INTERNATIONAL BACCALAUREATE EXTEND ESSAY

THE EFFECT OF SURFACTANTS ON THE SURFACE TENSION OF WATER

Research Question: How does the concentration of Persil © Washing Powder affects the surface tension of distilled water.

Word Count: 3985

Physics

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Research Question: How does the concentration of Persil © Washing Powder affects the surface tension of distilled water.

1.0 Introduction

1.1Reason Behind Undertaking the Study

When I witnessed a dragon-fly float on water in our park I was mesmerized, and when I learned this strange behavior is caused because of a unique physical concept called surface tension I was captivated. Countlessly relied on secondary data previously, I wanted to follow an experimental approach. Consequently, I decided to focus on a factor that alter surface tension -concentration of surfactants- as it is suitable for experimental investigation. In this extended essay, the effect of surfactants on the surface tension of water is experimentally investigated with two different methods. First, background information on the subject will be presented, then the experimental procedure will be described, and finally data will be presented and it will be evaluated regarding the research question.

1.2 Background Information

1.2.1 Introduction to Surface Tension

Surface tension can be defined as the property of the surface of a liquid that allows it to resist an external force, due to the cohesive nature of its molecules.[1] The name "surface tension" comes from the circumstance that surface is indeed under tension. This tension is formed mainly because liquids surfaces at rest tends to shrink into the minimum surface area possible –see "Causes for Water Tension". This tension of the surface causes objects with higher density than the liquid to float on that liquid although they aren't even partially submerged: like when dragon-flies, and razor blades float on water without a buoyant force. When such

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[1] *Surface tension and water*. Surface Tension and Water | U.S. Geological Survey. (n.d.). Retrieved July 22, 2021, from https://www.usgs.gov/special-topics/water-science-school/science/surface-tension-and-water

object is placed on a liquid, its weights compress the surface, and if surface tension and downward force become equal then it is balanced by the surface tension forces on either side. These forces are each parallel to the water's surface at the points where they contact the object.

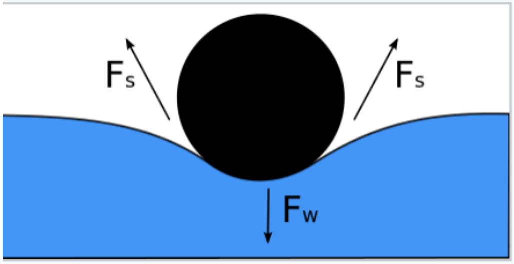


Figure 1: Cross-section of a needle floating on the surface of water. Fw is the weight and Fs are surface tension resultant forces.

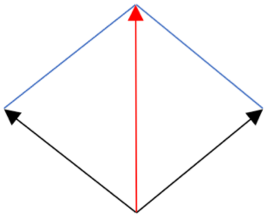


Figure 2: Addition of Fs vectors (black color) forming the resulting vector that Balances the weight of the object (red color)

As illustrated in figure 2, the horizontal components of the two F_s arrows point in opposite directions and have the same magnitude, so they cancel out each other, but the vertical components point in the same direction and therefore add up to balance the weight of the object.

1.2.2 Cause of Water Tension

Cohesive forces -the forces of attraction acting between molecules of the same type- act upon molecules in a liquid. Accordingly, each molecule forms a bond with the ones in its vicinity. Because of this, a liquid molecule away from the surface is attracted in all directions by neighboring liquid molecules. Consequently, this attraction from every direction results in a zero net force on the molecule. However, the situation is different for the molecules at the surfaces. As there isn’t liquid present “above” them, there are less molecules for surface molecules to cling to. As a result, surface molecules form stronger bonds between them, forming a layer of strongly bonded liquid molecules. Furthermore, as it is mentioned in “Introduction to Surface Tension” surface tension is particularly the tendency of liquids surfaces at rest to shrink into the minimum surface area possible. Indeed, this is behavior is formed because, although a molecule within a body of liquid experiences zero net force, the ones on the surface experience a net inward force because there will be no balancing attractive force acting from above. This inward net force causes the molecules on the surface to contract and to resist being stretched or broken.

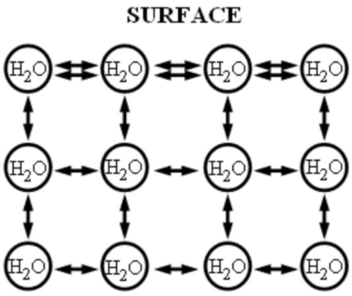


Figure 3: Illustration of stronger bonds between liquid (particularly water in the example above) molecules formed at the surface.

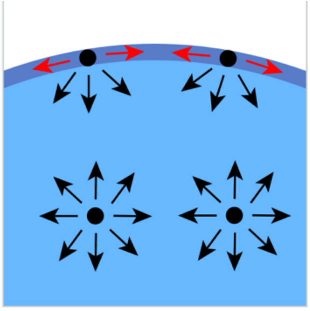


Figure 4: Illustration of the inward net force acting on the surface molecules.

1.2.3 Mathematical Consideration of Surface Tension

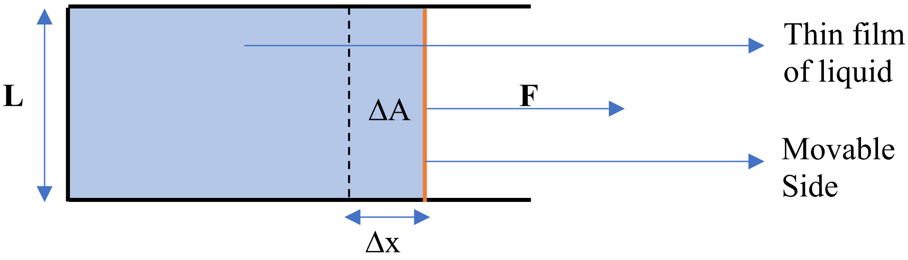


Figure 5: Illustration of the force necessary to increase the surface area.

In the illustration above, the three black sides that are fixed in position and the orange side that can move forms a rectangular frame. F is the force that prevents the movable side to move to the left. The liquid is in a thin, membrane like state because of the adhesion force between its molecules and the molecules of the frame.

When regarding this mathematical consideration, it should be noticed that surface tension and surface energy only differ as a matter of semantics and considered equal. The concept of surface energy -surface energy is the energy required to increase the surface area of the liquid by a unit area- is useful when explaining the concept of surface tension.

$$\text{Surface Energy} = \frac{\Delta \mathrm{E}}{\Delta \mathrm{A}} \; \mathbf{(1)}$$

Where ΔE is the change in energy stored by the surface and ΔA -as it is illustrated in Figure 5- is the change in the area of the film resulted because of the movable part of the frame. The equation above demonstrates that the energy stored in the surface is proportional to the growth in surface area. Here another explanation of the shrinking effect behavior of surface tension can be derived. Since liquids want to arrive at the state of least energy, they tend to minimize their surface area.

Considering the Newton's Second Law of Motion, and the force F, it can be noted that F is also the force that moves the movable side to the right at constant speed. As F pulls the side to the right, it does work on the liquid while the surface area of the liquid increases.

$$\mathrm{W} = \mathrm{F}\Delta \mathrm{x} \; \mathbf{(2)}$$

Where W is the work done by the force F while moving the movable side by a distance of Δx Concurrently the area of the film also increases when Δx increases.

$$\Delta \mathrm{A} = \mathrm{L}\Delta \mathrm{x} \; \mathbf{(3)}$$

When equation(2) and equation(3) are substituted into equation(1),

$$\text{Surface Energy} = \frac{\mathrm{F}\Delta \mathrm{x}}{\mathrm{L}\Delta \mathrm{x}} = \frac{F}{L}$$

Hence, recognizing surface energy and surface tension are semantics,

$$\text{Surface Tension} = \mathrm{T} = \frac{F}{L}$$

When mathematically representing how surface tension manifests itself as a force a factor of (1/2) is used as the film has two sides that has surface tension

$$\mathrm{T} = \frac{F}{2L}$$

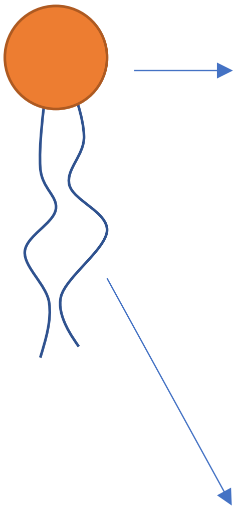
1.2.4 Surface Tension of Water

In this extend essay -since it is the liquid humans encounter the most in their daily lives- the effect on specifically water as a liquid is examined. After mercury, water is the liquid with highest surface tension. The main reason for this is the strong hydrogen bonds between water molecules. These strong bonds are formed because in water molecules oxygen, with its high electronegativity, will cause a dipole in the molecules which results in electrostatic attractions between these molecules. As it is explained in “Causes For surface Tension” the attraction between the liquid surface molecules is the driving factor of surface tension, because of this, the higher the attraction between molecules, the stronger the surface tension will be.

1.2.5 Surfactants

In this extend essay, the effect of a surfactant on surface tension is investigated. The term surfactant comes from the word surface active agent. Surfactant is a substance which tends to reduce the surface tension of a liquid in which it is dissolved. Such compounds can lower the surface tension between two liquids, a gas and a liquid or a solid and liquid.

1.2.5.1 Basic Structure and Behavior of Surfactants



Hydrophilic head shows an affinity to water. This group is water soluble. Surfactants are generally classified based on their polar (hydrophilic) head as hydrophobic tails are often similar. This group gives the molecule its ionic charge.

Hydrophobic group -an alkyl chain with 8 to 22 carbons - doesn’t show affinity to water. This group is water insoluble. The hydrophobic tail is a hydrocarbon, fluorocarbon or siloxane.

As it contains both hydrophobic and hydrophilic groups -two opposing functions- a surfactant is amphiphilic.

Figure 6: Illustration of the very basic structure of a surfactant molecule.

The hydrophilic group is strongly attracted to water, on the other hand, hydrophobic tail points towards the gaseous phase. As a result of this amphiphilic nature, the surfactant molecule tends to form strong interactions with both phases. Because of this behavior, surfactants adsorb -adhesion of atoms ions or molecules from a gas, liquid or dissolved solid to a surface- at interfaces.

1.2.5.2 Basic Effect of Surfactants on Surface Tension

As noted in the previous section, because of their amphiphilic nature, surfactants align themselves such that their hydrophilic group is in the air and the hydrophobic head is in the water.

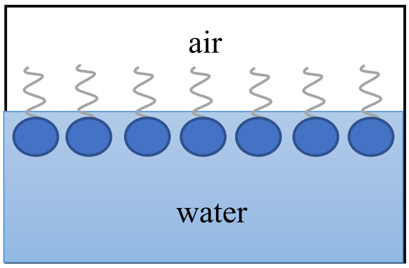


Figure 7: Illustration of alignment of surfactant molecules on the surface

As surfactants adsorb in surface like it is illustrated in *Figure 7,* their hydrophilic heads form new bonds with the water molecules located in the surface. When doing so, they break the strong hydrogen bonds between the water molecules. When such binding with surfactants occurs at the surface, the surface tension decreases due to fact that the intermolecular forces between surfactant and water molecule are much lower than between two water molecules.

1.2.5.3 Washing Powder

Washing powders are an example of surfactants. They contain mostly non-ionic or anionic surfactants, which are responsible for most of the cleaning performance in laundry detergent (by decreasing surface tension they increase wetting). In this study Persil© Washing Powder is used.

2.0Hypothesis

When the concentration of Persil© Washing Powder dissolved in distilled water increases, the surface tension of the solution will decrease linearly as the surfactants in the washing powder will adsorb in surface breaking the strong hydrogen between the water molecules. However, after a certain concentration, the solution will become saturated and thus, the surface tension will remain the same when the concentration is further increased.

3.0 The Experiment

Two methods are going to be used to investigate the concentration of dissolved surfactant on the surface tension of its solvent. **For both experiments, uncertainty calculations are shown in appendix.**

3.1 1st Method: An adaptation of Du Noüy Ring Method

Du Noüy ring method is historically considered as a reliable way of measuring surface tension. In the traditional method, by using a precise balance, the maximum pull exerted on a ring by the surface is measured. This usage of a precise balance is accurate, since surface tension is a very small force or energy: a direct measurement such as a measurement using a spring scale would be unwise because as these scales are not precise enough, and such measurements regarding small forces are prone to human error even like the shaking of hand, the accuracy of the results may be hampered. The adaptation is that in this experiment instead of a ring, the structure in Figure 9 is used to better illustrate the concept described in "Mathematical Consideration of Surface Tension".

3.1.1 Variables

Dependent Variable: The force exerted on the wire end due to surface tension to determine Surface tension of the solution

Independent Variable: Concentration of Persil © Washing Powder dissolved in distilled water.

Control Variables:

Table 1: Table Showing the control variables, why these variables are controlled and the method and management to control these variables.

Control Variable	Why the Variable is Controlled	Method of Management and Measurement
Heat of the Solution	The Eötvös Ramsay Shields rule states that with increasing temperature, the surface tension decreases.	In all trials, the solutions are heated up to the same temperature by using a water bath that is fixed to 50°. The temperature was double checked with an alcohol thermometer.
Washing Powder Used	Different washing powders include different types of surfactants, and they also include a variety of diverge impurities, which influence surface tension, beside surfactants.	Same brand and type of washing powder is used in all trials. The type used is Persil © Washing Powder
Type of Liquid Used	Different liquid has different water tensions as they have different covalent natures	Distilled water is used in all trials.

3.1.2Apparatus:

Table 2: Materials needed for the first method

Material	Size / Volume	Quantity
Measuring cylinder	100 ml	1
Distilled Water	400 ml	-
Beaker	200 ml	1
Persil © Washing Powder		-
Electrical Water Bath	-	1
Thermometer	-	1
Electrical Balance	-	1
Glass Stirring Rod	-	1
Scissors	-	1

Plastic Straw	20 cm	1
Equal Arm Balance	-	1
Wire	Diameter= 1 mm, Length = 20 cm	1

3.1.3 The Experiment Setup

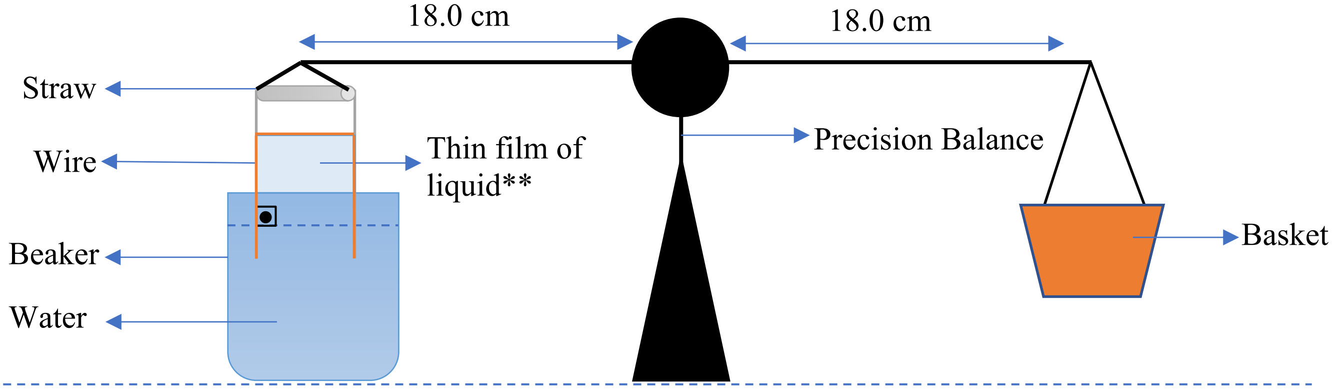


Figure 8: Illustration of the experiment setup: The illustration is not drawn to scale.

The uncertainty of each measurement is ±0.05 cm
*See The Wire for the examination of the wire segment
***See Mathematical Consideration of Surface Tension for the formation of thin film of liquid*

3.1.4 The Wire

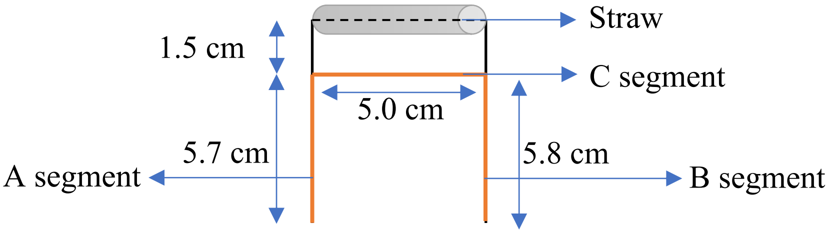


Figure 9: Illustration of the shape and dimensions of the wire component of the experiment setup: The illustration is not drawn to scale. The uncertainty of each measurement is ±0.01 cm

When the wire structure is lifted up, due to adhesive forces, a water film was formed between the main body of water and the 3 segments of wire component -marked with orange color in Figure 9 like it is illustrated in ”Mathematical Consideration of Surface Tension”. These 3 segments correspond to the 3 fixed sides in Figure 5. As explained in “Mathematical

Consideration of Surface Tension", surface tension exerts a force to all these three segments; however, it is important that when considering the net vertical force, only the force exerted by the water onto the C segment is measured to calculate surface tension since, the forces acting on the other segments are completely horizontal and doesn't contribute to the net vertical force.

A crucial component of the wire structure is the straw which enables the wire structure to turn freely where it is attached to the balance. As a result, the A and B segment are always perpendicular to the surface of the main body of water. This is significant because it enables the force exerted onto the C segment to be equal to the net vertical force exerted by surface tension. If the angle wasn't 90° then force exerted onto the C segment will also have a horizontal component and thus, it wouldn't be equal to the net vertical force exerted by surface tension.

3.1.5 Procedure

1. Using the electric balance measure the mass of the wire structure.
2. Using plier and the 1 mm thick wire, prepare the wire structure.
3. Cut the straw to the length of five centimeters. Then fit the prepared straw to the very top edge of the wire structure prepared in step 2 -as shown in figure 9.
4. Prepare the balance as shown in figure 9, attaching the wire structure and the basket.
5. Using the measuring cylinder, pour 80 ml of distilled water to a beaker.
6. Fill half of an electrical water bath with tap water and set it to 50°C. Double check the temperature using a thermometer once the water bath has reached the desired temperature.
7. Put the beaker with 80 ml of distilled water into the water bath. Wait for 600 seconds than remove the beaker from the water bath using a pair of heat resistant gloves. The

water is heated to enable the desired masses of washing powder completely dissolve in it.

8. Put the beaker with 50°C water under the wire component and add rice -as weight- to the basket until the wire lifts up the surface of the main body of water.
9. Using the electrical balance, measure the mass of the rice.
10. To set the temperature of water back at 50°C, put the beaker with distilled water back into the water bath, wait for 600 seconds and remove it using a pair of heat resistant gloves.
11. Place a weighing boat on a top-pan balance and press the 'tare' button. Measure 0.03grams of Persil © Washing Powder by adding it onto the weighing boat using a spatula. After that, add the 0.03grams of Persil © Washing Powder into the beaker and stir it with the glass stirring rod to dissolve the powder.
12. Measure the mass of rice following the steps 5 and 6
13. Repeat the steps 7 to 9, 4 more times to obtain 6 samples with increasing Persil © Washing Powder concentrations.
14. Repeat Steps 1 to 10 to have 5 trials for each sample

3.1.6 Raw Data

Table 3: Raw Data table for the 1st method: Mass of washing powder added vs mass of wire end and mass of rice end.

Sample Number	**Mass of powder added (±0.01g)**	**Mass of Wire End (±0.01g)**					**Mass of Rice End (±0.01g)**				
		Trial1	Tiral2	Trial3	Trial4	Trial5	Trial1	Trail2	Trial3	Trial4	Trial5
1	0	3.80	3.76	3.64	3.68	3.72	4.27	4.17	4.19	4.21	4.11

2	0	3.72	3.79	3.63	3.70	3.71	4.04	4.06	4.00	4.17	4.03
3	0.03	3.67	3.63	3.81	3.77	3.72	3.85	3.87	3.93	4.02	4.06
4	0.03	3.78	3.72	3.66	3.64	3.80	3.83	3.88	3.99	3.89	3.91
5	0.03	3.64	3.80	3.74	3.70	3.72	3.73	3.88	3.75	3.72	3.74
6	0.03	3.60	3.75	3.85	3.70	3.71	3.61	3.75	3.84	3.71	3.71
7	0.03	3.69	3.83	3.73	3.68	3.58	3.69	3.83	3.73	3.68	3.59
8	0.03	3.65	3.71	3.72	3.79	3.72	3.66	3.72	3.73	3.80	3.73
9	0.03	3.70	3.64	3.76	3.82	3.73	3.72	3.64	3.77	3.83	3.74

3.1.7 Processed Data

Calculating the Mass of Persil © Washing Powder in each trial.

Mass of Persil © Washing Powder in each trial = (sample number -1) x 0.03

Example Calculation (Sample 2):

Mass of Persil © Washing Powder in each trial = (2 - 1) x 0.03 = **0.06 g**

Calculating the Concentration of Persil © Washing Powder in each trial.

Concentration of Persil © Washing Powder in each trial = $\frac{mass\ of\ washing\ powder}{volume\ of\ distilled\ solution}$

Example Calculation (Sample 2):

Concentration of Persil © Washing Powder = $\frac{0.03}{80}$ = 0.4 mg/ml

Calculating the average mass of the wire end and average mass of the rice end

Average mass of wire end = $\frac{trial1+trial2+trial3+trial4+trial5}{number\ of\ trials}$

Average mass of rice end = $\frac{trial1+trial2+trial3+trial4+trial5}{number\ of\ trials}$

Example Calculation (sample 2):

Average mass of wire end = $\frac{3.72+3.72+3.72+3.72+3.72}{5} = 3.72$

Average mass of Rice end $= \frac{3.95+3.95+3.93+3.94+3.98}{5} = 3.95$

Table 4: Processed data table for concentration of Persil © Washing Powder, the average mass of the wire end and the average mass of the rice end.

Sample Number	**Concentration of Persil © Washing Powder**	**The average mass of the wire end**	**The average mass of the rice end**
1	0.0	3.72 ± 0.08	4.19 ± 0.08
2	0.4 ± 0.02	3.71 ± 0.08	4.06 ± 0.09
3	0.8 ± 0.03	3.72 ± 0.09	3.95 ± 0.1
4	1.1 ± 0.04	3.72 ± 0.08	3.90 ± 0.08
5	1.5 ± 0.06	3.72 ± 0.08	3.76 ± 0.08
6	1.9 ± 0.08	3.72 ± 0.13	3.72 ± 0.12
7	2.3 ± 0.09	3.70 ± 0.13	3.70 ± 0.12
8	2.6 ± 0.1	3.72 ± 0.08	3.73 ± 0.08
9	3.0 ± 0.1	3.73 ± 0.09	3.74 ± 0.09

Calculating Surface Tension

Method of Calculation

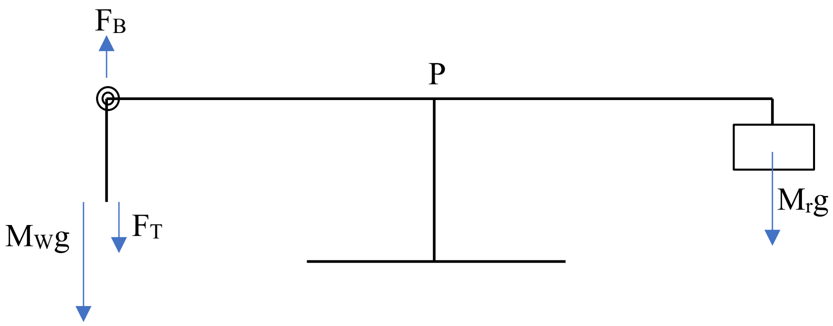


Figure 10: Illustration of forcing acting on precision balance

Definition of Symbols:

g: gravitational constant

M_R: Mass of the basket

M_W: Mass of the wire structure

F_T: Surface Tension Force

F_B: Buoyant force

For the precision balance to be in equilibrium, the net torque on point P resulted from the wire and the mass ends must be zero. Since the lengths of lever arms for both the wire and the rice end is equal as shown in Figure 8 the lengths of the levers cancel out. The mass of water lifted with the wire system is neglected.

Hence,

$$F_T + M_W g = F_B + M_R g$$

Isolating the surface tension force,

$$F_T = F_B + M_R g - M_W g$$

Buoyance is the tendency of a body to float or to rise when submerged in fluid, and it can be calculated by determining the weight of water displaced when the object is submerged. It is assumed that A segment and B segment of the wire structure that are shown in Figure 9 are fully submerged until the wire lifts up the surface of the water

Therefore, we can use the two equations *Mass = Density x Volume* and *Weight = Mass x gravitational acceleration* to rewrite the equation above

Hence,

$$F_T = \rho g V + M_R g - M_W g \Rightarrow F_T = g(\rho V + M_R - M_W)$$

Where V is the total volume of submerged wire and ρ is the density of the solution. When calculating the volume of submerged wire, segment A and Segment B are both assumed to be perfect cylinders Therefore the sum of the volumes of Segment A and Segment B is,

$$V = \pi r^2 h_1 + \pi r^2 h_2 \Rightarrow V = \pi r^2 (h_1 + h_2)$$

Where h_1 is the length of segment A, h_2 is length of segment B, and r is the volume of the wire.

As a result, the equation can be rewritten as,

$$F_T = g(\rho\pi r^2(h_1 + h_2) + M_R - M_W)$$

In “Background information,” formula below is derived,

$$T = \frac{F}{2L}$$

Putting these two equations together, the surface tension can be calculated as

$$T = \frac{g(\rho\pi r^2(h1 + h2) + M_R - M_W)}{2L}$$

Example Calculation (Sample1)

$$T = \frac{9.8(10^3 * \pi * 0.001^2 * (0.057 + 0.058) + 0.00419 - 0.00372)}{2 * 0.05}$$

T = 0.0579 N/m

Table 5: Processed Data table for the 1st method. Concentration of Persil © and surface tension

Sample Number	Concentration of Persil © Washing Powder	Surface Tension N/m
1	0.00	0.0815 ± 0.002
2	0.04 ± 0.02	0.0697 ± 0.002
3	0.8 ± 0.03	0.0579 ± 0.002
4	1.1 ± 0.04	0.0530 ± 0.002
5	1.5 ± 0.06	0.0393 ± 0.002
6	1.9 ± 0.08	0.0354 ± 0.003
7	2.3 ± 0.09	0.0354 ± 0.003
8	2.6 ± 0.1	0.0364 ± 0.002
9	3.0 ±0.1	0.0364 ± 0.002

3.2 2nd Method: Capillary Rise Method

Capillarity is the tendency of a liquid in a capillary tube or absorbent material to rise because of surface tension. This effect of capillarity is resulted due to adhesion - the force of adhesion is defined as the force of attraction between different substances, such as glass and water- and cohesive forces between the surface molecules of the liquid. In the example of a thin tube the attraction between the liquid molecules and the molecules of the wall of the tube -adhesion force- causes the liquid to be drawn up the sides of the tube against gravity. As result a meniscus– a concave surface of a liquid- is formed. The attractive or cohesive forces between liquid molecules -discussed in “causes of water tension”- then minimizes the distance between liquid molecules by drawing up the bottom of the meniscus against gravity. As a result, this effect of surface tension overall, results the rise of the liquid, eventually creating the effect of capillarity. The liquid rises until the upward force caused by surface tension balances the downward force caused by gravity.

3.2.1 Variables

Dependent Variable: Maximum height reached by solution in capillary tubes to determine Surface tension of the solution

Independent Variable: Concentration of washing powder

Control Variables:

Table 6: Table Showing the control variables, why these variables are controlled and the method and management to control these variables.

Control Variable	**Why the Variable is Controlled**	**Method of Management and Measurement**
Heat of the Solution	The Eötvös Ramsay Shields rule states that with increasing temperature, the surface tension decreases.	In all trials, the solutions are heated up to the same temperature by using a water bath that is fixed to 50°. The temperature was double checked with an alcohol thermometer.
Washing Powder Used	Different washing powders include different types of surfactants, and they also	Same brand and type of washing powder is used in

	include a variety of diverge impurities, which influence surface tension, beside surfactants.	all trials. The type used is Persil © Washing Powder
Type of Liquid Used	Different liquid has different water tensions as they have different covalent features	Distilled water is used in all trials.

3.2.2 Deriving the formula regarding the relation between surface tension and capillary action

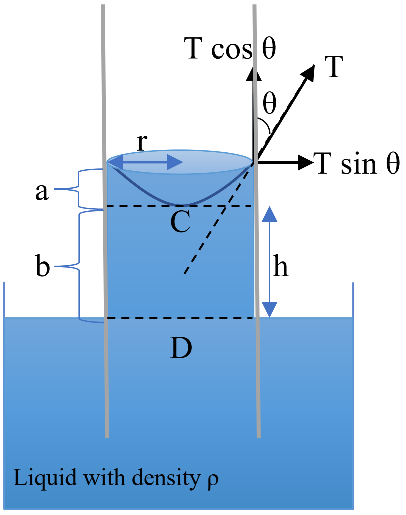


Figure 11: Illustration of capillary rise by surface tension

Definition of Symbols:
T: Surface tension force
θ: Angle of Contact
r: Radius of the tube
h: Height to which the liquid rises
a: volume of liquid above line C
b: Volume of liquid between line C and Line D
ρ: Density of liquid

The surface tension force acts at all points of contact between the liquid and the tube, and it is along the tangent to the surface. As illustrated in figure 8, this force can be broken down into two components -horizontal and vertical. As we are dealing with the upward force that results capillary rise, we can neglect the horizontal component and deal with the vertical component.

$\text{The total upward force} = (T \cos\theta)\ x\ (2\pi r) = 2\pi r T \cos\theta$

Furthermore, the volume of liquid column in the tube is equal to the sum of a and b.

$b = \text{volume of liquid column of radius } r \text{ and heigh } h = \pi r^2 h$

$a = \text{volume of liquid of radius } r \text{ and height } r - \text{Volume of the hemisphere of radius } r\ ^*$

* *the meniscus formed at the surface is assumed to have a perfect semi hemisphere surface*

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

$V = a + b = \pi r2h + [(\pi r^2 x r - (2/3)\pi r^3] = \pi r^2 h + (1/3)\pi r^3$

As stated in “Capillary rise method” the liquid rises until the upward force caused by surface tension balances the downward force caused by gravity. Consequently, the weight of the liquid column is equal to the *Total Upward Force.*

Total Upward Force = weight of liquid = mass of liquid x the gravitational constant

= volume of liquid column x density of liquid x the gravitational constant

$2\pi r T \cos\theta =[\pi r^2 h + (1/3)\pi r^3]\rho g = \pi r2[h + (1/3)r]\rho g$

Isolating T ➔ $T = \frac{r\left(h+\frac{1}{3}\right)\rho g}{2\cos\theta}$

When the capillary tube has a very tiny radius compared to its height like in this experiment, then ${}^{r}/_{3}$ can be neglected.

Therefore,

$$T = \frac{r\rho gh}{2\cos\theta}$$

For pure water and perfectly clean glass, the angle of contact is 0°.[2] Therefore we can assume that θ equals 0°. Correspondingly, the equation becomes,

$$T = \frac{r\rho gh}{2\cos 0}$$

Since cos0 = 1,

$$T = \frac{r\rho gh}{2}$$

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[2] “What Is Angle of Contact ?” *QuantumStudy*, 5 May 2021, https://www.quantumstudy.com/chemistry/liquid-solutions-13/.

3.2.3 Apparatus

Table 7: Materials needed for Capillary Rise Method

Material	**Size / Volume**	**Quantity**
Glass Capillary Tube	Radius = 0.1mm, Length = 170 mm	5
Measuring cylinder	100 ml	1
Distilled Water	400 ml	-
Beaker	200 ml	1
Black Ink	1ml	-
White Hardboard	Length 30 cm, Width 30 cm	1
Persil © Washing Powder		-
Ruler	30 cm	1
Electrical Water Bath	-	1
Thermometer	-	1
Electrical Balance	-	1
Glass Stirring Rod	-	1
Tape	40 cm	1
Scissors	-	1
Bubble Level	-	1
Wooden Stick	15cm	1
Pasteur Pipette	-	1
Heat Resistant Gloves	-	1

3.2.4 Experimental Setup

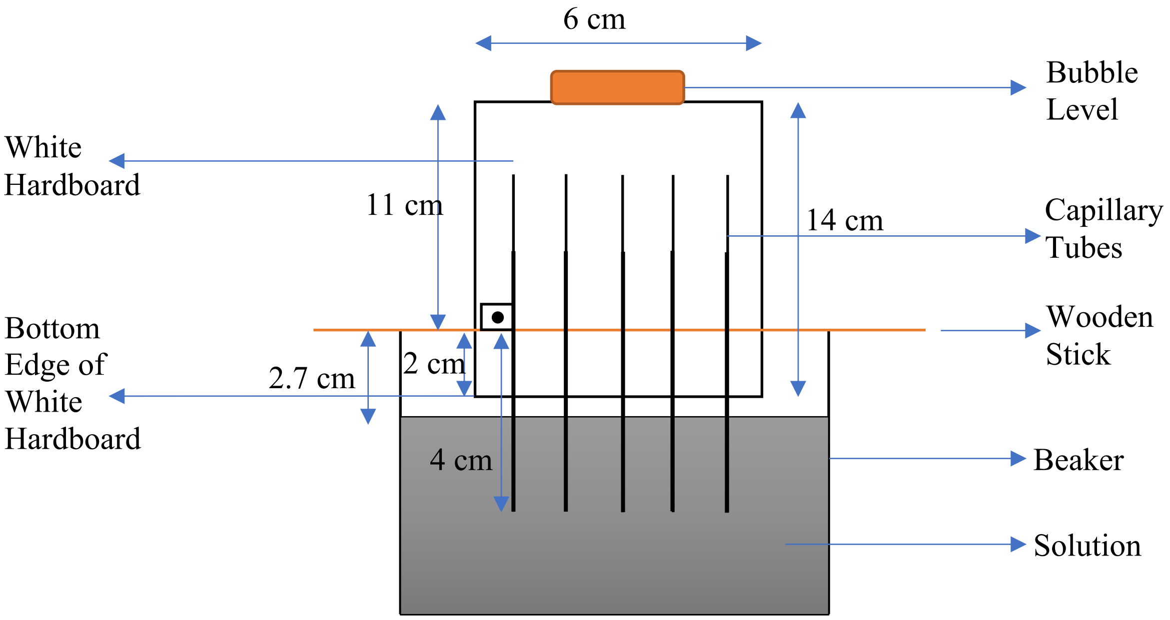


Figure 12: Illustration of the experimental setup. The illustration is not drawn to scale. The uncertainty of each measurement is ±0.05 cm

3.2.5 Procedure

1. Using the measuring cylinder, pour 80 ml of distilled water to a beaker. Using the Pasteur pipette add 1 drop of black ink into the water then stir it with the glass stirring rod to create contrast with the white hardboard and make the measurements easier in further steps.
2. Fill half of an electrical water bath with tap water and set it to 50°C. Double check the temperature using a thermometer once the water bath has reached the desired temperature.
3. Put the beaker with 80 ml of distilled water into the water bath. Wait for 600 seconds than remove the beaker from the water bath using a pair of heat resistant gloves. The water is heated to enable the desired masses of washing powder completely dissolve in it.

4. Using the scissor, cut the whiteboard with a length of 14 cm and a width of 6 cm to form the rectangle whiteboard. Measure and doublecheck the length of the sides using the ruler.
5. Use tape to attach the wooden stick to the white hardboard. Make sure that it is parallel to 6 cm edges of the white hardboard, and it is 3cm higher than the bottom edge as shown in the Figure 9.
6. Use the tape to attach 5 clean and dry glass capillary tube to the whiteboard. Make sure that they are perpendicular to the wooden stick.
7. Use tape to attach the bubble level on top of the white hardboard.
8. Put the prepared white hardboard with the glass capillary tubes, in the heated beaker as shown in Figure 12. Using the bubble level, make sure that the top edge of the white hardboard is parallel to the surface of the distilled water -to ensure that the glass capillary tubes are perpendicular to the surface of the distilled water.
9. Wait until the liquid reaches its maximum height, then mark the maximum height on the white hardboard using a pencil.
10. Using the ruler, measure the distance from the surface of the liquid in the water, to the maximum height reached in glass capillary tubes.
11. To set the temperature of water back at 50°C, put the beaker with distilled water back into the water bath, wait for 600 seconds and remove it using a pair of heat resistant gloves.
12. Place a weighing boat on a top-pan balance and press the 'tare' button. Measure 0.03grams of Persil © Washing Powder by adding it onto the weighing boat using a spatula. After that, add the 0.03grams of Persil © Washing Powder into the beaker and stir it with the glass stirring rod to dissolve the powder.

13. Measure the maximum height reached in glass capillary tubes following the steps 8 to 10.
14. Repeat the steps 11 to 13 4 more times to obtain 6 samples with increasing Persil © Washing Powder concentrations.
15. Repeat the steps 1 to 14 to have 25 other trails

3.2.6 Raw Data

Table 8: Raw Data Table for the Capillary Rise Method. Mass of powder added to distilled water and the height of maximum height reached by the liquid in the glass capillary tubes

Sample Number	**Mass of powder added (±0.001g)**	**The maximum height reached by the liquid in the glass capillary tubes (±0.05cm)**									
		Setup 1					**Setup 2**				
		Tube1 (Trial1)	**Tube2** (Trial2)	**Tube3** (Trial3)	**Tube4** (Trial4)	**Tube5** (Trial5)	**Tube1** (Trial6)	**Tube2** (Trial7)	**Tube3** (Trial8)	**Tube4** (Trial9)	**Tube5** (Trial10)
1	0	16.33	16.33	16.38	16.40	15.89	16.22	16.27	16.22	16.68	16.21
2	0.03	13.98	13.98	13.22	13.92	13.99	13.80	13.79	13.09	13.78	13.82
3	0.03	11.24	11.43	11.76	11.31	11.46	10.82	11.27	11.19	11.10	11.27
4	0.03	10.63	10.60	10.55	10.52	11.00	10.38	10.42	10.32	9.99	10.54
5	0.03	7.70	7.75	7.88	7.25	7.82	7.54	7.52	8.13	7.45	7.81
6	0.03	6.17	6.18	6.62	6.19	6.20	6.09	6.05	6.10	5.56	6.10
7	0.03	6.70	6.25	6.27	6.25	6.27	6.18	5.74	6.17	6.17	6.18
8	0.03	6.32	6.31	6.95	6.37	6.76	6.30	5.68	5.91	6.30	6.30
9	0.03	6.72	6.24	6.28	6.22	6.29	6.18	6.17	6.17	6.19	5.72

3.2.7 Processed Data

Calculating the Mass of Persil © Washing Powder in each trial.

Mass of Persil © Washing Powder in each trial = (sample number -1) x 0.03

Example Calculation (Sample 2):

Mass of Persil © Washing Powder in each trial = (2 - 1) x 0.03 = **0.06 g**

Calculating the average maximum height reached by the liquid in the glass capillary tubes

Average height = $\frac{trial1+trial2+trial3+trial4+trial5+trial6+trial7+trial7+trial9+trial10}{number\ of\ trials}$

Example Calculation (Sample 2):

Average height = $\frac{11.24 + 11.43+11.36 + 11.31+11.46 + 11.22 + 11.27 + 11.19 + 11.10 + 11.27}{10}$

= 11.29 cm

Table 9: Processed Data table for the Capillary Rise Method. Mass of Persil © Washing Powder in each trial and average maximum height reached by the liquid in the glass capillary tubes

Sample Number	**Mass of Persil © Washing Powder in each trial.**	**Average maximum height reached by the liquid in the glass capillary tubes**
1	0.00	16.29 ± 0.4
2	0.03 ±0.001g	13.74 ± 0.5
3	0.06 ±0.002g	11.29 ± 0.5
4	0.09 ±0.003g	10.50 ± 0.5
5	0.12 ±0.004g	7.69 ± 0.4
6	0.15 ±0.005g	6.14 ± 0.5
7	0.18 ±0.006g	6.22 ± 0.5
8	0.21 ±0.007g	6.32 ± 0.6
9	0.24 ±0.008g	6.22 ± 0.5

Calculating the Concentration of Persil © Washing Powder in each trial.

Concentration of Persil © Washing Powder in each trial = $\frac{mass\ of\ washing\ powder}{volume\ of\ distilled\ solution}$

Example Calculation (Sample 2):

Concentration of Persil © Washing Powder = $\frac{0.03}{80}$ ≈ 0.0004 g/ml ➔ 0.4 mg/ml

Calculating The Surface Tension of the Solution

It has been previously derived that,

$$T = \frac{rh\rho g}{2}$$

The washing powder solution in the experiment shows Tyndall effect thus it is considered as a heterogenous mixture. Because of this, it is not possible to simply calculate the density with increasing washing powder concentration. Accordingly, it is assumed that the density of the solution is 1000 ± 10 kg/m^3 since distilled water has a density of 1g/ml. The uncertainty is used to cover the unknown changes in density when washing powder is added.

Example Calculation (Sample 1):

Surface Tension = $\frac{(0.1*10^{-3})*(13.74*10^{-2})*(1.00*10^{3})*9.8}{2}$ = 0.0673 N/m

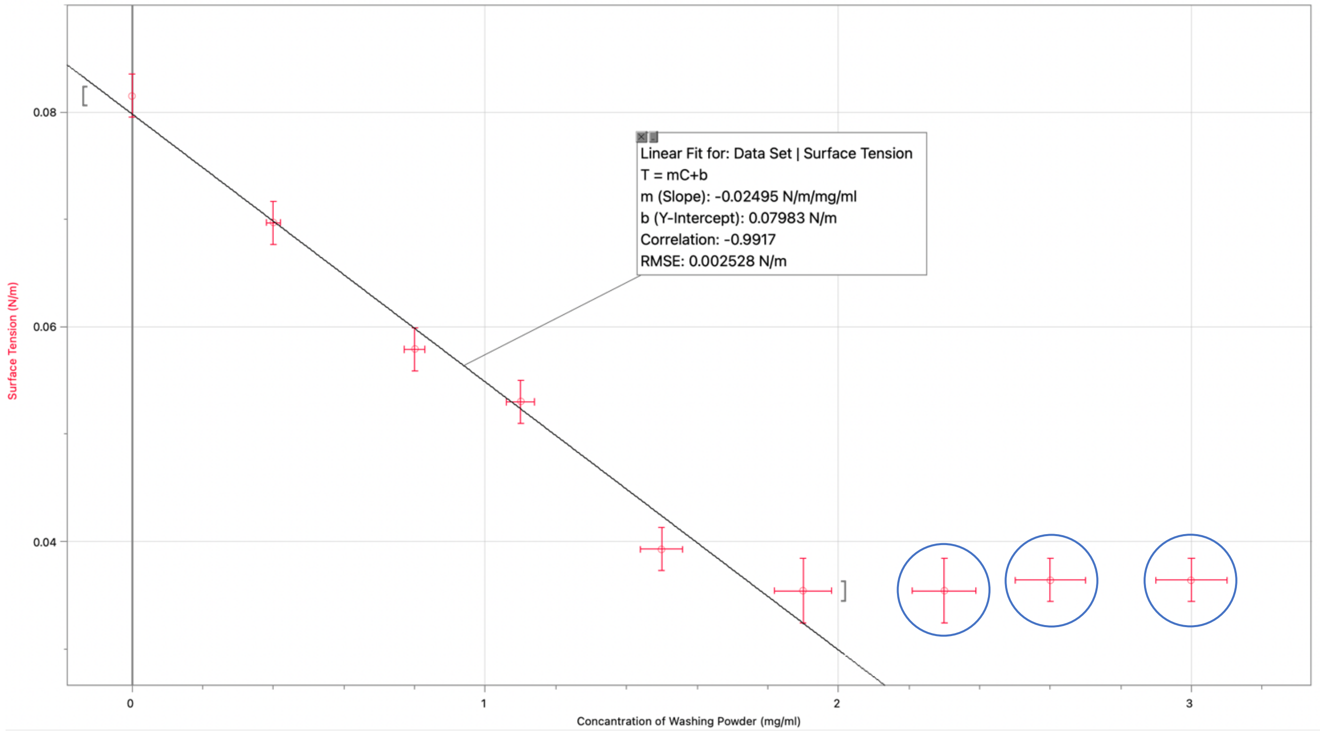
Table 10: Processed Data table for the Capillary Rise Method. Concentration of Persil © Washing Powder and Concentration of Persil © Washing Powder. See appendix for uncertainty calculations

Sample Number	**Concentration of Persil © Washing Powder (mg/ml)**	**Surface Tension (N/m)**
1	0.00	0.0798 ± 0.003
2	0.4 ± 0.02	0.0673 ± 0.003
3	0.8 ± 0.03	0.0553 ± 0.003
4	1.1 ± 0.04	0.0515 ± 0.003
5	1.5 ± 0.06	0.0377 ± 0.002
6	1.9 ± 0.08	0.0301 ± 0.003
7	2.3 ± 0.09	0.0305 ± 0.003
8	2.6 ± 0.1	0.0310 ± 0.003
9	3.0 ± 0.1	0.0305 ± 0.003

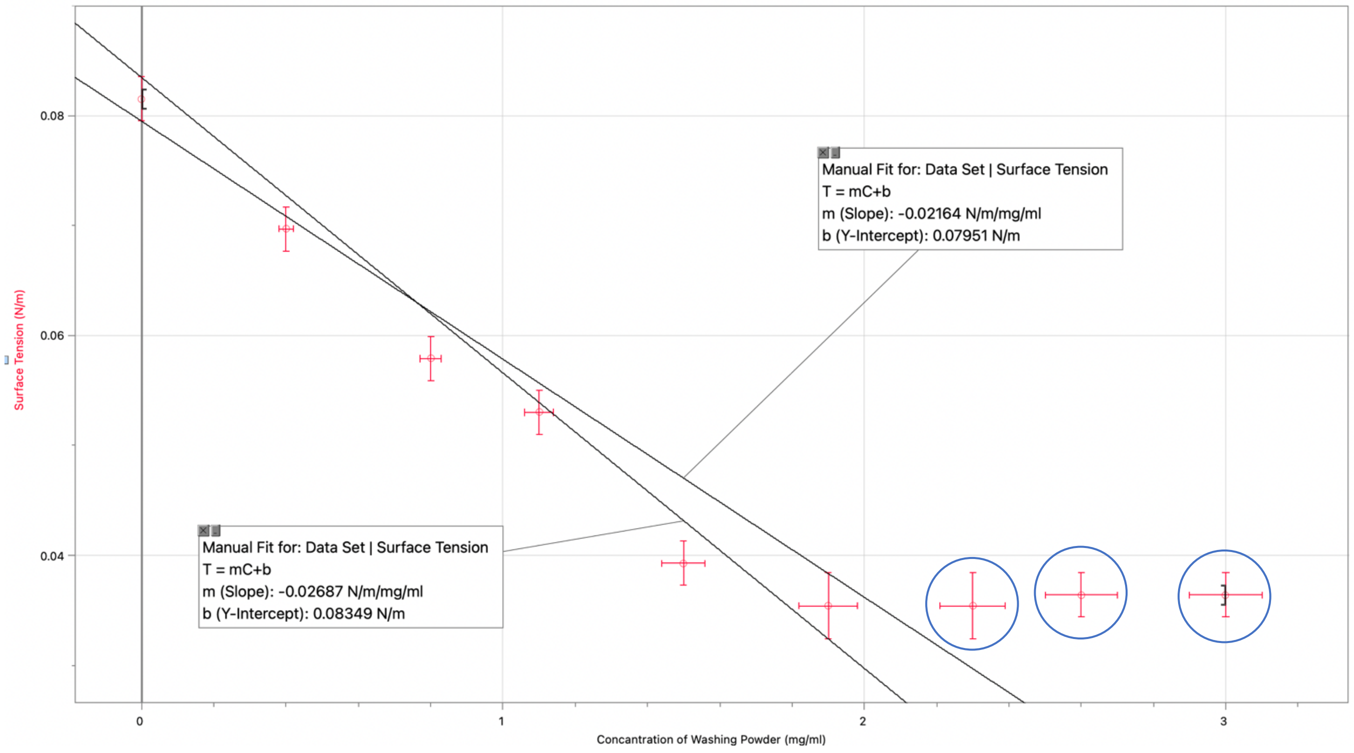
4.0 Data Presentation

In the graphs below, data from the 1st and 2nd method are presented. Lines of best fit and worse fit are drawn **only for the first six samples**. See Conclusion for explanation. Data which are not used when drawing best and worse fit lines are marked with blue circles.

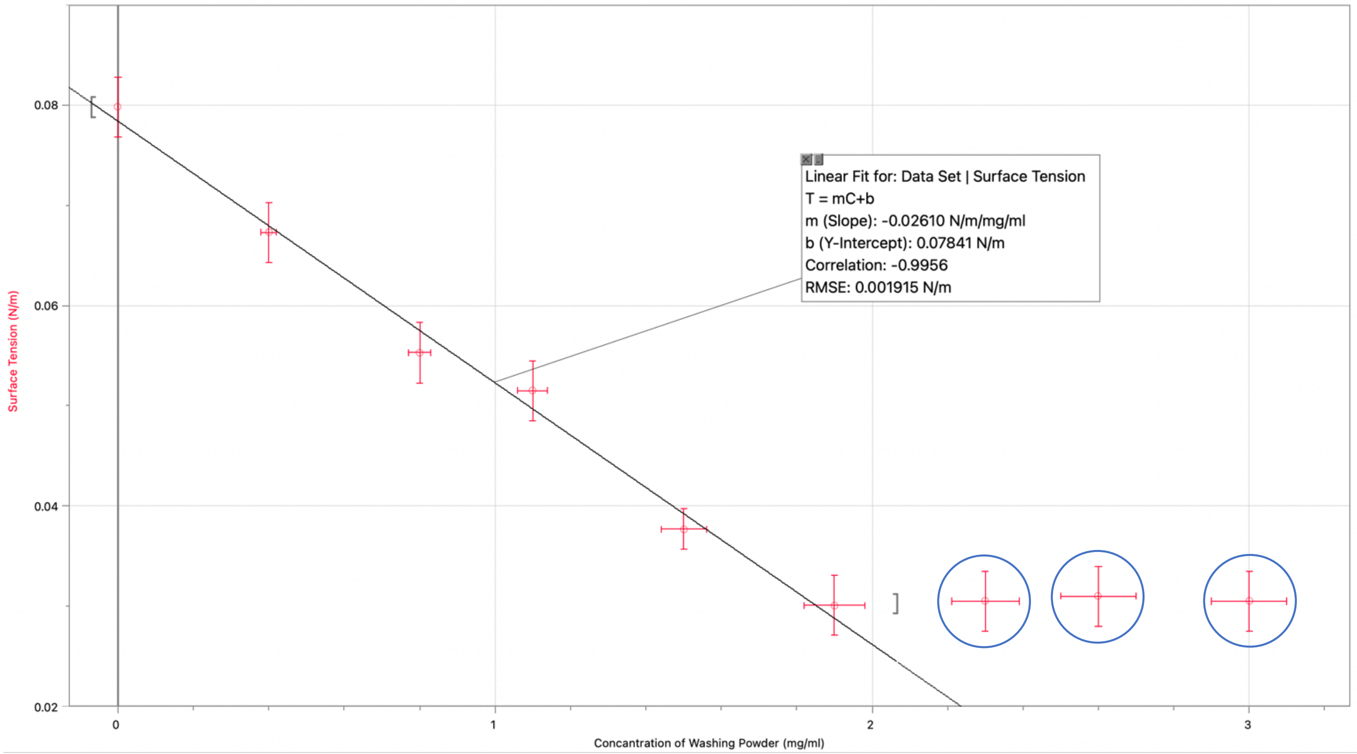
Graph 1: Graph of Data on the effect of surfactants on surface tension measured using the 1st method. It includes the line of best fit for the first six samples.



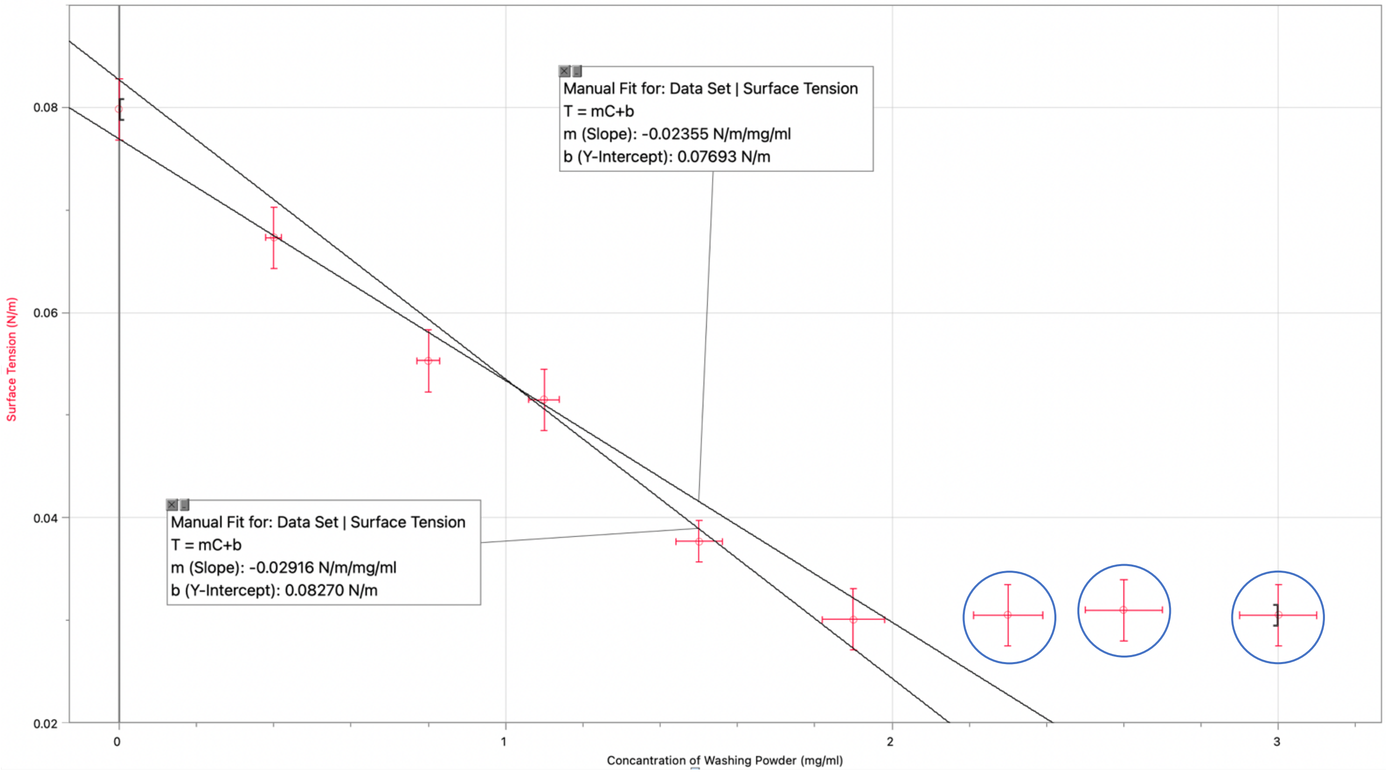
Graph 2: Graph of Data on the effect of surfactants on surface tension measured using 1st method. It includes the lines of worse fit for the first six samples



Graph 3: Graph of Data on the effect of surfactants on surface tension measured using the 2nd method. It includes the line of best fit for the first six samples.



Graph 4: Graph of Data on the effect of surfactants on surface tension measured using the 2nd method. It includes the lines of worse fit for the first six samples.



5.0 Analysis of Graphs

In all the graphs the best fit, and worse fit lines are drawn considering the data for the first six samples. This is because the data follow a linear trend until the 6th sample, however after the 6th sample the solution becomes saturated and the linear function turns into a constant function. This is explained in a more detailed way in conclusion. Accordingly, all analysis below regards the first six samples.

The 1st method has found the relationship between variables can modeled by the following equation of the best fit trend line,

$$T = (-0.02495 \pm 0.003)C + (0.07983 \pm 0.003)$$

The 2nd method has found the relationship between variables can modeled by the following equation of the best fit trend line,

$$T = (-0.02610 \pm 0.003)C + (0.07841 \pm 0.003)$$

Both best fit lines have a correlation value magnitude greater than 0.9 (Graph 1 has correlation value of -09917, Graph 2 has a correlation value of -0.9956) This high correlation shows that there is indeed a strong linear relationship between the variables.

The 1st method has a 12% gradient uncertainty, and the 2nd method has a 10% gradient uncertainty. This shows both experiments have considerable but acceptable random error. On the other hand, the percent difference between the experimental y intercept and the y intercept is considerably small (2 % in both methods) indicating a small systematic error.

6.0 Conclusion

There isn’t a theoretical way of calculating the surface tension of water with different concentrations of surfactants. Because of this, a comparison of theoretical and experimental results wouldn’t be possible to evaluate the accuracy of results. Consequently, in this research, in the absence of theoretical results, two different methods -capillary rise method and an adaptation of Du Noüy Ring Method- were used to strengthen the results. This will allow combination and comparison of data, making the results of the experiments stronger. From Graph 1, it can be determined that the surface tension decreases (0.02495 ± 0.003) N/m for every 1 mg/ml increase in washing powder concentration until saturation and from Graph 3, it can be determined that the surface tension decreases (0.02610 ± 0.003) N/m for every 1 mg/ml increase in washing powder concentration until saturation. After saturation surface tension remains constant in both methods. Consequently, data from both experiments follow the same trend: linear in first 6 samples (showing strong linear correlation with correlation values greater than 0.9), then constant for the 6th 7th, 8th and 9th samples. Besides following the same trend their gradients and y intercepts are remarkably similar with considerably small differences (with a gradient difference of 5% and y intercept difference of 2%), strengthening the results.

When investigating this common trend in both experiments -first linear than constant- consideration of the "Critical Miscelle Concentration" is significant. Below this concentration surface tension decreases linearly as concentration of surfactant increase. Refer to the "Background information" for the explanation of such behavior. Above this concertation, any addition of surfactants doesn't alter the surface tension. Because at this concentration, the interference is fully saturated, thus, an increase in surfactant concentration won't introduce new surfactant molecules that decrease the surface tension by adsorbing at surface, to the interference. Instead, the excess surfactant molecules form clusters called miscellas where the clustered surfactant molecules shield their non-polar chains from surrounding water with their polar head groups.

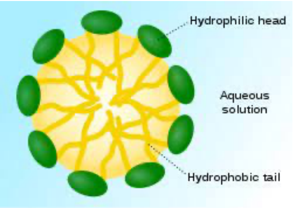


Figure 13: Illustration of a miscelle[3]

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[3] "Surfactant." *Wikipedia*, Wikimedia Foundation, 26 Feb. 2022, https://en.wikipedia.org/wiki/Surfactant.

In this investigation, the aim was to experimentally identify how the concentration of surfactants dissolved in water alter its surface tension. A hypothesis has been made. Using two experimental methods each having a distinctive approaches, I arrived at data -data can be considered strong as data from both methods yield correlating results- that confirms the hypothesis. The experiment confirms the hypothesis which states: until critical miscelle concentration (saturation), as the concentration of surfactants increase, the surface tension decreases following a linear trend.

7.0 Limitations

Table 6: Limitations, significance of the limitations, and improvements to minimize their effects.

Limitations	**Significance**	**Improvement**
After it has been taken out of the water bath, the solution loses heat when the experiment is taking place	According to the Eötvös Ramsey Shields rule, as the temperature increases, surface tension decreases. That is why temperature is a control variable that should be strictly regulated. Changes in temperature will cause error.	$Q = m*c*c*\Delta t$, thus doing the experiment more quickly will reduce the heat loss. Also beakers with heat isolation can be used to minimize temperature difference.
Change in Humidity	Changes in humidity alter intermolecular forces at the air-water interference. With an increase in humidity, the surface tension decreases since water vapor in the air attracts water molecules at the surface of the liquid. Humidity that is uncontrolled will be prone to random changes and thus, it will account for random error altering the surface tension.	Experiment could be undertaken in an isolated environment with controlled humidity.

Change in Air Flow	The balance and the surface of the water move as a result of air movement and vibrations, distrupting the contact between the two and consequently the measurement of the surface tension. Surface tension is measured using the assumption that air acts like an ideal gas, with no intermolecular interactions between air particles and the water.	Experiments could be undertaken where air circulation is controlled
Washing Powder	Washing powder is not pure surfactant. While the in surfactant concentration could decrease the surface tension of water, an increasing concentration of other impurities would increase the surface tension, introducing error.	Pure surfactants instead of Washing powder can be used

8.0 Extension

Further experiments regarding the effect of temperature on surface tension can be investigated. The Eötvös Ramsay Shields rule state a correlation between temperature and surface tension. With an experimental approach, theoratical and experimental results can be compared.

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10.0 Appendix

Uncertainty Calculation for the Concentration of Persil © Washing Powder for both methods:

Absolute Uncertainty of Mass of Persil © Washing Powder in each trial =

= (Sample number -1) x 0.001

Example Calculation (Table 9, sample 3)

(3 – 1) x 0.01 = **0.0002 g**

Absolute Uncertainty of Concentration of Persil © Washing Powder in each trial =

(F.U uncertainty of washing powder mass+F.U. of solution volume)*concentration of sample

Example Calculation (Table 9, sample 2)

$\left(\frac{0.01}{0.3}+\frac{0.5}{80}\right) x\ 0.4 \approx$ **0.02 mg/ml**

Uncertainty Calculation for Surface Tension for 1st Method

Absolute uncertainty of average mass of the wire end in each sample =

$= \frac{\max mass - \min mass}{2}$

Example Calculation (Table 8, Sample 2)

$\frac{3.80-3.64}{2}$ ≈ **0.8 g**

Absolute uncertainty of average mass of the basket end in each sample =

$= \frac{\max mass - \min mass}{2}$

Example Calculation (Table 8, Sample 2)

$\frac{3.99-3.83}{2}$ ≈ **0.8 g**

Recall the formula used in the 1st method,

$$T = \frac{g(\rho\pi r^2(h_1 + h_2) + M_R - M_W)}{2L}$$

Δ is used as absolute uncertainty in the calculations below i.e., Δx = absolute uncertainty of x,

Fractional Uncertainty of the numerator of the formula used in 1st Method =

$$= \frac{\left(\frac{\Delta\rho}{\rho} + \frac{\Delta h_1 + \Delta h_2}{h_1 + h_2}\right)[\rho\pi r^2(h_1 + h_2)] + \Delta M_g + \Delta M_w}{g(\rho\pi r^2(h_1 + h_2) + M_R - M_W)}$$

Fractional Uncertainty of the Denominator of the equation used in the 1st method =

$$= \frac{\Delta L}{2L}$$

Absolute Uncertainty of Surface Tension in the 1st Method =

(fractional uncertainty of numerator + fractional uncertainty of denominator)*surface tension

$$=\left(\frac{\left(\frac{\Delta\rho}{\rho} + \frac{\Delta h_1 + \Delta h_2}{h_1 + h_2}\right)[\rho\pi r^2(h_1 + h_2)] + \Delta M_g + \Delta M_w}{g(\rho\pi r^2(h_1 + h_2) + M_R - M_W)} + \frac{\Delta L}{2L}\right) x \; \frac{g(\rho\pi r^2(h_1 + h_2) + M_R - M_W)}{2L}$$

<u>Example Calculation (Table 1 Sample 1)</u>

$$\left(\frac{\left(\frac{10}{1000} + \frac{0.0001 + 0.0001}{0.057 + 0.058}\right)[10^3\pi\, 0.001^2(0.057 + 0.058)] + 0.00009 + 0.00008}{9.8(10^3\pi 0.001^2(0.057 + 0.058) + 0.00406 - 0.00371)} + \right.$$

$$\left. \frac{0.0001}{2*0.05}\right) x \; \frac{9.8(10^3\pi 0.001^2(0.057 + 0.058) + 0.00406 - 0.00371)}{2*(0.05)} \approx \mathbf{0.002\ N/m}$$

Uncertainty Calculation for Surface Tension for the 2nd Method

Absolute uncertainty of average maximum height reached by the liquid in the glass tubes =

$$= \frac{\max height - \min height}{2}$$

<u>Example Calculation (Table 8, Sample 2)</u>

$$\frac{13.99 - 13.09}{2} \approx \mathbf{0.5\ cm}$$

Absolute uncertainty of surface tension for each trail =

= (F.U uncertainty of maximum height reached+F.U. of density of solution)*surface tension

Example Calculation (Table 8, Sample 2)

$\left(\frac{0.5}{13.74}+\frac{10}{1000}\right) x\ 0.0673 \approx \mathbf{0.003}$ **N/m**

Calculations for Graphical Analysis

Absolute Uncertainty in Gradient = $\frac{\max gradient\ -\min gradient}{2}$

Example Calculation (graph 2):

$\frac{0.02916-0.02355}{2}$ ≈ **0.003 N/m/mg/ml**

Percentage Uncertainty in Gradient = $\frac{Absolute\ uncerainty\ of\ Gradient}{Gradient\ of\ the\ Best\ fit}$ x 100

Example Calculation (graph 2):

$\frac{0.003}{0.0249}$ x 100 ≈ **12%**

Absolute Uncertainty of y Intercept = $\frac{y\ intercept\ of\ the\ steepest\ line - y\ intercept\ of\ \text{shallowest}\ line}{2}$

Example Calculation (graph 4)

$\frac{0.08270-0.07693}{2}$ ≈ 0.003 N/m

Percentage Uncertainty of y intercept = $\frac{\text{Absolute uncertainty of y intercept}}{y\ intercept\ of\ best\ fit}\ x\ 100$

Example Calculation (graph 4)

$\frac{0.003}{0.07841}$ x 100 ≈ **4 %**

Percent difference in gradients of best fits for the 1st method and 2nd method =

= $\frac{gradient\ of\ best\ fit\ of\ 2nd\ method - gradient\ of\ best\ fit\ of\ 1st\ method}{gradient\ of\ best\ fit\ of\ 2nd\ method}\ x\ 100$

Example Calculation

$$\frac{0.02610-0.02495}{0.02610}\ x\ 100 \approx \mathbf{5\ \%}$$

Percent difference between y intercepts of the best fits for the 1st method and 2nd method =

$$\frac{y\ intercept\ of\ best\ fit\ of\ 1st\ method - y\ intercept\ of\ 2nd\ method}{gradient\ of\ best\ fit\ of\ 1st\ method}\ x\ 100$$

$$\frac{0.07983 - 0.07841}{0.07983}\ x\ 100\ \approx \mathbf{2\ \%}$$

Percent difference between the experimental y intercept, and y intercept of best fit for the 1st method =

$$\frac{experimental\ y\ intercept - best\ fit\ intercept}{best\ fit\ intercept}\ \text{x100}$$

Example Calculation

$$\frac{0.0815-0.07983}{0.07983}\ x\ 100\ \approx \mathbf{2\%}$$

Percent difference between the experimental y intercept, and y intercept of best fit for the 2nd method =

$$\frac{experimental\ y\ intercept - best\ fit\ intercept}{best\ fit\ intercept}\ \text{x100}$$

Example Calculation

$$\frac{0.0798-0.07841}{0.07841}\ x\ 100 \approx \mathbf{2\%}$$