**Material and Energy Balances**
**CHEN 2120**

Class Meeting #18
March 2nd, 2007

“Single component gas-liquid systems: saturation and Raoult’s law”

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**Outline**
- Show your work!!
- Saturation
- Raoult’s Law!!
- Relative humidity

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### Saturation

<table>
<thead>
<tr>
<th>Time</th>
<th>State</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>t = 0</td>
<td>Air only</td>
<td>Air is not saturated; it can hold more water.</td>
</tr>
<tr>
<td></td>
<td>Air and water</td>
<td></td>
</tr>
<tr>
<td>t &gt; 0</td>
<td>Air saturated with water</td>
<td>Air is saturated; it cannot hold any more water.</td>
</tr>
</tbody>
</table>

What happens if the temperature is slightly decreased?

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<td></td>
</tr>
<tr>
<td></td>
<td>water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>equilibrium</td>
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Air is saturated; it cannot hold any more water.

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Air is saturated; it cannot hold any more water.

If the temperature is slightly decreased, then water will condense out of the vapor phase.

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### Crystallization

<table>
<thead>
<tr>
<th>Time</th>
<th>State</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water saturated with salt</td>
<td></td>
</tr>
<tr>
<td>Cool</td>
<td></td>
<td>If the temperature is decreased, then salt will precipitate (crystallize) out of the liquid phase.</td>
</tr>
</tbody>
</table>
Raoult’s Law (single component)

• If a gas at temperature T and pressure P contains a saturated vapor whose mole fraction is \( y_i \) (mol vapor/mol total gas), and if this vapor is the only species that would condense if the temperature were slightly lowered, then the partial pressure of the vapor in the gas equals the pure-component vapor pressure \( p^*(T) \) at the system temperature:

\[
p_i = y_i P = p^*(T)
\]

Example

• Methane and water are contained at equilibrium in a closed container at 50°C and 760 mm Hg.
• Degrees of freedom:
  \[ DF = 2 + c - x = 2 + 2 - 2 = 2 \]
  Thus, if we specify 2 intensive variables (in this case, T and P), we can determine every other intensive variable.
• Raoult’s Law: \( y_{H_2O} P = p^*_{H_2O}(T) \cdot p^*_{H_2O}(T) \) from Table B.3
• \( y_{H_2O} = p^*_{H_2O}(50°C)/P = (92.51 \text{ mm Hg})/(760 \text{ mm Hg}) = 0.121 \)
  \( \Rightarrow y_{CH_4} = 1 - 0.121 = 0.879 \)

Superheated vapors

• A gas in equilibrium with a liquid must be saturated with the volatile components of that liquid.
• The partial pressure of a vapor at equilibrium in a gas mixture containing a single condensable component cannot exceed the vapor pressure of the pure component at the system temperature.
• If \( p_i = p^* \), the vapor is saturated; any attempt to increase \( p_i \) (by adding more vapor or increasing pressure) will lead to condensation.
• If \( p_i = y_i P < p^*(T) \), then the vapor is a superheated vapor (gas mixture can hold more vapor).

Dew point

• If a superheated gas containing a single condensable species is cooled at constant pressure, the temperature at which the vapor becomes saturated is known as the dew point of the gas.
• From Raoult’s law, \( p_i = y_i P = p^*(T_{dp}) \).
• The difference between the temperature and \( T_{dp} \) is known as degrees of superheat.

Relative saturation (relative humidity)

• Relative saturation \( s_r(h_r) \):
  \[ s_r(h_r) = \frac{p}{p^*(T)} \times 100\% \]

Example: a relative humidity of 85% means that the partial pressure of water vapor equals 85% of the vapor pressure of water at the system temperature.

Now you try… (Clicker Prob. 18.1)

• Air at 50% relative humidity is cooled isobarically at 1 atm absolute from 90°C to 25°C.
• Estimate the dew point of the air at 90°C.
  A) 72.8°C  B) 84.3°C
  C) 53.2°C  D) 64.5°C
Now you try… (Clicker Prob. 18.1)

- Air at 50% relative humidity (H₂O in air) is cooled isobarically at 1 atm absolute from 90°C to 25°C.
- Estimate the dew point and degrees of superheat of the air at 90°C.
- \( h_r = 50\% = \frac{p_{H₂O}}{p^{*}_{H₂O}(T)} \times 100\% \)
- \( p^{*}_{H₂O}(90°C) = 525.8 \text{ mm Hg} \) (Table B.3)
- \( p_{H₂O} = (0.50)(525.8 \text{ mm Hg}) \)
  \( = 262.9 \text{ mm Hg} \)
- Look on Table B.3 to see at what temperature \( p_{H₂O} = 262.9 \) ~72.8°C (Answer A)

Now you try… (Clicker Prob. 18.2)

- Air at 50% relative humidity is cooled isobarically at 1 atm absolute from 90°C to 25°C.
- How many degrees of superheat does the air have?
  A) 3.4°C  B) 17.2°C  C) 23.1°C  D) 43.8°C

Now you try… (Clicker Prob. 18.3)

- Air at 50% relative humidity is cooled isobarically at 1 atm absolute from 90°C to 25°C.
- How much water condenses (mol) per cubic meter of feed gas?
  A) 3.4 mol  B) 15.5 mol  C) 10.3 mol  D) 23.4 mol

Now you try… (Clicker Prob. 18.2)

- \( p_{H₂O} = 262.9 \text{ mm Hg} \)
- \( y_{H₂O} = \frac{p_{H₂O}}{p} \) (Raoult’s Law)
  \( = \frac{262.9 \text{ mm Hg}}{760 \text{ mm Hg}} \)
- \( y_{H₂O} = 0.346 \) at 90°C

Now you try… (Clicker Prob. 18.2)

- \( y_{H₂O} = 0.346 \) at 90°C
- \( y_{H₂O} = 0.031 \) at 25°C
- \( n_{tot} = \frac{PV}{RT} \) (\( V = 1 \text{ m}^3, P = 1 \text{ atm} \))
- \( n_{H₂O} = y_{H₂O} n_{tot} \)
- \( n_{H₂O,90°C} = 11.61 \text{ mol} \)
- \( n_{H₂O,25°C} = 1.27 \text{ mol} \)
- \( n_{H₂O,\text{cond}} = (11.61-1.27) \text{ mol} = 10.3 \text{ mol} \) (Answer C)
Meteorology

- This is one measure meteorologists can predict how much snow or rain will fall!!
- A warm air mass (warmer air can hold more water than colder air) colliding with a cold front results in rain or snow!
- Any decrease in the temperature of a saturated mass of air will result in precipitation