EXPERIMENT: To determine the surface tension of water by capillary tube method

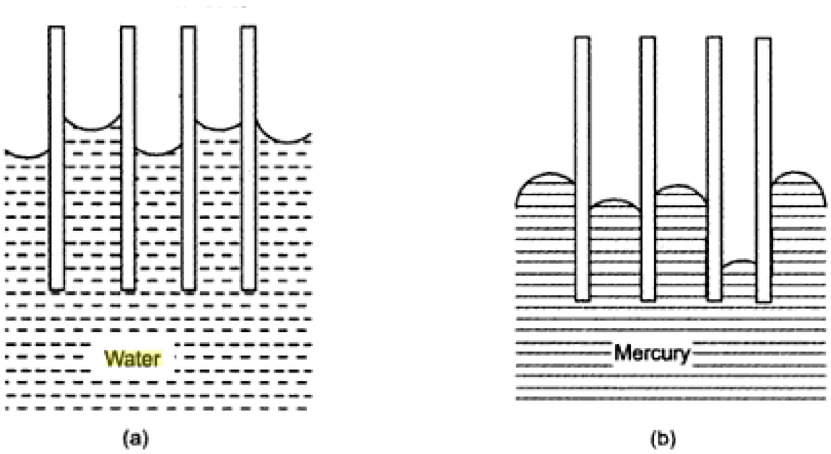
Apparatus:

1. Capillary tubes (of uniform bore and different diameters)
2. Travelling microscope (shown in **Figure 1**)
3. Thermometer
4. Glass strip
5. Needle
6. Clamping stand
7. Glass beaker
8. Adjustable stand

Figure 1: Travelling microscope

Theory:

Cappillarity: when a glass capillary tube open at both ends is dipped vertically in water, the water rises up in the tube to a certain height above the water level outside the tube. The narrower the tube, the higher is the rise of water as shown in Figure **2(a)**. But if the tube is dipped in mercury, the mercury is depressed below the outside level, shown in Figure **2(b)**. "The phenomenon of rise or depression of liquid in the capillary tube is known as capillarity." The liquids which wet glass rise up in the capillary tube, while which do not wet glass is depressed down in the capillary tube.



<u>Figure 2</u>: Rise and fall of liquids in capillary tube

<u>Surface tension:</u> The force per unit length of imaginary line on the surface of liquid and acting perpendicular to it is known as surface tension.
If "F" be the force acting on a line of length "L" on the surface of a liquid then ----

$$T = F/L$$

<u>Contact angle:</u> When free surface of a liquid comes in contact with a solid, it becomes curved near the place of contact. The angle inside the liquid between the tangent to the solid surface and tangent to the liquid surface at the point of contact is defined as the angle of contact for that pair of solid and liquid (shown in **Figure 3**).

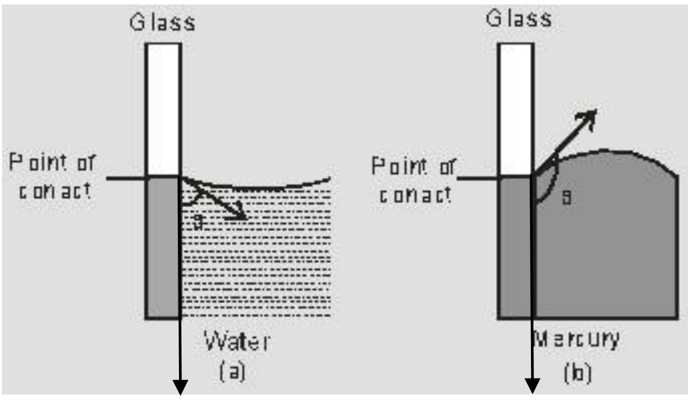


Figure 3: Contact angle for (a) water-glass interface and (b) mercury-glass interface.

<u>Formula Derivation:</u>

Consider a glass capillary tube is dipped vertically in water. Let "h" be the height of water rise in it. If "m" is mass of water column, then weigh of this column of water is

Weight of water= mg …………….. (1)

Let "r" be the radius of capillary tube and θ be the angle of contact, then the length of the line of contact is $2\pi r$.

Since upward component of surface tension T is $T\cos\theta$ therefore, the total upward force is given by

Net upward force=$2\pi rT\cos\theta$ ---------- (2)

For balance, the net upward force is equal to weight mg.

Therefore, $mg = 2\pi r \mathbf{T}\cos\theta$

For water - glass contact angle $\theta = 0$, $\cos\theta = 1$, then

$$mg = 2\pi r\mathbf{T}$$

$$2\pi r\mathbf{T} = \mathbf{mg} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

If V be the volume of water column in the capillary tube, then

$$V = \pi r^2 h + \text{volume of meniscus} \text{ ------- } (4)$$

Volume of meniscus = volume of cylinder of height "r" - volume of hemisphere

$$= \pi r^2 \times r - (½)\,(4/3)\times \pi r^3$$

$$= \pi r^3 - (2/3)\times \pi r^3$$

$$= (1/3).\, \pi r^3 \text{ ---------------- } (5)$$

From equation (5) & (4) -----

$$V = \pi r^2 h + (1/3).\, \pi r^3 \text{ --------------- } (6)$$

But mass = volume × density and therefore,

$m = V.\rho$ -------------------- (7), where ρ is the density of the water used.

From equation (3), (6) and (7) ------

$$\boldsymbol{T = (1/2).[(h + r/3).\, \rho r g]} \text{ ----------- } \boldsymbol{(8)}$$

From the knowledge of "h" and "r", the surface tension "T" of water can be calculated using equation (8).

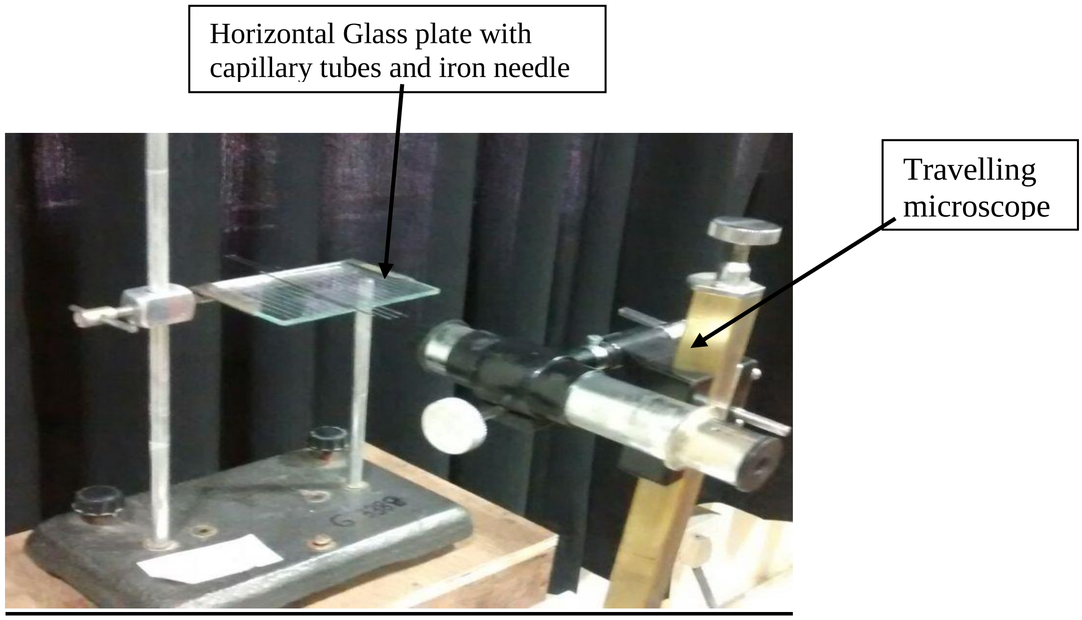


Figure 4(a): Set up for the determination of the radius of capillary tube.

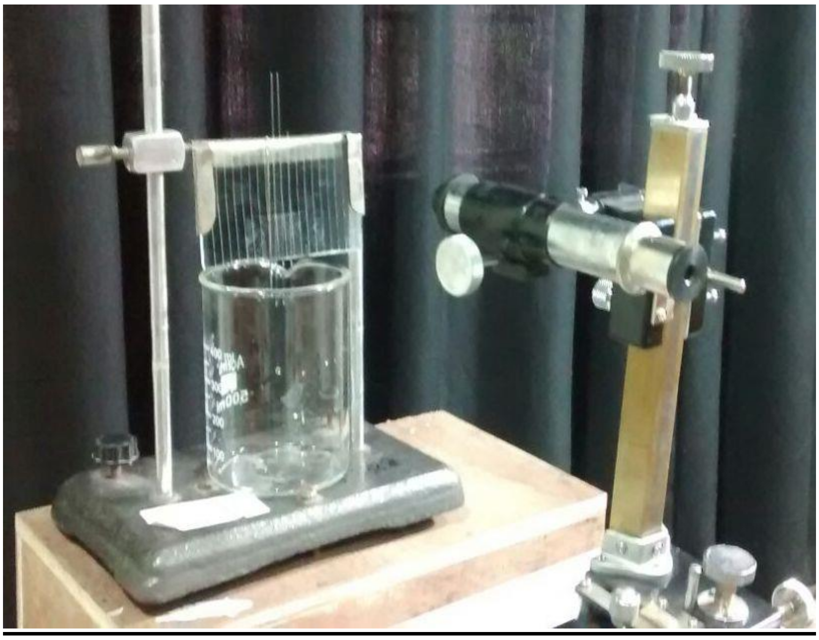


Figure 4(a): Set up for the determination of height "h" of water rise in capillary tube.

Setup & procedure:

1. Select three capillary tubes of uniform bore and different diameters,
2. Mount the capillary tubes on a glass strip with wax or rubber bands or transparent cello tap.
3. Mount also a pointed needle near the glass strip parallel to the capillary tubes with its lower end slightly above the lower ends of the capillary tubes [shown in **Figure 4(a)**]. Fill the water to the rim of the pot and then lower the needle to just touch the surface.
4. Clamp the glass- tubes set up horizontally and find its inner diameter AB along one direction and CD along perpendicular direction with respect to AB [shown in **Figure 4(a)**]. Calculate the mean diameter [(AB+CD)/2] and hence mean radius r.
5. Clamp the glass strip vertically in an iron stand [**Figure 4(b)]**.
6. Place a clean flat bottom glass beaker on the (may or may not be adjustable) table and adjust the entire setup as shown in the **Figure 4(b)**.
7. Now fill the beaker with water slowly until the lower pointed end of the needle just touches the water surface.
8. Calculate the height h of water rise in capillary tube above the water level in the beaker as shown in **Figure 4b**.
9. The experiment is repeated for different capillary tubes.
10. Calculate the surface tension of water using equation (8).

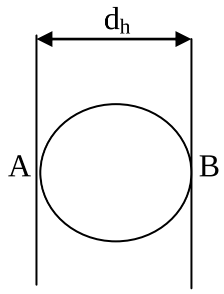
Observation & calculation:

Temperature of water at the beginning =T_b=…………………^{0}C
Temperature of water at the end =T_e=…………………^{0}C
Mean Temperature =T_m=[(T_b+T_e)/2]..............^{0}C
Density of water at T_m ^{0}C =ρ=------------gm/cc

Angle of contact of water =θ=---------------

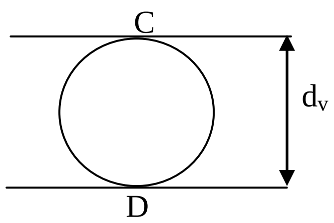
A). <u>Determination of capillary tube diameter using travelling microscope:</u>

Horizontal diameter (AB=d_h):



Tube No.	a=MSR (cm)	b=VSR×L.C. (cm)	A_1=a+b (cm)	Zerro corrected A_1 (cm)	a_1=MSR (cm)	b_1=VSR×L.C. (cm)	B_1=a+b (cm)	Zerro corrected B_1 (cm)	B_1-A_1 =AB

Vertical diameter (CD=d_v):



Tube No.	c=MSR (cm)	d=VSR×L.C. (cm)	C_1=a+b (cm)	Zerro corrected C_1 (cm)	c_1=MSR (cm)	d_1=VSR×L.C. (cm)	D_1=a+b (cm)	Zerro corrected D_1 (cm)	D_1-C_1 =CD

Mean diameter = [(AB+CD)/2] cm
= [(d_h+d_v)/2] cm

B). <u>Determination of height of liquid column in capillary tube using travelling microscope:</u>

<table>
<tr><td>Tube No.</td><td colspan="4">For lower meniscus of water</td><td colspan="4">For lower tip of the needle</td><td>Height (h)</td></tr>
<tr><td></td><td>a=MSR (cm)</td><td>b=VSR×L.C. (cm)</td><td>A=a+b (cm)</td><td>A_1=Zerro corrected A (cm)</td><td>b_1=MSR (cm)</td><td>c_1=VSR×L.C. (cm)</td><td>B=a+b (cm)</td><td>B_1=Zerro corrected B (cm)</td><td>B_1-A_1 =h</td></tr>
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<u>Result and discussion:</u>

(a). Result: Mean value of surface tension at temperature T_m ^{0}C =-------------------dynes/cm
(b). Standard literature value of surface tension at T_m ^{0}C =-------------------dynes/cm
(c). Do the error analysis using standard method.
(d). Sources of error in your experiment.
(e). Discuss your result in view of (c) & (d).