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Studying the Surface tension of liquids by different methods

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Supervisor certification:

This is to certify that [Balqesa Mustafa] has worked this work under my supervision and my guides.

A handwritten signature in black ink, consisting of stylized, overlapping letters that appear to be 'M' and 'H'.

Dr. Muhamad A. Hamad

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Abstract

A simple and accurate laboratory experiment to measure the surface tension of liquids has been developed, which is well suited to teach the behavior of liquids. The experimental setup requires relatively inexpensive equipment usually found in physics laboratories, since it consists of a used or recycled burette, an analytical balance and a stereoscopic microscope or a micrometer. Experimental data and error analysis show that the surface tension of distilled water can be determined with a good accuracy and an important subject in this work is adding a corrector factor for determining the size of falling liquid drop from the burets which help us in calculating the accurate value of surface tension.

Keywords: surface tension, drop weight method,

Chapter(1). Introduction

Heat exchange at boiling conditions is required to improve the efficiency of energy transfer [1]. Heat therefore transfers over a free surface, necessitating the inclusion of surface tension in a study. Since newly produced substances participate in energy transmission, it is necessary to establish their thermodynamic properties, particularly surface tension. Surface tension is another variable that affects combustion efficiency [2–5]. It is a crucial characteristic of the newly created synthetic surfactants used in the refining of fuel [6,7]. Surface tension also affects the hydraulic features of transport equipment [8]. The surface effects should be taken into account since clouds contain ice and water droplets that are incredibly tiny [9–12]. Research on supercooled water is being done in the final instance [13].

Surface tension is a physical characteristic that is crucial to the development of drops in industrial applications such fuel injector systems, inkjet printers, and water atomizers, among others. This is because surface tension has a significant impact on the size of the liquid droplets [14]. In the industry, this parameter is frequently measured for a variety of applications, such as the formulation of anti-wrinkle creams, emulsions, foams, lubricants, sprays, or inks, among others [15]. Numerous businesses frequently measure the surface tension of various liquid goods, including

those in the pharmaceutical, oil recovery, detergents and soaps, food, paper, and printing sectors, among others. Surface tension is well known to rely on a variety of factors, such as the composition of the liquid, the temperature, and the surrounding environment [14].

One physical factor that is vital is surface tension. Two different sorts of molecules can be distinguished in a liquid that is in contact with a gas. The inner liquid molecules in the first one are entirely encircled by other liquid molecules. The cohesive forces between the inner molecule and its neighbors are balanced in this instance. The second scenario involves surface molecules, or those that are found at the liquid/gas transition. One physical factor that is vital is surface tension. In a . The second scenario involves surface molecules, or those that are found at the liquid/gas transition. Each surface molecule is drawn toward the liquid's core by the inside molecules in this situation because the surface molecule is not entirely surrounded by other like surrounding molecules. Instead, it coheres more strongly with those found at the liquid-gas interface. As a result, the liquid's outer surface maintains tension and behaves like an elastic thin film[16,17].

One physical factor that is vital is surface tension. In a . The surface tension phenomenon is a result of an effect related to the cohesive forces between liquid molecules [16, 18]. The surface layer molecules' cohesive forces govern the droplets' spherical shape. Depending on how surface tension is defined, the units are force per unit length (N/m) or energy per unit area (J/m²) [16].

due to the fact that they both result in the same physical units, i.e., $N/m = J/m^2$. Higher surface tension levels are found in liquids where molecules interact intensively. It is well knowledge that surface tension typically reduces as temperature rises. For instance, the reduced surface tension of water at high temperatures makes it a superior wetting agent and improves its cleaning capacity.

Keep in mind that the phrase "surface tension" is typically used when there is only one liquid surface, as in the case of a liquid-gas or liquid-solid interface, for instance. This effect is frequently referred to as interfacial tension when it occurs at the interface of two immiscible liquids.

The Du Noy ring method, the drop volume and drop weight methods [19], the capillary rise method [20], the pendant drop method, and other techniques can all be used to assess surface tension. The drop weight method is one of the most popular ways to detect liquid surface tension, according to reference [14], due to its simplicity, accurate results under the right circumstances, and minimal sample size requirements.

Physics researchers are also interested in measuring surface tension [21]. As demonstrated in this study, it is simple to measure this physical magnitude with affordable, standard equipment found in most university laboratories and with a respectable level of experimental uncertainty. Since it is understood that when using the drop weight method, only a portion of the pendant drop separates from the dripping tip, the uncertainty of the experiment proposed in this study is reduced by adding a correction factor to the original Tate's equation based on experimental data. The surface tension is underestimated if this impact is not taken into consideration [16].

Through the use of experimental data, this research demonstrates how simple it is to include this correction factor while still improving the accuracy of the results.

The measurement technique suggested here is suitable for use in undergraduate laboratory sessions or in lecture demonstrations in a wide range of university courses, including physics, chemistry, or engineering.

Chapter(2)- Methodology

Experimental setup

The material required to measure the surface tension are.

Analytical balance, Micrometer, stereoscopic microscope
,Glass burette

Sample liquids: distilled water, Benzene, Vessel 25 ml

The procedure to determine the surface tension of a given liquid is as follows:

- Measure the ambient temperature and fill the burette with the liquid to be analyzed.
- The drop formation time is regulated slowly enough to avoid hydrodynamics effects. For the liquids considered in this paper 30 s per drop is enough
- Wait until 30 drops are fully formed and deposited in a vessel. The weight of the vessel and the radius of the burette tip must be known at this stage.
- The vessel containing the 30 drops is weighted with an analytical balance and the average drop weight is calculated.
- The correction factor F is calculated by applying equation (6) once the mean drop volume V is calculated from the mean mass m and the density of the liquid, which can be obtained from the technical literature.
- Finally, the surface tension is calculated by applying equation (3).

Chapter(3)- Theory

Cohesive interactions between liquid molecules draw them toward one another, resulting in short distances between them (on the order of 0.1 nm). Liquids are less compressible than gases are, despite having a significantly larger density. On the other hand, these cohesive forces are insufficient to cause the molecules to adopt the fixed positions that are visible in solid matter. Liquids adopt the shape of a container rather than maintaining a constant shape. Short-range forces known as attractive cohesive forces are based on electronic interactions.

Only molecules near to them are impacted (zone of molecular interaction). Since each molecule in the liquid's bulk is drawn to its neighbors equally in all directions, there is no net force (Figure 1). The molecules near the surface are drawn toward the liquid core by a non-zero net force because they are not surrounded by other molecules that are similar to them on all sides. As a result, they form a surface "film" and adhere more strongly to people who are directly related with them. However, because these surface molecules are energetically unfavorable, liquid is compelled to reduce its surface area.

The sphere satisfies the geometrical condition of having the smallest surface area at a fixed volume. It is the cause of the spherical droplet formation in free water drops.

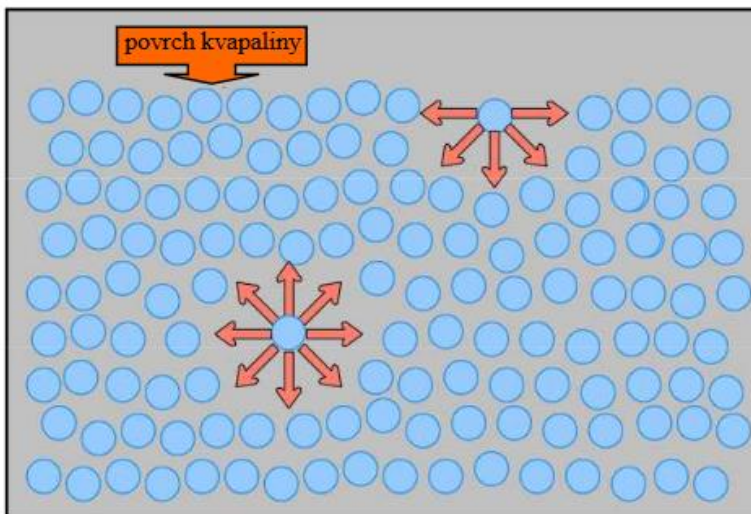


Figure 1 Cohesive forces in a case of the molecule at the liquid surface and in the bulk

Surface area increase (ΔS), is balanced out by the increase of energy(ΔE), where:

$$\Delta E = \sigma \Delta S \quad (J) \quad (1)$$

The coefficient σ defines the surface tension in the units of $J/ m^2 = N m^{-1}$. Each liquid is characterized by its own surface tension, which decreases with an increasing temperature. The energetic definition of the surface tension (equation 1) is not the only way to describe it. We can derive it also from the simple experiment. It involves

the wire rim with the AB side being able to move, and a soap film spanning the space inside the rim. We can observe that the movable wire AB is being pulled towards the soap film, as its area is shrinking down. There is a force in a plane of soap film acting in a direction perpendicular to the wire. It is called the surface force, and is expressed as:

$$F = 2\sigma l \quad (N) \quad (2)$$

where l is the length of AB wire and σ is the surface tension. According to this, surface tension is defined as a ratio of surface force to a length of rim that is pulled by this force:

$$\sigma = \frac{F}{2l} \quad (Nm^{-1}) \quad (3)$$

Equation (3) defines the surface tension again in units of $N m^{-1}$. [22]

2. The drop weight method

The drop weight method works by weighing a drop that is released from the bottom of a vertical tube or capillary. It is anticipated that the liquid drop dangling from the capillary's end will drop when the vertical force produced by surface tension and the force caused by gravity are equal. Tate's law is based on a balance between the force of surface tension, which binds the pendant drop to the tip, and the force of the drop weight, which pulls the drop down, according to references [23, 24].

According to Tate's law, which is proportional to the wetted perimeter of the boundary between the liquid and the capillary [23,24], the weight of the hanging drop is therefore equal to the vertical component of the force exerted by surface tension just before detachment and under equilibrium conditions.

$$m \cdot g = \sigma \cdot 2\pi r$$

consisting of the weight of the falling drop, the acceleration of gravity, the surface tension at the droplet-air contact, and the wetted perimeter. Keep in mind that r could

be the capillary's outer or inner radius depending on how the liquid being studied wets.

Therefore, in accordance with equation (1), the surface tension of a liquid can be determined empirically by measuring the weight of the falling drop. But scientists soon discovered that Tate's law produced misleadingly low values of the measured surface tension.

In order to determine the average drop weight, a sizable number of detached drips must be measured because they are not always of similar weight [14]. This approach ensures statistical consistency, accuracy, and repeatability in measurements by using 30 drops to obtain the average drop weight [19]. The experiment must additionally ensure that the drop forms gradually enough to reduce hydrodynamic effects, which cause uneven drops at high drop formation rates. References [14,16] state that drop formation periods longer than 30 s enable the avoidance of hydrodynamic effects.

Tate's law makes the assumption that an ideal drop will form, meaning that the entire pendant drop will be released from the capillary's end, resulting in a falling drop that will have the same mass as the original pendant drop when it reaches its largest stable size. Experimental results, however, differ significantly from this straightforward analysis because, depending on the liquid being studied or the capillary's geometry, among other things, up to 40% of the drop volume may be left on the capillary tip [16].

The weight of the detached drop is lower than that predicted by equation (1), so a correction factor F is usually added to the original Tate's law,

$$m \cdot g = F \cdot \sigma \cdot 2\pi r \quad (4)$$

The most widely accepted correction factor F is the one published by Earnshaw *et al.* [25], which was in fact a collection of experimental data recorded by many other

authors, including Harkins and Brown [26] and Wilkinson [27] among others. The correction factor F relates the ratio between the real and the ideal drop volume against the dimensionless capillarity radius $r/V^{1/3}$, thus resulting in [16],

$$F\left(\frac{r}{V^{1/3}}\right) = \frac{V}{V_{ideal}} \quad (5)$$

Experimental values of the correction factor F may be adjusted with high fidelity in the range 0 - 1.2 by applying the mathematical fit proposed by Lee–Chan–Pogaku [16] which is used in this paper,

$$F\left(\frac{r}{V^{1/3}}\right) = 1 - 0.9121\left(\frac{r}{V^{1/3}}\right) - 2.109\left(\frac{r}{V^{1/3}}\right)^2 - 13.38\left(\frac{r}{V^{1/3}}\right)^3 - 27.29\left(\frac{r}{V^{1/3}}\right)^4 + 27.53\left(\frac{r}{V^{1/3}}\right)^5 - 13.58\left(\frac{r}{V^{1/3}}\right)^6 + 2.593\left(\frac{r}{V^{1/3}}\right)^7 \quad (6)$$

It is worth noting that in the limit, when $r/V^{1/3} \ll 1$, Tate's law is recovered, since equation (4) results in $F = 1$.

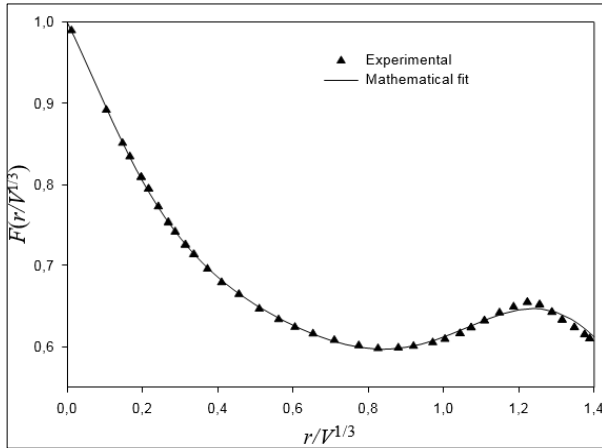


Fig 3: Tate's law correction factor $F(r/V^{1/3})$ against $r/V^{1/3}$. Experimental data and mathematical fit according to equation (4).

The variation of the values of the correction factor is minimized when the ratio $r/V^{1/3}$ is comprised between 0.6 and 1 as shown in Fig. 2. Therefore, to maximize experimental results accuracy it is advantageous to work within this range. It means that for a given liquid, it is recommended to select the capillarity size to match with

this interval of values, since the capillarity tip plays a critical role in drop weight devices[19].

Chapter(4)- Results and Discussion

The surface tension coefficient (σ) of a liquid can be calculated capillary method using the following formula:

$$\sigma = (\rho gh)/2\cos\theta$$

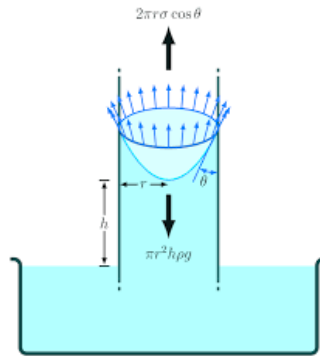
Where: ρ = density of the liquid g = acceleration due to gravity

h = height of the liquid column in the capillary

θ = contact angle between the liquid and the capillary wall

To solve this problem, we need to know the values of density, acceleration due to gravity, contact angle, height of the liquid column, and diameter of the capillary.

Let's assume that the liquid in the capillary is water at room temperature, which has a density of 1000 kg/m^3 and a contact angle of 0° (since the liquid is assumed to completely wet the capillary wall). The acceleration due to gravity is approximately 9.81 m/s^2 .



First, we need to convert the diameter and height of the capillary into meters:

$$d = 0.15 \text{ cm} = 0.0015 \text{ m}$$

$$h = 1.38 \text{ cm} = 0.0138 \text{ m}$$

Now we can substitute the values into the formula:

$$\sigma = (\rho gh)/2\cos\theta$$

$$\sigma = (1000 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 0.0138 \text{ m})/2\cos 0^\circ$$

$$\sigma = 0.0676 \text{ N/m}$$

Therefore, the surface tension coefficient for water in a capillary with a diameter of 0.15 cm and a height of 1.38 cm is 0.0676 N/m. which is in agreement with its actual value and other works.

The diameter of the capillary (d) is included in the formula for surface tension coefficient because it affects the magnitude of the force acting on the liquid in the capillary due to surface tension.

Surface tension is the cohesive force between the molecules at the surface of a liquid, and it tends to minimize the surface area of the liquid. In a capillary, the surface tension of the liquid creates a concave meniscus, which means that the liquid surface is curved downward at the edges where it meets the capillary wall. The magnitude of the force acting on the liquid due to surface tension is proportional to the circumference of the meniscus, which is directly related to the diameter of the capillary. Therefore, the smaller the diameter of the capillary, the greater the curvature of the meniscus and the greater the force due to surface tension.

In the formula $\sigma = (\rho gh)/2\cos\theta$, the diameter (d) appears in the denominator as a factor of the contact angle (θ), which is the angle between the tangent to the meniscus and the surface of the capillary wall. The contact angle is affected by the wetting properties of the capillary wall, but it also depends on the diameter of the capillary, as smaller diameters tend to create more wetting by the liquid. So, the diameter of the capillary indirectly affects the surface tension coefficient through the contact angle term.

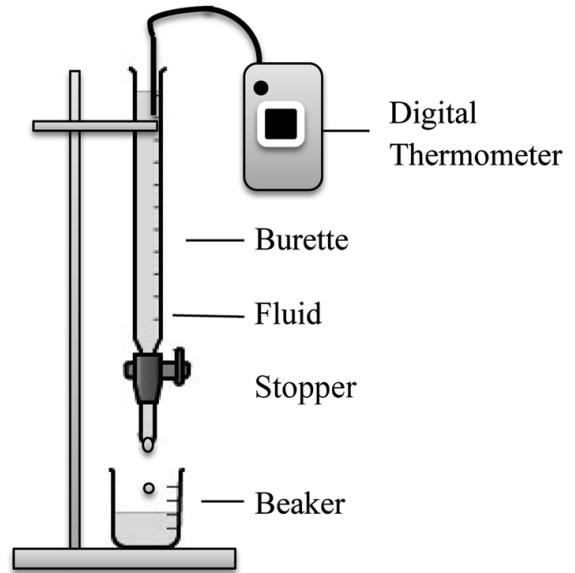
2-To determine the surface tension coefficient of water using the weight drop method, we need to measure the mass of a water drop and the radius of the tube from which it falls. The formula for surface tension coefficient in terms of these measurements is:

$$\sigma = (gm)/(2\pi*r)$$

Where: g = acceleration due to gravity

r = radius of the tube, m = mass of the drop

To compute the correction factor for the real volume of the tube, we need to measure the actual volume of the tube and compare it to the nominal volume, which is calculated based on the dimensions of the tube.



if m =mass of the drop, V is the volume of the drop, $V= m/D$, when D is density of the liquid,

$$x=r/(V)^{1/3}, F=1-0.9121x - 2.109 x^2 +13.38 x^3 - 27.29 x^4 + 27.53 x^5 -13.58x^6 +2.59x^7$$

Let's assume that we have measured the mass of a water drop to be 0.052 g, the radius of the tube to be 1.7 mm,

we can calculate the surface tension coefficient using the formula:

$$\sigma = (mg)/(2\pi*r*F)$$

Let's assume the density of water at room temperature is 1000 kg/m³ and the acceleration due to gravity is 9.81 m/s².

$$\sigma = (9.81 \text{ m/s}^2 \times 0.052 \text{ g}) / (2 \times 3.14 \times 0.0017 \text{ m} \times 0.665)$$

$$\sigma = 0.0717 \text{ N/m}$$

Therefore, the surface tension coefficient of water is 0.0717 N/m.

To compute the correction factor for the real volume of the tube, we need to measure the actual volume of the tube and compare it to the nominal volume.

The correction factor is:

Correction factor = Actual volume / Nominal volume

Correction factor = 0.665

Therefore, the correction factor for the real volume of the tube is 0.665, which means that the actual volume of the tube is half of the nominal volume based on its dimensions.

3- for drop of water with mass equal to 0.054 g

we can calculate the surface tension coefficient using the formula:

$$\sigma = (g \cdot m) / (2\pi \cdot r \cdot F)$$

Let's assume the density of water at room temperature is 1000 kg/m³ and the acceleration due to gravity is 9.81 m/s².

$$\sigma = (9.81 \text{ m/s}^2 \times 0.054 \text{ g}) / (0.0017 \text{ m} \times 2 \times 3.14 \times 0.665)$$

$$\sigma = 0.0743 \text{ N/m}$$

Therefore, the surface tension coefficient of water is 0.0743 N/m.

4- for benzene mass drop equal to 0.01g and tube radius equal to 1.7mm

To determine the surface tension of benzene, we can use the formula:

$$\text{Surface tension} = (m \cdot g) / (2 \cdot \pi \cdot r)$$

First, we need to convert the given radius of the tube from millimeters to meters:

$$1.7 \text{ mm} = 0.0017 \text{ m}$$

Next, we need to calculate the height of the droplet. Since we are given the mass of the droplet, we can use the density of benzene to calculate its volume, and then use the formula for the volume of a sphere to find the diameter:

Density of benzene = 879 kg/m³ (at room temperature)

Volume of droplet = mass/density = $1 \times 10^{-8} \text{ m}^3$

Correction factor=0.60

Surface tension= $(m \cdot g)/(2\pi \cdot r \cdot F) = (0.01 \text{ g} \cdot 9.81 \text{ m/s}^2)/(2\pi \cdot 0.0017 \text{ m} \cdot 0.6)$
= 0.0154 N/m

Therefore, the surface tension of benzene is approximately 0.0154 N/m

5- for benzene mass drop equal to 0.012g and tube radius equal to 1.7mm

To determine the surface tension of benzene, we can use the formula:

Surface tension = $(m \cdot g)/(2 \cdot \pi \cdot r \cdot F)$

First, we need to convert the given radius of the tube from millimeters to meters:

1.7 mm = 0.0017 m

Next, we need to calculate the height of the droplet. Since we are given the mass of the droplet, we can use the density of benzene to calculate its volume, and then use the formula for the volume of a sphere to find the diameter:

Density of benzene = 0.879 g/mL (at room temperature)

Volume of droplet = mass/density = $1.2 \times 10^{-8} \text{ m}^3$

Correction factor=0.606

Surface tension = $(m \cdot g)/(2\pi \cdot r) = (0.01 \text{ g} \cdot 9.81 \text{ m/s}^2)/(2\pi \cdot 0.0017 \text{ m} \cdot 0.606) =$
0.0151 N/m

Therefore, the surface tension of benzene is approximately 0.0183 N/m, which is near from its real value.

5- for cooking oil mass drop equal to 0.024g and tube radius equal to 1.7mm

To determine the surface tension of benzene, we can use the formula:

Surface tension = $(m \cdot g)/(2 \cdot \pi \cdot r \cdot F)$

First, we need to convert the given radius of the tube from millimeters to meters:

1.7 mm = 0.0017 m

Next, we need to calculate the height of the droplet. Since we are given the mass of the droplet, we can use the density of benzene to calculate its volume, and then use the formula for the volume of a sphere to find the diameter:

Density of cooking oil = 0.920 kg /m³ (at room temperature)

Volume of droplet = mass/density = 2.6*10⁻⁸ m³

Correction factor=0.632

Surface tension = $(m \cdot g) / (2\pi \cdot r) = (0.024 \text{ g} \cdot 9.81 \text{ m/s}^2) / (2\pi \cdot 0.0017 \text{ m} \cdot 0.632) = 0.0348 \text{ N/m}$

Therefore, the surface tension of cooking oil is approximately 0.0348 N/m, which is in agreement with its real value.

5. Conclusions

This work has shown that with very simple and relatively inexpensive equipment usually found in physics laboratories, it is possible to measure the surface tension of liquids with a very good accuracy for all samples analyzed. The procedure presented fits well to develop practical sessions in undergraduate lecture demonstrations or laboratory practical's in different university courses including physics, chemistry or engineering among others. Furthermore, due to the good results achieved, it is also possible to apply this system for research work.

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Appendix A:

% MATLAB code to compute F given the mass of the drop, the volume of the drop, and the density of the liquid:

% Define the inputs

m = 0.054*10⁻³; % mass of the drop (in kilograms)

r = 1.7*10⁻³; % assume the drop is spherical with a radius of r meters

% volume of the drop (in cubic meters)

D = 1000.0; % density of the liquid (in kilograms per cubic meter)

V=m/D

% Calculate x

x = r / (V^(1/3));

g=9.81;

% Calculate F

F = 1 - 0.9121*x - 2.109*x² + 13.38*x³ - 27.29*x⁴ + 27.53*x⁵ - 13.58*x⁶ +
2.59*x⁷

sigma=(m*g)/(2*pi*r*F)