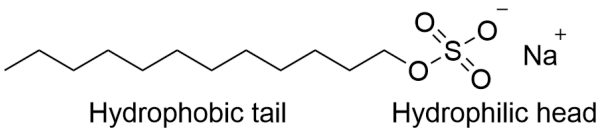
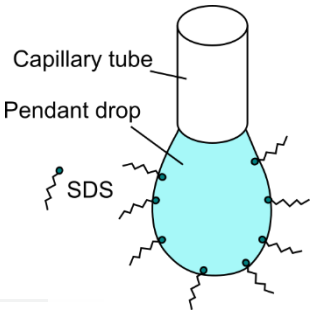
Pendant Drop Tensiometry of SDS in Water to Estimate the Critical Micellular Concentration.

Abstract





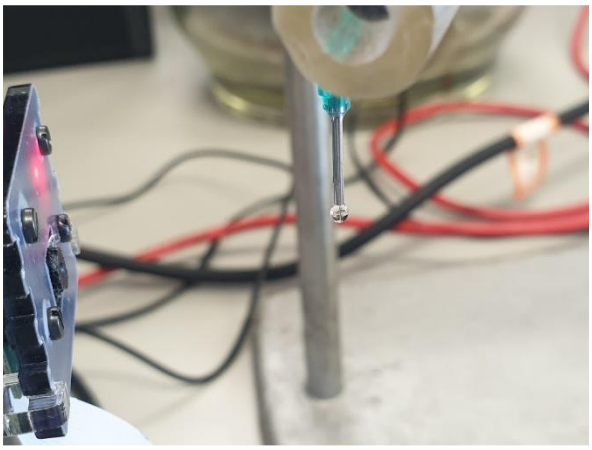
The critical micellular concentration (CMC) for the surfactant sodium dodecyl sulphate in water was determined to be 6.73 ± 5.30 mM. This utilized pedant drop tensiometry. Droplets with varying SDS concentrations were extruded from a capillary tube and photographed for later analysis. The shape of a droplet depends on its surface tension, which can be extracted and used to determine the CMC, where the surface of the droplet is saturated with SDS, causing micelles to form.

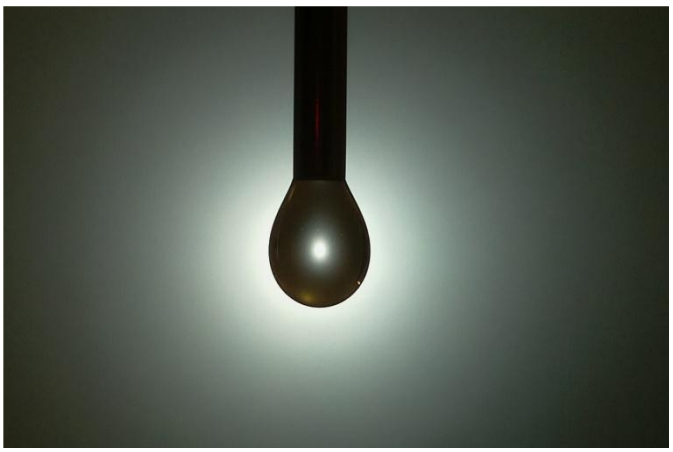
Introduction and theoretical background

Surface tension is force per unit length at a liquid-vapour interface. It is indicative of the strength of the intermolecular bonding within the liquid, as well as the strength of interaction between the two fluids.
The surface tension of a fluid interface can be altered using a surfactant. This occurs because it is unfavourable for the hydrophobic part of the surfactant to be solvated in water. This leads to the surfactant adsorbing at the surface of the water, with the hydrophobic tail sticking into the air. This disrupts the intermolecular bonding between water molecules at the surface, thus reducing the surface tension.

At the CMC the surface of the water is saturated by the surfactant. The next most favourable configuration is the formation of micelles, with the hydrophobic tails sticking inwards, mutually separated from the water. At this point, the interface is saturated therefore there will be no change in surface tension. By plotting surface tension against log([SDS]) the CMC can be determined from the point where the graph plateaus.

Pendant drop tensiometry can be used to determine the surface tension of a liquid in air from the capillary length of the droplet[1] using this equation $\gamma = \Delta\rho g l^2$ .The capillary length is determined by using a droplet analyser plugin for imageJ[2].





The picture in figure 1 was taken in a lit room. The bright light shining behind the droplet causes the camera to significantly decrease its ISO (percieved brightness). This means that the droplet and capillery tube appear black

despite reflecting light from a lit room. The bright spot in the middle of the droplet is because light passing at a close to the normal to both the camera and the droplet isn't internally reflected, see figure 3.

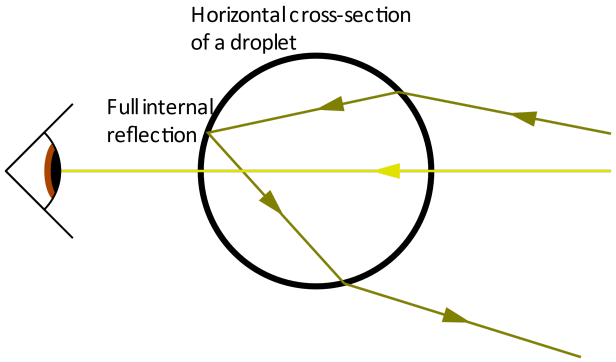


Figure 3 Path of light through droplet, light behind the droplet only passes through the middle.

Aims and objectives

The aim of the experiment was to produce in focus, high contrast images of droplets extruded form capillary tubes, ideal for edge detection in the software imageJ[2], with the aim of determining the surface tension of each droplet using a pendant drop analyser plugin to determine the CMC of SDS in water in air.

Experimental methods

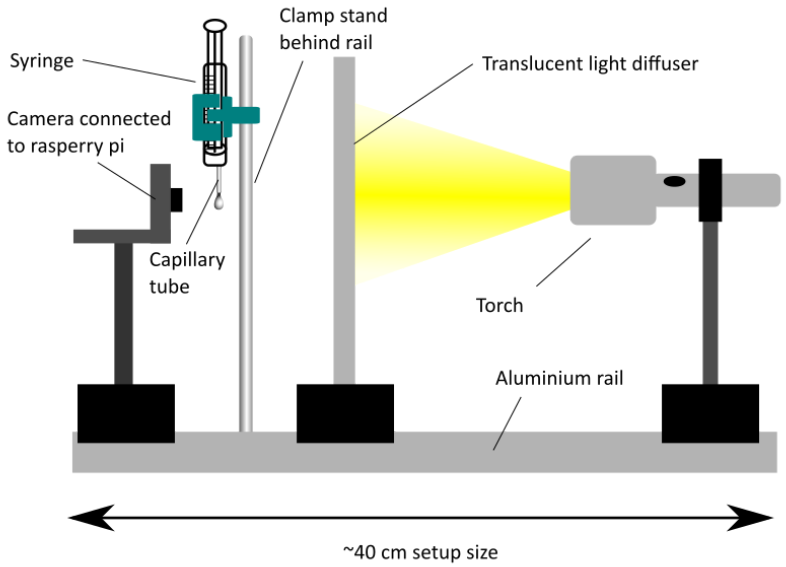


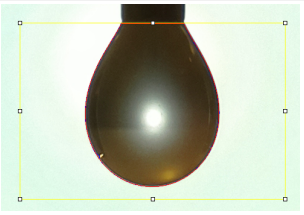
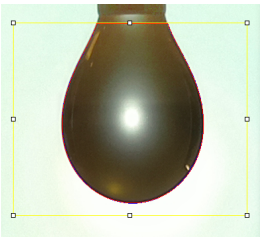
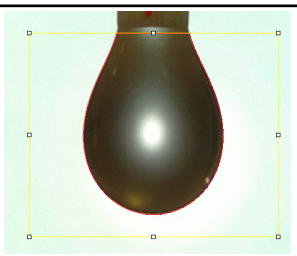
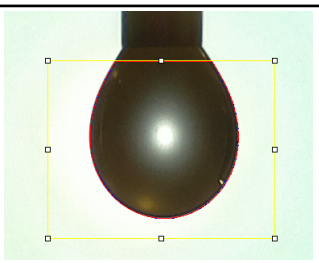
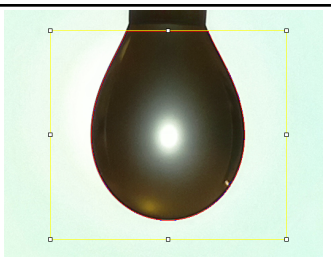
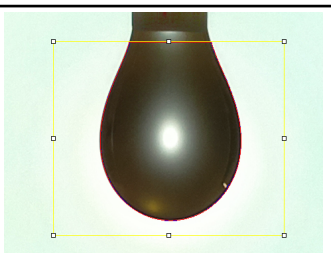
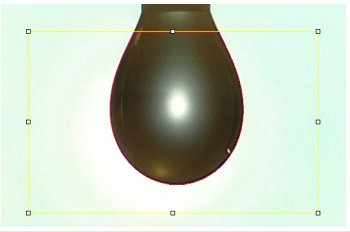
Figure 4: Apparatus

For each image taken, the capillary tube was positioned so that it was in the centre of the image, in focus, ~5cm away from the camera and in the centre of the bright spot on the light diffuser. The torch could be repositioned to centre the bright spot, and to increase its diffuseness.

Procedure:

9 different concentrations of SDS in water were prepared: 1, 2, 3, 4, 6, 8, 10, 15, 20 mM. Before being drawn into a syringe with a capillary tube mounted on the end, each solution was shaken to ensure the SDS remained fully dissolve. ~3 mL of solution would be drawn into a clean syringe which was then mounted in the clamp stand depicted in figure 4. The capillary tube was dried on the outside with tissue to prevent the droplet climbing the tube. A droplet would be extruded by applying light pressure on the plunger. The droplet would be left until it stopped shaking: 10-20 s. An image would be taken using the camera. The droplet would then be wiped off, and the capillary tube dried, and another droplet extruded. 5 repeat images would be recorded for each solution before unclamping the syringe and drawing a new solution into a new clean syringe.

Results and discussion

SDS concentraton / mM	Droplet parameter fit	Mean surface tension Nm^{-1}
1		50.69
2		45.63
3		36.63
4		39.38
6		40.35
8		35.59
10		36.79

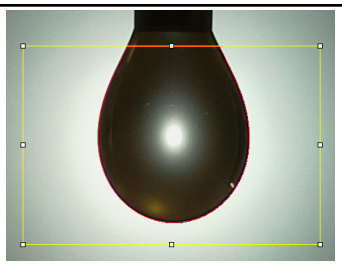
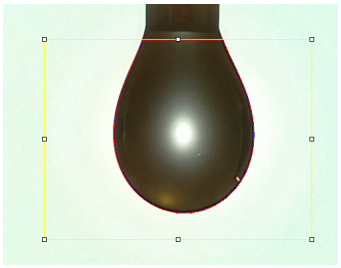
15		37.12
20		35.12

Figure 5: Table of SDS concentrations and corresponding parameter fits (red outline) of images with the background removed and surface tension.

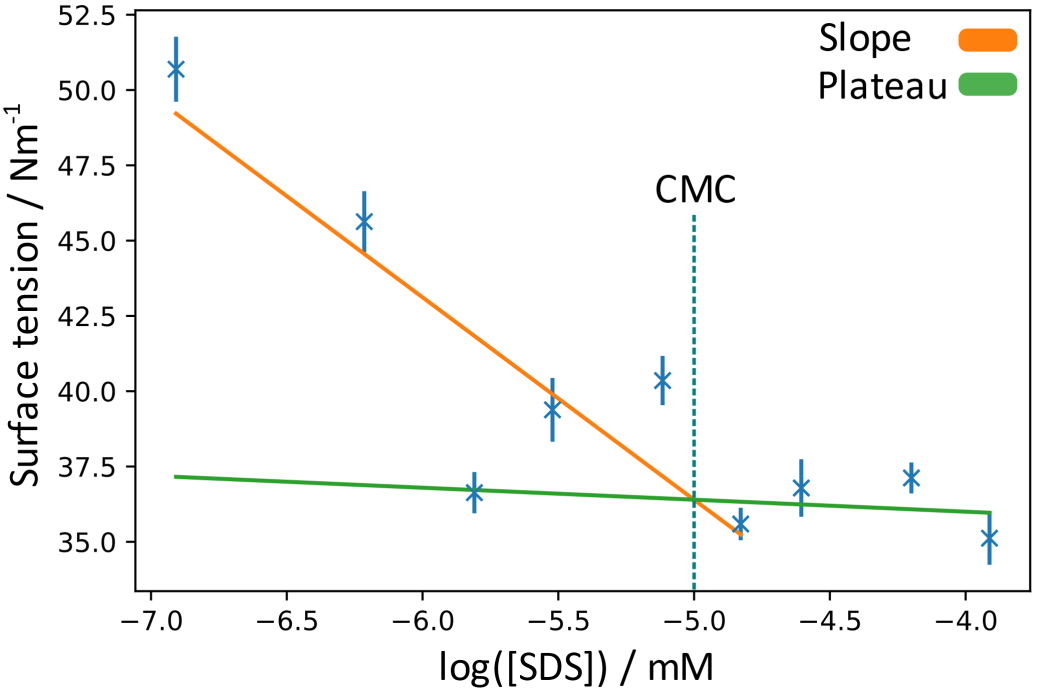


Figure 6: Plot of solution surface tension against log([SDS]) with standard deviation error bars.

From figures 2 & 5, photographing the droplets was a successful endeavour, as the edge of the droplet is well defined due to high contrast and focus.

The plotted points don't follow the expected shape very well. A linear negative gradient is expected, followed by no change in surface tension with log([SDS]). The graph does show a negative gradient at the very least, confirming the expectation that increased presence of SDS decreases surface tension. I chose to include all points for log([SDS]) > -5.0 in the plateau region, and the remainder in the slope, as this gave a fit indicative of a plateau. Raising e to the power of the intersection between to two lines gives:

CMC of SDS: 6.73 ± 5.30 mM

The value of the concentration has a 78% error. This is because the straight-line fits have a high error in both the gradients and the y intercepts. Using the covariance (σ) of the straight-line fits, the standard error for each gradient and intercept was calculated using: $\frac{\sqrt{\sigma}}{f}$ where f is the sample frequency for each fit.

This result is very imprecise but remains positive. It would be unreasonable to have a negative concentration. This result appears to be accurate. Literature[3] quotes a CMC of SDS in water at 8 mM, which falls within the range of possible values for the CMC determined above.

Impatience meant that the droplets weren't given sufficient time to stabilize, producing photographs at different extents of stabilization, altering determined surface tension. The pendant drop analyser took account of the density and volume of the droplet, but different volumes would give different stabilization times, as a lower surface area to volume ratio would stabilize faster than a smaller droplet.

Conclusion

The acquired images were of sufficient quality for edge detection thus a success. The acquired data left a lot to be desired with a large amount of error but ultimately gave an idea of the magnitude of the CMC and showed to be accurate. Regulation of droplet volume could be achieved with a highly precise, narrow syringe. Patience could be increased with the prospect of improved data.

References

1. Berry JD, Neeson MJ, Dagastine RR, Chan DYC, Tabor RF. Measurement of surface and interfacial tension using pendant drop tensiometry. *J Colloid Interface Sci*. 2015;454:226-237. doi:10.1016/j.jcis.2015.05.012

2. pendent-drop/Goutte_pendante.pdf at master · adaerr/pendent-drop · GitHub. Accessed June 4, 2021. https://github.com/adaerr/pendent-drop/blob/master/article/Goutte_pendante.pdf

3. Hammouda B. Temperature Effect on the Nanostructureof SDS Micelles in Water. *J Res Natl Inst Stand Technol*. 2013;118:151. doi:10.6028/jres.118.008