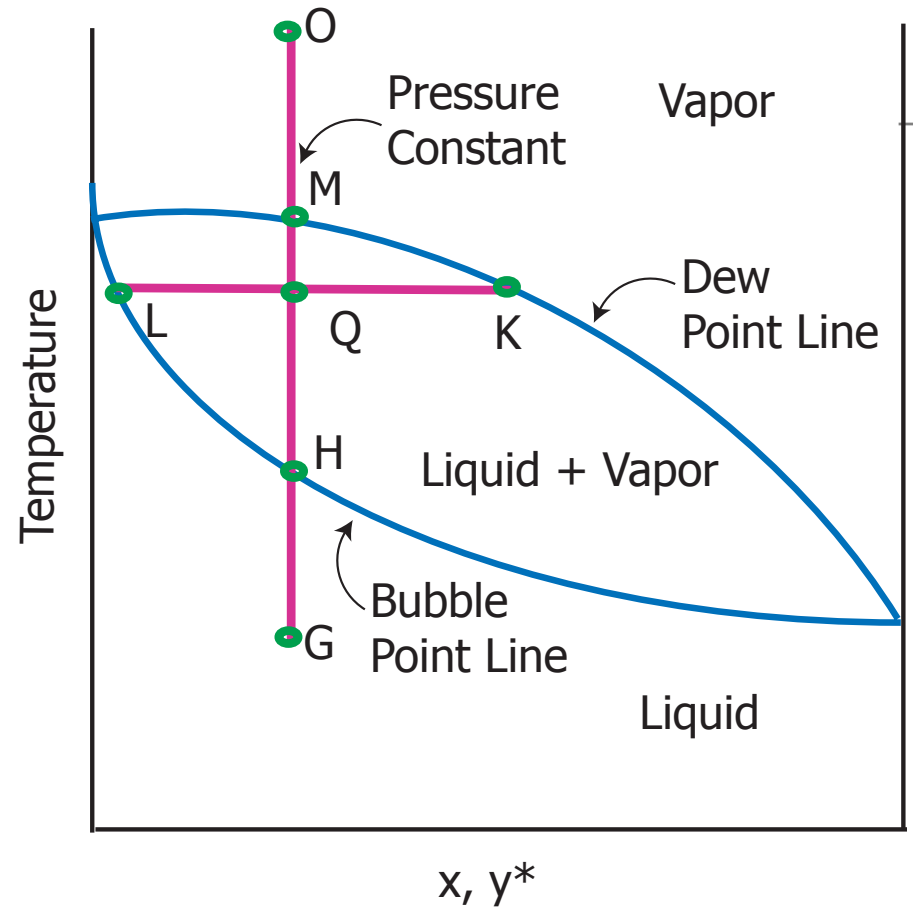


- At point H , the mixture is a **saturated liquid**.
- At point J , the mixture is a **saturated vapor**.
- At point E , the mixture is a **two phase** mixture with liquid phase composition of H and vapor phase composition of J such that the **average** composition of the entire mixture is E .

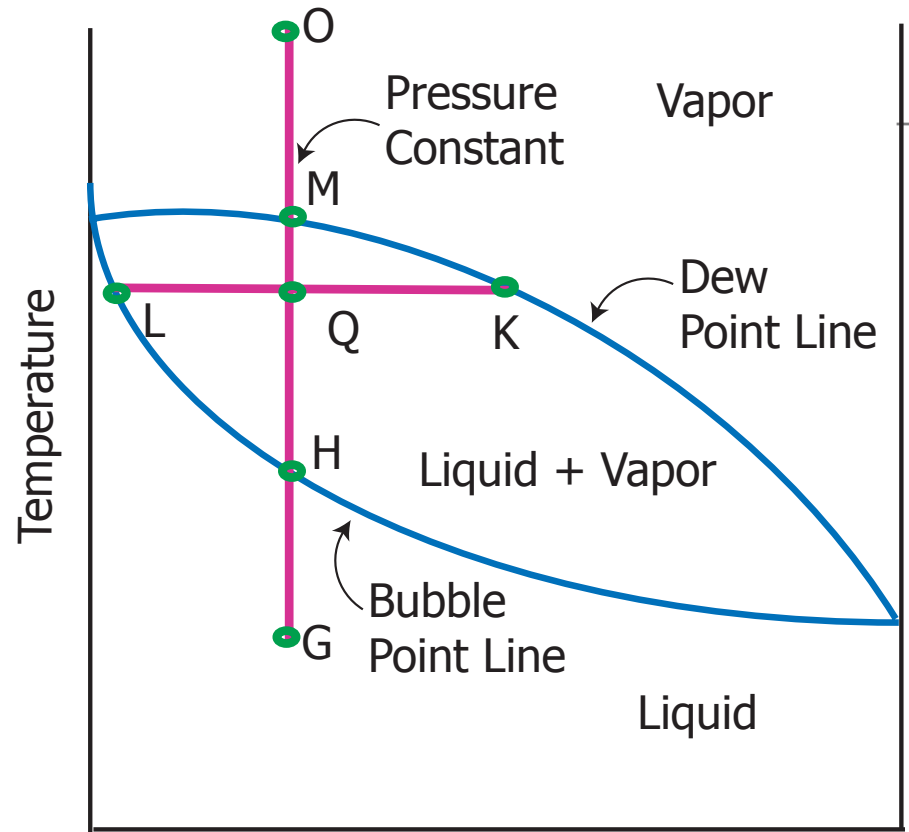
- At point G , the mixture is a **liquid**.



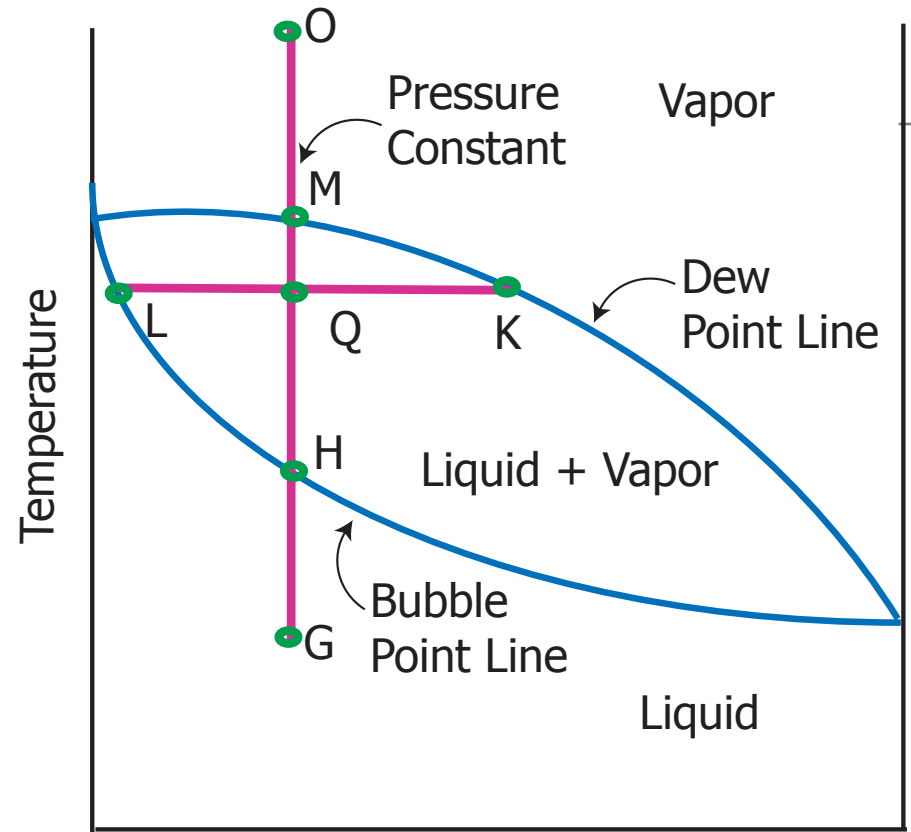
- At point G , the mixture is a **liquid**.
- As temperature is raised, at point H , the mixture is a **saturated liquid**.



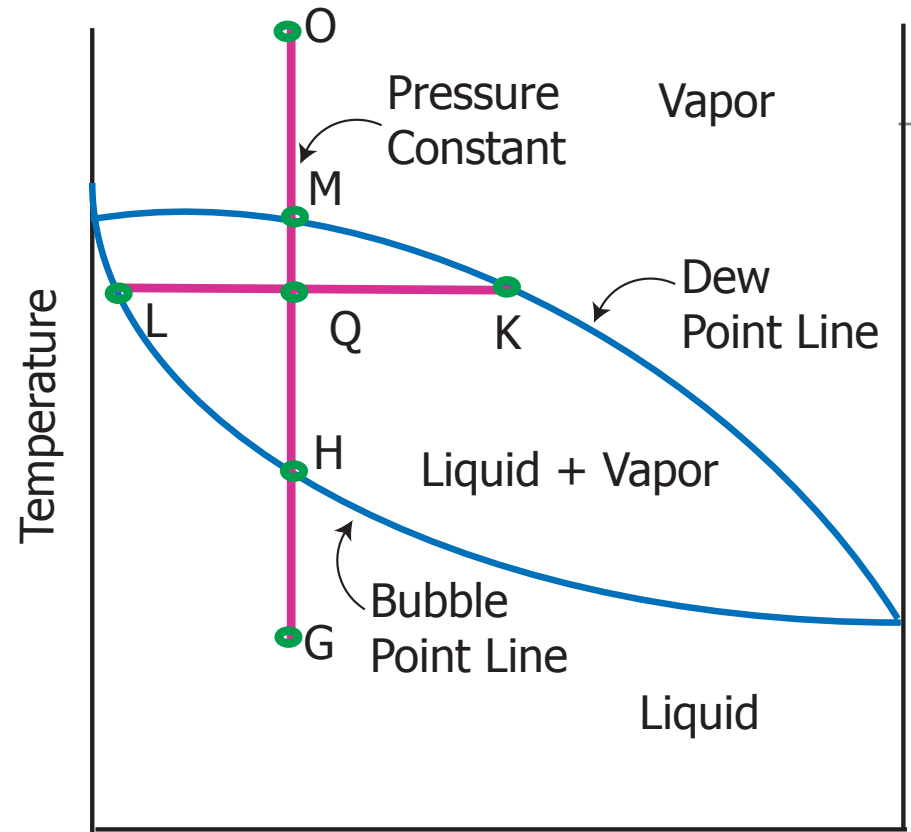
- At point G , the mixture is a **liquid**.
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- At point O , the vapor is **superheated**.



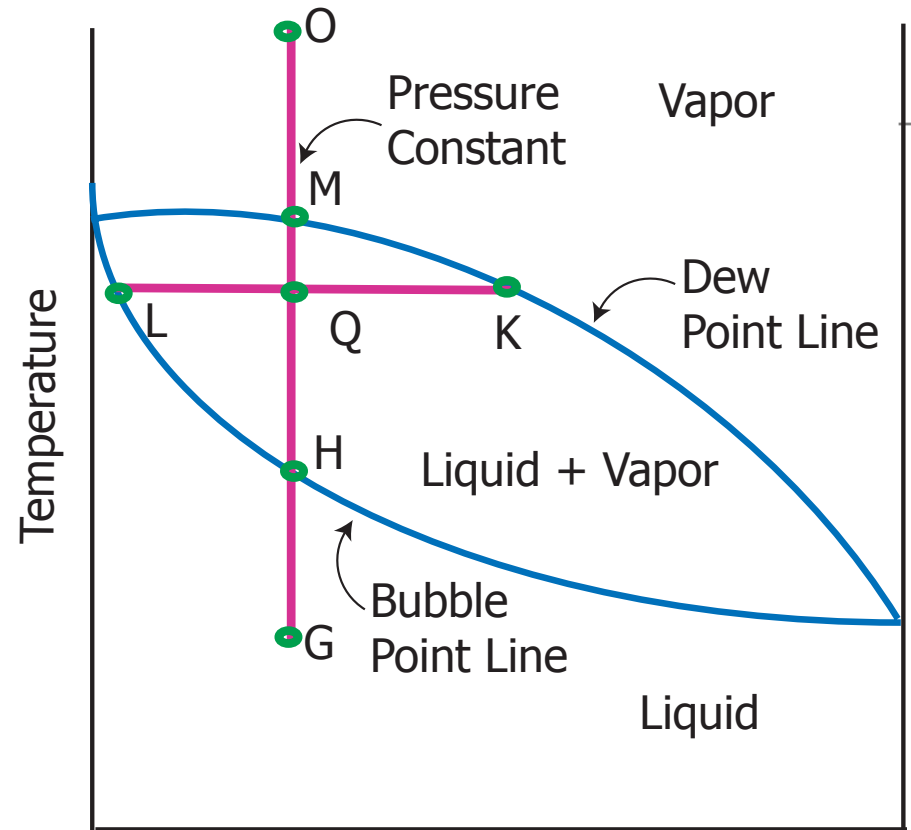
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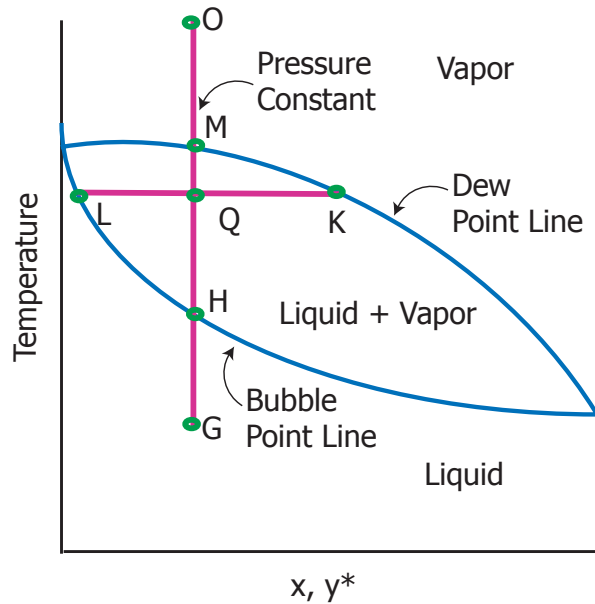
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Note that “boiling” occurs between H and M , and **not** at a constant temperature as in pure substances.

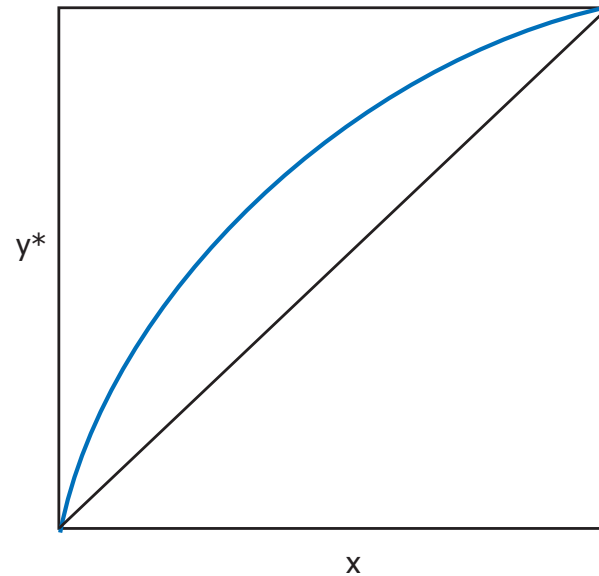
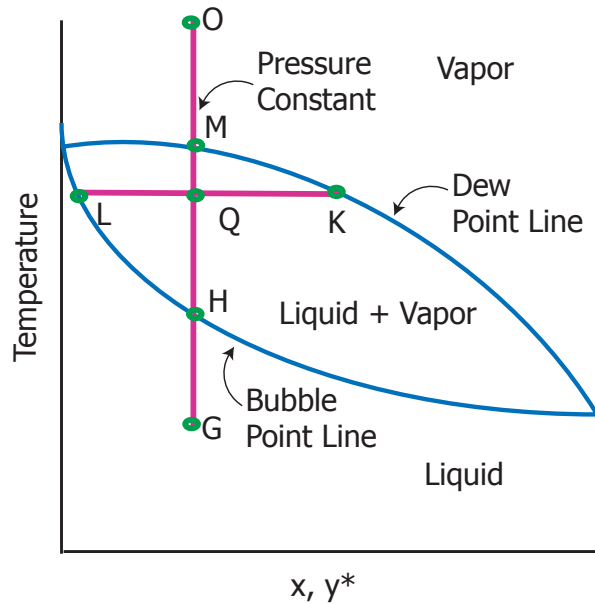
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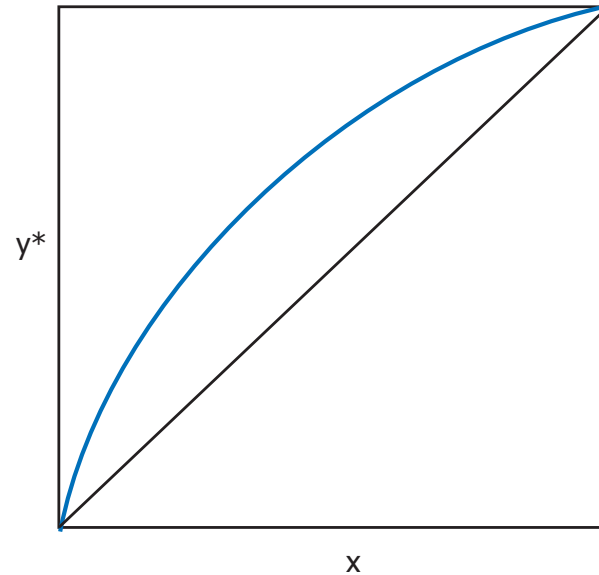
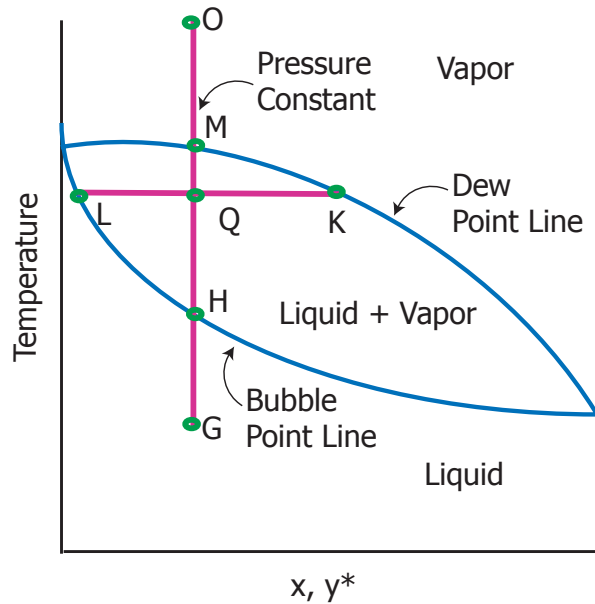
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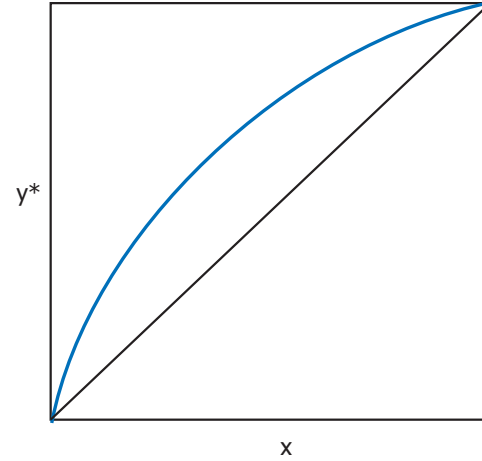


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A numerical measure of **ease of separation** is called **relative volatility**

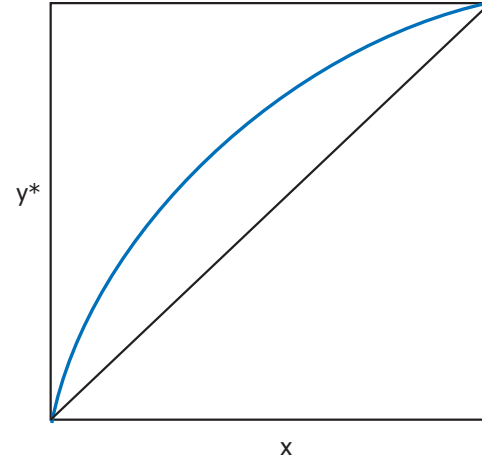
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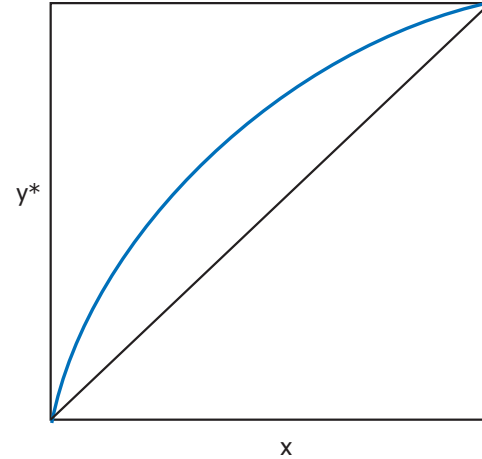
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$$\alpha = \frac{\text{ratio of } A \text{ and } B \text{ in } \textcolor{red}{vapor} \text{ phase}}{\text{ratio of } A \text{ and } B \text{ in } \textcolor{red}{liquid} \text{ phase}}$$

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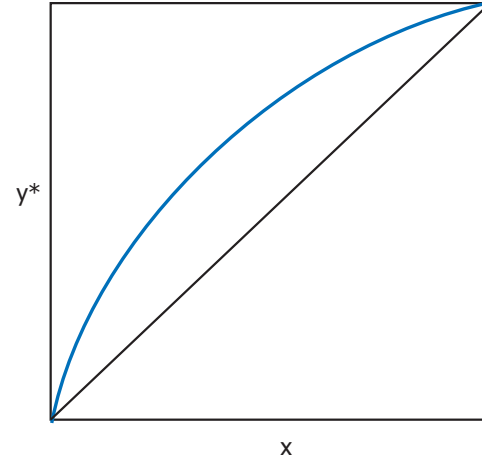
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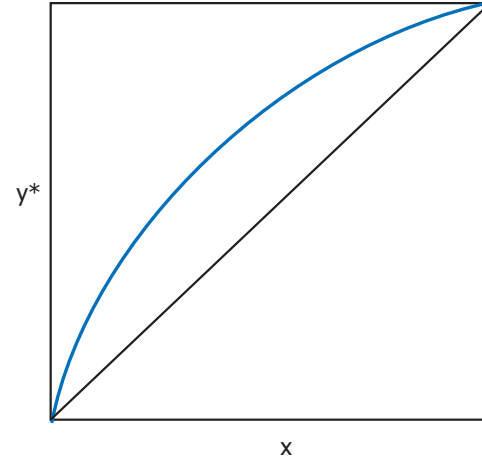
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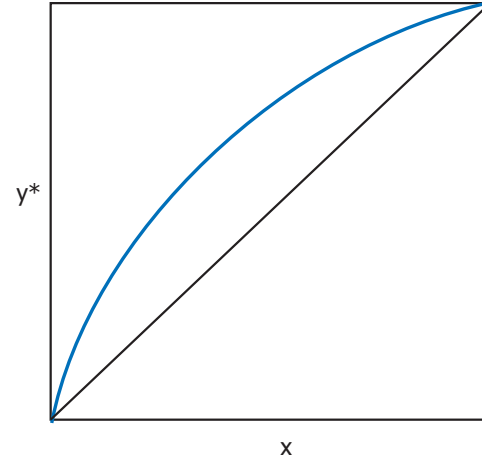


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At a given pressure and temperature, one mole of **any gas** that is ideal will have **exactly** the same volume. One does not need to do **experiments** to determine this volume.

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Characteristics of Ideal Solutions:

1. The average intermolecular forces of attraction and repulsion in the solution are unchanged on mixing the constituents.
2. The volume of the solution varies linearly with composition.
3. There is neither absorption nor evolution of heat in mixing the constituents.
4. The total vapor pressure of the solution varies linearly with composition expressed as mole fraction.

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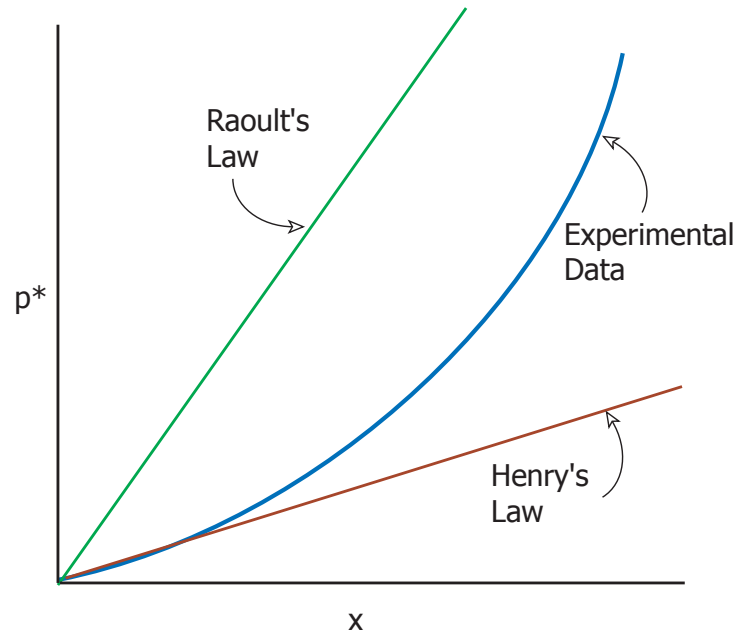
1. The **nature** of the solvent liquid does not enter into consideration.
2. Solubility of a particular gas in **any solvent** is the same.
3. If the gas behavior is **non-ideal**, the pressure can be replaced by **fugacity**.

Non-Ideal Liquid Solutions

Henry's Law is used for non-ideal solutions.

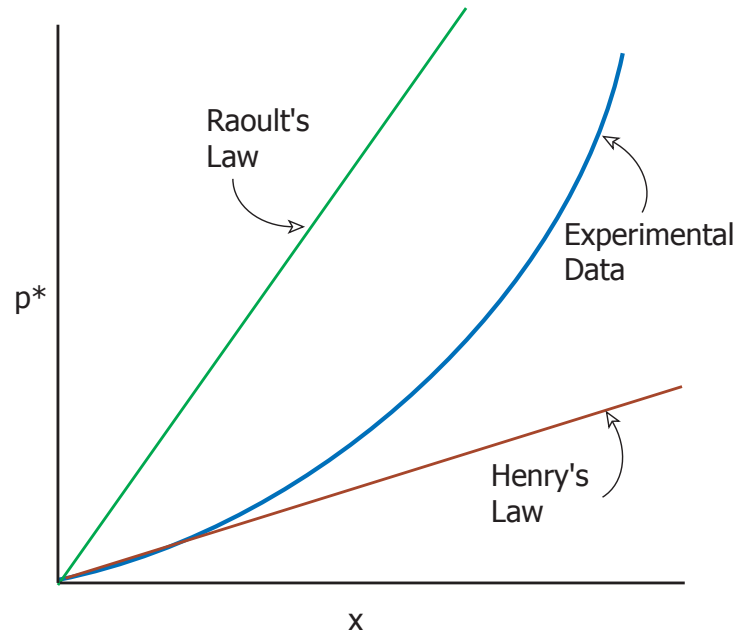
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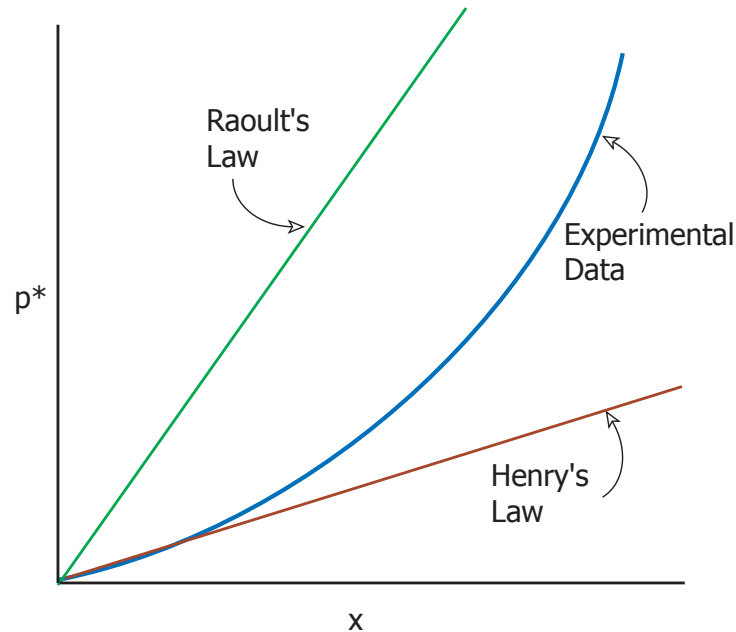
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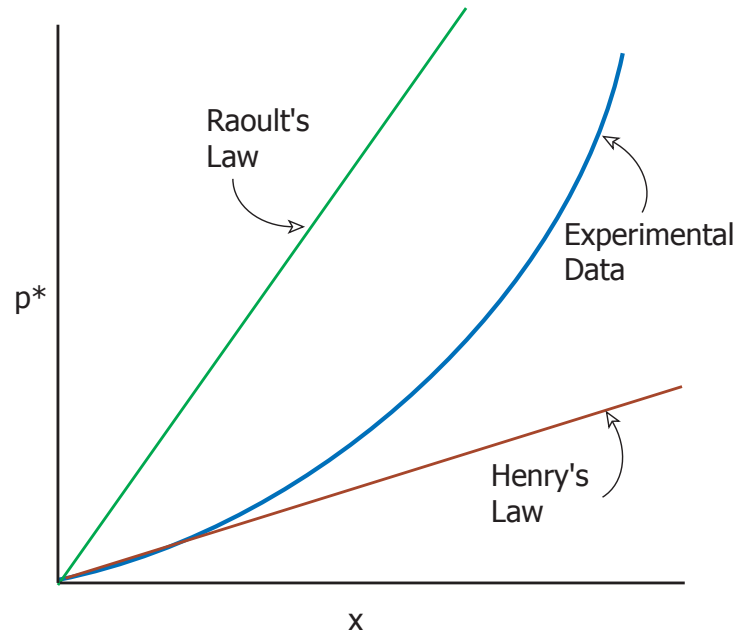


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where K is a “constant”. K is a **function** of P , T , and x .

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Thus, while **vapor pressures** of A and B may vary considerably at different temperatures, their **ratio** will be constant **provided** the solution is **ideal**.

Example

Compute the vapor-liquid equilibria of n-heptane (A) and n-octane (B) at 760 mm Hg given the following vapor pressure data:

T ($^{\circ}\text{C}$)	p_A^0 (mm Hg)	p_B^0 (mm Hg)
98.4	760	333
105.0	940	417
110.0	1050	484
115.0	1200	561
120.0	1350	650
125.6	1540	760

Verify that α is nearly constant in the above temperature range.

Solution Strategy

- Using $p_t = 760$ mm Hg, compute x from:

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- Compute α from:

$$\alpha = \frac{p_A^0}{p_B^0}$$

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T ($^{\circ}\text{C}$)	p_A^0 (mm Hg)	p_B^0 (mm Hg)	x	y^*	α
98.4	760	333	1.000		
105.0	940	417	0.655		
110.0	1050	484	0.487		
115.0	1200	561	0.312		
120.0	1350	650	0.157		
125.6	1540	760	0.000		

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115.0	1200	561	0.312	0.492	
120.0	1350	650	0.157	0.279	
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120.0	1350	650	0.157	0.279	2.08
125.6	1540	760	0.000	0.000	2.03

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An average value of α is 2.16.

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The equation $\alpha = \frac{y^*(1-x)}{x(1-y^*)}$ can be rearranged to give:

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The equation $\alpha = \frac{y^*(1-x)}{x(1-y^*)}$ can be rearranged to give:

$$y^* = \frac{2.16x}{1 + 1.16x}$$