PH1202

Physics Laboratory II

Experiment No. - 04

To determine the surface tension of water by capillary tube method

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Submitted to: Dr. Prof. Dhananjay Nandi, Dr. Prof. Rangeet Bhattacharyya, Dr. Prof. Rumi De
Submitted By: Priyanshu Mahato
Roll No.: pm21ms002
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Contents

1 Aim

To determine the surface tension of water by capillary tube method.

2 Apparatus Required

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

3 Theory

3.1 Capillarity

When a glass capillary tube open at both ends is dipped vertically in the 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 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, as shown in Figure 2(b). "The phenomenon of rising or depression of liquid in the capillary tube is known as capillarity." The liquids that wet glass rises up in the capillary tube, while which do not wet glass are depressed down in the capillary tube.

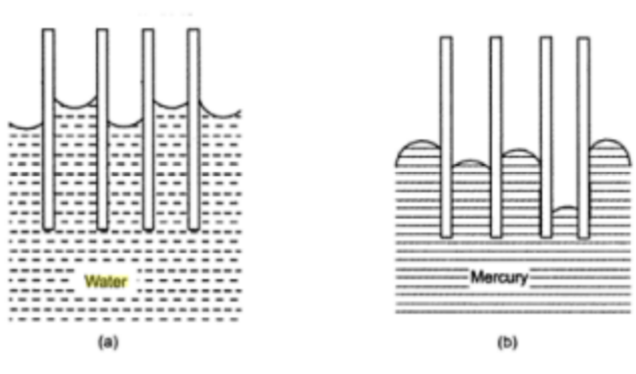


Figure 1: Rise and Fall of liquids in capillary tube

3.2 Surface Tension

The force per unit length of an imaginary line on the surface of the 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

$$T = \frac{F}{L}$$

3.3 Contact Angle

When the 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 the 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).

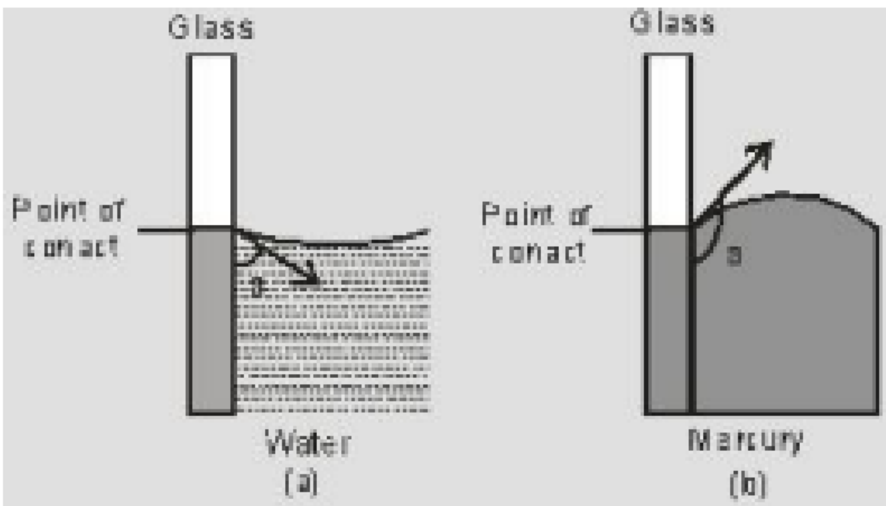


Figure 2: Contact angle for (a) water-glass interface and (b) mercury-glass interface

4 Formulae Derivation

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

$$The\ weight\ of\ water = mg \tag{1}$$

Let "r" be the radius of the capillary tube and θ be the angle of contact, then the length of the line of contact is $2\pi r$. Since the upward component of surface tension T is $T\cos\theta$ therefore, the total upward force is given by

$$Net\ Upward\ Force = 2\pi rT\cos\theta$$

For balance, the net upward force is equal to weight mg.
Therefore, $mg = 2\pi rT\cos\theta$

For water - glass contact angle $\theta = 0$, $\cos\theta = 1$, then, $mg = 2\pi r T$.

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

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

$$V = \pi r^2 h + Volume\ of\ meniscus \tag{3}$$

$$\begin{aligned} Volume\ of\ meniscus &= Volume\ of\ cylinder\ of\ height\ r - Volume\ of\ hemisphere \\ &= \pi r^2 \times r - \frac{1}{2} \times \frac{4}{3}\pi r^3 \\ &= \pi r^3 - \frac{2}{3}\pi r^3 \end{aligned}$$

$$= \frac{1}{3} \times \pi r^3 \tag{4}$$

From Equation (4) and (3),

$$V = \pi r^2 h + \frac{1}{3}\pi r^3 \tag{5}$$

But $Mass = Volume \times Density$, and therefore,

$$m = V \cdot \rho \tag{6}$$

where, ρ is the density of the water used. From equations (2), (5) and (6),

$$T = \frac{1}{2}\left[\left(h + \frac{r}{3}\right) \cdot \rho r g\right] \tag{7}$$

From the knowledge of "h" and "r", the surface tension "T" of water can be calculated using Equation (7).

5 Setup and Procedure

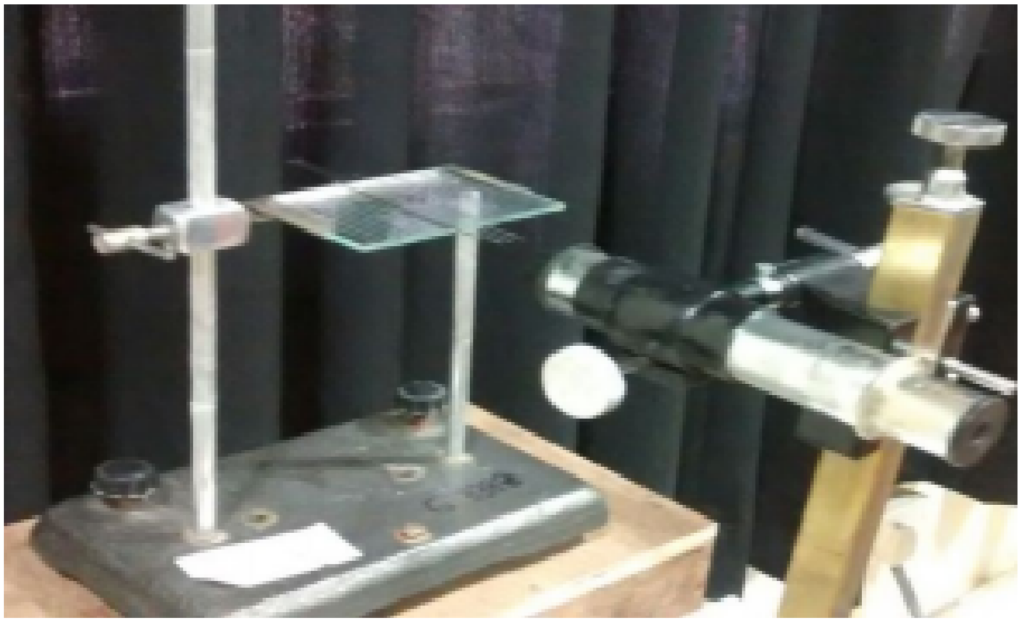


Figure 3: Set up for the determination of the radius of the capillary tube

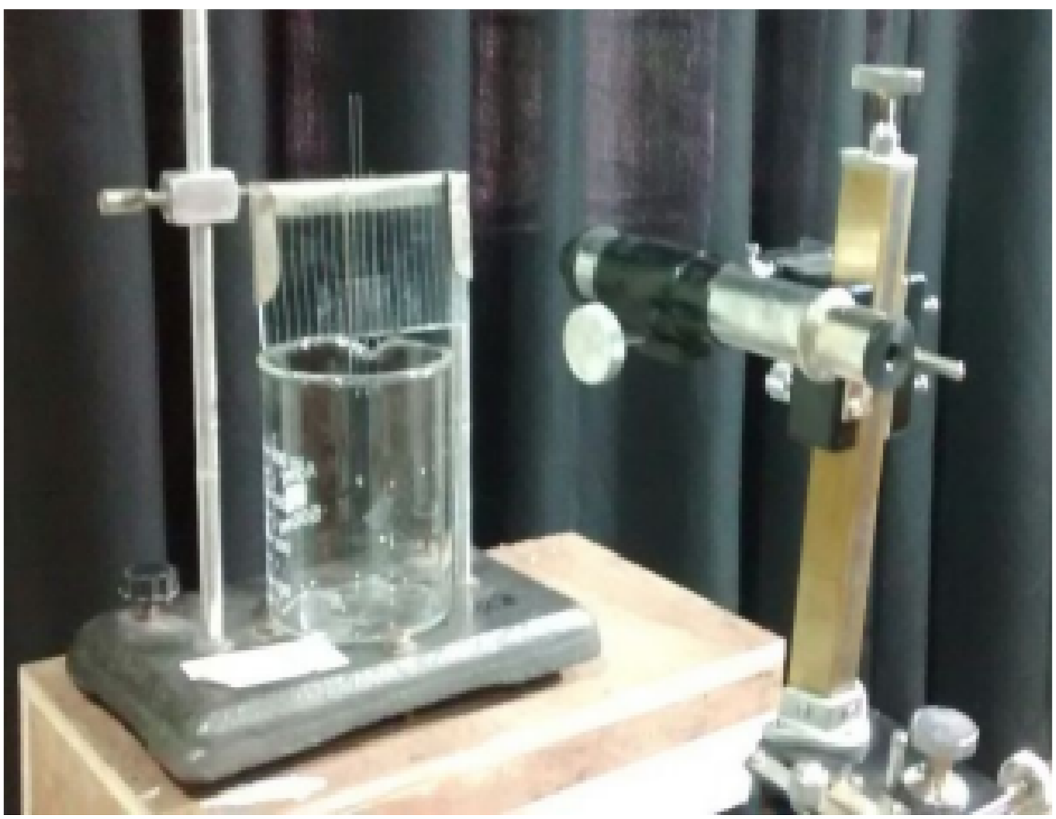


Figure 4: Set up for the determination of height "h" of water rise in a capillary tube

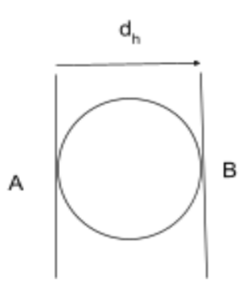
1. Select three capillary tubes of the uniform bore and different diameters.
2. Mount the capillary tubes on a glass strip with wax or rubber bands or a transparent cello tape.
3. Mount also a pointed needle near the glass strip parallel to the capillary tubes with its lower end slightly above the lower ends of the capillary tubes [shown in Figure 3]. 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 the perpendicular direction with respect to AB [shown in Figure 3]. Calculate the mean diameter [(AB+CD)/2] and hence mean radius r.
5. Clamp the glass strip vertically in an iron stand [Figure 4].
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 Figure 4.
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 the capillary tube above the water level in the beaker as shown in Figure 4.
9. The experiment is repeated for different capillary tubes.
10. Calculate the surface tension of water using Equation (7).

6 Observation and Calculation

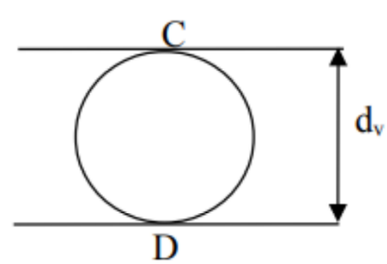
Temperature of water at the beginning = T = $27°C$
Density of water at $27°C$ = ρ = 996.52 kgm^{-3}
Angle of contact of water = $\theta = 0°$
Acceleration due to gravity = g = 9.80 ms^{-1}

6.1 Determination of capillary tube diameter using travelling microscope

Horizontal diameter (AB=d_h):



Vertical diameter (CD=d_v):



Tube No.	a=MSR (cm)	b=VSR×L. C. (cm)	A_1=a+b (cm)	a_1=MSR (cm)	b_1=VSR×L.C. (cm)	B_1=a_1+b_1 (cm)	A_1-B_1 =AB	Avg. AB (cm)
1.	3.20	0.040	3.240	2.95	0.026	2.976	0.264	0.249
	3.20	0.024	3.224	2.95	0.031	2.981	0.243	
	3.25	0.023	3.273	3.00	0.032	3.032	0.241	
2.	5.35	0.030	5.380	5.15	0.002	5.152	0.228	0.215
	5.30	0.034	5.334	5.10	0.015	5.115	0.219	
	5.40	0.023	5.423	5.20	0.025	5.225	0.198	
3.	7.55	0.010	7.560	7.40	0.011	7.411	0.149	0.140
	7.55	0.007	7.557	7.40	0.013	7.413	0.144	
	7.55	0.010	7.560	7.40	0.032	7.432	0.128	

Tube No.	a=MSR (cm)	b=VSR×L. C. (cm)	C_1=a+b (cm)	a_1=MSR (cm)	b_1=VSR×L.C. (cm)	D_1=a_1+b_1 (cm)	C_1-D_1 =CD	Avg. CD (cm)
1.	6.90	0.025	6.925	6.70	0.002	6.702	0.223	0.220
	6.90	0.025	6.925	6.70	0.006	6.706	0.219	
	6.90	0.025	6.925	6.70	0.006	6.706	0.219	
2.	6.90	0.023	6.923	6.65	0.040	6.690	0.233	0.206
	6.85	0.035	6.885	6.70	0.001	6.701	0.184	
	6.90	0.002	6.902	6.70	0.002	6.702	0.200	
3.	6.85	0.003	6.853	6.70	0.007	6.707	0.146	0.142
	6.80	0.048	6.848	6.70	0.009	6.709	0.139	
	6.80	0.048	6.848	6.70	0.008	6.708	0.140	

$$Mean\ Diameter = \frac{AB + CD}{2} cm$$
$$= \frac{d_h + d_v}{2} cm$$

1. Tube 1: 0.234 cm
2. Tube 2: 0.211 cm
3. Tube 3: 0.141 cm

Mean Radius $= \dfrac{Mean\ Diameter}{2}$

1. Tube 1: 0.1170cm
2. Tube 2: 0.1055 cm
3. Tube 3: 0.0705 cm

6.2 Determination of height of liquid column in capillary tube using travelling microscope

Tube No.	For lower meniscus of water				For lower tip of the needle				Height (h)
	a=MSR (cm)	b=VSR× L.C. (cm)	A=a+b (cm)	Avg A	a_1=MSR (cm)	b_1=VSR×L.C. (cm)	B=a_1+b_1 (cm)	Avg B	A-B =h(cm)
1)	4.25	0.045	4.295	4.273	3.50	0.012	3.512	3.513	0.76
	4.25	0.012	4.262		3.50	0.010	3.510		
	4.25	0.013	4.263		3.50	0.016	3.516		
2)	4.60	0.014	4.614	4.614	3.50	0.012	3.512	3.513	1.10
	4.60	0.016	4.616		3.50	0.010	3.510		
	4.60	0.011	4.611		3.50	0.016	3.516		
3)	5.00	0.030	5.030	5.030	3.50	0.012	3.512	3.513	1.52
	5.00	0.035	5.035		3.50	0.010	3.510		
	5.00	0.025	5.025		3.50	0.016	3.516		

Therefore, Surface Tension(S):-

1. Tube 1: 0.0456 Nm^{-1}
2. Tube 2: 0.0585 Nm^{-1}
3. Tube 3: 0.0531 Nm^{-1}

Average S = 0.0524 Nm^{-1}

7 Error Analysis

7.1 Accuracy

$S_{Calculated} = 0.0524Nm^{-1}$
$S_{Expected} = 0.0717Nm^{-1}$
$Accuracy = 1 - \frac{S_{Expected} - S_{Calculated}}{S_{Expected}} \times 100\% = 73.08\%$

7.2 Precision

As we know,

$$S = \frac{1}{2}\left[\left(h + \frac{r}{3}\right) \cdot \rho r g\right]$$

Since, g and ρ are given,

$$\delta S = \left|\frac{\delta S}{\delta h}\right| \delta h + \left|\frac{\delta S}{\delta r}\right| \delta r$$

$\delta h = \delta r = 0.001cm$
$S_1 = 0.0456 \pm 0.0005\ N/m$
$S_2 = 0.0585 \pm 0.0006\ N/m$
$S_3 = 0.0531 \pm 0.0008\ N/m$
To report S_{avg}, we take the average of individual errors of S_1 ,S_2, S_3.

$$S_{avg} = \frac{[(S_1 + S_1) + (S_2 + S_2) + (S_3 + S_3)]}{3} = \frac{[S_1 + S_2 + S_3]}{3} \pm \frac{[S1 + S2 + S3]}{3}$$

by the law of propagation of error in addition.

$$S_{avg} = 0.0524 \pm 0.0006\ Nm^{-1}$$

8 Result

The calculated value of surface tension of water(tap) is $0.0524 \pm 0.0006Nm^{-1}$.

9 Discussion on the sources of error

The accuracy of 73.08% is seemingly low as, we have used tap water in our experiment and thus, it need not be giving the same result as distilled water. This is due to different cohesion and adhesion, causing slightly different contact angles as well. So, the main source of error is contaminated tap water with no standard across the globe.
In terms of comparison to the absolute value of S of the tap water, we have the following sources of errors –

9.1 Human error

In measuring properly with the measuring telescope, as it is in our hands to place the pointer, leading to a different measurement of the height of rising or radius of the tube every time we measured. It can also be due to not properly identifying the point of coincidence on the vernier caliper fixed or not placing the pin dip on the water level correctly.

9.2 Random error

Due to fault in the shaky microscope, the airflow in the room, or temperature of the room. Maybe the evaporation of water as we measure.

9.3 Systematic error

The direction of facing of the telescope not being parallel to the plate holding the tubes, causing parallax. Zero error doesn't affect as we take the difference of the markings so it does not matter if we add or reduce the same correction to both the terms.