Overview of Chapter 13

- Intermolecular Forces
- Liquids and their Properties
- Solids and Their Properties
- Phase diagrams

Today's Topics

- Heats of vaporization and condensation
- Vapor Pressure
- Pressure-Temperature relationships in liquids
- Phase diagrams

Questions to consider:

- What happens when liquids boil?
- What is a triple point?
- How are the phase diagrams for water and CO_2 different?

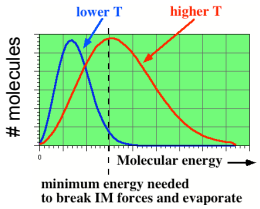
Liquids

HEAT OF VAPORIZATION is the heat needed (at constant P) to vaporize the liquid.

Liquid + heat ---> Vapor

Compound	ΔH_{vap} (kJ/mol)	IM Force
H_2O	40.7 (100 °C)	H-bonds
SO_2	26.8 (-47 °C)	dipole
Xe	12.6 (-107 °C)	induced dipole

Liquids



At higher T, more molecules have enough energy to break IM forces and move from liquid to vapor.

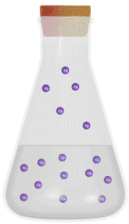
High E molecules carry away E.

==> You cool down when sweating or after swimming.

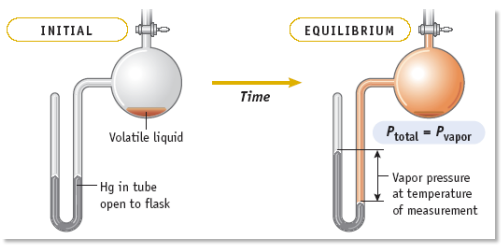
Liquids

Molecules in the vapor state exert a VAPOR PRESSURE

EQUILIBRIUM VAPOR PRESSURE is the pressure exerted by a vapor over a liquid in a closed container when the rate of evaporation = the rate of condensation.

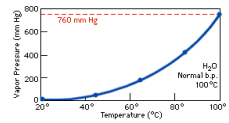


Measuring Equilibrium Vapor Pressure



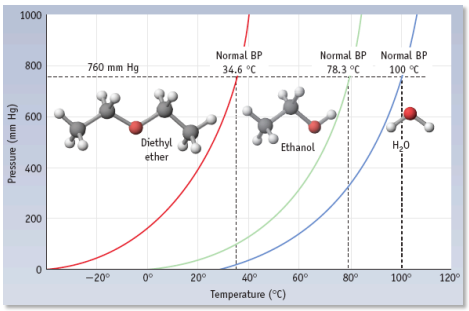
Liquid in flask evaporates and exerts pressure on manometer.

Liquids: Boiling



Liquid boils when its vapor pressure equals atmospheric pressure.

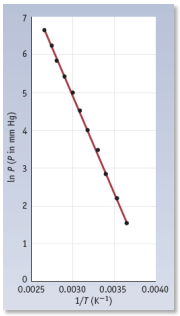
Equilibrium Vapor Pressure



Equilibrium Vapor Pressure

1. The curves show all conditions of P and T where liquid and vapor are in **equilibrium**.
2. The VP rises with T.
3. When VP = external P, the liquid boils.
   (The boiling points of liquids change with altitude.)
4. If external P = 760 mm Hg, T of boiling is the **normal boiling point**.
5. VP of a molecule at a given T depends on intermolecular forces.

Equilibrium Vapor Pressure: The Clausius-Clapeyron Equation



- Clausius-Clapeyron equation is used to find ΔH°_{vap}.
- The ln (=natural log) of the vapor pressure P is proportional to $\Delta H_{vaporiation}$ and to 1/T.
- $\ln P = -(\Delta H^\circ_{vap}/RT) + C$

(Recall y = mx + b for a straight line: Here, the slope m = $-\Delta H^\circ_{vap}/R$)

(C = a constant depending on the substance)

Clausius-Clapeyron equation

$$\ln P = \left(\frac{-\Delta H_{vap}}{RT}\right) + c$$

Subtract two of these equations at different temperatures:

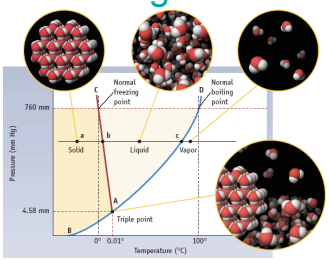
$$\ln P_2 = \left(\frac{-\Delta H_{vap}}{RT_2}\right) + c$$

$$-\ \ln P_1 = \left(\frac{-\Delta H_{vap}}{RT_1}\right) + c$$

$$\ln P_2 - \ln P_1 = \left(\frac{-\Delta H_{vap}}{RT_2}\right) - \left(\frac{-\Delta H_{vap}}{RT_1}\right) \Rightarrow \ln\left(\frac{P_2}{P_1}\right) = \left(\frac{-\Delta H_{vap}}{R}\right)\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

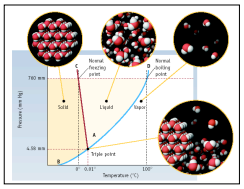
$$\boxed{\ln\left(\frac{P_2}{P_1}\right) = \left(\frac{\Delta H_{vap}}{R}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

Phase Diagrams



In the shaded regions, only 1 phase exists.
On the boundary lines, 2 phases are in equilibrium.
At the triple point, 3 phases are in equilibrium.

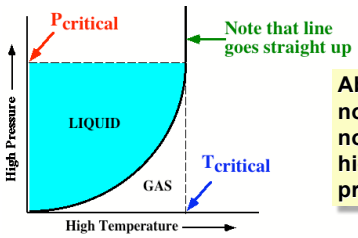
Phase Diagrams—Important Points for Water



	T(˚C)	P(mmHg)
Normal boil point	100	760
Normal freeze point	0	760
Triple point	0.0098	4.58

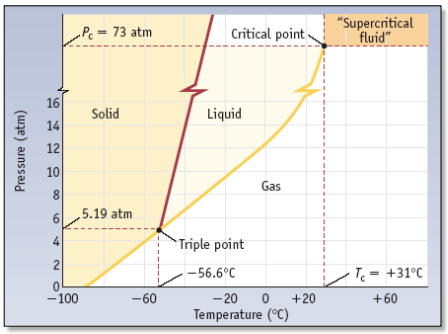
Critical T and P

As P and T increase, you finally reach the CRITICAL T and P

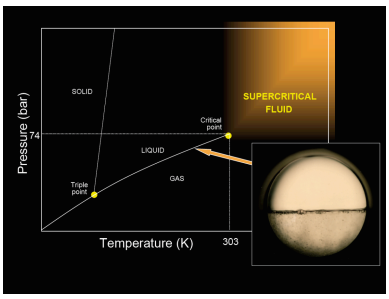


Above critical T no liquid exists no matter how high the pressure.

CO_2 Phase Diagram

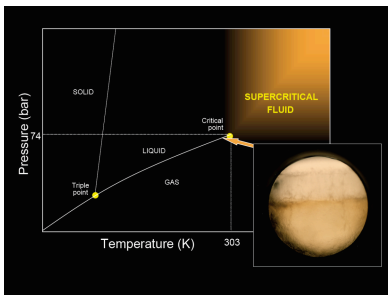
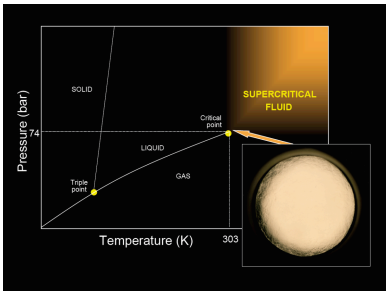


CO_2 critical point



http://www.chem.leeds.ac.uk/People/CMR/criticalpics.html

CO_2 critical point



CO_2 critical point