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# Process Chem and Pharmaceutical Engineering 1

## Vapour-liquid Separation Part 1

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By Wan Nurul Huda

<http://ocw.ump.edu.my/course/view.php?id=350#section-6>

# Chapter Description

- **Aims**
  - Solve problems related to extraction process by applying the formula relevant to specific operations
- **Expected Outcomes**
  - Describe the vapour-liquid separation in single condensable component and multicomponent systems
  - Apply Raoult's law and Henry's Law in problem solving
  - Comprehend the distillation process
- **References**
  - Principles of Mass Transfer and Separation Processes, Binay K. Dutta, PHI Learning Private Limited, 2009



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# The Nature of Equilibrium

Equilibrium: a static condition, whereby no changes occur in the macroscopic properties of a system with time

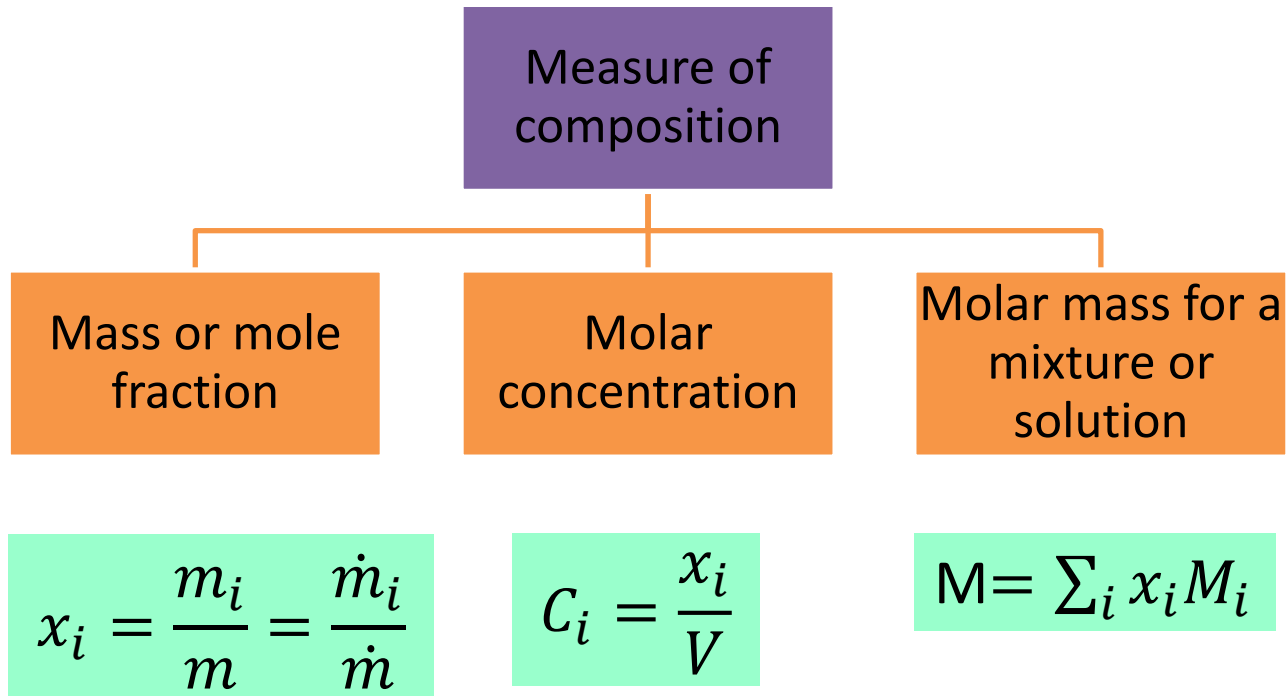


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# Measure of Composition



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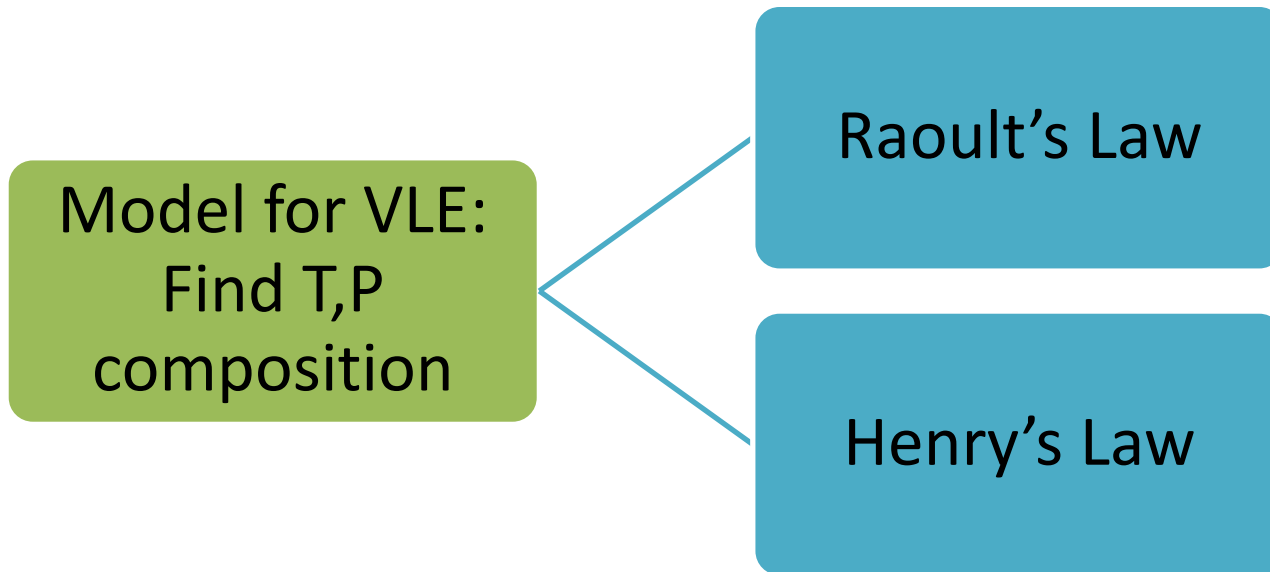
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# Bubble Point and Dew Point

- The **bubble point** is the temperature (at a given pressure) where the first bubble of vapour is formed when heating a liquid consisting of two or more components.
- **Dew point** is the atmospheric temperature (varying according to pressure and humidity) below which water droplets begin to condense and dew can form.

# VLE Model



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# Raoult's Law

## Assumptions

- V phase is an ideal gas – applicable for low to moderate pressure
- L phase is an ideal solution – valid only if the species are chemically similar (size, same chemical nature, e.g. isomers such as ortho-, meta- & para-xylene)



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$$y_i P = x_i P_i^{sat} \quad (i = 1, 2, \dots, N)$$

Where:

$x_i$  = L-phase mole fraction

$y_i$  = V-phase mole fraction

$P_i^{sat}$  = vapour pressure of pure species

$P$  = total pressure



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# Dew Point & Bubble Point Calculations with Raoult's Law

	FIND	GIVEN
Bubble P	Calculate $\{y_i\}$ and P,	given $\{x_i\}$ and T
Dew P	Calculate $\{x_i\}$ and P,	given $\{y_i\}$ and T
Bubble T	Calculate $\{y_i\}$ and T,	given $\{x_i\}$ and P
Dew T	Calculate $\{x_i\}$ and T,	given $\{y_i\}$ and P



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For binary systems to solve for bubble point calculation (T is given);

$$\sum_i y_i = 1$$

$$P = \sum_i x_i P_i^{sat}$$

$$P = P_2^{sat} + (P_1^{sat} - P_2^{sat})x_1$$

$$y_i = \frac{x_i P_i^{sat}}{P}$$



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Raoult's law equation can be solved for  $x_i$  to solve for dew point calculation (T is given)

$$\sum_i x_i = 1$$

$$P = \frac{1}{\sum_i y_i / P_i^{sat}}$$

$$P = \frac{1}{\frac{y_1}{P_1^{sat}} + y_2 / P_2^{sat}}$$

$$y_i = \frac{y_i P}{P_i^{sat}}$$



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# Example 1

Binary system acetonitrile(1)/nitromethane(2) conforms closely to Raoult's law. Vapour pressure for the pure species are given by the following Antoine equations:

$$\ln \frac{P_1^{sat}}{kPa} = 14.2724 - \frac{2945.47}{t/^{\circ}C + 244} \quad \ln \frac{P_2^{sat}}{kPa} = 14.2043 - \frac{2972.64}{t/^{\circ}C + 209}$$

a. Prepare a table showing P vs  $x_1$  and P vs  $y_1$  at temperature 75 °C ( $x_1=0.6$ )



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a. Bubble P calculations are required. Since this is a binary system

$$P = P_2^{sat} + (P_1^{sat} - P_2^{sat})x_1$$

At 75 oC, the saturated pressure is given by Antoine equation:

$$P_1^{sat} = 154.31 \quad P_2^{sat} = 41.98$$

Substitute both values in (A) to find P:

$$P = 41.98 + (154.31 - 41.98)(0.6)$$

$$P = 109.38 \text{ kPa}$$



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The corresponding value of  $y_1$  is found from:

$$y_i P = x_i P_i^{sat}$$

$$y_i = \frac{x_i P_i^{sat}}{P} = \frac{(0.6)(154.31)}{109.38} = 0.8464$$

$x_i$	$y_i$	P/kPa
0.0	0.0000	41.98
0.2		
0.4		
0.6	0.8464	109.38
0.8	0.9363	131.84
1.0	1.0000	154.32



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# Conclusion of The Chapter

- This chapter discussed about bubble and dew point
  - Raoult's law and Henry's law
  - Azeotrope
  - Flash calculation



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