Sections 12.1 – 12.3
Properties of Liquids

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Properties of Liquids

In these sections…

a. Phases of Matter
b. Phase Changes
c. Properties of Liquids:
    1. Enthalpy of Vaporization
    2. Boiling Point
    3. Relating Vapor Pressure, Boiling Point and Enthalpy of Vaporization
    4. Surface Tension, Viscosity and Capillary Action

Phases of Matter on the Bulk Scale

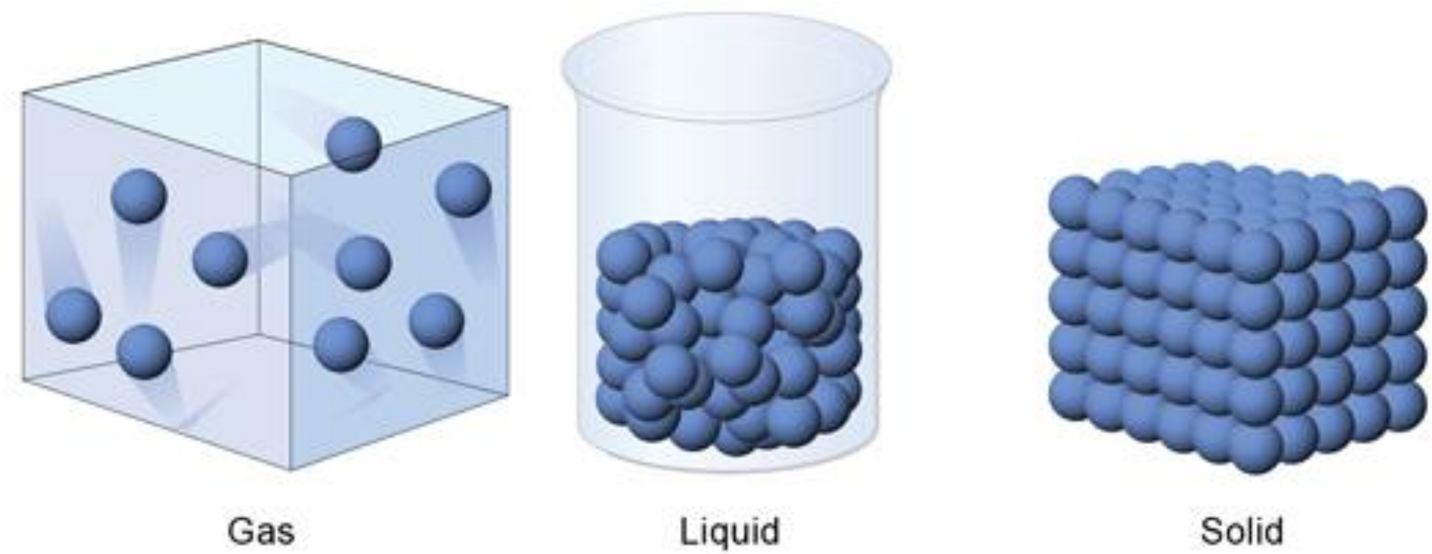
Densities of H_2O:

$H_2O(g)$	0.000804 g/cm^3
$H_2O(\ell)$	0.9999 g/cm^3
$H_2O(s)$	0.9150 g/cm^3

Table 11.1.1: Properties of Solids, Liquids, and Gases

Physical State	IMFs between Particles	Compressibility	Shape and Volume	Ability to Flow
Gas	Generally weak	High	Takes on shape and volume of container	High
Liquid	Generally intermediate	Very low	Takes on shape of container; volume limited by surface area	Moderate
Solid	Generally strong	Almost none	Maintains own shape and volume	Almost none

Phases of Matter on the Molecular Scale



- All have molecules in motion.
- Gases and Liquids have molecules that can move freely.
- Liquid and Solids have molecules in close proximity.
- Only Solids have molecules that cannot change positions with one another.

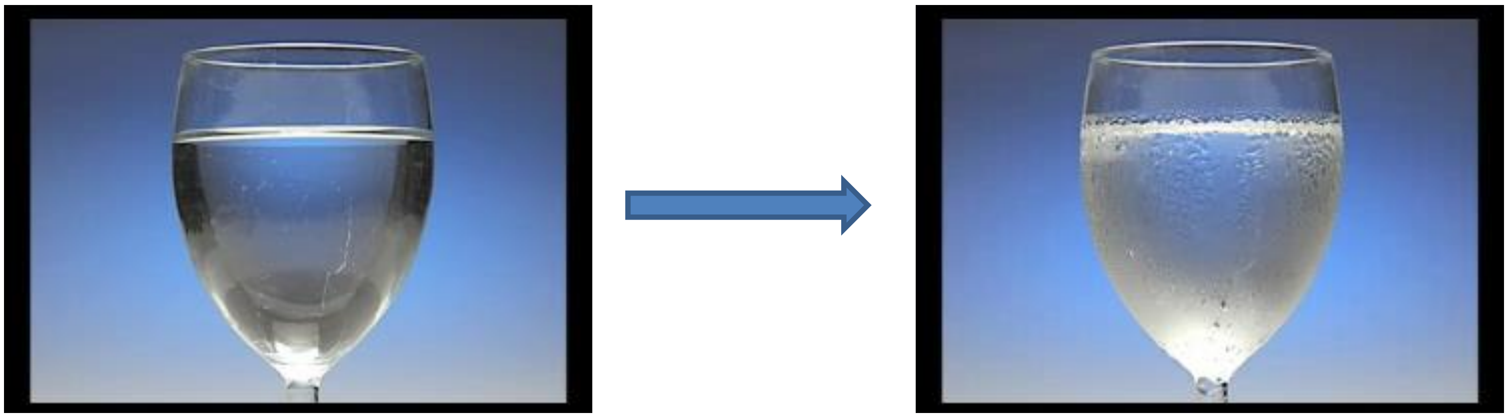
Solids and Liquids have molecules held near one another by Intermolecular Forces (IMFs)

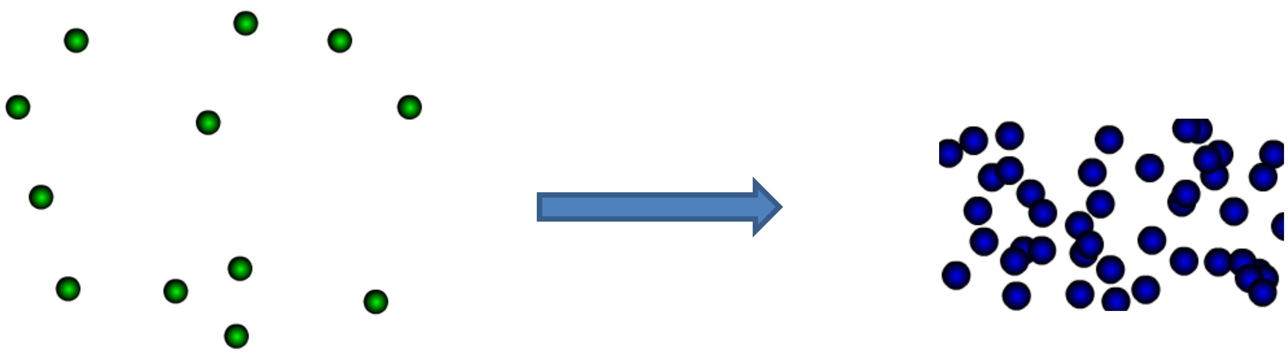
Phase Changes on the Bulk Scale

Table 11.1.2: Phase Changes

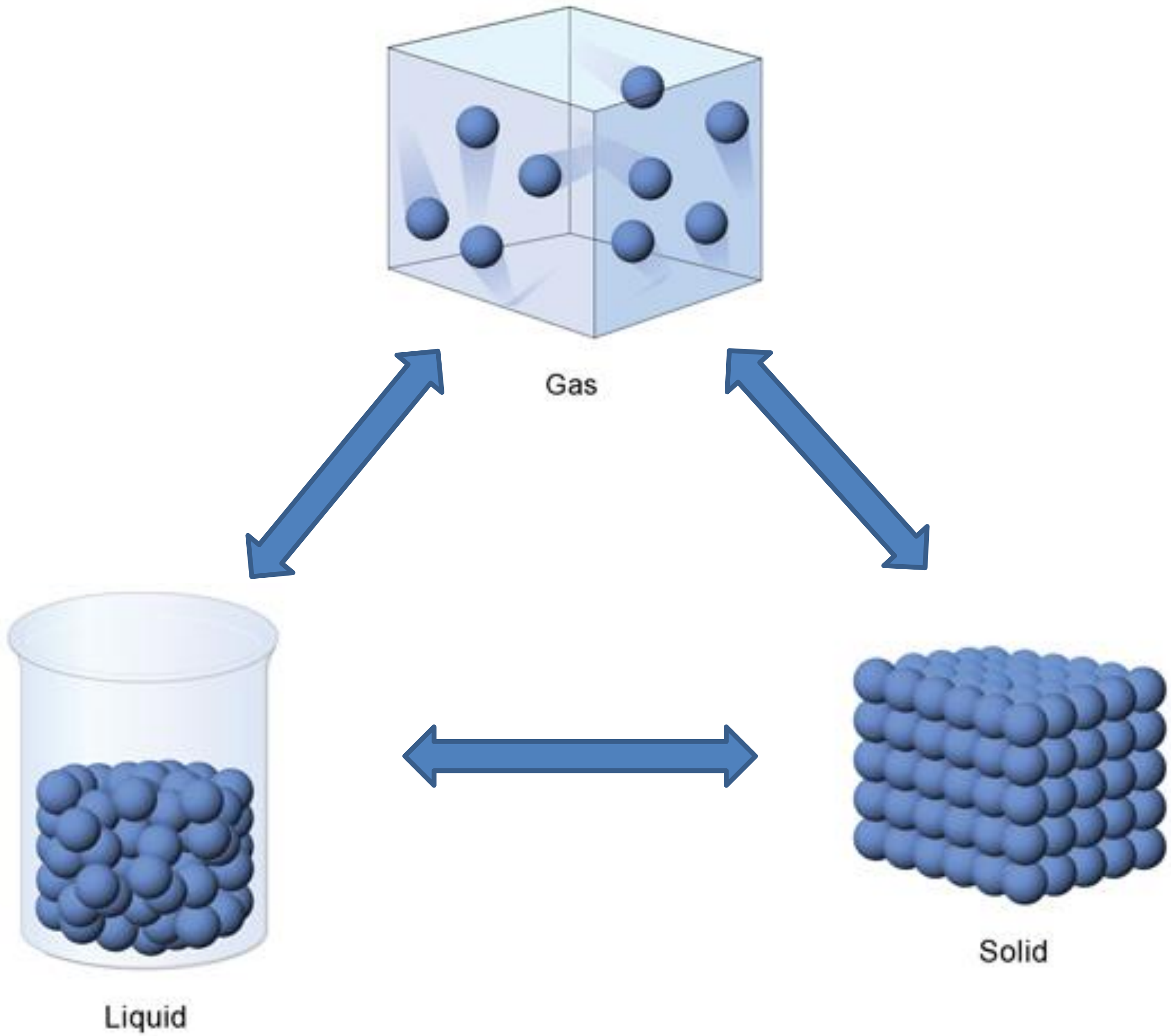
Phase Change	Physical Process	Energy Change
Fusion (melting)	solid → liquid	Energy is absorbed.
Vaporization	liquid → gas	Energy is absorbed.
Sublimation	solid → gas	Energy is absorbed.
Freezing	liquid → solid	Energy is released.
Condensation	gas → liquid	Energy is released.
Deposition	gas → solid	Energy is released.

Phase Changes on the Molecular Scale





Phase Changes on the Molecular Scale



Different Liquids have Different Properties

CH_3CH_2OH

H_2O

In this case: ethanol has higher vapor pressure

Properties of Liquids

Enthalpy of Vaporization: Energy required to vaporize a liquid.

Vapor Pressure: The gas pressure of a vapor
(a vapor is a gas that comes from a liquid vaporizing.)

Boiling Point: Temperature at which vapor pressure reaches
external atmospheric pressure.

Surface Tension: The tendency of a liquid surface to resist change.

Viscosity: The resistance of a liquid to flowing.

Enthalpy of Vaporization

Also called heat of vaporization, ΔH_{vap}.

Energy required to vaporize a liquid to form a gas.

1 mol $H_2O(l) \rightarrow$ 1 mol $H_2O(g)$ $\Delta H = 40.7$ kJ

So,

$\Delta H_{vap}(H_2O) = 40.7$ kJ/mol

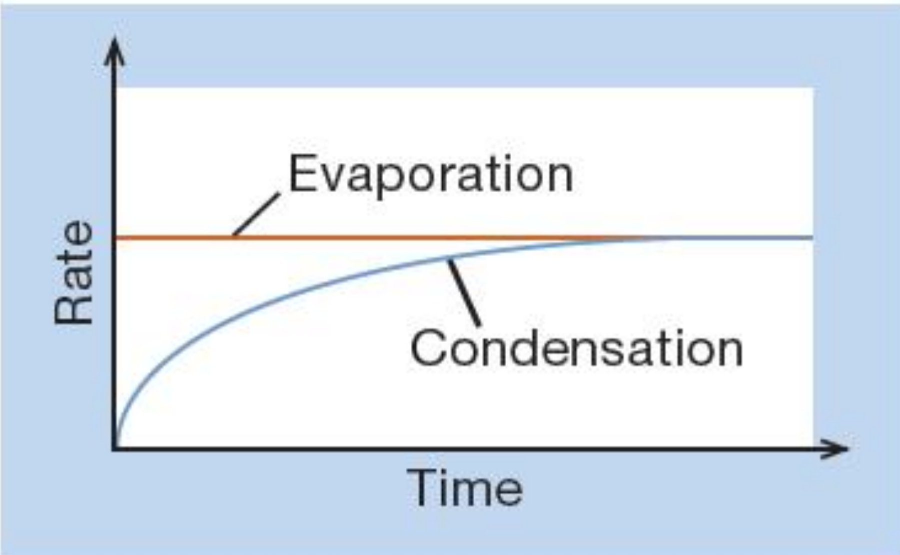
Enthalpy of Vaporization: Trends

Table 11.1.3 Enthalpy of Vaporization for Some Common Substances

Compound	Enthalpy of Vaporization (kJ/mol)
Helium, He	0.0828
Argon, Ar	6.43
Methane, CH_4	8.17
Ethane, CH_3CH_3	14.7
Methanol, CH_3OH	35.4
Water, H_2O	40.7
Benzene, C_6H_6	34.1

Stronger IMFs lead to larger enthalpy of vaporization.

Vapor Pressure



The pressure exerted by a vapor in equilibrium with the liquid from which it vaporizes.

Vapor pressure represents a "dynamic equilibrium."

Vapor Pressure: Trends

Table 11.2.1 Vapor Pressures (mm Hg) of Some Common Liquids

Liquid	0 °C	25 °C	50 °C	75 °C	100 °C	125 °C
Water	4.6	23.8	92.5	300	760	1741
Benzene	27.1	94.4	271	644	1360	—
Methanol	29.7	122	404	1126	—	—
Diethyl ether	185	470	1325	2680	4859	—

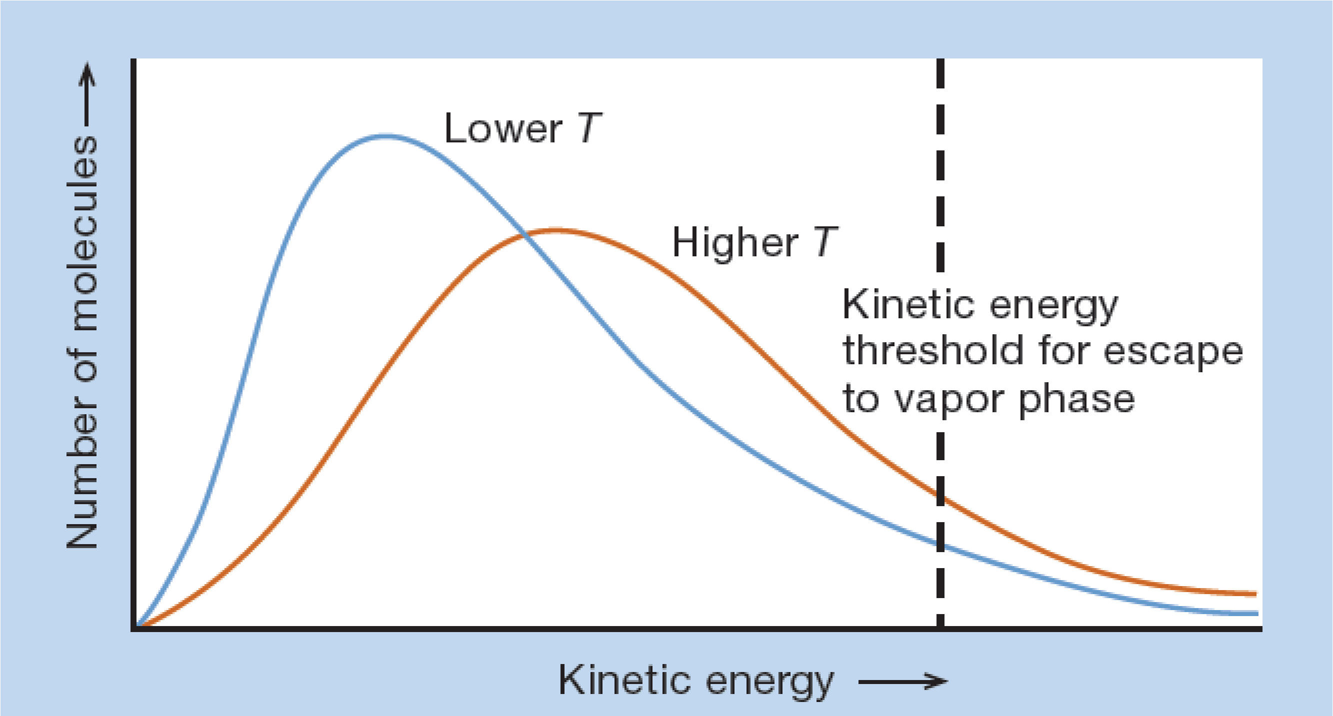
Vapor pressure increases with increasing temperature.

Strong IMFs lead to low vapor pressure.

simulation

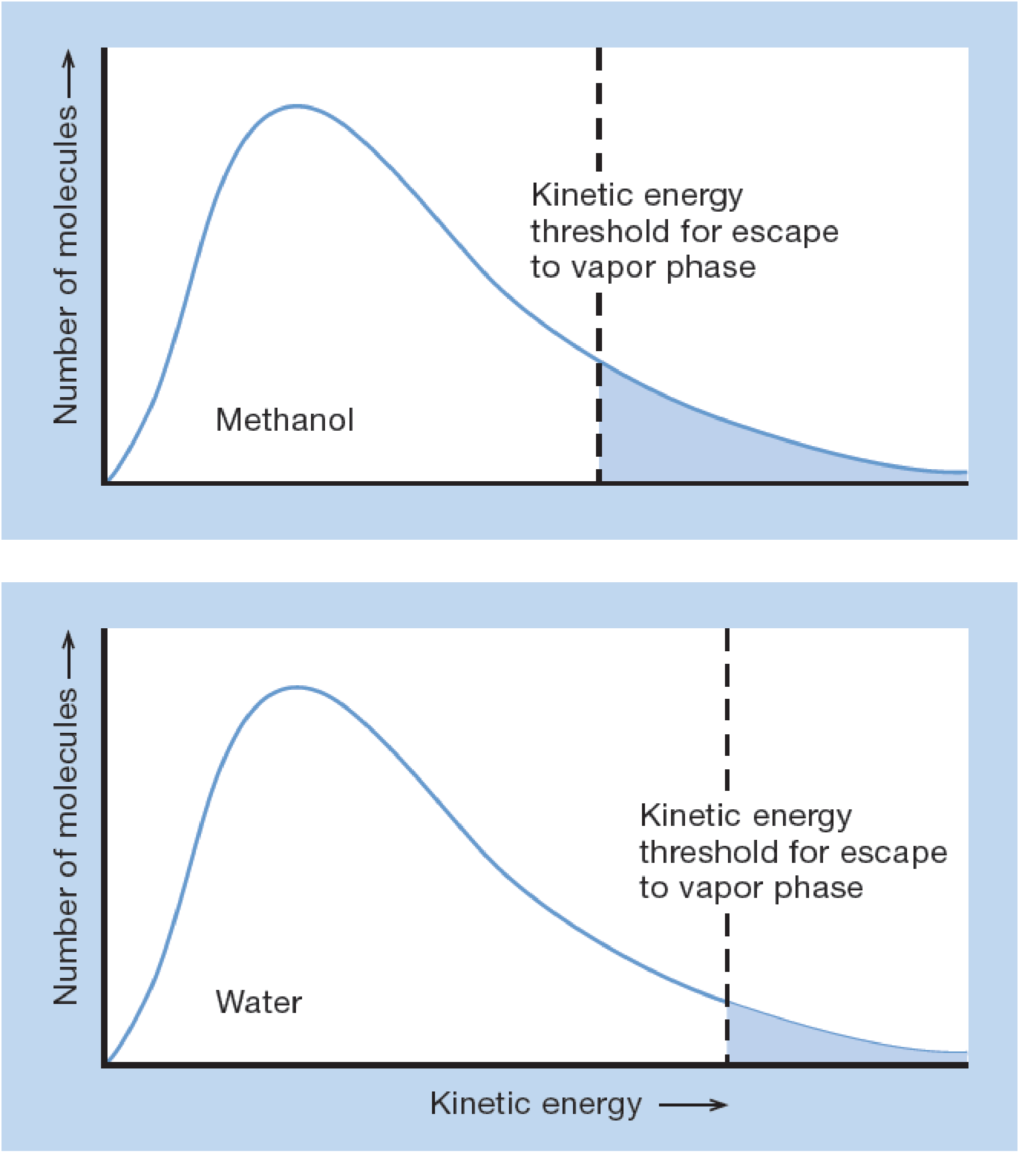
Vapor Pressure: Trends on the Molecular Scale

Vapor pressure increases with increasing temperature.

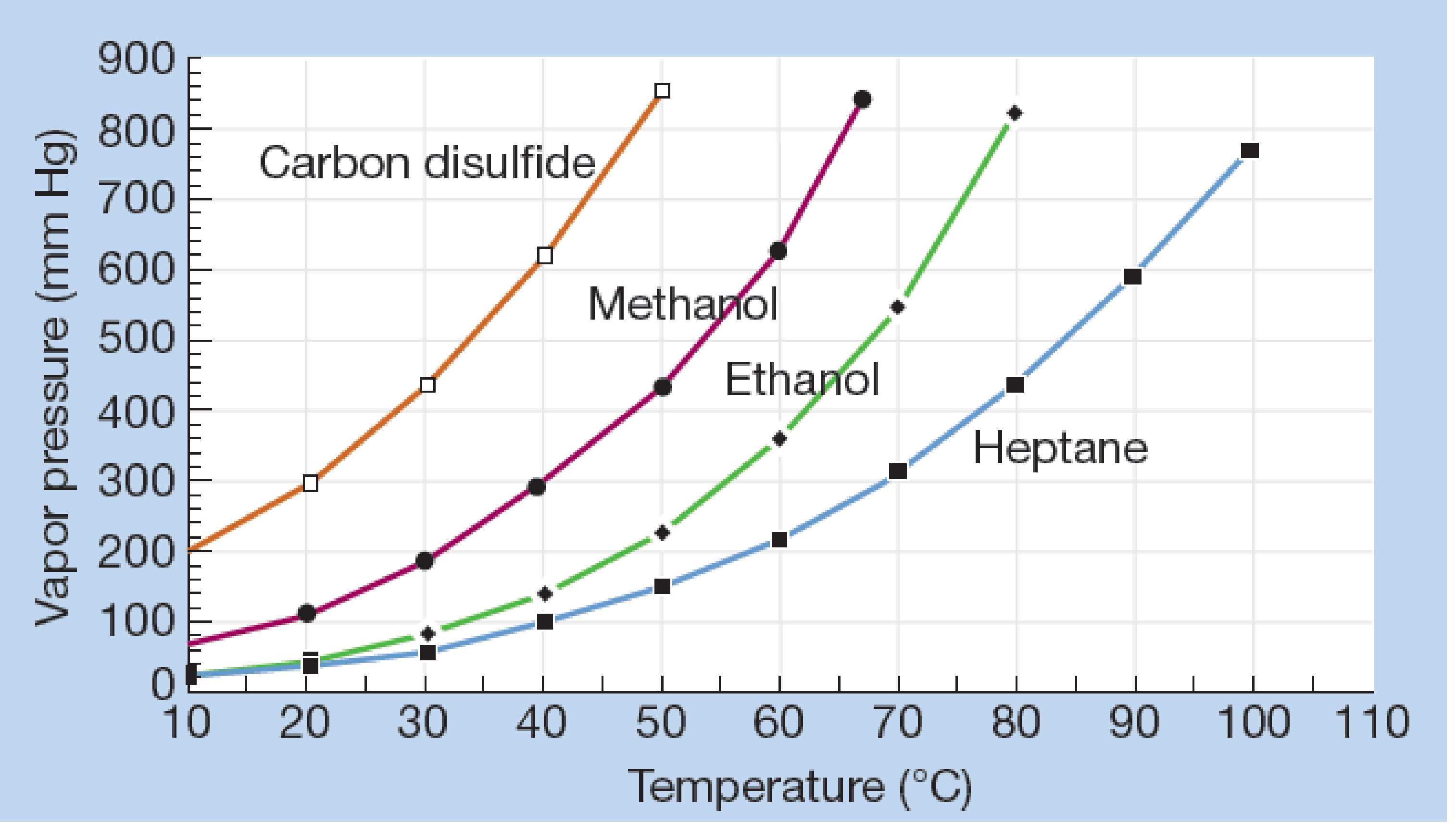


Vapor Pressure: Trends on the Molecular Scale

Strong IMFs lead to low vapor pressure.

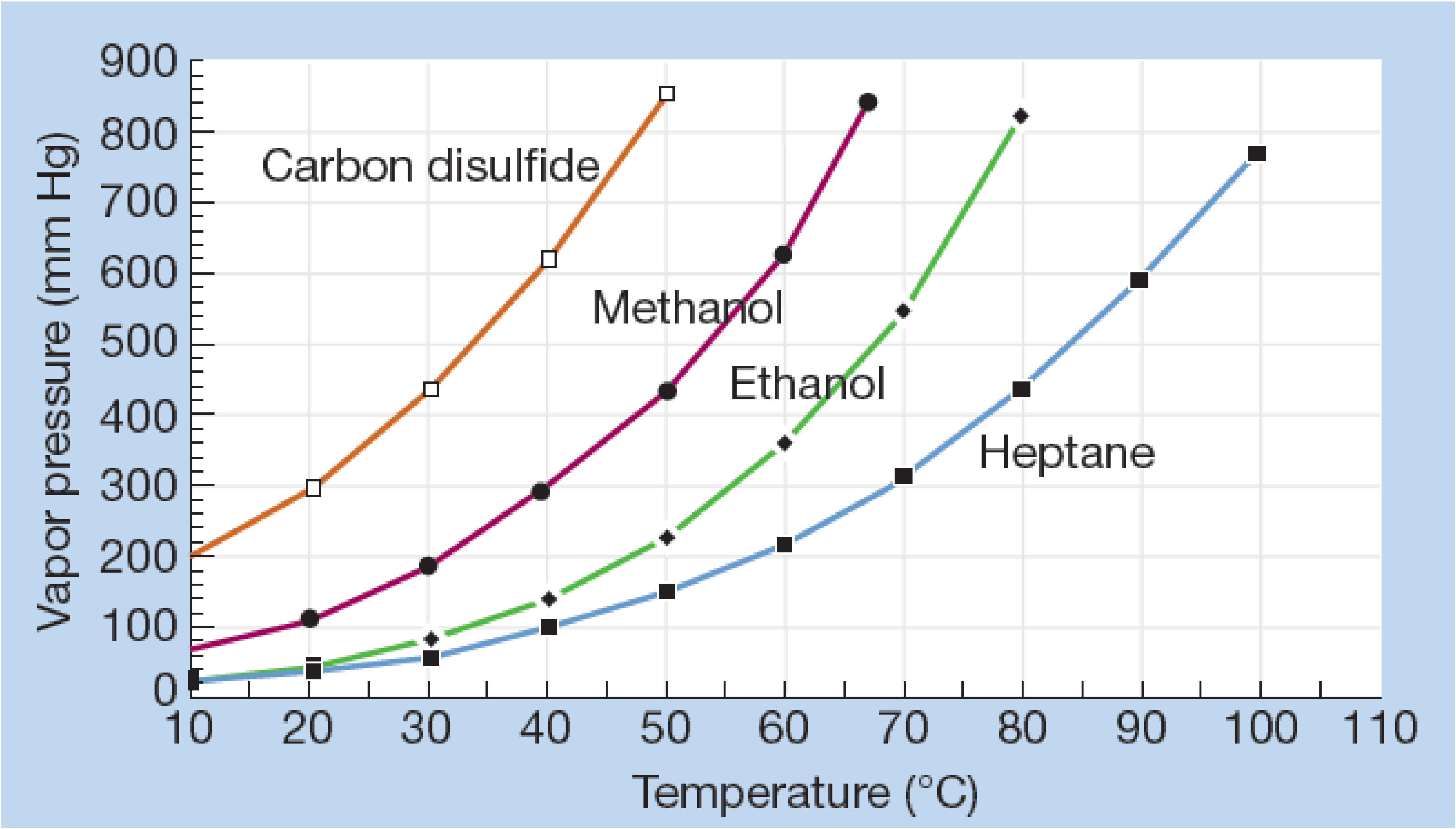


Vapor Pressure and Temperature



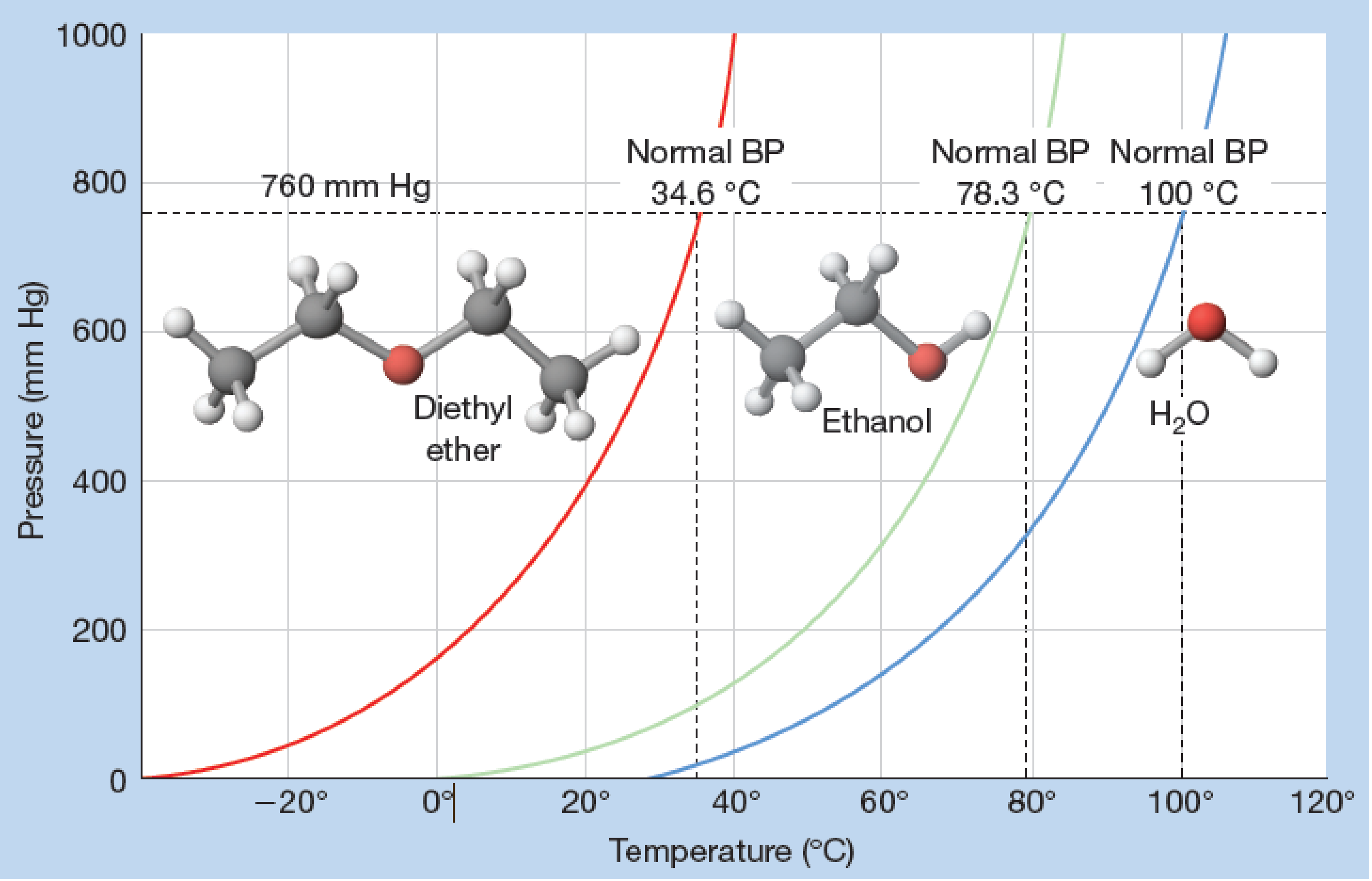
Vapor Pressure and Boiling Point

Boiling Point: The temperature at which the vapor pressure of a liquid reaches the external atmospheric pressure.



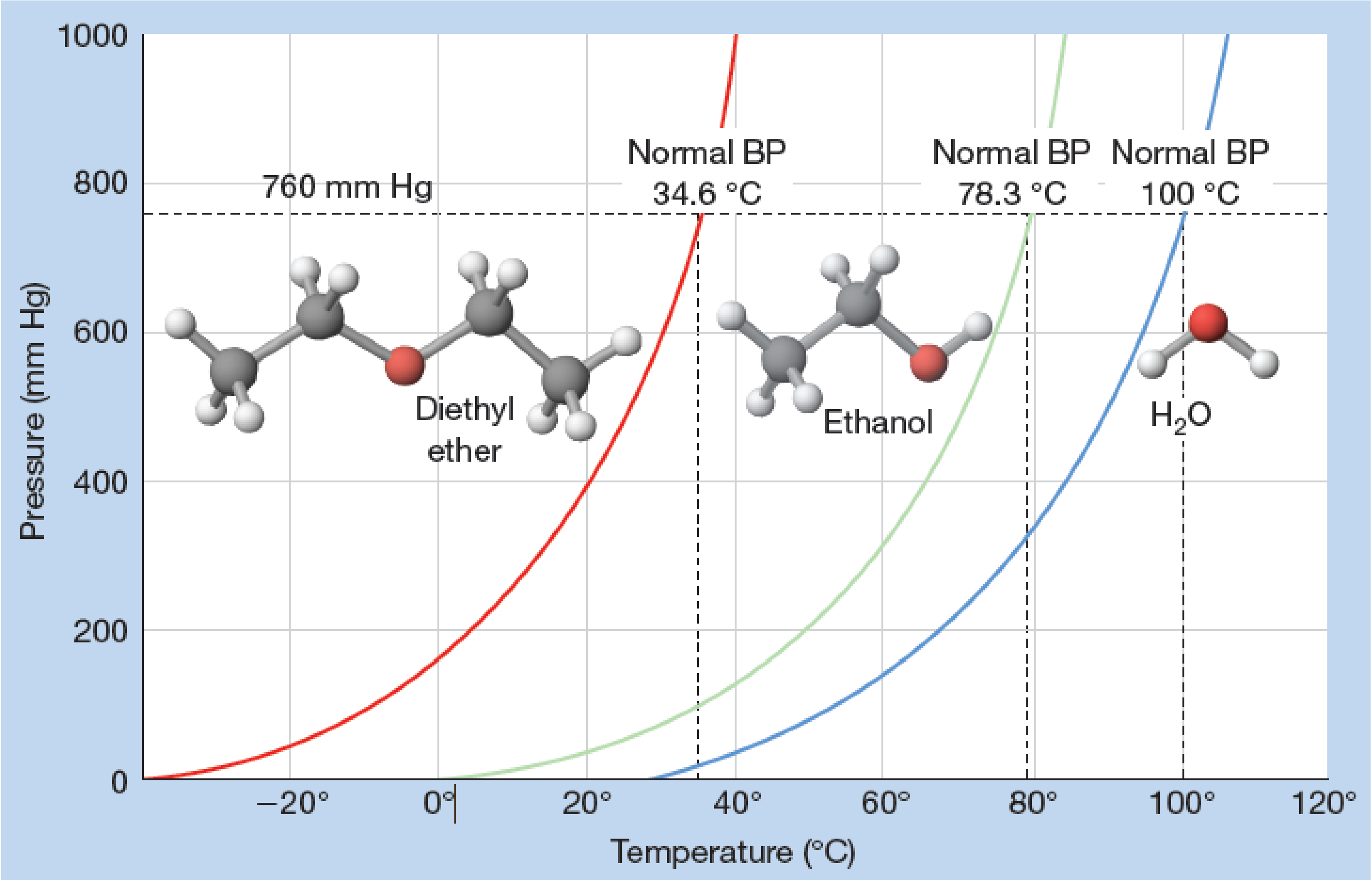
Normal Boiling Point

Normal Boiling Point: The temperature at which the vapor pressure of a liquid reaches 1 atm (760 mm Hg).



Normal Boiling Point: Trends

Normal Boiling Point increases with increasing IMF strength.

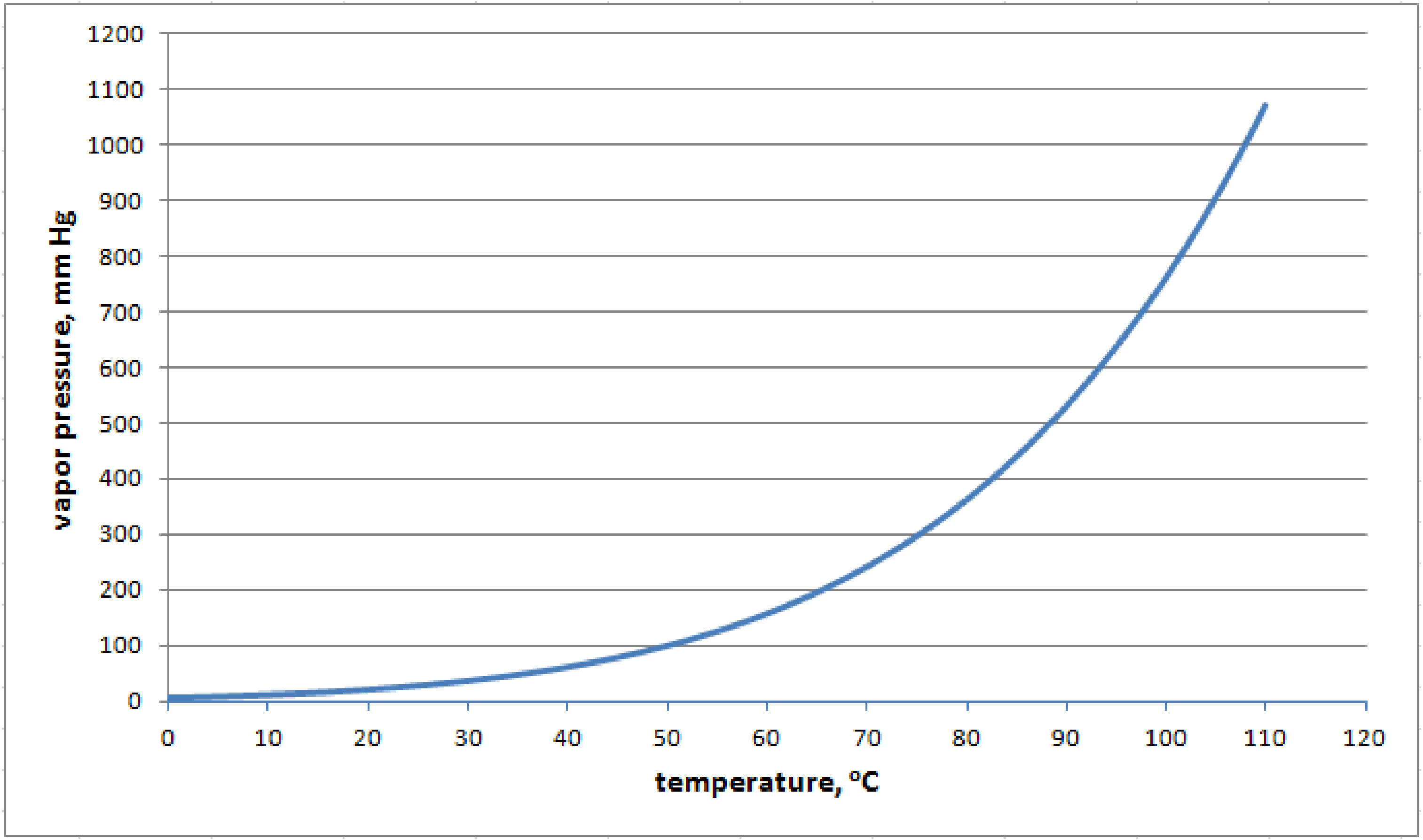


Trends Summary

As IMF Strength

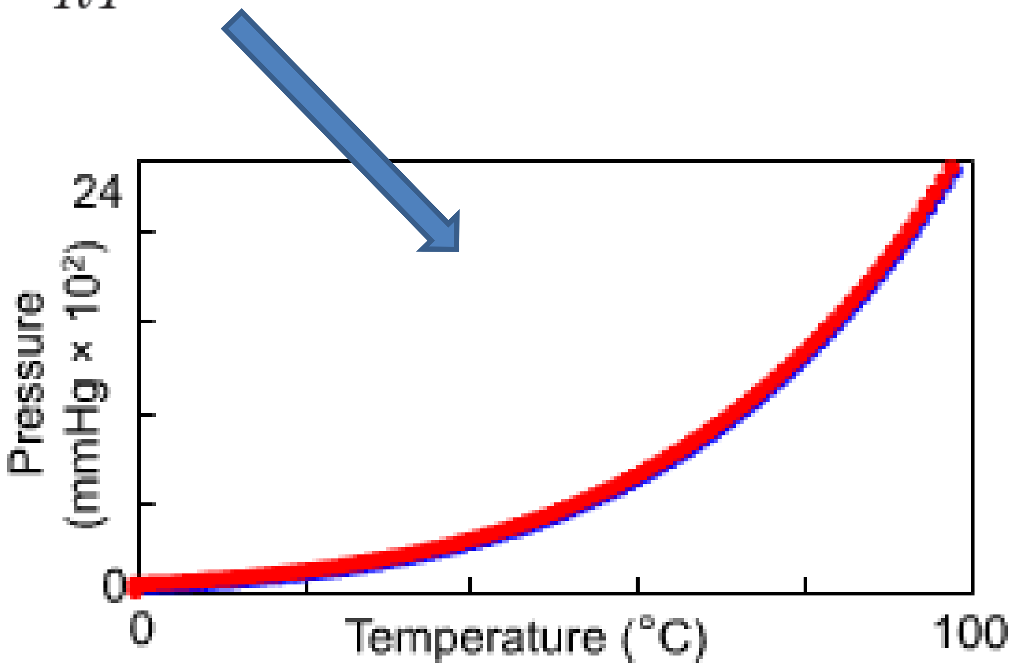
Vapor Pressure Curves: Will it rain?

If the partial pressure of a vapor > vapor pressure, gas will condense to liquid until pressure drops to vapor pressure.



Vapor Pressure, Temperature and ΔH_{vap}

$$\ln P = \frac{-\Delta H_{\text{vap}}}{RT} + C$$



Vapor pressure of CH_3OH.

The Clausius-Clapeyron Equation: Vapor Pressure, Temperature and ΔH_{vap}

Relationship: $$\ln P = \frac{-\Delta H_{\text{vap}}}{RT} + C$$ R = 8.3145 J/K·mol

Straight line version: $$\ln P = \frac{-\Delta H_{\text{vap}}}{R}\left(\frac{1}{T}\right) + C$$

$$y = m \quad x + b$$

Two point version: $$\ln \frac{P_2}{P_1} = \frac{-\Delta H_{\text{vap}}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Determining ΔH_{vap} Using Vapor Pressure Data

Straight line version: $$\ln P = \frac{-\Delta H_{\text{vap}}}{R}\left(\frac{1}{T}\right) + C$$

$$y = \quad m \quad x + b$$

Vapor Pressure date for SO_2:

T (K)	P (mm Hg)
220	81.6
230	147.4
240	253.6
250	417.7

Make a plot of ln(P) vs. 1/T.

Slope = $-\Delta H_{vap}/R$

Using the Two-Point Version of the Clausius-Clapeyron Equation

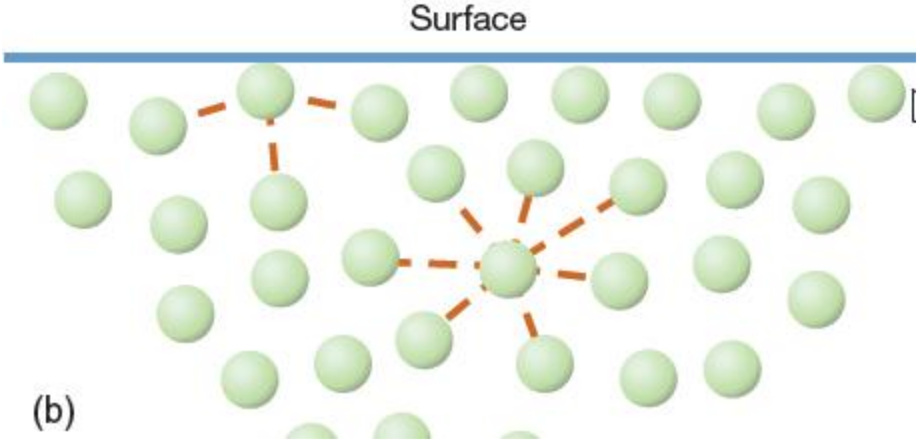
Two point version: $$\ln\frac{P_2}{P_1} = \frac{-\Delta H_{\text{vap}}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

The vapor pressure of liquid aluminum is 400. mm Hg at 2590 K. Assuming that ΔH_{vap} for Al (296 kJ/mol) does not change significantly with temperature, calculate the vapor pressure of liquid Al at 2560 K.

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

Surface Tension

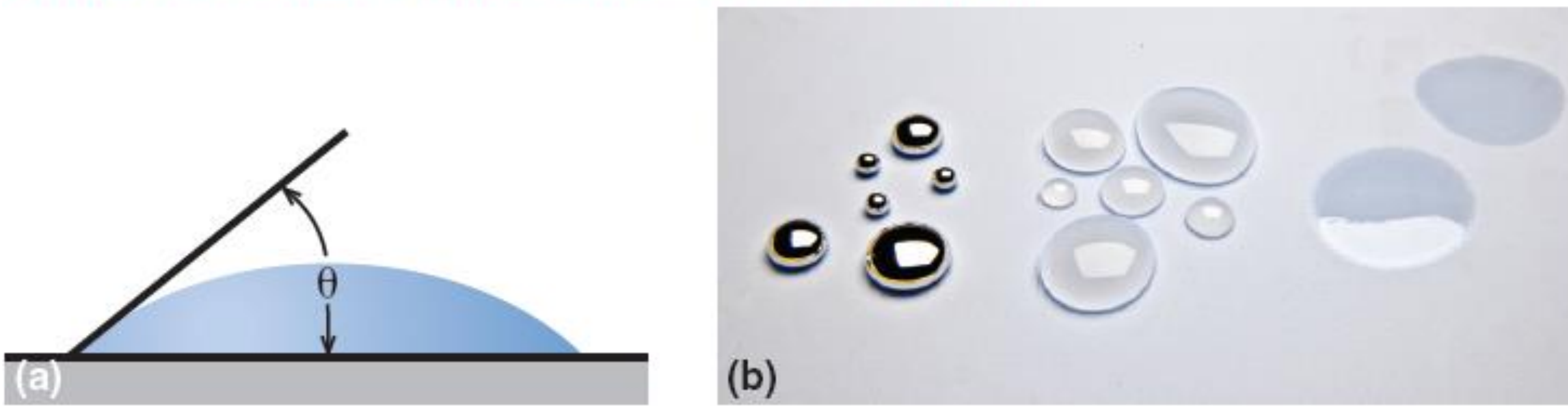
Surface tension is a measure of force required to "break" the surface of a liquid. Surface tension tries to minimize the amount of surface area.



Surface Tension: Drops!

A sphere has the smallest surface area per volume, so liquids want to be spheres.

Explore contact angle and surface tension.



(a) Measuring contact angle for a liquid; (b) droplets of mercury, water, and acetone

A drop is a contest between surface tension and gravity.

Surface Tension: Trends, such as they are

Table 11.3.1 Surface Tension Values and Boiling Points for Some Common Liquids

Substance	Formula	Surface Tension (J/m^2 at 20 °C)	Normal Boiling Point (°C)
Octane	C_8H_{18}	2.16×10^{-2}	125.5
Ethanol	CH_3CH_2OH	2.23×10^{-2}	78.4
Chloroform	$CHCl_3$	2.68×10^{-2}	61.2
Benzene	C_6H_6	2.85×10^{-2}	80.1
Water	H_2O	7.29×10^{-2}	100.0
Mercury	Hg	46×10^{-2}	356.7

Viscosity

Viscosity is a measure of a liquid's resistance to flow.

Water vs. Honey
Corn starch
Mercury

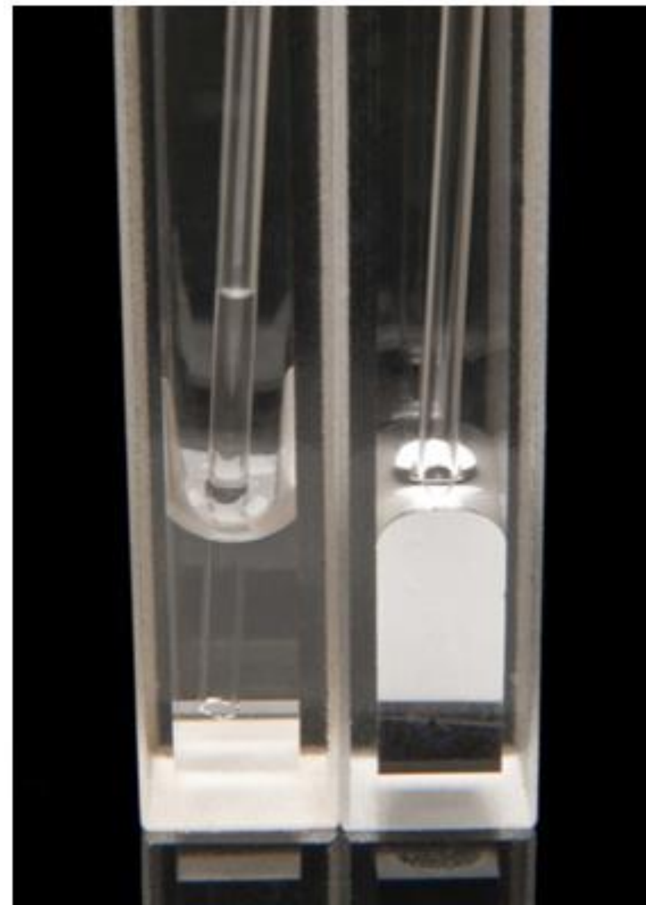
Trends:

- Long molecules have high viscosity.
- No good correlation with IMF strength.

Capillary Action

Movement of a liquid up a capillary tube or up a paper towel are examples of capillary action.

Capillary action represent an **adhesive force**.



Capillary tubes in water and mercury