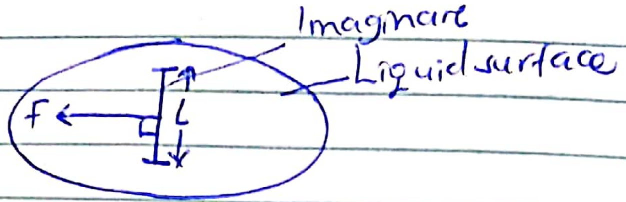
16/05/22 SURFACE TENSION (8)

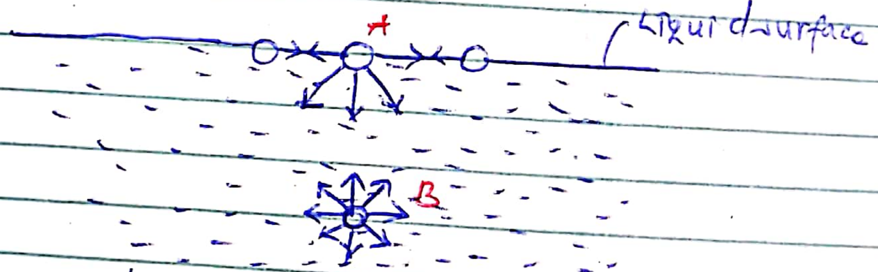


- Immagine a straight line of length L in the surface of a liquid. If the force at right angle to this line following the maginary line
- If Than the surface tension

Defn Surface tension γ is the force per unit length acting in the surface perpendicular to one side of a line in the surface.
Its S.I unit Nm^{-1}

MOLECULAR THEORY / EXPLAINATION OF SURFACE TENSION.

1st explanation.



- The molecules below the surface of the liquid they have no resultant because they experience constant repulsion and attraction from ē neighbouring molecules from all directions
- Molecules at ō surface of ō liquid have a resultant of downward force due to the molecules below them and are widely spaced.
- At the same time, the surface molecules have strong intermolecular forces of attraction w/c holds them together
- The surface tension are thus under tension and this effect phenomena is known as surface tension.

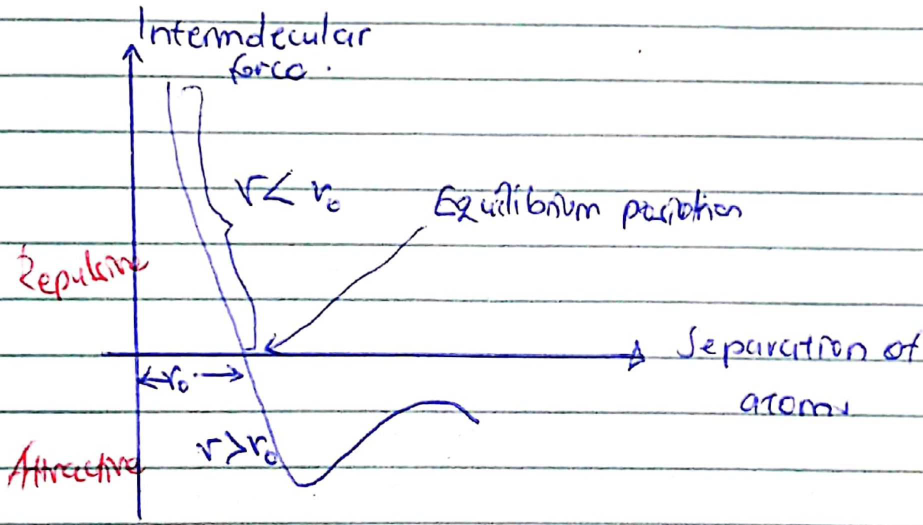
Explanation 2

→ Molecules in ē surface ō ē liquid are further apart than those in the body ō ē liquid ie ē surface layer has a lower density than the liquid in bulk.

- This follows b'se ē increased separation ō molecules that accompanies the change 4rm liquid 2 vapour is not a sudden transition

- The density ō ē liquid must there4 decrease thru ē surface.

→ The intermolecular forces in ē liquid are both attractive and repelling and these balance when the spacing btwn ē molecules has it's equilibrium value as r_0 however 4rm ē intermolecular of separation curve

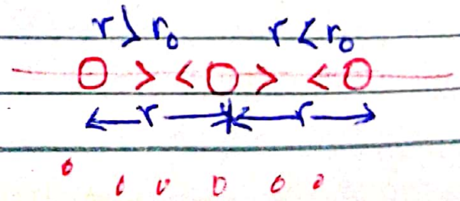


- When ē separation is btwn ē molecules greater than the equilibrium value r_0, the attractive force btwn ē molecules exceeds the repelling force.

- This is the situation with ē more widely spaced surface layer molecules ō a liquid.

- They experience attractive forces from either sides due to eir neighbours, wc puts them in a state ō tension.

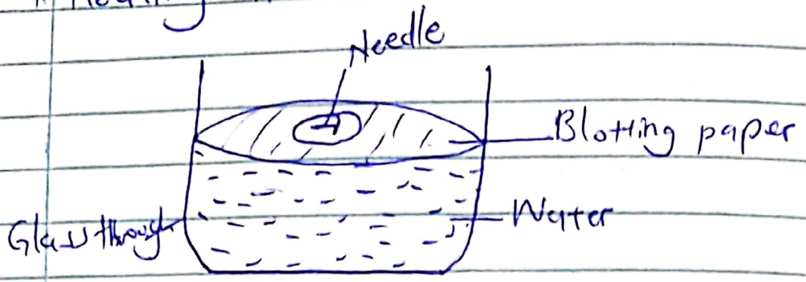
- The liquid surface consequently behaves like a stretched elastic skin



Expt 2 demonstrate surface tension.

SOME SURFACE TENSION PHENOMENA.

1. Floating needle



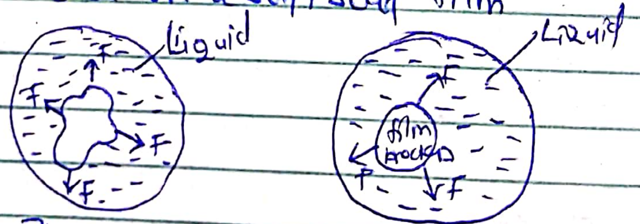
- Place a blotting paper on water surface
- Drop a needle on the blotting paper and then observe
- The blotting paper absorbs the water.
- Then after some minutes the blotting paper sinks to the bottom.
- The needle remains floating on water.

How to reduce surface tension in liquids

- Soap solution
- Detergent solution
- Oil

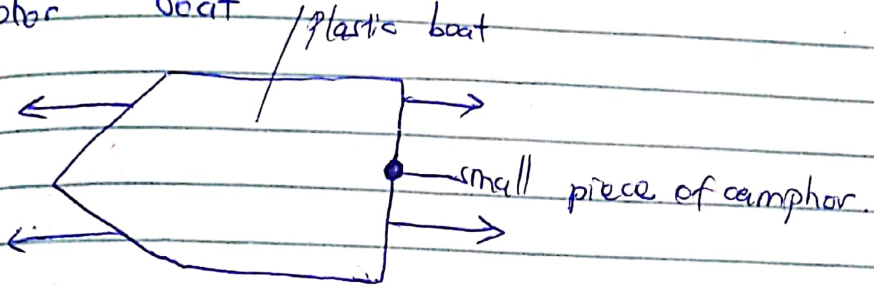
Nelkon,
Tom Duncan

2. Thread on a ~~soft~~ soap film



- There are equal and opposite forces on each side of the thread and thereft it stays where it has been placed. If the film is brocken in the region bounded by the thread.
- There are forces on the outside of the thread only.
- The thread is theref pulled into acircle and thereft the liquid film has the minimum posible area.

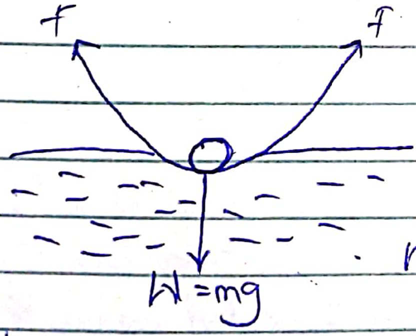
3. Camphor boat



- The camplor suplimes and interacts with the water at the back of the boat, reducing the surface there, so that F' is less than F. There is therefore a net which drags the boat through the water.

Motion of insects of water

- Some insects are able to walk on water surfaces although their densities are high.
- Water coming from the tap is spherical
- A needle can float on water.



F = Surface tension force.
W = Weight of the needle

- The needle creates a depression in the liquid surface so that the surface tension forces F (w/c act in the surface) now have an upward directed component w/c is capable of supporting the weight of the needle.

Some definitions:

1st Intermolecular forces:

→ These are forces btwn 2 molecules on ė surface.

• Intermolecular forces are basically electric in nature and can either be attractive or repulsive

Two types of intermolecular forces exist.

① - Cohesive force

• Is the attractive force exerted on a liquid molecule by the neighbouring liquid molecules.

or

• forces of attraction existing btwn molecules of the same substance.

2: Adhesive force.

• Is the attractive force exerted on a liquid molecule by molecules in the surface of the solid

or

• forces of attraction btwn molecules of a liquid and molecules of a solid.

ANGLE OF CONTACT

0.02

2+3.6

→ Consider a liquid in a container with vertical sides. If the adhesive force is large compared to cohesive force, the liquid tends to stick to the wall and so has a concave meniscus. figure A below

On the other hand if the adhesive force is small compared to the cohesive force, the liquid surface is pulled away 4rm ė wall and the meniscus is convex figure B below.

When the meniscus is convex or concave, depends on the liquid concerned and on the solid with wc it is in contact e.g water has a concave meniscus when in contact with glass and a convex meniscus when in contact with watts.

Mercury has a convex meniscus with clean glass

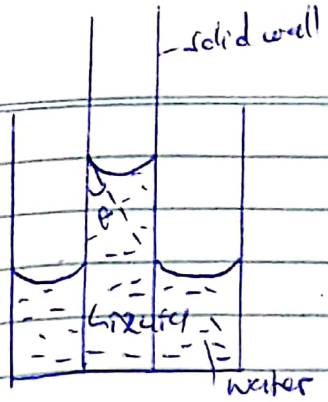


fig (a) concave meniscus

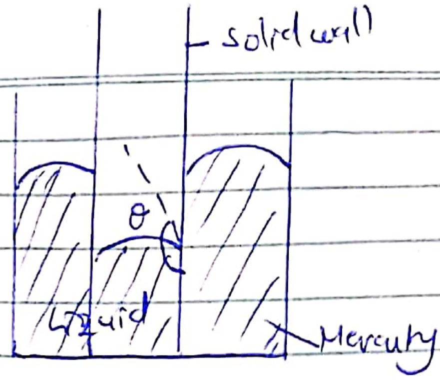


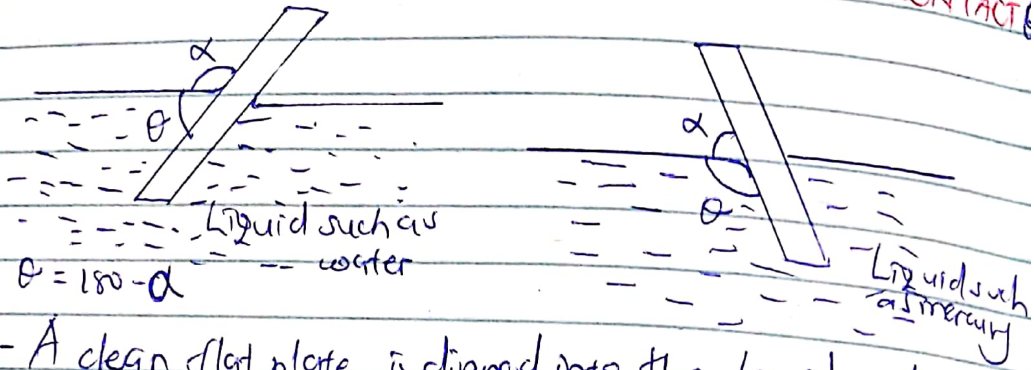
fig (b) convex meniscus

- The angle of contact θ btwn the solid surface and the tangent ~~to~~ ~~the~~ plane to the liquid surface to the angle of intersection ~~btwn~~ measured thru the liquid.

- from the figure (a) above, it can be seen that the meniscus is concave when θ is less than 90° and it's convex when θ is greater than 90°
- A liquid ~~sur~~ is said to "wait" a surface with w/c it's angle of contact is less than 90°.
- The angle ō contact bewn water and clean glass is 0, that btwn mercury and clean glass is 137°. Thus water wets clean glass and mercury doesnot
- The angle of contact bewn water and clean glass is due to ē adhesive force bewn water and glass being very much larger than a cohesive force ām selves.
- This explains why water tend to spread into a continuous film when splash on a horizontal surface
- Mercury on the other hand forms into little drops; Water on a roof of a flashly washed car

The addition of a deregent to a liquid lowers it's surface tension and reduces the angle of contact also increase in temperature lowers surface tension

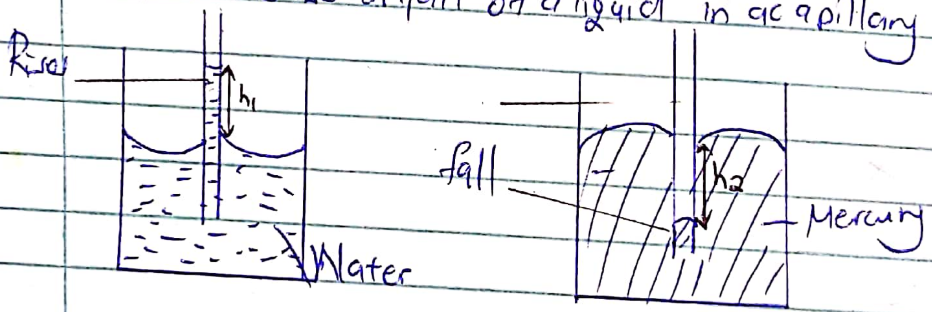
EXPERIMENT TO DETERMINE THE ANGLE OF CONTACT



- A clean flat plate is dipped into the liquid and tilted until the liquid surface on one side of the plate is horizontal up to the point / line of contact.
- The angle α ~~into~~ btwn the flat plate and the liquid surface is measured by means of protractor suitably placed against the edge of the plate.
- The angle of contact = 180 - α.

CAPILLARITY

- It is the rise or fall of a liquid in a capillary tube



Explain why there is a rise of water in a tube dipped in a basin halfway filled with water, while when the same tube is dipped in a basin half way filled with mercury there is a fall off of mercury in the tube.

Illustrations of Capillarity

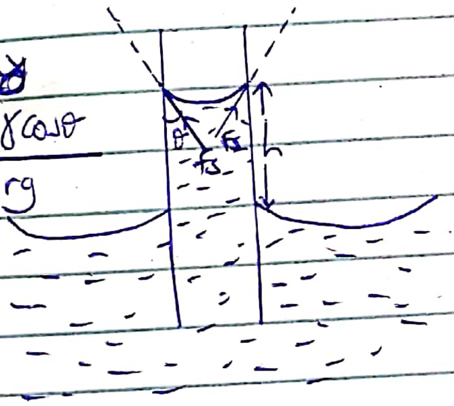
- Blotting paper absorbs ink by capillary action- The pores in the blotting paper appr act as capillaries
- The oil in a lamp rises up the wick through the narrow spaces btwn the thread of the wick
- A sponge retains water due to capillary action.
- Walls get damped during rainy season due to absorbtion of water by the bricks.

Derivation of the expression ~~~~.h.

- Consider a liquid wc rises up in a clean capillary tube. ~~The~~
- The liquid stops rising when the weight of the raised column acting vertically downwards equals to the vertical components of the surface tension force

~~$h = 2\theta$~~

$$h = \frac{2\gamma\cos\theta}{\rho r g}$$



At equilibrium,

Weight of the risen liquid column $= F_s \cos\theta$

$mg = F_s\cos\theta$ but $\gamma = \frac{F_s}{L}$ $F_s = \gamma L$ $= 2\pi r\gamma$

$\rho V g = 2\pi r\gamma\cos\theta$

$\rho A h g = 2\pi r\gamma\cos\theta$

$\rho \cancel{\pi} r^{\cancel{2}} h g = 2\cancel{\pi}\cancel{r}\gamma\cos\theta$

$$\boxed{h = \frac{2\gamma\cos\theta}{\rho r g}}$$

- If θ is greater than 90°, the meniscus is convex upwards, $\cos\theta$ is negative and h will be negative.
- This means that the liquid falls in a capillary tube below the level of the surrounding liquid.

NOTE: for a given liquid and solid at a given place, $h\alpha\frac{1}{r}$

where γ, α, ρ and g are constants.

- This means that the lessor the radius of the capillary tube, the greater will be the rise and vise versor.

1. A capillary tube of a diameter 0.2mm is placed vertically inside a liquid of density 800km per cubic metre and surface tension of $5\times10^{-2}Nm^{-1}$ and angle of contact 30°. Calculate the height through which the liquid rises

soln.

$d = 0.2mm$ $\qquad \theta = 30^\circ$

$r = 0.1\times10^{-3}$ $\qquad \gamma = 5\times10^{-2}Nm^{-1}$

$\rho = 80$

$$h = \frac{2(5\times10^{-2})\cos 30^\circ}{80\times(0.1\times10^{-3})\times 9.81}$$

0.1

$$h = \cancel{0.086} \quad \frac{0.08660}{0.07848}$$

$$h = 1.1035$$

2. A capillary tube of diameter 0.2mm is placed vertically mercury angle of contact ~~130~~ 139°c and surface tension $0.52Nm^{-1}$. Calculate the height through which mercury rise if the density of mercury is $13600kgm^{-3}$

$r = 0.1\times10^{-3}$

1.04

$$h = \frac{2\gamma\cos\theta}{\rho r g}$$

$$= \frac{2(0.52)\cos 139}{13600\times(0.1\times10^{-3})(9.81)}$$

$$= \frac{-0.784898}{13.3416}$$

$$= -0.0588$$

Density of H_2O = 1000

3. Calculate the capillary rise in tube of diameter 1mm if the surface tension is $0.06 Nm^{-1}$ assume that the angle of contact is 0°

$$r = \frac{1\times10^{-3}}{2} = 5\times10^{-4}$$

$$h = \frac{2\gamma\cos\theta}{\rho r g}$$

$$= \frac{2(0.06)\cos 0^\circ}{(1000)\times(5\times10^{-4})\times(9.81)}$$

$$= \frac{0.12}{4.905}$$

$$= 2.4cm$$

9. Water rises to a height in 10cm in a tube and mercury falls depth 3.9cm in the same capillary tube. If the density of mercury is $13.6 g cm^{-3}$ and it's angle of contact is $134^\circ c$ and the density of water is $1g cm^{-3}$ and it's angle of contact is $0^\circ c$, calculate the ratio of surface tension of the to liquids.

Water	Mercury
$h = 10cm$	$h = 3.9cm$
$\rho = 1gcm^{-3}$	$\rho = 13.6$
$\theta = 0^\circ c$ $\gamma = ??$	$\theta = 134^\circ c$ $\gamma = ??$

For water.

$$h = \frac{2\gamma\cos\theta}{\rho r g}$$

$$10 = \frac{2\gamma\cos 0}{(1)(r)(9.81)}$$

$$2\gamma\cos 0 = 10(9.81 r)$$

$$\gamma_w = \frac{10(9.81 r)}{2\cos\theta}$$

For mercury

$$h = \frac{2\gamma\cos\theta}{\rho r g}$$

$$\gamma_m = \frac{h_m \rho_m r g}{2\cos\theta_m}$$

$$h = \frac{2\gamma\cos\theta}{\rho r g}$$

$$\gamma_w = \frac{h_w \rho_w r g}{2\cos\theta_w}$$

$$\frac{\gamma_w}{\gamma_m} = \left(\frac{h_w \rho_w r g}{2\cos\theta_w}\right) \div \left(\frac{h_m \rho_m r g}{2\cos\theta_m}\right)$$

$$= \frac{h_w \rho_w \cancel{rg}}{\cancel{2}\cos\theta_w} \times \frac{\cancel{2}\cos\theta_m}{h_m \rho_m \cancel{rg}}$$

$$= \frac{h_w \rho_w \cos\theta_m}{h_m \rho_m \cos\theta_w}$$

$$= \frac{10 \times 1 \cos 134}{(3.5)(13.6)\cos 0.}$$

$$= \frac{\cancel{9.998}}{}$$

$$= \frac{-6.9466}{47.6}$$

$$= -0.1459$$

$$\frac{\gamma_w}{\gamma_m} = \frac{5}{34}$$

Two capillaries made of the same material but of different radii are dipped in the liquid the rise in one capillary is 2.2cm and that in the other is 6.6 cm. Calculate the ratio of their ~~rag~~ radii

Formu

Sln

$h \propto 1/r_1$

$r_1 \propto 1/h_1$

$r_1 = k/h_1$ ——— ①

$r_2 = \frac{k}{h_2}$ ——— ②

$$\frac{r_1}{r_2} = \frac{h_2}{h_1}$$

$$= \frac{\cancel{2.2}}{\cancel{6.6}}$$

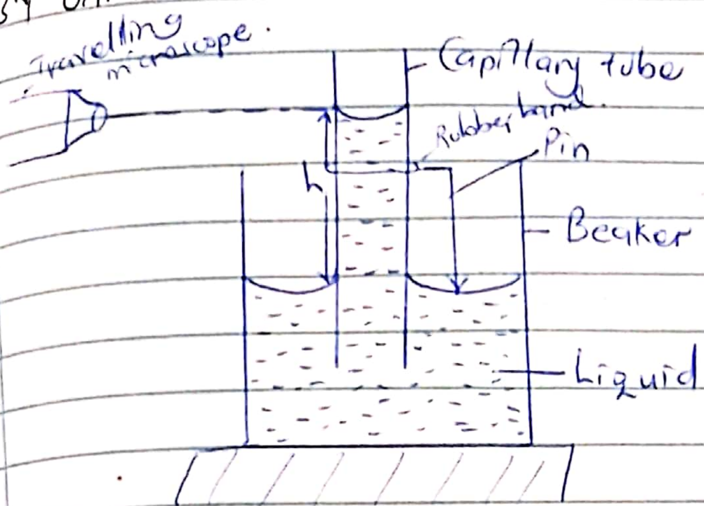
$$\frac{r_1}{r_2} = \frac{h_2}{h_1}$$

$$= \frac{2.2}{6.6}$$

$$\frac{r_1}{r_2} = \frac{1}{3}$$

EXP'T TO DETERMINE SURFACE TENSION OF A LIQUID BY CAPILLARY TUBE METHOD.

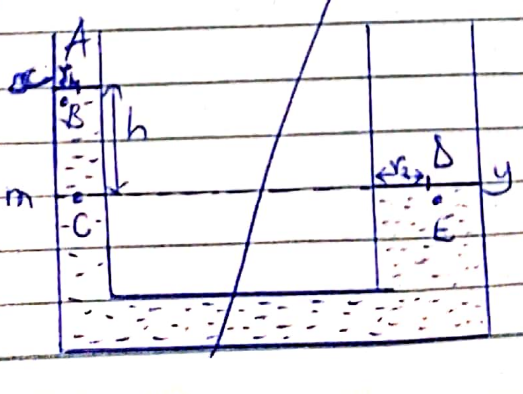
Assumptions
- Temperature is constant



- A clean capillary tube of uniform diameter is supported vertically with it's lower end dipped in a liquid.
- A pin bent at right angles is tied to the capillary tube with rubber band and it's position adjusted until it's tip just touches the horizontal level of the liquid in the beaker
- Travelling microscope is focused on the bottom of the meniscus in the tube and then on the tip of the pin when the beaker is removed
- The column length h is obtained.
- If the radius r of the capillary tube is known and the angle of the contact θ of the liquid is also known and density ρ o ō liquid is also known then surface tension

$\gamma = \frac{h\rho r g}{2\cos\theta}$ where g – Acceleration due 2 gravity

Difference in levels of liquid in a U-tube

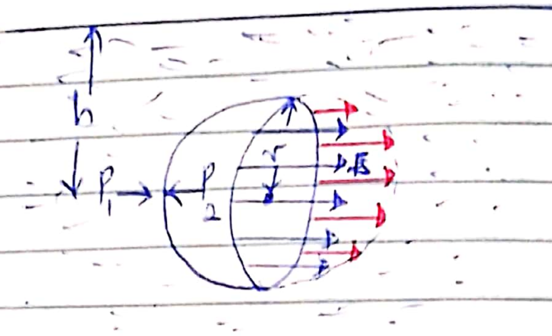


$\gamma = F/L$

$F = \gamma L$

PRESSURE DIFFERENCE INSIDE AN AIR BUBBLE.

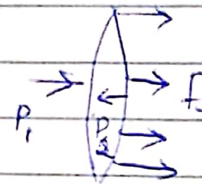
- Consider an air bubble of radius r inside a liquid of surface tension γ



- F_s = Surface tension force

P_1 = External pressure

P_2 = Internal pressure



$A = \pi r^2$

$P = F/A$

$F_1 = P_1 A$.

$\cancel{F_1 + F_2}$ · $F_1 + F_s = F_2$

$P_1 A + \gamma L = P_2 A$

$P_1 \cdot \pi r^2 + \gamma \cdot 2\pi r = P_2 \times \pi r^2$

$P_1 r + 2\gamma = P_2 r$

$(P_2 - P_1) r = 2\gamma$

$$\boxed{P_2 - P_1 = \frac{2\gamma}{r}}$$

where $P_2 - P_1$ = Pressure difference (Excess pressure

1, Calculate the pressure difference inside the spherical air bubble of diameter 0.1cm at a depth of 20cm. below the surface of the liquid of density $1.26 \times 10^{-3} kgm^{-3}$ and surface tension $0.064 Nm^{-1}$. Given that atmosphere pressure is 760 mmHg and density of mercury is $13.6 gm^{-3}$

$P_2 - P_1 = \frac{2\gamma}{r}$

$= \frac{2(0.064)}{5 \times 10^{-4}}$

$r = \frac{0.1 \times 10^{-2} m}{2}$ $h = 20cm$

$\gamma = 0.064 Nm^{-1}$ $\rho_L = 1.36 \times 10^{-3} kgm^{-3}$

$P_1 = 760 mmHg$ $\rho_m = 13.6 gm^{-3}$

$$P_2 - P_1 = \frac{2\gamma}{r}$$

$$= \frac{2(0.064)}{5 \times 10^{-4}}$$

$$P_2 - P_1 = 256\ Nm^{-2}$$

NOTE: A ~~sep~~ soap bubble has two surfaces in contact with air, pressure difference $= \frac{4\gamma}{r}$

2. Calculate the pressure inside the spherical air bubble of diameter 0.1 cm at a depth of 20cm below the surface of a liquid of density ~~1.26~~ 1.26×10^3 kgm^{-3} and surface tension $0.064\ Nm^{-1}$ given that atmospheric pressure 760mmHg and density of mercury is $13.6 \times 10^3\ kgm^{-3}$

$$r = \frac{d}{2} = \frac{0.1}{2} \times 10^{-2} m$$

$$= 5 \times 10^{-4} m$$

$$\rho_L = 1.26 \times 10^{3}\ kgm^{-3}$$

$$\gamma = 0.064\ Nm^{-1}$$

$$H = \cancel{660}\ 760mmHg$$

$$\rho_m = 13.6 \times 10^3\ kg/m^3$$

From $P_2 - P_1 = \frac{2\gamma}{r}$

$$P_2 = P_1 + \frac{2\gamma}{r}$$

$$= H + h\rho g + \frac{2\gamma}{r}$$

$$= \frac{760}{1000} \times (13.6 \times 10^3) \times 9.81 + \frac{20}{100} \times (1.26 \times 10^3) \times 9.81 + \frac{2 \times 0.064}{5 \times 10^{-4}}$$

$$P_2 = 1.0165 \times 10^5\ Pa$$

3. Calculate the total pressure within a bubble of air of radius 0.1mm in water. If the bubble is formed 10cm below the water surface. Surface tension of water is $7.27 \times 10^{-2}\ Nm^{-1}$ and atmospheric pressure is $1.07 \times 10^{5}\ Pa$.

Sln

$r = 0.1 \times 10^{-3}\ m$

$\gamma = 7.27 \times 10^{-2}\ Nm^{-1}$

$H = 1.07 \times 10^{5}\ Pa$

$h = 10 \times 10^{-2}\ m$

$$P = H + h\rho g + \frac{2\gamma}{r}$$

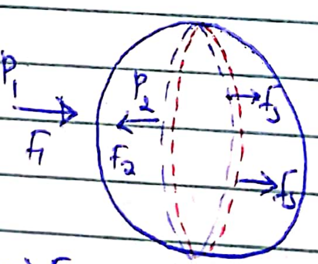
$$= 1.07 \times 10^{5} + (10 \times 10^{-2}) \times (1000)(9.81) + \frac{2(7.27 \times 10^{-2})}{0.1 \times 10^{-3}}$$

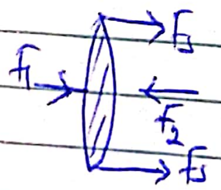
$$= 1.07 \times 10^{5} + 981 + 1454$$

$$= 1.0944 \times 10^{5}\ Pa$$

Excess pressure across a soap bubble.

→ Since the soap bubble has two surfaces in contact with air, one inside and one outside, then surface tensional force $f = 2(\gamma L)$





At equilibrium

$$F_1 + 2F_3 = F_2$$

$$P_1 A + 2(\gamma L) = P_2 A$$

$$P_1 \cdot \pi r^2 + 2\gamma \cdot 2\pi r = P_2 \cdot \pi r^2$$

$$P_1 r + 4\gamma = P_2 r$$

$$\boxed{P_1 - P_1 = \frac{4\gamma}{r}}$$

CamScanner

1 - A soap bubble has a diameter of 4mm. Calculate the pressure inside it if the atmospheric pressure is $10^5 Nm^{-1}$ and surface tension of soap solution is $2.8 \times 10^{-2} Nm^{-1}$

$\gamma = 2.8 \times 10^{-2}$

$r = \frac{d}{2} = \frac{4}{2} \times 10^{-3}$

$= 2 \times 10^{-3} m$

$P_1 = 10^5 Nm^{-1}$

$P_2 - P_1 = \frac{4\gamma}{r}$

$P_2 = \frac{4\gamma}{r} + P_1$

$P_2 = \frac{4(2.8 \times 10^{-2})}{2 \times 10^{-3}} + 10^5$

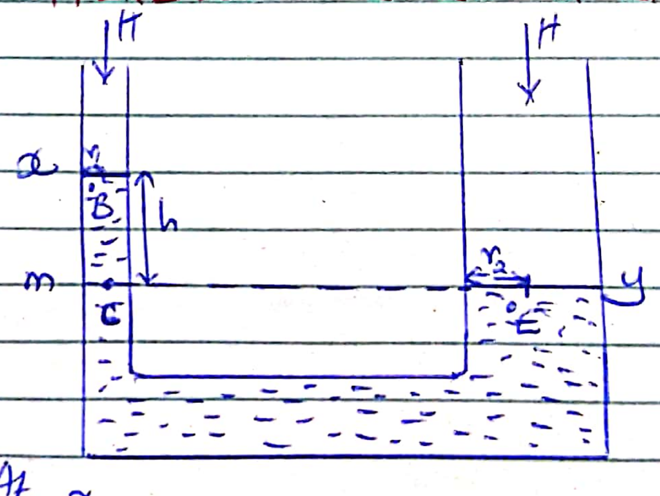
$= 56 + 10^5$

$\underline{P_2 = 100056 \ Pa}$

2. The pressure on the concave side of each liquid surface exceeds by $\frac{2\gamma}{r}$ where r is the radius of curvature of surface

~~Difference~~

DIFFERENCE IN LEVELS OF LIQUID IN A U-TUBE.



At x

$H - P_B = \frac{2\gamma}{r_1}$ ——— ①

At y:

$$H - P_E = \frac{2\gamma}{r_2} \quad \text{———} (ii)$$

At C,

$$P_C = h\rho_l g + P_B \quad \text{———} (iii)$$

Also

$$P_E = P_C \quad \text{———} (iv)$$

(i) − (ii)

$$(H - P_B) - (H - P_E) = \frac{2\gamma}{r_1} - \frac{2\gamma}{r_2}$$

$$P_E - P_B = 2\gamma\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

but $P_E = P_C$

$$P_C - P_B = 2\gamma\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$h\rho_l g + P_B - P_B = 2\gamma\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$h\rho_l g = 2\gamma\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$h = \frac{2\gamma}{\rho_l g}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

The above expression applies best if the angle of contact is 0°.

H = Atmospheric pressure.
r_1 = Radius of smaller limb
r_2 = Radius of larger limb.

ρ_l = Density of the liquid.

For a liquid of angle of contact $h°$ then.

$$h = \frac{2\gamma\cos\theta}{\rho g}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Example.

1. A U-tube of diameter 7mm and 4mm contains water of surface tension $7.0 \times 10^{-2} Nm^{-1}$, angle of contact $0°$ and density $1000 kgm^{-3}$. Find the difference in the levels

Sln.

$r_1 = d/2 = \frac{4}{2} \times 10^{-3} m$ $\qquad$ $r_2 = \frac{7}{2} \times 10^{-3} m$

$= 2 \times 10^{-3} m$ $\qquad$ $= 3.5 \times 10^{-3} m$

$\gamma = 7.0 \times 10^{-2}$

$$h = \frac{2\gamma}{\rho g}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$= \frac{2(7.0 \times 10^{-2})}{(1000)(9.81)}\left(\frac{1}{2 \times 10^{-3}} - \frac{1}{3.5 \times 10^{-3}}\right)$$

see -

$$= 1.427112 \times 10^{-5}(214.2857)$$

$$h = 3.058 \times 10^{-3}$$

2. Mercury is poured into a glass U-tube with vertical libs of diameters 4mm and 12mm respectively. If the angle of contact btwn mercury and glass is $140°$ and surface tension is 0.52, Calculate the difference in the levels of mercury (Ans = 2.488×10^{-3})

3. A glass U-tube is such that the diameter of limb is 4mm and of the other is 8mm. The tube is inverted vertically with the open ends below the surface of water in the beaker given that $7.2 \times 10^{-2} Nm^{-1}$, angle of contact of water and glass $0°$ and the density of water is $1000 kgm^{-3}$. What is the diff btwn the height to w/c the water rises in the limbs. ($A = 3.7 \times 10^{-5} m$

$\nearrow$ Ans (0.031).

4. 4. A glass U-tube is inverted with the open ends of the straight limbs of diameters respectively 0.50mm and 1.00mm below the surface of water in a beaker. The air pressure in the upper part is increased until the meniscus in one limb is | with water outside. Find the height of water ~~of~~ in the other limb (ρ water = 1000 kg m^{-3})

Sln.

2. $r_1 = d/2$ ~~= 4×10~~ $\quad r_2 = d/2 = \frac{12mm}{2}$

$r_1 = 2\times10^{-3}m \quad = 6\times10^{-3}m$

$\gamma = 0.52$

$$h = \frac{2\gamma}{\rho g}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$= \frac{2(0.52)}{13.6\times10^3\times9.81}\left(\frac{1}{2\times10^{-3}} - \frac{1}{6\times10^{-3}}\right)$$

~~x.xxxx~~ $= 7.795\times10^{-6}\times 333.33$

$$h = 2.5\times10^{-3}m$$

3. $r_1 = d/2 = \frac{4mm}{2} \quad r_2 = \frac{8mm}{2}$

$= 2\times10^{-3}m \quad = 4\times10^{-3}m$

$\gamma = 7.2\times10^{-2}Nm^{-1} \quad \rho = 1000kgm^{-3}$

$$h = \frac{2\gamma}{\rho g}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$= \frac{2(7.2\times10^{-2})}{1000\times9.81}\left(\frac{1}{2\times10^{-3}} - \frac{1}{4\times10^{-3}}\right)$$

$= 1.467\times10^{-5}\times 250$

$$= 3.7\times10^{-3}m$$

4. $r_1 = d/2 = \frac{0.50mm}{2} \quad r_2 = d/2 = \frac{1.00mm}{2}$

$= 0.25\times10^{-3}m \quad = 0.5\times10^{-3}m$

$\rho = 1000kgm^{-3} \quad \gamma = 7.27\times10^{-2}Nm^{-1}$

$$h = \frac{2\gamma}{\rho g}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$= \frac{2(7.27\times10^{-2})}{1000\times9.81}\left(\frac{1}{0.25\times10^{-3}} - \frac{1}{0.5\times10^{-3}}\right)$$

$= 1.48\times10^{-5}\times 2000$

$h = 0.0296$

$h = 0.031m.$

SURFACE ENERGY (σ)

→ Surface energy is the amount of work done to produce a fresh surface of a liquid of area $1m^2$ under isothermal conditions

OR

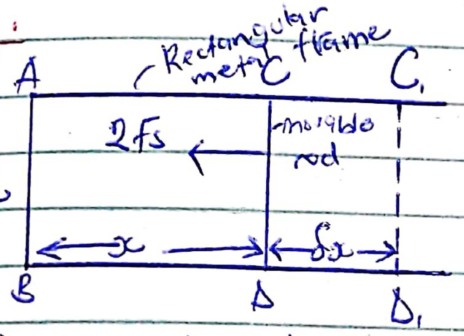
→ Surface energy is the potential energy per metre of the surface film.

Numerically surface energy = $\dfrac{\text{Workdone in increasing surface area}}{\text{Increase in surface area}}$

◇ The relationship btwn surface tension and surface energy:

$\gamma = \frac{f_s}{L}$

$f_s = \gamma L$



- Consider a liquid (soap film) stretched on a rectangular metal frame isothermally from CD to C'D' through a distance δx against force.

- Workdone $= f \times d$

$= 2f_s \times \delta x$

$= 2\gamma L\,\delta x$

$= \cancel{\gamma(2L\delta x)} = \gamma(\underbrace{2L\delta x}_{\Delta A})$

$= \gamma(\Delta A)$

But surface energy, $\delta = \dfrac{W\cdot d}{\Delta A}$

$$\delta = \frac{\gamma(\Delta A)}{\Delta A}$$

$$\boxed{\delta = \gamma.}$$

∴ δ and surface

Surface energy, δ and surface tension γ is numerically equal.

Dfn: Surface tension is the workdone to produce a fresh surface of a liquid film of area $1m^2$ under Isothermal conditions.

NOTE: This workdone is stored as surface energy in a liquid film

Workdone in drawing a liquid ~~draw~~ drop or soap bubble.

1. If the initial radius of a liquid drop is r_1 and final radius of a liquid is r_2 then workdone, W
~~If the initial area of a liquid drop is~~

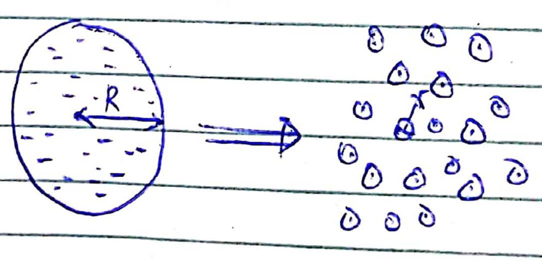
$$W = \gamma(\text{Increase in surface area})$$
$$= \gamma(\Delta A)$$

Since a liquid drop has one free surface in contact with air, Workdone, $W = \gamma[4\pi r_2^2 - 4\pi r_1^2]$
$$\boxed{= \gamma 4\pi(r_2^2 - r_1^2)}$$

(ii) In case of a soap bubble, it has two free surfaces in contact with air

$$W = \gamma \cdot 2\Delta A$$
$$= \gamma \cdot 2 \cdot 4\pi(r_2^2 - r_1^2)$$
$$\boxed{= \gamma \cdot 8\pi(r_2^2 - r_1^2)}$$

Splitting of a bigger liquid drop.



- When a drop of radius R splits into n smaller drops ~~any~~ of radius r, then the surface area of the liquid increases hence work has to be done against surface tension.
- Since the volume of the liquid remains constant, then

From conservation of volume

$$\frac{4}{3}\pi R^3 = n\left(\frac{4}{3}\pi r^3\right)$$

$$\boxed{R^3 = nr^3}$$

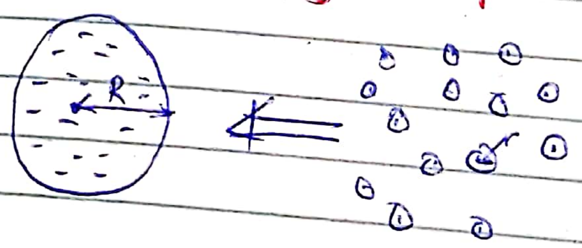
- Workdone $= \gamma \times \Delta A$

$$= \gamma\left[\begin{matrix}\text{surface area of} \\ \text{n drops}\end{matrix} - \begin{matrix}\text{Surface area of} \\ \text{big drop}\end{matrix}\right]$$

$$= \gamma\left[(4\pi r_1^2)n - 4\pi R^2\right]$$

$$= \gamma \cdot 4\pi\left[nr_1^2 - R^2\right]$$

Formation of bigger drop



- The ~~volume is ofcourse conserved~~

→ If n small drops of radius r coarse to form a big drop of radius R, then surface area of the liquid decreases

• ~~Am~~

Conservation of volume

→ From conservation of volume

$$\frac{4}{3}\pi R^3 = n\left(\frac{4}{3}\pi r^3\right)$$

$$\boxed{R^3 = nr^3}$$

Amount of surface energy released $=$ Initial surface energy $-$ final surface energy

$$W = \gamma A_1 - \gamma A_2$$

$$= \gamma(A_1 - A_2)$$

$$= \gamma\left((4\pi r_1^2)n - 4\pi R^2\right]$$

$$= \gamma \cdot 4\pi(nr_1^2 - R^2)$$

Example.

1. Calculate the W.D in blowing a soap bubble of radius 10cm given that the surface tension in the soap solution is $0.03Nm^{-1}$.

$W.D = 8\pi R^3$ sln.

$W.D = 8\pi\gamma(r_2^2 - r_1^2)$

$= 8\pi\gamma(r^2)$

$= 8\pi(0.03)(10\times10^{-2})^2$

$= 7.5398\times10^{-3}$ J

2. A drop of mercury of radius 2mm is split into 8 identical droplets. Find the increase in surface energy if the surface ~~tens~~ tension of mercury is $0.465Nm^{-1}$

0.465

sln.

$W.D = \gamma.4\pi[nr_1^2 - R^2]$

$= 0.465.4\pi(8(2\times10^{-3})]$

$= 5.843\times0.016$

$=$

Sln.

No of drops $= 8$

$\frac{4}{3}\pi R^3 = n\left(\frac{4}{3}\pi r^3\right)$

$R^3 = nr^3$

$(2\times10^{-3})^3 = 8r^3$

$r^3 = \frac{(2\times10^{-3})^3}{8}$

$r^3 = \boxed{2.5\times10^{-4}}$ 1×10^{-9}

$r = \boxed{\sqrt[3]{2.5\times10^{-4}}}$ $\sqrt[3]{1.10^{-9}}$

$r = 1\times10^{-3}$ m

$W.D = \gamma(A_2 - A_1)$

$= \gamma[(4\pi r^2)n - 4\pi R^2]$

$=$ ~~0.465[(~~

$= 0.465.4\pi(8(1\times10^{-3}) - (2\times10^{-3})]$

$= 0.465.4\pi(6\times10^{-3})$

$W.D = 2.337\times10^{-5}$ J

3. The W.D in increasing the size of the soft film from 10cm by 6cm to 10cm by 11cm is 3×10^{-4} J. Calculate the surface tension of the film ($0.03 Nm^{-1}$).

soln.

$W.D = 3\times10^{-4} J$

$A_1 = L\times\omega$ $\qquad$ $A_2 = L\times\omega$

$= 10\times6$ $\qquad$ $= 10\times11$

$= 60 cm$ $\qquad$ $= 110 cm$

$A_1 = 60\times10^{-2} m$ $\qquad$ $A_2 = 110\times10^{-2} m$.

$W.D = \gamma(A_2 - A_1)$

$3\times10^{-4} = \gamma(110\times10^{-2} - 60\times10^{-2})$

$3\times10^{-4} = \gamma(0.5)$

$W.D = \gamma(2\Delta A)$

$3\times10^{-4} = \gamma(2\times50\times10^{-2})$

$\gamma = (3\times10^{-4})\times100$

$\gamma = 0.03 Nm^{-1}$

4. Calculate the amount of workdone in breaking up a drop of water of radius 0.5cm into tiny droplets of water each of radius 1mm assuming isothermal conditions and find the number of droplets formed given that the surface tension of water is $7\times10^{-2} Nm^{-2}$

Soln.

$R = 0.5\times10^{-2} m$ $\qquad$ $r = 1\times10^{-3} m$

$\gamma = 7\times10^{-2}$

$R^3 = nr^3$

$(0.5\times10^{-2})^3 = n(1\times10^{-3})^3$

$1.25\times10^{-7} = 1\times10^{-9} n$

$n = 125$

ΔA = Area of small droplets − Area of a big drop.

$= n(4\pi r^2) - 4\pi R^2$

$= 4\pi(nr^2 - R^2)$

$= 4\pi[125\times(1\times10^{-3})^2 - (0.5\times10^{-2})^2]$

$= 1.257\times10^{-3} m^2$

$W \cdot d = \gamma \Delta A$

$= (7\times10^{-2})(1.257\times10^{-3})$

$= 8.79\times10^{-5}\ J.$

A liquid drop of diameter 0.5cm breaks up into 27 tiny droplets all of the same size. If the surface tension of the liquid is $0.07Nm^{-1}$. Calculate the resulting change in energy.

sln.

$r = d/2 = \frac{0.5}{2}$ $\qquad n = 27$

$\gamma = 0.07Nm^{-1}$

$R = 0.25\times10^{-2}m$

$R^3 = nr^3$

$(0.25\times10^{-2})^3 = 27r^3$

$r^3 = \frac{(0.25\times10^{-2})^3}{27}$

$r^3 = 5.787\times10^{-10}$

$r = \sqrt[3]{5.787\times10^{-10}}$

$r = 8.33\times10^{-4}m.$

$\Delta A = n(4\pi r^2) - 4\pi R^2$

$= 4\pi(nr^2 - R^2)$

$= 4\pi[(27(8.33\times10^{-4})^2 - (0.25\times10^{-2})^2]$

$= 4\pi(1.2485\times10^{-5})$

$= 1.57\times10^{-4}m^2$

$W \cdot d = \gamma \Delta A$

$= (0.07)(1.57\times10^{-4})$

$= 1.098\times10^{-5}\ J.$

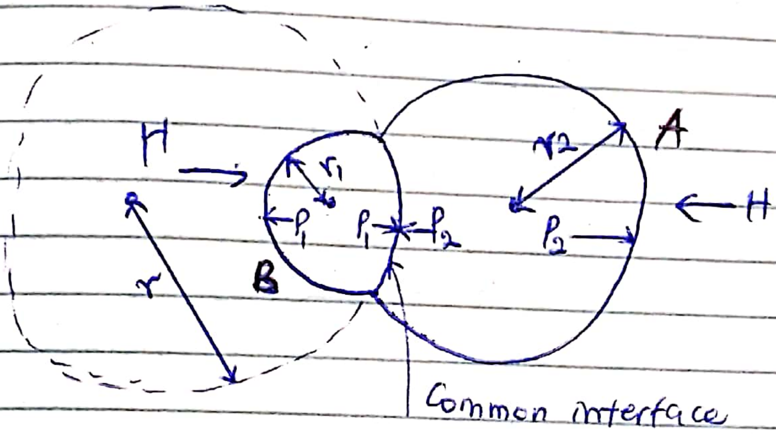
COMBINED BUBBLES

⇒ Consider two soap bubbles A and B of radii r_2 and r_1 respectively where $r_2 > r_1$.

⇒ If the two soap bubbles come into contact and have common interference, then the radius of curvature r of common interference can be ~~calculate~~ calculated using pressure difference.

Case I

Bigger
|H|
|P|



At B,

$$P_1 - H = \frac{4\gamma}{r_1} \quad \text{—— (i)}$$

At A,

$$P_2 - H = \frac{4\gamma}{r_2} \quad \text{—— (ii)}$$

At common interface,

$$P_1 - P_2 = \frac{4\gamma}{r} \quad \text{—— (iii)}$$

eqn (i) - (ii)

$$(P_1 - H) - (P_2 - H) = \frac{4\gamma}{r_1} - \frac{4\gamma}{r_2}$$

$$P_1 - P_2 = 4\gamma\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad \text{—— *}$$

(iii) = *

$$\frac{4\gamma}{r} = 4\gamma\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

CS CamScanner

$$\frac{1}{r} = \left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\frac{1}{r} = \frac{r_2 - r_1}{r_1 r_2}$$

$$\boxed{r = \frac{r_1 r_2}{r_2 - r_1}}$$

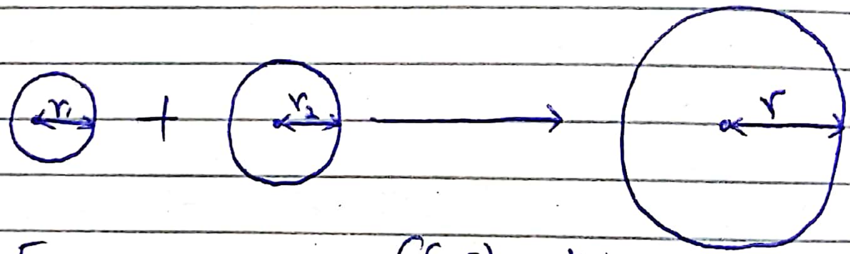
∵ The difference in pressure $P_1 - P_2 = \frac{4\gamma}{r}$

$$\boxed{P_1 - P_2 = 4\gamma\left[\frac{r_2 - r_1}{r_1 r_2}\right]}$$

Case II

→ Consider two soap bubbles A and B of radii r_1 and r_2 coalesing to form a single bubble.

→ To find the radius, r of the common interface of the resulting soft bubble, we use the conservation of surface energy



from surface energy (S.E) $= \gamma A$

$$\gamma \times (4\pi r_1^2) \times 2 + \gamma(4\pi r_2^2) \times 2 = \gamma(4\pi r^2) \times 2$$

$$r_1^2 + r_2^2 = r^2$$

$$r = \sqrt{r_1^2 + r_2^2}$$

1. → Two soap bubbles of radii 2cm and 4cm coorace under isothermal conditions.

If the surface tension of the soap ~~cond~~ solution is $2\times10^{-2}\,Nm^{-1}$, Calculate the excess pressure inside resulting soft bubble

$r_1 = 2\times10^{-2}\,m$ $\quad r_2 = 4\times10^{-2}$

$\gamma = 2\times10^{-2}\,Nm^{-1}$

$r = \sqrt{r_1^2 + r_2^2}$

$= \sqrt{(2\times10^{-2})^2 + (4\times10^{-2})^2}$

$= 0.0447m$

$P_1 - P_2 = \frac{4\gamma}{r}$

$= \frac{4\times 2\times10^{-2}}{0.0447}$

$\Delta p\ (P_1 - P_2) = 1.7897N$

2. Two soap bubbles of radii 6cm and 10cm coalesce so as to have a portion of their surfaces in common. Calculate the radius of curvature of this common surface and hence the pressure difference $\gamma = 2.8\times10^{-2}Nm^{-1}$

$r_1 = 6\times10^{-2}m \quad r_2 = 10\times10^{-2}m$

$r = \sqrt{r_1^2 + r_2^2}$

$= \sqrt{(6\times10^{-2})^2 + (10\times10^{-2})^2}$

$r = 0.1166m$

$P_1 - P_2 = \frac{4\gamma}{r}$

$= 4($

$r = \frac{r_1 r_2}{r_2 - r_1}$

$= \frac{(6\times10^{-2})\times(10\times10^{-2})}{(10\times10^{-2}) - (6\times10^{-2})}$

$= \frac{6\times10^{-3}}{0.04}$

$= 0.15$

$P_1 - P_2 = 4\gamma\left[\frac{r_2 - r_1}{r_1 r_2}\right]$

$= 4(2.8\times10^{-2})\left[\frac{10\times10^{-2} - 6\times10^{-2}}{(6\times10^{-2})(10\times10^{-2})}\right]$

$= 4(2.8\times10^{-2})\left(\frac{0.04}{6\times10^{-3}}\right)$

$= 0.747$

3. A mercury drop of radius 4.0 mm falls vertically and on hitting the ground it splits into 2 drops of radius 0.5mm. Calculate the change in surface energy given that surface tension of mercury is $0.52\,Nm^{-1}$

$R = 2.0 \times 10^{-3} m \qquad r_1 = 0.5 \times 10^{-3} m$

$\gamma = 0.52\,Nm^{-1} \qquad n = 2$

$\Delta A = n(4\pi r^2 - 4\pi R^2)$

$= 4\pi(nr^2 - R^2)$

2009(4) $= 4\pi(2\times(0.5\times10^{-3})^2 - 2.0\times10^{-3})^2)$

$= 4\pi(3.4 \times 10^{-5})$

$= 4.273 \times 10^{-4} \qquad \Delta A = 5.78 \times 10^{-4}$

$W.D = \gamma \Delta A \qquad W.D = \gamma \Delta A$

$= 0.52 \times 4.273 \times 10^{-4} \qquad = 0.52 \times (5.78 \times 10^{-4})$

$= 2.22 \times 10^{-4} \qquad \underline{= 2.28 \times 10^{-5} J.}$

OR

$W.D = \gamma 4\pi (nr^2 - R^2)$

$= 0.52 \times 4\pi(2\times(0.5\times10^{-3})^2 - (2.0\times10^{-3})^2)$

$\underline{= 2.28 \times 10^{-5} J.}$

FACTORS AFFECTING SURFACE TENSION.

1. Impurities present in the liquid appreciably affect surface tension. A highly soluble substance like salt increase surface tension whereas a sparingly soluble substance like soap decreases the surface tension.

2. Temperature
   - The surface tension decreases with rise in temp. The temp. at w/c surface tension of a liquid become 0 is called critical temp. of the liquid.

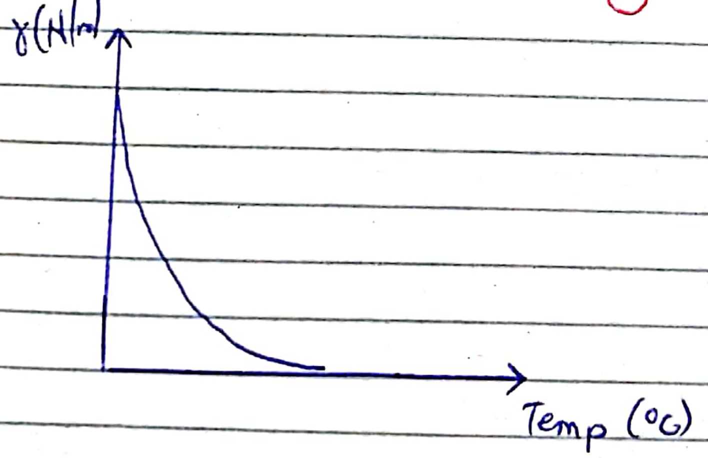
Effect of temperature on surface tension.

Explain of effect of temp. of surface tension

→ When temperature of a liquid increases, the mean kinetic energy of the molecules increases.

→ The forces of attraction between molecules decreases since the molecules spend less time in neighbourhood of the given molecule hence surface tension decreases.

A graph of surface tension against temperature.



Expt to show that surface tension of a liquid decrease with an increase in temp.

- Like Ocodium powder is sprinkled in a surface of water in a flat metal dish
- One side of the dish is heated for some time and observations made

- It is observed that the particles of a powder are swept away from the heated part.
- This implies that surface tension forces can no longer hold the particles in its previous position hence surface tension of a liquid decreases with increase in temp.

Qn. Explain why soap is used to wash clothes.

S/n.

→ This is b'se soap solution reduces the surface tension of water causing the water to wet the fibres of the cloth thoroughly hence removing the dirt.

Qn. Explain why clothes are washed using warm water containing detergents.

S/n.

→ Detergents are mixed with warm water in order to increase its cleaning power this is b'se ~~deter~~ warm water and detergents lower surface tension of water thus increasing the wetting power of the fibres of the cloth w/c removes the dirt thoroughly well.

Qn. Explain why small drops are spherical and larger ones tend to flatten out.

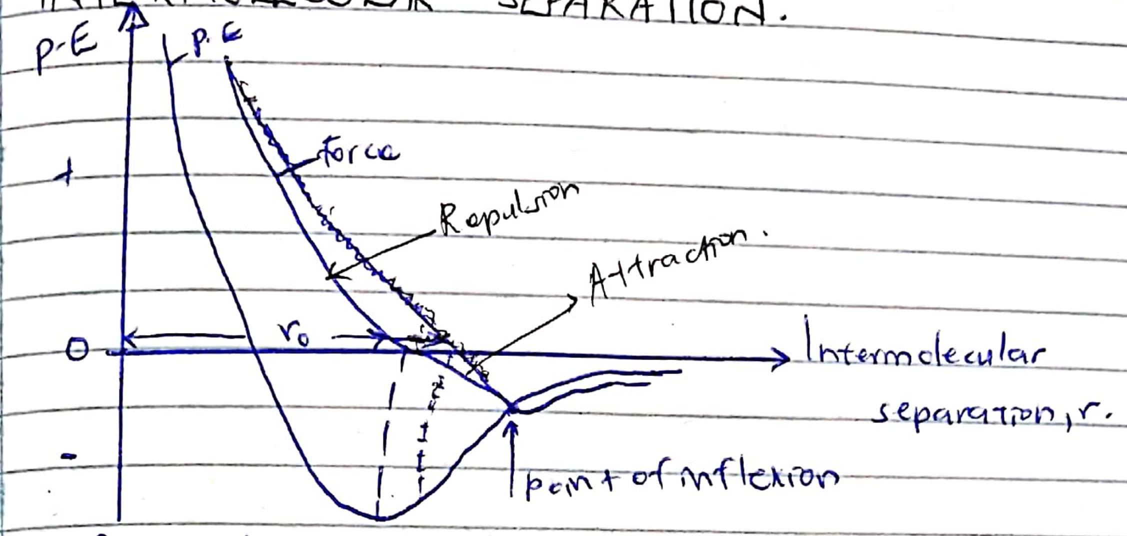
S/n

→ A small drop takes on a spherical shape to minimise the surface energy w/c tends to exceed gravitational energy while a large drop flattens out to minimise gravitational potential energy w/c tends to exceed the surface energy due to large weight.

→ The gravitational force distorts the spherical shape of the large drop.

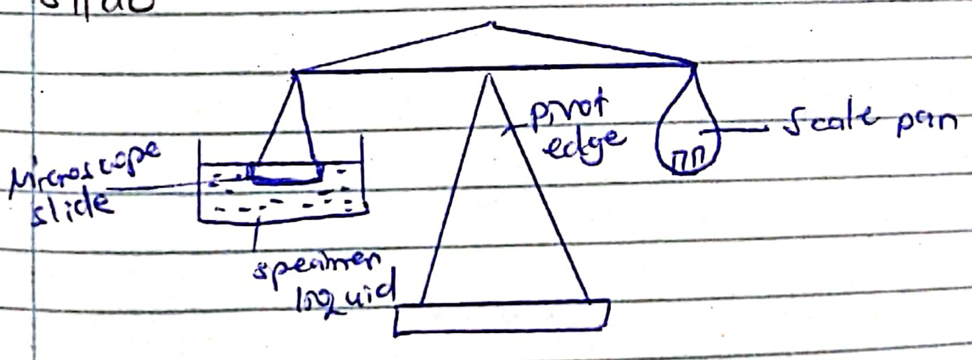
NOTE: A sphere is one that gives a smallest surface ~~are~~ area.

A GRAPH OF POTENTIAL ENERGY AGAINST INTERMOLECULAR SEPARATION.



→Potential energy of each 2 molecules is taken to be 0 at infinity or infinite separation
→ Because the two molecules have no influence on each other
→ Potential energy is negative at equilibrium separation b/se workdone has to be done to separate molecules to infinity.
→ The minimum point on the potential energy curve corresponds to 0 on the 4th curve
→ The point of inflexion on the potential energy curve corresponds to/minimum on the 4th curve.

Determination of surface tension using a microscope slide



- When the microscope slide in air, m, kg lower the slide until it just touches a surface of the liquid
- Add a mass m kg to the scale pan so as to counter balance the system

- If A and B are the length and thickness of the slide then downward force on the side = $2\gamma(a+b) + m_1 g$
- At balance, net downward force on slide = weight in the scale pan

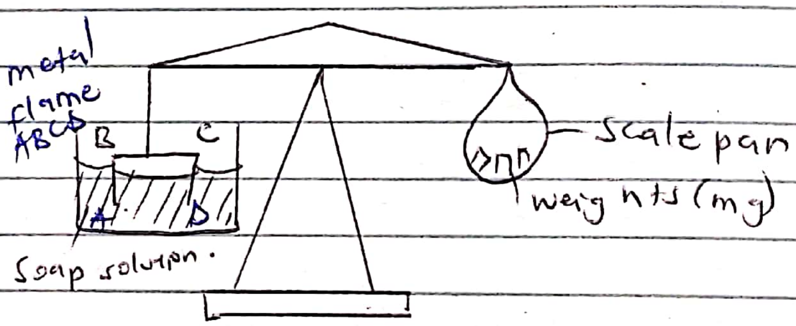
so; $2\gamma(a+b) + m_1 g = mg$

$$\gamma = \frac{(m - m_1)g}{2(a+b)}$$

- If m_1 is taken to be negligible then;

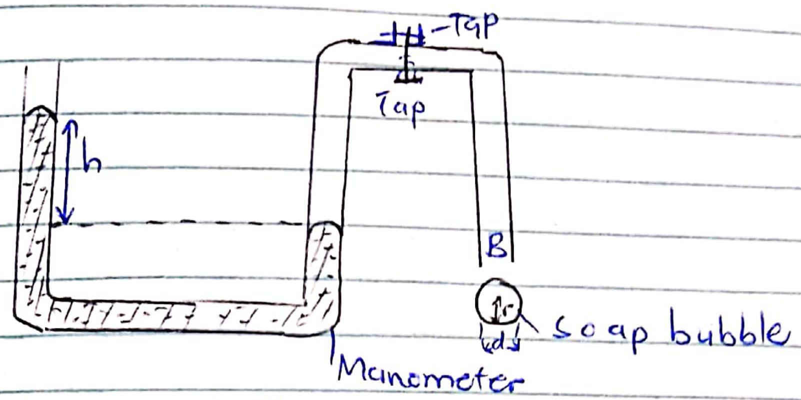
$$\gamma = \frac{mg}{2(a+b)}$$

Determination of surface tension of soap solution.



- A soap film is formed in a 3 sided metal flame ABCD and apparent weigh found mg
- A soap film is brocken by piercing it in the middle, th
- The system is observed to collapse showing that

Determination of surface tension using soap bubble



- A soap bubble is blown at the end B of the tube connected to a manometer.
- A tap is closed, the diameter d of the bubble is measured using a travelling microscope
- The diff. h in the manometer is observed / measured using a travelling microscope.

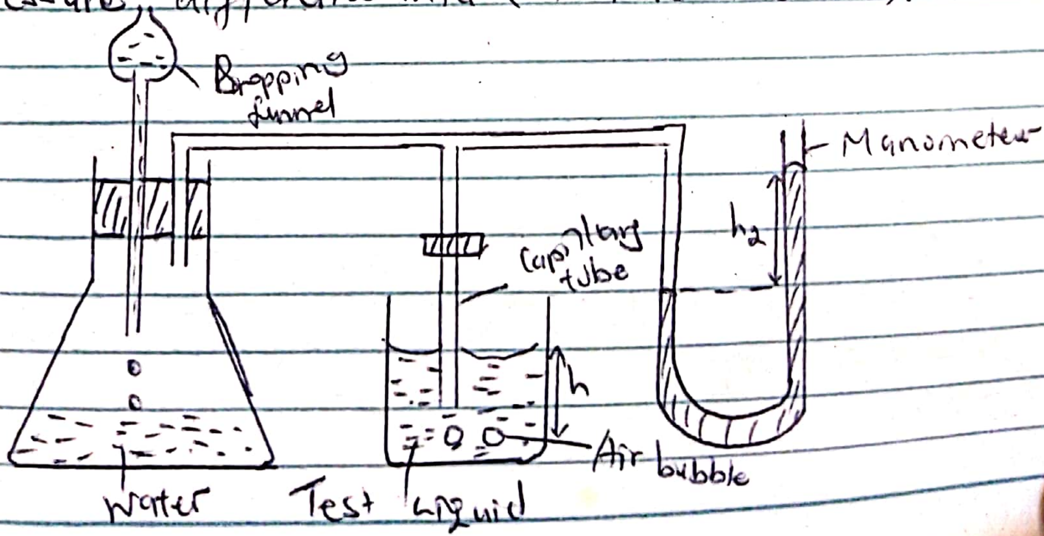
→ ~~At~~ At equilibrium, excess pressure in a bubble ~~must~~ = Pressure diff. in the manometer.

$$\frac{4\gamma}{r} = h\rho g$$

$$\gamma = \frac{h\rho g r}{4} \quad \text{but } r = d/_2$$

$$\gamma = \frac{h\rho g d}{8}$$

Determination of surface tension of a liquid by the pressure difference mtd (JAEGER'S METHOD).



- The apparatus is arranged as shown above.
- Water is allowed to enter the flask from the dropping funnel
- This slowly drives air through the capillary tube, increasing the pressure inside the manometer.
- A bubble slowly forms at the end of the capillary tube in the beaker of the test liquid
- As the bubble blows the pressure inside it rises to the maximum and falls as the bubble breaks away from the capillary tube.
- This occurs when the radius of the bubble formed is minimum (equal to the radius of the capillary tube) then excess pressure in the air bubble $= \frac{2\gamma}{r}$

$$P_1 - P_2 = \frac{2\gamma}{r} \qquad \text{where } P_1 = H + h_2\rho_m g$$

$$(H + h_2\rho_m g) - (H + h_1\rho_l g) = \frac{2\gamma}{r}$$

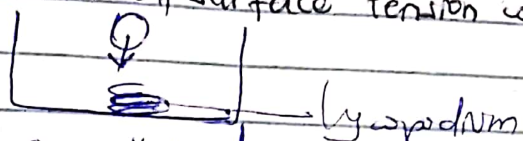
$$h_2\rho_m g - h_1\rho_l g = \frac{2\gamma}{r}$$

$$\gamma = \frac{(h_2\rho_m - h_1\rho_l)gr}{2}$$

where g - acceleration due to gravity
r - radius of the bubble (capillary tube)
h_2 - Maximum manometer reading
h_1 - Depth of the end of the capillary tube.
ρ_m - Density of liquid in the manometer
ρ_l - Density of liquid in the manometer.
H - Atmospheric pressure.

NOTE: h_1 and h_2 and r should be measured accurately using a travelling microscope.

Experiment to study variation of surface tension with temperature.



Qn Explain why a drop of methylated spirit or soap solution is dropped into the centre of a dish of water whose sur surface has been sprinkled with ~~methopodeum~~ lycopodeum powder, the powder rushes out to the sides living a clear patch

Sln

→ This is due to surface tension of water being greater than that of methylated spirit or soap solution causing an imbalance btwn a surface tension process to the boundary ~~to~~ of the two liquids.

→ The powder is thus carried away from the centre by the water