

Candidate 3 evidence

INVESTIGATION OF SURFACE TENSION OF WATER

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1. Introduction

1.1. Abstract

This report is to compare different methods of finding the surface tension of water as well as to determine the relationship between temperature and the surface tension of water.

After the experiments it was determined that the direct pull method this is because it produced values very similar to the values expected under the circumstances. The average value collected in the experiment being 0.0727Nm^{-1} compared to the value of 0.0724Nm^{-1} . [4]

It was found from the graph for the jaeger's method experiment that the surface tension of water was directly proportional to temperature, as temperature increases the surface tension of water also increases with the equation being $y=0.0103x-0.1679$ this is the equation we calculated which was a far bit off the actual relationship between temperature and surface tension.

1.2. Background to surface tension

The strong attractive forces between liquid molecules are the reason that we have surface tension. The molecules on the surface do not have other molecules like them on the surface this makes them have a strong coherent force and attract to each other more strongly on the surface. With this coherent force it creates a kind of 'film' on the surface of the water, this film makes it harder to move an object through the surface than if the object is completely submerged.

Surface tension is measured in Nm^{-1} (force per unit area), the force in newtons required to break a film of 1m length. Different liquids have different surface tensions with water having the surface tension of $0.0724Nm^{-1}$ [4] compared to liquids ethyl alcohol and mercury being $0.0223Nm^{-1}$ and $0.465Nm^{-1}$ [4].

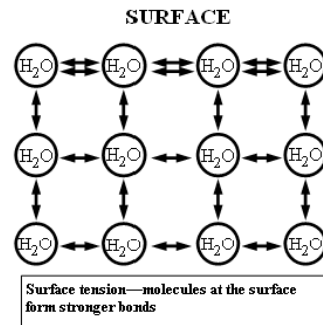


Figure 1.2- Interactions between water molecules.

This diagram shows how surface tension makes the "skin" on top of the water which is just a stronger force of attraction between the molecules on the surface compared to the rest of the water. With the arrows symbolising the attracting forces between the water molecules.

2. Experiment 1 – drop weight method

2.1. Underlying physics

In the drop weight method, a liquid is introduced in large volumes through a capillary. A drop, which tries to move upward due to buoyancy, forms at the tips of the capillary. Because of this, the interfacial tension γ the drop tries to keep as little contact with the bulk volume travelling through the capillary. As a new comes into being when the drop leaves the end of the capillary tube, it is necessary for the drop to overcome the corresponding interfacial tension. The drop wants to have as little contact with the bulk as possible with a new interface appearing when the initial drop, drops from the capillary tube. With this the drop will need to over come the corresponding interfacial tension. The drop will not drop until the weight or the lifting/buoyancy force compensates the interfacial force. [5]

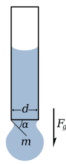


Figure 2.1- combinations of forces acting on a drop exiting a capillary tube

The force from the internal pressure must first be calculated. The internal pressure is given by $\frac{\gamma}{r}$. [5]

$$\begin{aligned} F &= PA \\ &= \frac{\gamma}{r} \times \pi r^2 \\ &= \gamma \pi r \end{aligned}$$

Then the sum of the downward forces is:

$$F = \gamma \pi r + mg$$

The upwards force is given by using the formula for surface tension,

$$\gamma = \frac{\text{Force}}{\text{Length}}$$

So

$$F = \gamma l$$

Force this experiment l is the circumference of the drop so $2\pi\gamma r$,

$$F = 2\gamma \pi r$$

By then equating the upwards and downwards forces we can find the equation for surface tension, [2].

$$\begin{aligned} 2\pi r \gamma &= \gamma \pi r + mg \\ \gamma(2\pi r - \pi r) &= mg \\ \gamma(\pi r) &= mg \end{aligned}$$

$$y = \frac{mg}{\pi r}$$

2.2. Procedure

All the glassware was scrubbed clean and soaked in an acid bath. A clamp stand was then set up holding a burette, attached to this burette was an extra glass tube this was to reduce the flow of water with a clamp being on the connector to get only small drops out of the apparatus. The beaker was then placed under the apparatus after it was weighed on a balance. The beaker was always emptied and dried, so the mass was the same every time. Then water was placed in the burette and the flow was severely restricted due to the clamp to one drop per minute. This time intervals allows the drop to form correctly. A counted number of drops (10) were collected in the beaker. The total mass was found and the mean mass of a drop was also found. To measure the radius of the tube a set of callipers were used.

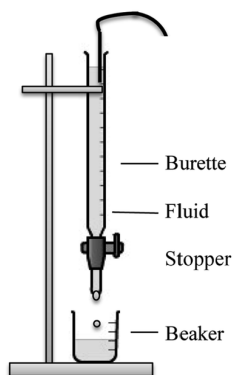


Figure 2.2- Functional diagram of drop weight.

This diagram doesn't include a stop watch that was used to time the intervals of the drops and the callipers which was used to measure the inner radius of capillary tube.

2.3. Results

Mass of Beaker (g)	Mass of beaker + drops	Number of Drops
39.43	40.15	10
39.42	40.18	10
39.4	40.25	10
39.41	40.24	10
39.41	40.23	10
Mean mass of Drops (g)	Radius of orifice (mm)	Surface tension (Nm⁻¹)
0.072	3.6	0.0623
0.076	3.6	0.0659
0.085	3.6	0.0737
0.083	3.6	0.0719
0.082	3.6	0.0711
Overall mean mass of drop (g)	Average surface tension (Nm⁻¹)	
0.080	0.069	

2.4. Analysis

The formula used for calculating the surface tension:

$$y = \frac{mg}{\pi r}$$

g- acceleration due to gravity which is 9.8ms^{-2}

r- the radius of the orifice and it was measured to be 3.6mm

m- mass of a singular drop

$$\begin{aligned} \text{mass of drop} &= \frac{\text{Mass of beaker and drops} - \text{mass of beaker}}{10} \\ &= \frac{40.15 - 39.43}{10} \\ &= 0.072 \times 10^{-3}\text{kg} \end{aligned}$$

The mean mass of the 5 experiments was then found,

$$\begin{aligned} m &= \frac{0.072 + 0.076 + 0.085 + 0.083 + 0.082}{5} \\ &= 0.080 \times 10^{-3}\text{kg} \end{aligned}$$

These values were then subbed into the equation:

$$\begin{aligned} y &= \frac{mg}{\pi r} \\ &= \frac{0.08 \times 10^{-3} \times 9.8}{\pi \times 3.6} \\ &= 0.069\text{Nm}^{-1} \end{aligned}$$

2.5. Uncertainties

Errors occurred in the measurements of the mass of each of the drops, m , and in the radius of the tube r .

For m , the random uncertainty and the scale reading uncertainty must be found.

$$\text{RandomUnc} = \frac{(\text{Max} - \text{min})}{n}$$

For the example for m :

$$\text{RandomUnc} = \frac{(0.85 - 0.72)}{5}$$

$$\text{RandomUnc} = \pm 0.026g$$

Scale reading uncertainty is half the smallest unit on the scale which is $\pm 0.01g$

To combine the uncertainties, we must convert them into percentage form

$$\%unc = \frac{Unc}{\text{value}} \times 100$$

For example

$$\frac{0.01}{0.80} \times 100 = \pm 1.25\%$$

The combination follows the following formula

$$Unc^2 = (\%unc)^2 + (\%unc)^2 + \dots$$

$$Unc^2 = ((3.25)^2 + (1.25)^2)$$

$$Unc = \pm 3.48\%$$

The uncertainty for one drop is

$$= \pm 0.348\%$$

We must combine the uncertainty of r and the uncertainty for one drop

$$Unc^2 = (0.348)^2 + (0.277)^2$$

$$Unc = \pm 0.44\%$$

$$\text{Absolute uncertainty} = \frac{0.44}{100} \times 0.069$$

$$= \pm 0.0003Nm^{-1}$$

2.6. Evaluation

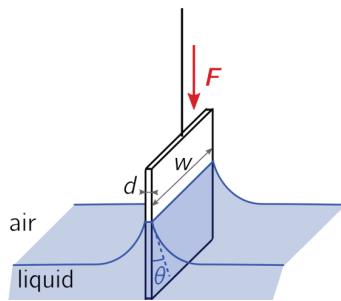
Comparing the results that we have gained from this experiment for surface tension (0.069Nm^{-1}) with the actual value of surface tension (0.0742Nm^{-1}) we can see that both values have the same magnitude. The experimental values came out to be smaller than the actual value, this is due to the uncertainties of a possibility of a mark on the glass or a draft making the drop detach prematurely leading to an uncertainty in the mass of the drop. We could sort this out by putting the apparatus in a draft less room.

A way that we could improve the experiment is by not emptying the beaker at the end of each experiment, with this we can take the final mass of the previous experiment as the start mass of the next experiment. This would save a lot of time and help reduce any chance of residue water from the previous experiment.

3. Experiment 2 – direct pull method

3.1. Underlying physics

The direct pull method describes the use of a torsion balance to measure the surface tension forces acting on a microscope slide or a frame which is suspended to touch the surface of the liquid. The torsion balance is used to get a scale for the tension force acting on the slide this is done by a skin forming around the bottom of the slide and the scale reads the force needed to break the skin. This occurs as the water wants to reduce its surface area but is attracted to the slide, so a force is



created pulling the slide into the water.

Figure 3.1- forces acting upon a microscope slide

The downward force on the slide can be represented as $\gamma(2L+2t)$, where γ is the surface tension, L is the length of the slide and t is the thickness of the slide. Using the balance beam the force acting on the slide can be counteracted by adding masses to the dish on the opposite end of the torsion balance. As a result, $\gamma(2L+2t)$ can be equal to the weight of the masses

$$\text{Hence } \gamma(2L+2t)=mg \quad [3]$$

This can then be rearranged for γ to be the subject:

$$\gamma = \frac{mg}{2L+2t}$$

This is the equation needed to find surface tension.

3.2. Procedure

A torsion balance was set up with the scale set at 0, this was done by adding masses to the opposite end of the scale to make it 0. A microscope slide and a dish was then attached to the side with the scale. A large beaker was then filled with water and placed on a lab jack. Once on the lab jack the beaker was raised to that the microscope slide just touches the water. Then the beaker is lower slowly as to be able to see when the slide breaks away from the water, just before it breaks take a note of the scale and where the indicator lies. Then the beaker is removed and then masses are added to the dish by the scale the get the same reading that was produced by the water this is the value for m in kg. The mass of the masses was calculated using a set of scales. This experiment was repeated five times with four different slides, which had their length and breadth measured by callipers. All the glassware was cleaned thoroughly.

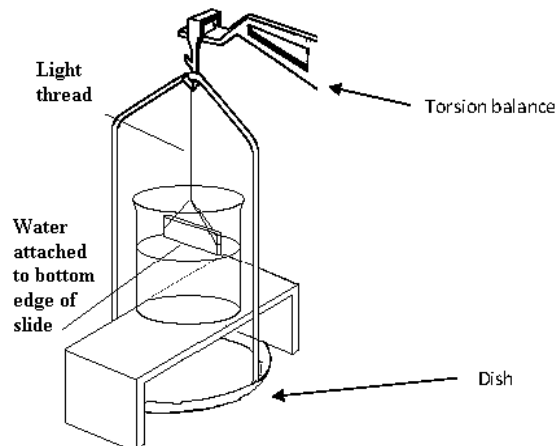


Figure 3.2-
a functional
diagram of
direct pull

method

This diagram does not include a set of callipers which was used to measure the length and breadth of the microscope slide.

3.3. Results

L (m)	B (m)	Slide	Mass (kg)					Mean mass (kg)
			1	2	3	4	5	
0.07496	0.00098	1	0.00112	0.00112	0.00122	0.00109	0.00110	0.00113
0.07532	0.00097	2	0.00110	0.00111	0.00111	0.00109	0.00108	0.00110
0.07539	0.00098	3	0.00110	0.00109	0.00108	0.00107	0.00108	0.00108
0.07507	0.00099	4	0.00120	0.00121	0.00120	0.00123	0.00120	0.00121

Since the slides were from the same manufactured batch I made a mean of the length and breadth.

$$L = 0.07519\text{m}$$

$$t = 0.00098\text{m}$$

3.4. Analysis

Using the formula to calculate surface tension:

$$\gamma = \frac{mg}{2L + 2t}$$

g- gravitational constant due to gravity

m- mass used to get the value on the torsion balance (kg)

L- length of slide (m)

t- breadth of slide

The values from the table was then substituted into the equation

Slide 1:

$$\gamma = \frac{mg}{2L + 2t}$$

$$\gamma = \frac{0.00113 \times 9.8}{(2 \times 0.07519) + (2 \times 0.00098)}$$

$$\gamma = 0.0727 \text{ Nm}^{-1}$$

Slide 2:

$$\gamma = \frac{0.0011 \times 9.8}{(2 \times 0.07519) + (2 \times 0.00098)}$$

$$\gamma = 0.07076 \text{ Nm}^{-1}$$

Slide 3:

$$\gamma = \frac{(0.00108 \times 9.8)}{(2 \times 0.07519) + (2 \times 0.00098)}$$

$$\gamma = 0.06948 \text{ Nm}^{-1}$$

Slide 4:

$$\gamma = \frac{0.00121 \times 9.8}{(2 \times 0.07519) + (2 \times 0.00098)}$$

$$\gamma = 0.07784 \text{ Nm}^{-1}$$

3.5. Uncertainties

With using this method uncertainties arose creating many varying results, one of which was the masses which was set on the dish the other being the length and breadth of the microscope slide. To get the uncertainty for the mass, the masses were measured multiple times to get the correct value on a balance.

The random uncertainty was calculated for the four different slides:

$$\text{RandomUnc} = \frac{\text{Max} - \text{min}}{n}$$

For example:

$$\text{RandomUnc} = \frac{1.22 \times 10^{-3} - 1.09 \times 10^{-3}}{5}$$

$$\text{RandomUnc} = \pm 26 \times 10^{-3} \text{ kg}$$

This was then converted into a percentage and combined with the length and breadth uncertainty.

$$\% \text{Unc} = \frac{\text{unc}}{\text{value}} \times 100$$

$$\% \text{Unc} = \frac{26 \times 10^{-6}}{1.155 \times 10^{-3}} \times 100$$

$$\% \text{Unc} = \pm 2.25\%$$

The random uncertainty in L was found to be $\pm 1.075 \times 10^{-4}$ m as

$$\text{RandomUnc} = \frac{75.39 \times 10^{-3} - 74.96 \times 10^{-3}}{4}$$

$$\text{RandomUnc} = \pm 1.075 \times 10^{-4} \text{ m}$$

The random uncertainty for t was found to be $\pm 5 \times 10^{-6}$ as

$$\text{RandomUnc} = \frac{0.99 \times 10^{-3} - 0.97 \times 10^{-3}}{4}$$

$$\text{RandomUnc} = \pm 5 \times 10^{-6} \text{ m}$$

The percentage uncertainty was then calculated for L and t being $\pm 0.14\%$ and $\pm 0.51\%$ respectively. With the percentage for the masses being larger than three multiples the values for L and t can be ignored.

The random uncertainty for the surface tension through the different slides was found to be $\pm 2.09 \times 10^{-3} \text{ Nm}^{-1}$ which in percentage form is $\pm 2.87\%$ this will then be combined with the value for mass which comes out at $\pm 3.65\%$

The definitive answer comes out at $0.0727 \pm 0.00265 \text{ Nm}^{-1}$

3.6. Evaluation

The results obtained from this experiment, when compared to the true value with the uncertainty covering the true value.

Ways this experiment could be improved is by having the glassware more thoroughly cleaned as a single mark on the glassware can cause a large uncertainty to occur. Another problem that occurred was when the indicator had to be zero on the scale on the torsion balance this caused a problem when trying to get the correct scale inclinations. Another problem which occurred was with the slide staying attached to the water with slight vibrations due to people walking by, creating oscillations in the equipment which then breaks the skin on top of the water.

4. Experiment 3 – Jaeger's method

4.1. Underlying physics

The coefficient of surface tension decreases with increasing temperature, with this water can drip into a large flask with an airtight seal, so forcing bubbles of air out of the capillary tube which drips into a beaker of water. The lower end of the capillary tube is a depth h_1 below the water surface. It can be shown that the bubble will break free from the end of the tube when the radius is equal to the internal radius of the tube. Using the manometer, the total pressure within the apparatus may be found; with this the internal pressure will be equal to the hydrostatic pressure which is $(h_1 r_1 g)$. The excess pressure within the air bubble is due to surface tension of water. With the total pressure being given with the equation

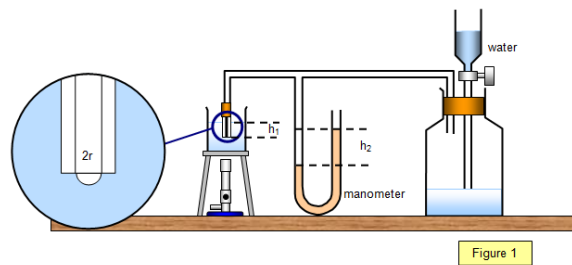
$$h_2 r_2 g = h_1 r_1 g + \frac{2T}{r} \quad [1]$$

With r_1 being the density at a specific temperature, r_2 is the density of the liquid in the manometer, r is the radius of the capillary tube and with h_2 being the difference in levels within the manometer. The coefficient of surface tension of water T , with heating the water in the large flask giving a range of values for T . This equation can then be changed to get T as the subject:

$$T = \frac{1}{2} r g (h_2 r_2 - h_1 r_1)$$

4.2. Procedure

The apparatus used is shown in figure 4.2. The glassware was first cleaned with an acid bath and scrubbed thoroughly to get any marks or stains off the glass that will affect the experiment. Then that glassware was assembled with there being a conical flask, a U tube, a T tube, 2 other tubes to connect them and a funnel or something else that allows water to drip slowly. Water was then added to the beaker, as well as the liquid being added to the manometer of which it is toluene (safety precautions must be made as toluene is an irritant). Once an airtight seal is in place run water through the funnel until a bubble is just about to leave the end of the tube this gets a displacement in the manometer, this displacement was then measured using a ruler being the values for h_2 . The ruler was also used to find the value for h_1 with it being the distance under the water the end of the bubble producing tube. A pair of callipers was used to find the value for r . This water done for



beaker temperatures of 22, 27, 32 and 37°C, it was also repeated four times.

Figure 4.2- a function diagram for Jaeger's method.

This diagram does not include the ruler stick which was used to measure the displacement in the manometers.

4.3. Results

Temperature (oC)	Mean displacement (m)	Density of water (kg/cm ³)	Surface tension (Nm ⁻¹)	Absolute uncertainty in surface tension (Nm ⁻¹)	Actual value of surface tension (Nm ⁻¹)
22	0.0295	1000	0.0467	0.0027	0.0724
27	0.0413	996.5	0.1327	0.0036	0.0720
32	0.0443	995.1	0.1547	0.0145	0.0711
37	0.0520	993.3	0.2113	0.0073	0.0706

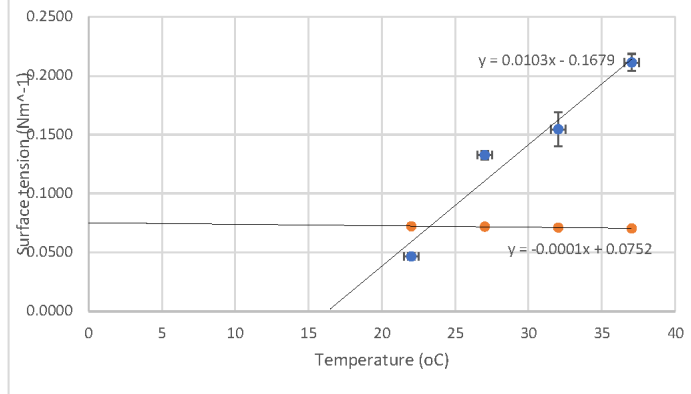


Figure 4.4- graph of results top line was calculated, and bottom line is actual values.

4.4. Analysis

The formula used to find the surface tension through jaeger's is:

$$y = \frac{1}{2}rg(h_2r_2 - h_1r_1)$$

In each experiment g is constant at $9.8ms^{-2}$, also the value for r was constant through out the experiment being $0.00171m$ for the radius of the capillary tube.

r_2 and h_1 also remained constant through out the experiment with r_2 being the density of toluene which was calculated as follows

$$r_2 = \frac{m}{V} = \frac{867}{1000} = 0.867kg l^{-1}$$

h_1 was found by using a ruler stick and measuring the distance in the water capillary tube was this was kept constant by keeping the equipment set up and not moving any parts.

r_1 was found using a table of values [6].

h_2 was found out by using a ruler stick and measuring the displacement just before a bubble leave the end of a capillary tube.

The values were substituted into the equation;

$$y = \frac{1}{2}rg(h_2r_2 - h_1r_1)$$

$$y = \frac{1}{2} \times 0.00171 \times 9.8(0.0295 \times 867 - 0.02 \times 1000)$$

$$y = 0.04567Nm^{-1}$$

4.5. Uncertainties

Many uncertainties contributed to the experiment with the main one being random uncertainty of the surface tension of water which was caused by the measuring of the manometers.

$$\text{randomUnc} = \frac{\text{max} - \text{min}}{n}$$

Example;

$$\begin{aligned} &= \frac{0.031 - 0.028}{4} \\ &= 0.00075m \end{aligned}$$

This turned into a percentage

$$\begin{aligned} \%Unc &= \frac{0.00075}{0.0295} \\ \%Unc &= 2.5\% \end{aligned}$$

This then onto the value for surface tension gives the absolute value once converted

$$\text{absolute uncertainty} = 0.0027Nm^{-1}$$

This is like in the table

4.6. Evaluation

Many problems occurred during this experiment that could have caused such a large uncertainty and completely wrong equation for the graph.

One of these reasons one of these could be because the glass wear wasn't properly clean, a way to sort this is by scrubbing it thoroughly and bathing it in acid.

another reason could be because a proper airtight seal could not be achieved, a way this could be improved is by making sure the pieces properly fit and have spares if any break.

Another reason could be because a bubble appeared in the U bend tube which can cause problems to the pressure in the apparatus.

another reason could be put down to the way it was measured using a ruler stick instead of a travelling microscope which is a more accurate form of measuring.

As can be seen from the graph the results are showing the wrong gradient for the graph as the gradient is supposed to be negative this could have been caused by the bubble occurring in the U tube and a failure to measure properly.

5. Discussion

5.1. Conclusion

The best method for measuring surface tension was found out by carrying out 3 different experiment and evaluating the results gained from them.

To determine the best method for finding the surface tension we must consider multiple factors these being; the values closest to the actual value, the values of uncertainties and the simplicity of the apparatus and how easy it was to set up and use.

The direct pull method got the closest to that actual value of the surface tension. We calculated that the surface tension through the direct pull method was 0.0727Nm^{-1} this is then compared with the actual value for surface tension being 0.0724Nm^{-1} with this we can see that both values are in the same magnitude with our value being out by 0.41% this is incredibly close to the actual value more so than the drop weight with it being out by 4.7% which is still close but the direct pull method still beats it out

The direct pull method was also the easiest to set up with it having a very little amount of apparatus and it being very easy to set up. Reasons for this is because of the simplicity of the method with the beaker and scale being the only variables which change in the experiment. This is unlike Jaeger's method which the experiment relies on many aspects being right for the experiment to work, for example the apparatus has to have an air tight seal as well as the water has to run through at a certain volume for the bubble to be produced, also with the pressure was affect with small movements of the apparatus which affected the results.

The most consistent results were from the drop weight method with the uncertainty for it being $\pm 0.44\%$ compared to the uncertainties for the direct pull method being $\pm 3.45\%$. This show that the drop weight method was far more consistent than the drop weight.

5.2. Evaluation

Whilst doing the experiments there were many factors which contributed to the uncertainties for example in the direct pull method it was found that the scale was sometimes offset this was caused by the counter balance weights slipping and putting off the scale a slight bit. A way this could be improved is by having a mass that makes the scale at 0 and securing it properly. This will reduce the uncertainty in the scale.

The largest uncertainty was increasing the temperature in the Jaeger's method we used a hot plate to heat the beaker in which it was hard to get proper intervals and assumptions had to be made for increasing temperature. A way this could be improved upon is by doing the experiment more times at the temperatures and by measure the temperature of the water more times before starting the experiment.

The biggest problem in the three experiments was the jaegers method as the graph shows a completely different relationship to the actual relationship this causes huge problems to its uncertainties as well.

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