Surface Tension

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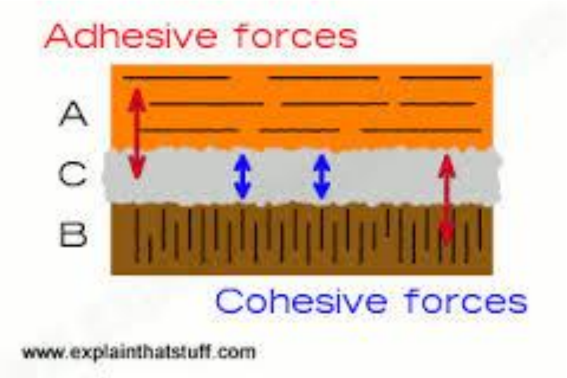
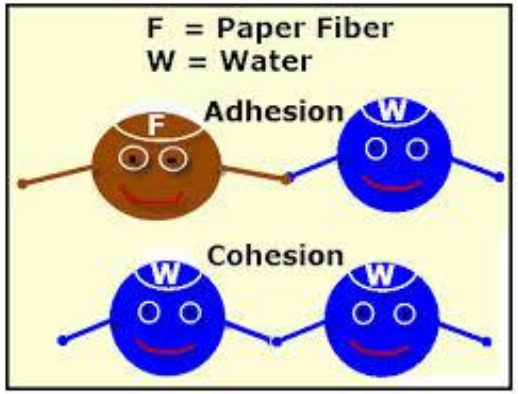
Molecular Forces

- 2 types

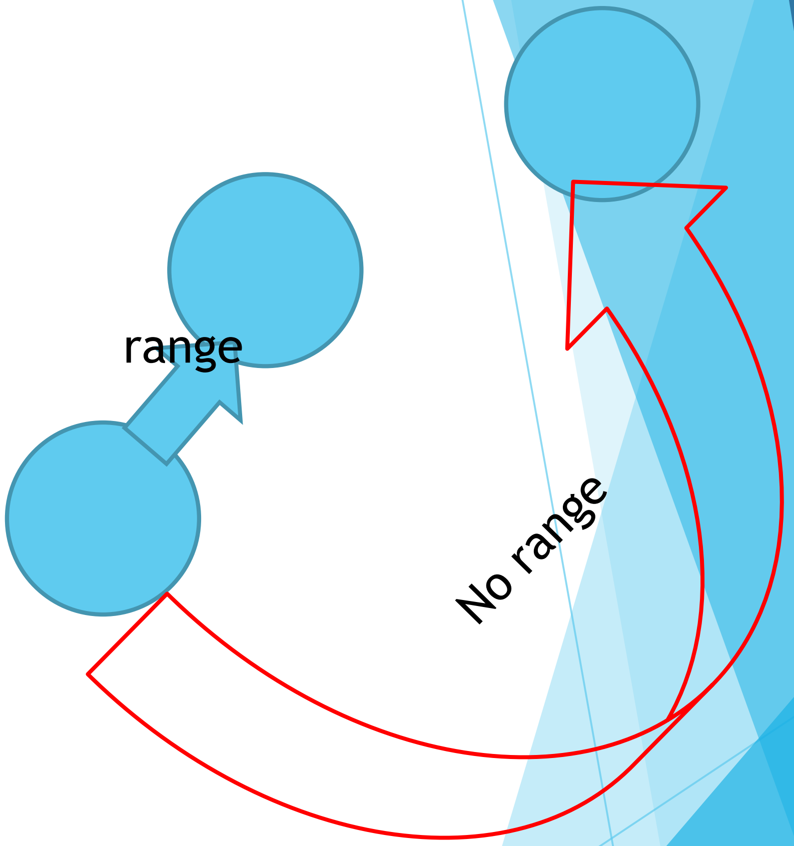
Adhesive Force	Cohesive Force
Force of attraction between	
Molecules of different substance	Molecules of same substance

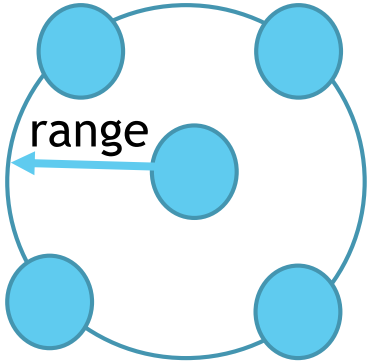




Molecular Range

- Maximum distance upto which the force of cohesion between the molecules exist
- Order of 10^{-9}m
- Different for different substances



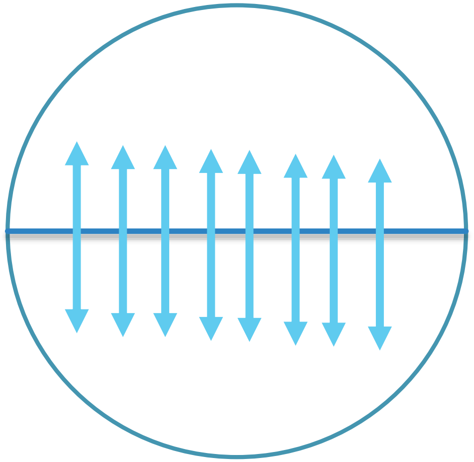


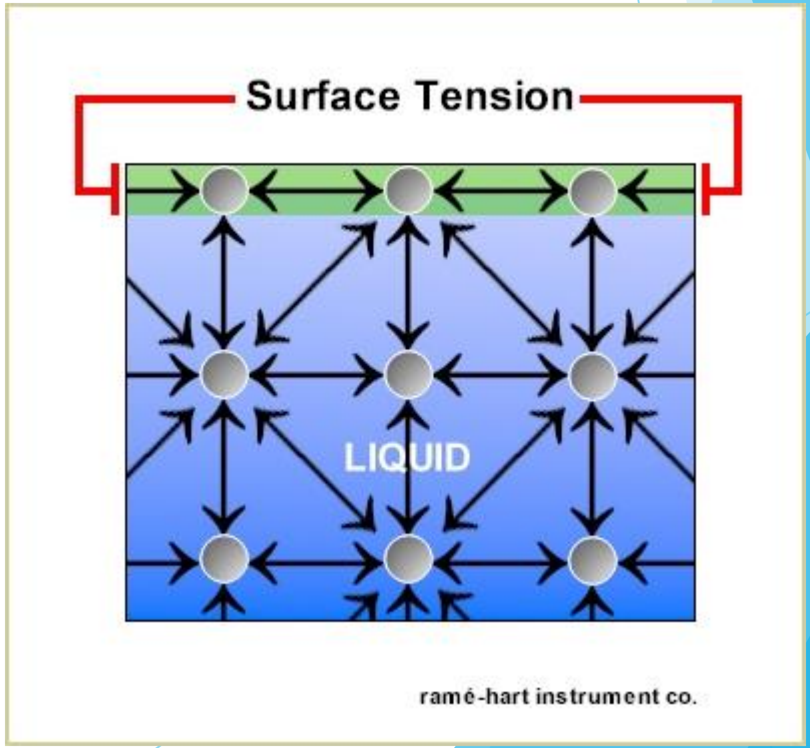
Sphere of Influence

A sphere with molecule as centre & molecular range as radius

Surface Tension

- Pull or tension of the liquid surface
- Tangential force per unit length, acting at right angles on either side of a line imagined to be drawn in the free liquid surface
- Surface Tension=$\frac{F}{L}$





Unit - Nm^{-1}

Dimension-

Surface Tension=$\frac{F}{L}$ =$\frac{MLT^{-2}}{L}$=MT^{-2}

Surface Energy

- Inside molecule-balanced pull by other surrounding molecules
- Surface Molecule-Unbalanced pull by other molecules
- $PE_{\text{surface molecule}} > PE_{\text{inside molecule}}$
- Surface Energy = $\frac{PE}{Area\ of\ liquid\ surface} = \frac{Work\ done}{Area\ of\ liquid\ surface}$
- Surface Energy=work done in increasing surface area of liquid film to unity
- Surface Energy = |Surface tension|

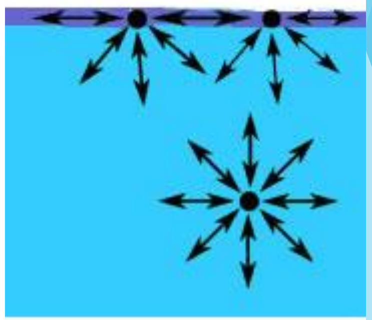
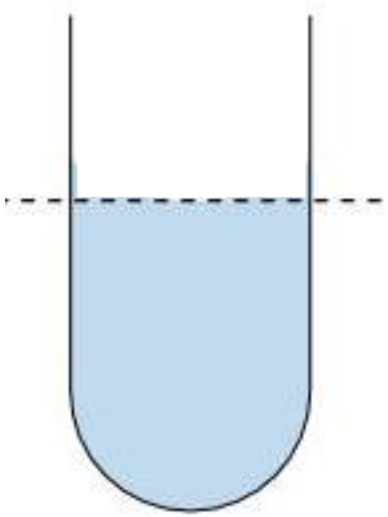


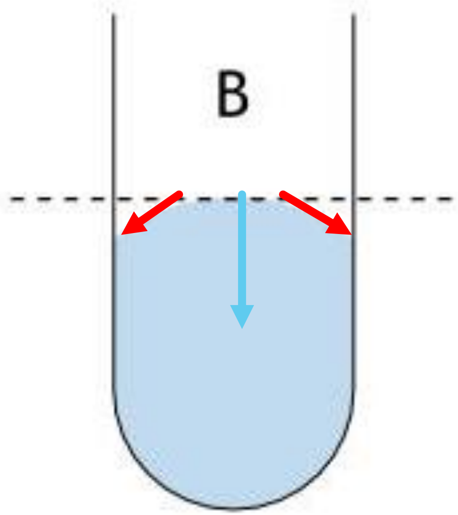
Fig 1. Forces between water molecules

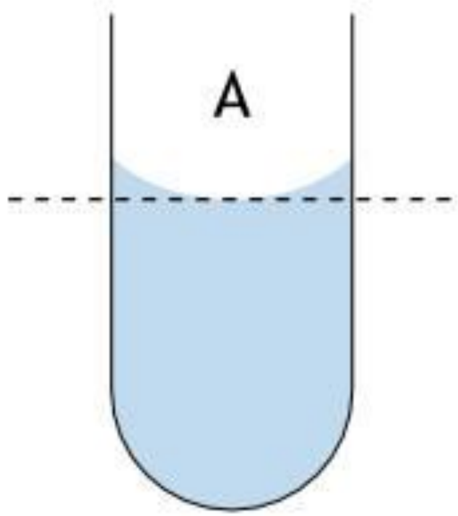
Surface Tension & Surface Energy

		Unit	Dimension
Surface Tension	$\frac{F}{L}$	Nm^{-1}	$\frac{MLT^{-2}}{L}=MT^{-2}$
Surface Energy	$\frac{PE}{Area\ of\ liquid\ surface}$	$\frac{Nm}{m^2}=Nm^{-1}$	$\frac{MLT^{-2}L}{L^2}=MT^{-2}$

Pressure difference across a curved surface



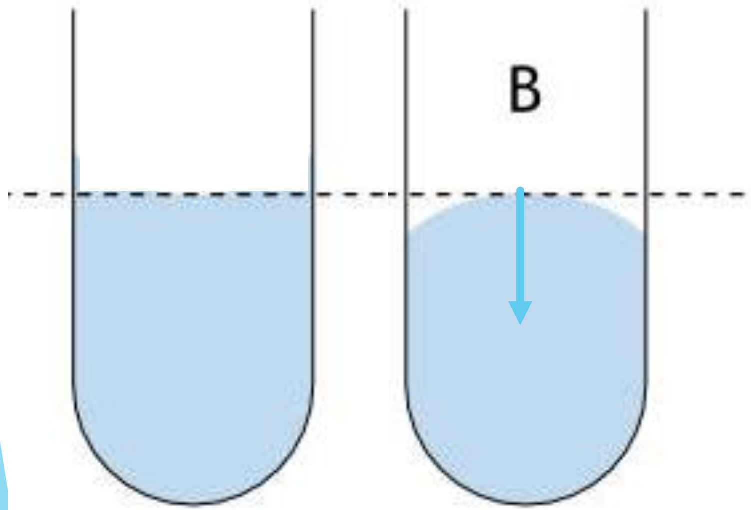


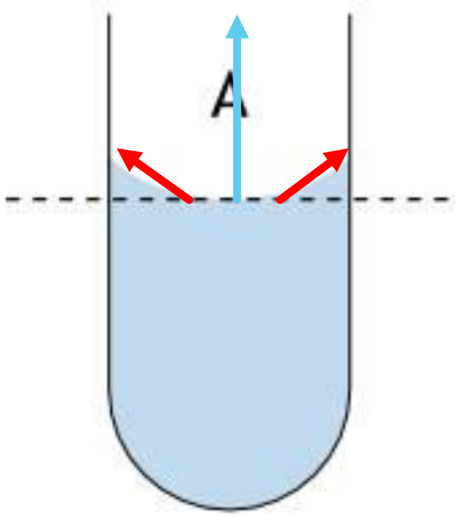


Liquid surface is plane
Inward force=Outward force
No pressure difference

Liquid surface is CONVEX
Net force due to surface tension is inward
For equilibrium, Pressure $_{inside}$ > Pressure $_{outside}$
Pressure $_{inside}$ - Pressure $_{outside}$=Excess of pressure
Force due to excess pressure balances surface tension

Pressure difference across a curved surface



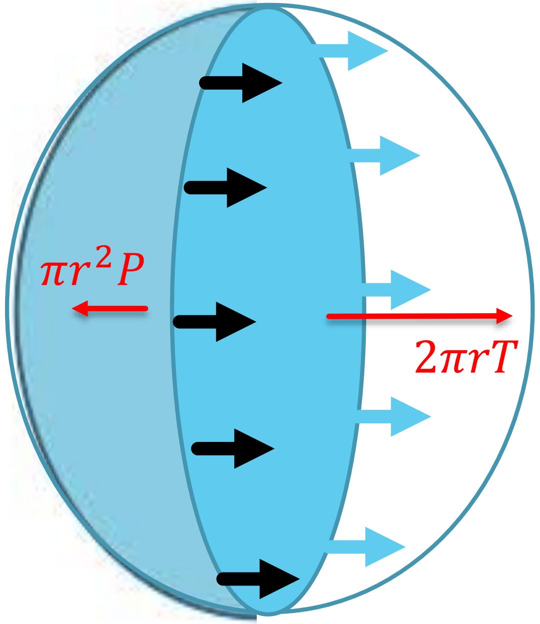


Liquid surface is CONCAVE
Net force due to surface tension is outward
For equilibrium, Pressure $_{inside}$ < Pressure $_{outside}$
Pressure $_{outside}$ - Pressure $_{inside}$ = Excess of pressure
Force due to excess pressure balances surface tension

Excess of Pressure inside a liquid drop

- For a spherical drop
  - Liquid surface-convex
  - surface tension-inward
  - Pressure $_{inside}$ > Pressure $_{outside}$
- Liquid Drop-2 hemispheres
- 2 forces acting- Force due to
  - Excess of pressure=$\pi r^2 P$
  - Surface tension =$2\pi r T$
- In equilibrium,

$$\pi r^2 P = 2\pi r T$$

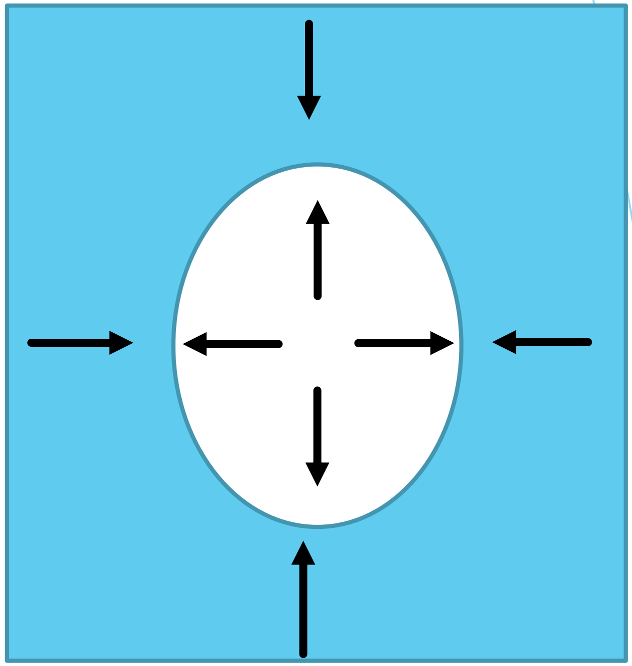


Excess of pressure, P=$\frac{2T}{r}$

Excess of Pressure inside a Bubble
a. Air bubble formed inside a liquid

- For a small air bubble in liquid
  - Liquid pressure is same throughout
- Only one liquid surface
- 2 forces acting
  - Surface tension $=2\pi rT$
  - Excess of pressure$=\pi r^2 P$
- In equilibrium,

$$\pi r^2 P=2\pi rT$$

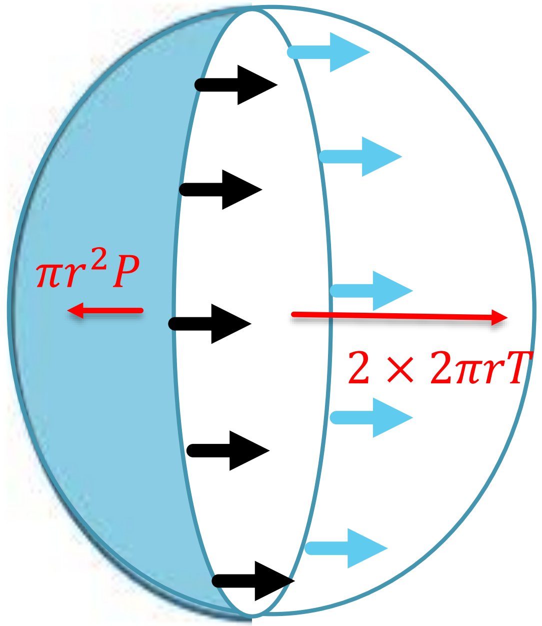


Excess of pressure, $P=\frac{2T}{r}$

Excess of Pressure inside a Bubble
b. Bubble formed by Liquid in air

- 2 liquid surfaces
- 2 forces acting
  - Excess of pressure=$\pi r^2 P$
  - Surface tension =$2 \times 2\pi r T$
- In equilibrium,

$$\pi r^2 P = 4\pi r T$$



Excess of pressure, P=$\frac{4T}{r}$

Effect of Electrostatic Pressure on a bubble

- Consider
  - A charged conducting surface – plane/ hollow/ solid sphere
  - Charges on any surface is repelled by all the other charges
  - This produce outward force on the surface
- Applying Gauss Law
  - Electrostatic Pressure = Mechanical Force per unit area

$$= \frac{\sigma^2}{2\varepsilon_0 \varepsilon_r}$$

ε_0 - Permittivity of free space = 8.854 $\times 10^{-12}$ Farad/m
ε_r - Relative Permittivity of the medium
For bubble in air, ε_r=1

σ – Surface charge density

$$= \frac{Charge}{Area} = \frac{q}{4\pi r^2}$$

Effect of Electrostatic Pressure on a bubble

- Electrostatic pressure=$\frac{\sigma^2}{2\varepsilon_0\varepsilon_r}$
- Excess of Pressure =$\frac{4T}{r}$

- In equilibrium,

$$\frac{4T}{r} = \frac{\sigma^2}{2\varepsilon_0\varepsilon_r} = \left(\frac{q}{4\pi r^2}\right)^2 \times \frac{1}{2\varepsilon_0\varepsilon_r} = \frac{q^2}{32\pi^2\varepsilon_0\varepsilon_r r^4}$$

$$4T = \frac{q^2}{32\pi^2\varepsilon_0\varepsilon_r r^3}$$

$$r^3 = \frac{q^2}{128\pi^2\varepsilon_0\varepsilon_r T}$$

$$r \propto q^{2/3}$$

- As q increases, r increases
- Because of outward electrostatic pressure, size of bubble (r) increases
- Then Excess of pressure ($\frac{4T}{r}$)reduces

Work done in blowing a bubble

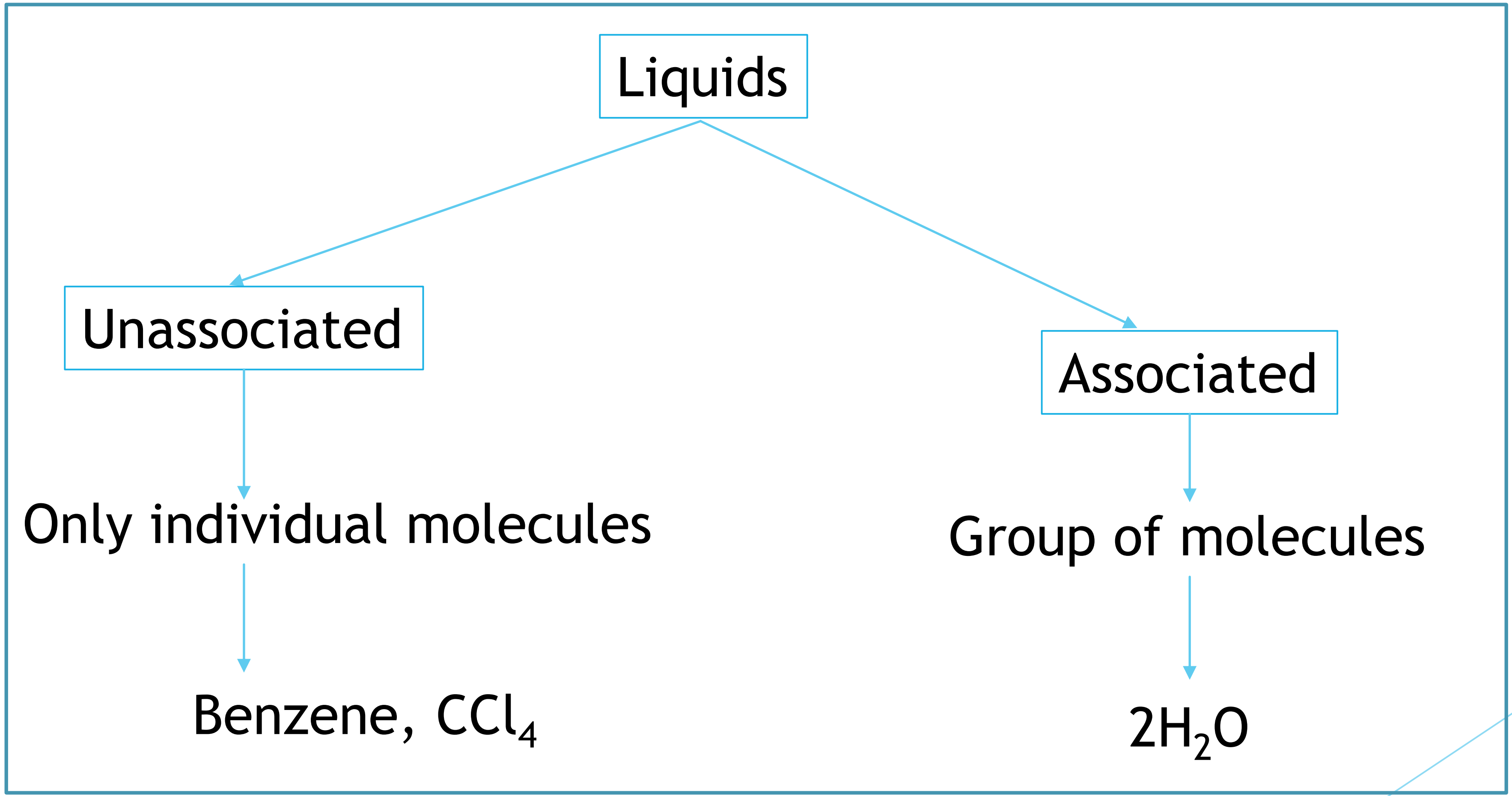
- Bubble has 2 surfaces
- Change in surface area = $8\pi r^2$
- Work done in blowing the bubble = Surface Energy × change in surface area

= Surface Tension × change in surface area

= $T \times 8\pi r^2 = 8\pi r^2 T$

Surface Tension and Temperature

- 2 types of liquids



Surface Tension and Temperature

- For unassociated molecules,
  - Surface tension decreases linearly with temperature

$$T = T_0(1 - \alpha t)$$

t – Temperature in Celsius scale
T – Surface tension at t^0c
T_0 - Surface tension at 0^0c
α - Temperature coefficient of surface tension of liquid

- The rate of variation of surface tension with temperature is

$$\frac{dT}{dt} = -\alpha T_0 = -k$$

Surface Tension and Temperature

For all liquids,

- Vander waals relation is,

$$T = A\left[1 - \frac{\theta}{\theta_c}\right]^{3/2}$$

θ - Temperature in Absolute scale
θ_c - Critical Temperature
A - Constant

- Fergusen modified this as

$$T = A\left[1 - \frac{\theta}{\theta_c}\right]^{n}$$

n - Constant for a liquid
For most liquids,
n=1.21

Surface Tension and Temperature

- Eotvos law

$$T\left[\frac{M}{\rho}\right]^{2/3} = K(\theta_c - \theta)$$

T - Surface tension
M -Molecular weight
ρ - density
θ - Temperature in Absolute scale
θ_c - Critical Temperature
K - Universal Constant≈ 2.2

- Ramsay & Shields modified it as

$$T\left[\frac{M}{\rho}\right]^{2/3} = K(\theta_c - \theta - \delta)$$

$$T[Mvx]^{2/3} = K(\theta_c - \theta - \delta)$$

δ-constant for a liquid
varies from 6-8 for most liquids

v-specific volume

x - $\frac{\text{effective molecular weight of associated liquid}}{\text{effective molecular weight of the same unassociated liquid}}$

Surface Tension and Temperature

- According to Eotvos law,

$$T\left[\frac{M}{\rho}\right]^{2/3} = K(\theta_c - \theta)$$

T=0, When, $\theta = \theta_c$

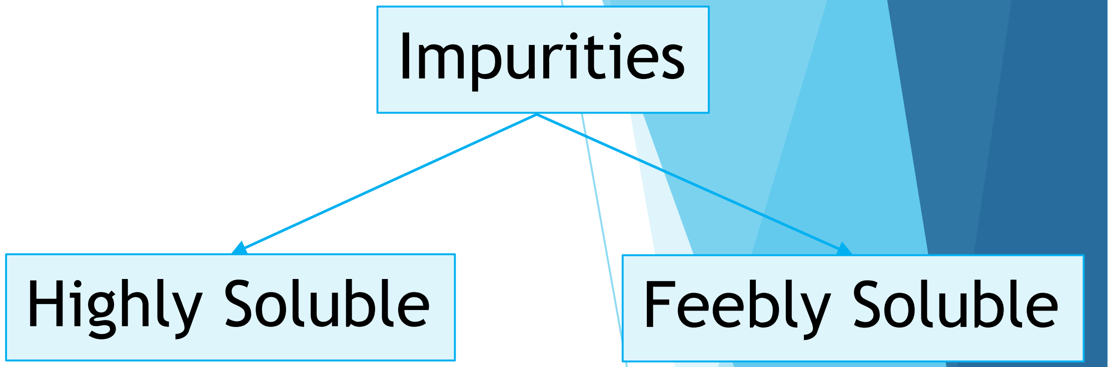
- According to Ramsay & Shields equation,

$$T\left[\frac{M}{\rho}\right]^{2/3} = K(\theta_c - \theta - \delta)$$

T=0, When, $\theta = \theta_c - \delta$

- Callender proved Ramsay & Shields equation
  - T_{H_2O}=0 when $\theta = 647\ K$, But θ_c =653 K
  - T=0, When, $\theta = \theta_c - \delta$

Surface Tension & Impurities



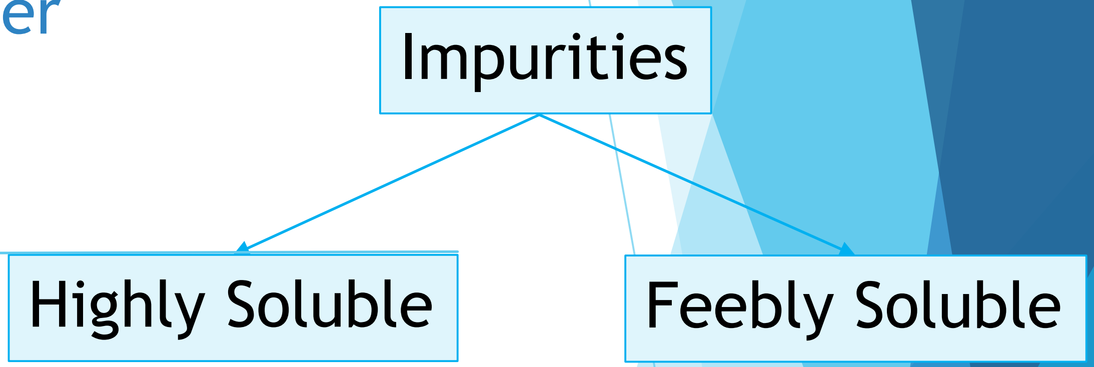
- Dissolved impurities affect surface tension

- Case I :- Highly Soluble
  - Force of attraction$_{solute}$>Force of attraction$_{liquid}$
  - Presence of impurities increase surface energy& surface tension
  - Eg: T_{water}-0.072N/m $T_{salt\ water}$-0.082N/m

  - Any system has the tendency to reduce PE
  - Solute molecules will pull to the interior of the liquid
  - Impurity concentration$_{surface}$ $<$ Impurity concentration$_{interior}$
  - $T_{Freshly\ prepared\ solution} > T_{solution\ at\ equillibrium}$

Surface Tension & Impurities

- Case II :- Feebly Soluble
  - Force of attraction$_{solute}$<Force of attraction$_{liquid}$
  - Presence of impurities reduce surface energy& surface tension
  - Eg: Soap solution & solution of phenol in water
  - T_{water}-0.072N/m > $T_{soap\ solution}$-0.06N/m



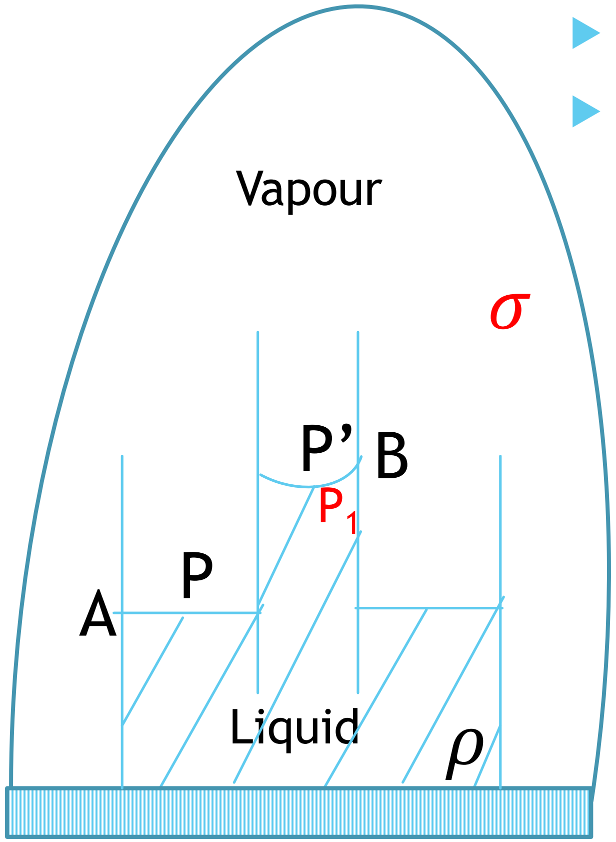
- Any system has the tendency to reduce PE
- Liquid molecules will pull to the interior
- Impurity concentration$_{surface}$ > Impurity concentration$_{interior}$
- $T_{Freshly\ prepared\ solution}$ (0.068)> $T_{solution\ at\ equilibrium}$ (0.043)

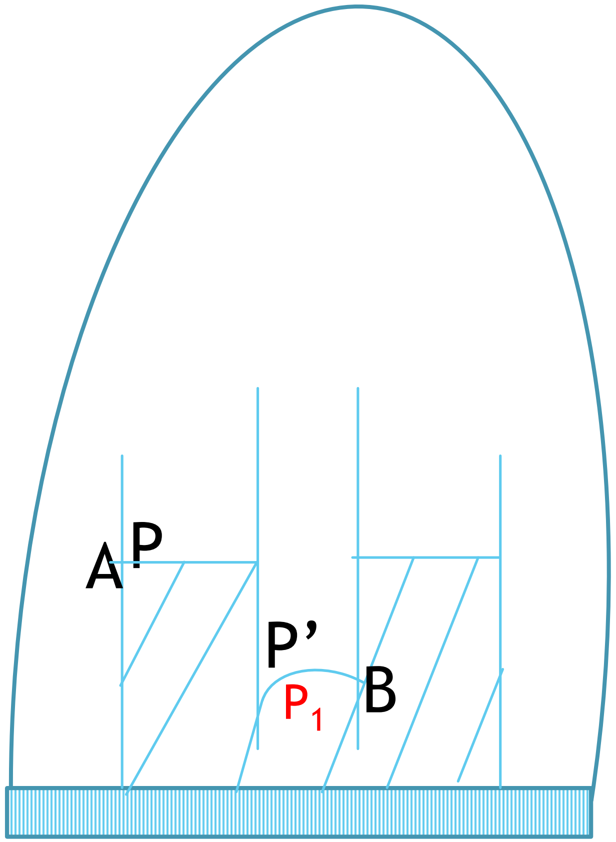
Surface Tension & Evaporation

- P – Pressure of Vapour at A
- P'- Pressure of vapour at B
- P_1-Liquid pressure at B
- σ – Density of vapour
- ρ –Density of liquid

$$P' = P - h\sigma g$$
$$P_1 = P - h\rho g$$

Pressure decreases with increasing **altitude**



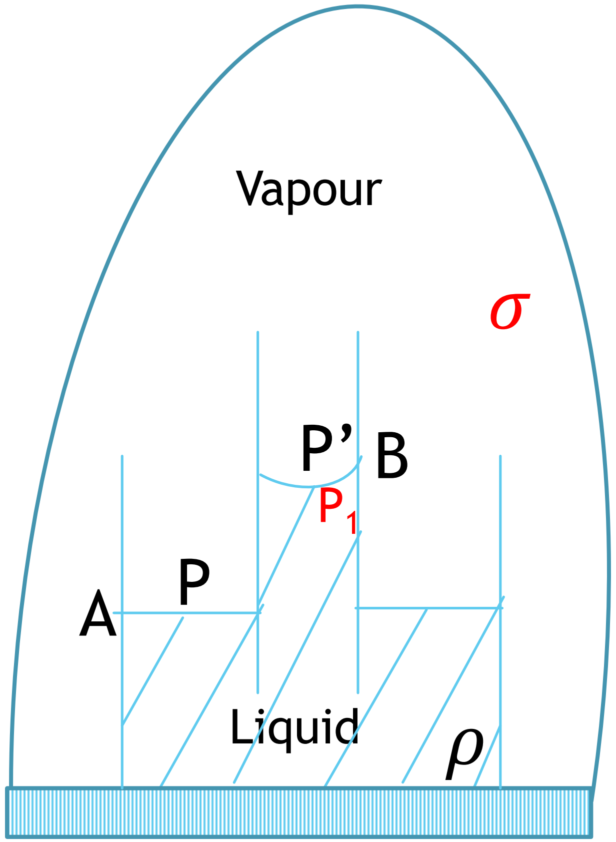


Excess of Pressure at B=P'-P_1

$$\frac{2T}{r} = P' - P_1 = P - h\sigma g - (P - h\rho g)$$

$$= h\rho g - h\sigma g = h(\rho - \sigma)g$$

Surface Tension & Evaporation

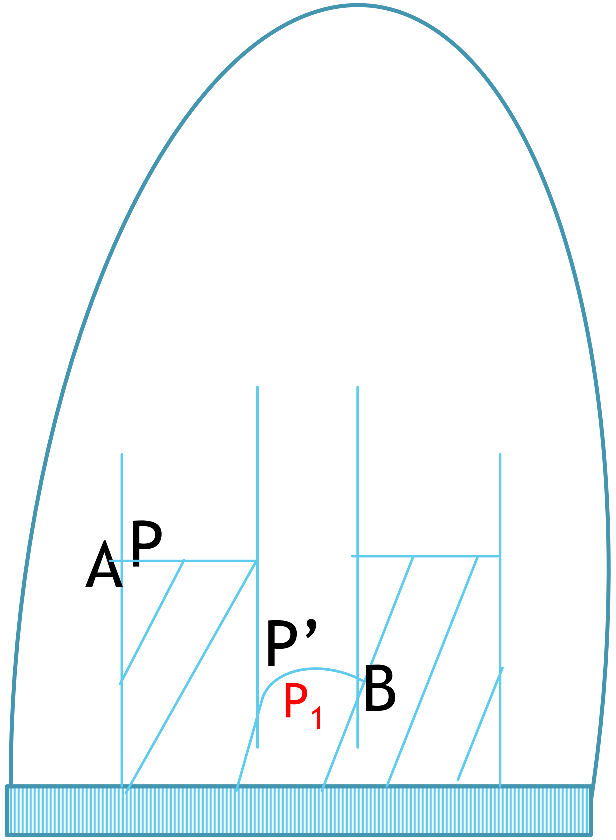


- For a concave surface, $P' < \mathrm{P}$

Pressure decreases with increasing **altitude**

P – Pressure of Vapour at A-Plane surface
P'- Pressure of vapour at B- Concave surface

Surface Tension & Evaporation



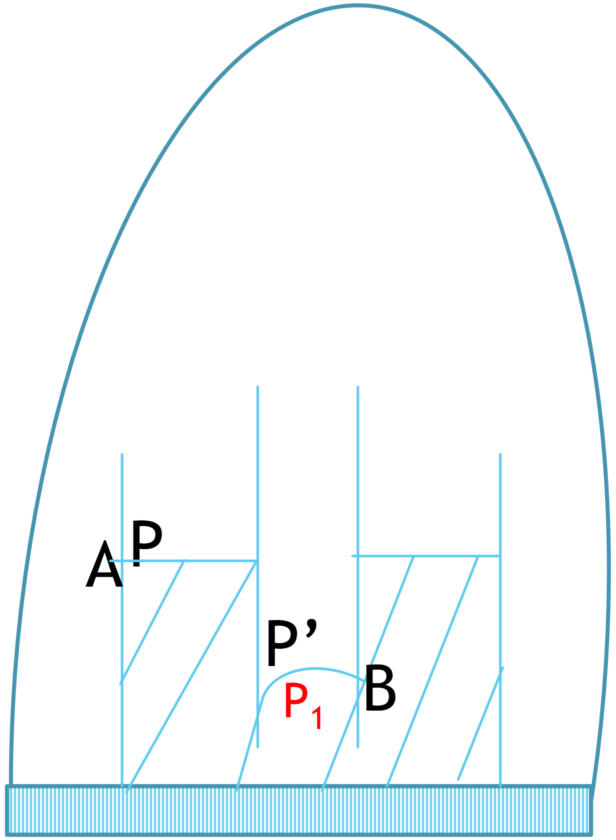
- For a convex surface, $P' > \mathrm{P}$

Pressure decreases with increasing **altitude**

P – Pressure of Vapour at A-Plane surface
P'- Pressure of vapour at B- Convex surface

- A spherical drop placed in a plane surface will begin to evaporate in order to increase the vapour pressure needed for convex surface
- Due to evaporation, the size decreases and it becomes more convex
- So more evaporation & whole drop will evaporate

Surface Tension & Evaporation



- Latent heat is provided by surface energy

  L – Latent heat of vaporization per unit volume
  T- Surface Tension
  r- Critical radius of the drop

- $\frac{4}{3}\pi r^3 L = 4\pi r^2 T$

  $r = \frac{3T}{L}$

- If the radius of the drop is less than critical radius- the whole drop will automatically evaporate
- For water, r_c=1.2x10^{-10}m

Surface Tension & Condensation

- A saturated vapour cannot automatically condense into drops
- As soon as the drop is formed, actual vapour pressure is less than what needed for a drop since For a convex surface, $\mathrm{P} < P'$

P – Pressure of Vapour at A-Plane surface

P'- Pressure of vapour at B- Convex surface

- So drop will evaporate & condensation will not occur
- Condensation can be induced only in the presence of dust particles, charged ions etc.
- The dust particle acts as the nucleus for condensation
- The drop formed on this dust particle has radius greater than critical radius which helps further condensation
- Vapour pressure of concave surface < Vapour pressure of plane surface. Vapour will condense more readily on a concave surface than on plane surface


Thank You