

Determining the viscosity of water

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I. INTRODUCTION

Derived experimentally by Poiseuille in 1838 and Hagen in 1839 [1], the volume flow rate $\frac{dV}{dt}$ of a fluid passing through a tube can be expressed as a function of the density of the fluid ρ , the value for acceleration due to gravity g , the height the fluid leaves the tube h , the radius a and length L of the tube, and the viscosity of the fluid η ,

$$\frac{dV}{dt} = \frac{\pi \rho g h a^4}{8 \eta L}. \quad (1)$$

Noting that the group $\rho g h$ can be collectively termed the pressure difference ΔP between the two ends of the tube [2].

If we consider that a fluid is flowing through said tube, it experiences both friction with the inner wall and internal friction within itself. The latter can be defined more readily as the viscosity of the fluid η , and this results in shear stress when two adjacent layers (laminas) of fluid move relative to each other.

We find that as η increases, the volume flow rate decreases, the shear stress between two laminas becomes greater and so restricts the movement of the fluid's molecules trying to flow through the tube.

Generally we can say that the lamina flow streamlines are smooth, top layers sliding over other laminas without the system having any turbulent motion - this condition is required for equation [1] to be valid.

Using the relation derived by Hagen and Poiseuille it is possible to experimentally calculate a value for the viscosity of water, η_{water} .

Density of water changes with temperature????!!

II. METHOD

A flow of water was created by fixing a capillary tube to a water tank, the tank was then filled up with water from 2cm to 16cm at 2cm intervals, this height was measured with the markings on the side of the tank. We had to ensure that we did not create parallax between the level of the water and the marking.

Water was allowed to flow out of the tube for a period of 90s for each height of water, this time was measured with a digital stopwatch. As the water flowed out it was caught in a large beaker so that the mass and volume of it could be measured after the allotted time had passed.

The mass was found by having the beaker already on a set of electronic scales, and initially zeroed to account for the beaker's mass. The volume on the other hand required the water to be transferred from the beaker to a measuring cylinder, this was performed by using a pipette. Care was again taken so that there was no parallax and that no water remained within the beaker. It was also necessary to clear the tube once air bubbles formed within it, this reduced the flow rate of the water. The bubbles were cleared out using a long piece of copper wire.

Three total sets of data were taken for each three of the capillary tubes, each tube varied in their internal diameter. The first tube had a diameter of 0.110cm, the next at 0.094cm, and the final tube of 0.093cm, these values were measured using a vernier scale in the horizontal direction, this was done multiple times to ensure an accurate value was taken.

The collected data was then fitted to a least square fitting to create an initial model, then chi-squared analysis was performed to check if our model would hold true and if our data was accurate.

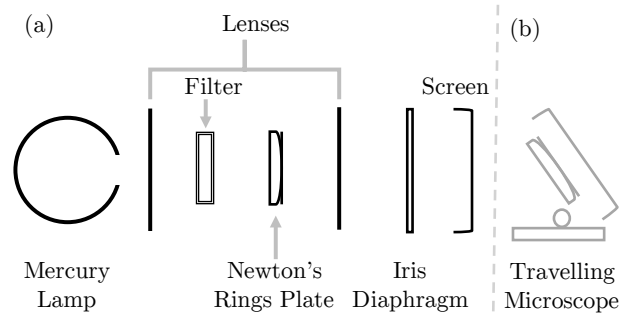


FIG. 1: (a) A schematic of the experimental set-up used to collect the initial set of data. Entire set-up was placed on an optical bench, allowing accurate positioning of the lenses. (b) Modified set-up used in subsequent investigations - Newton's Rings Plate is moved, the screen is adjusted, and a Travelling Microscope is added.

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III. RESULTS

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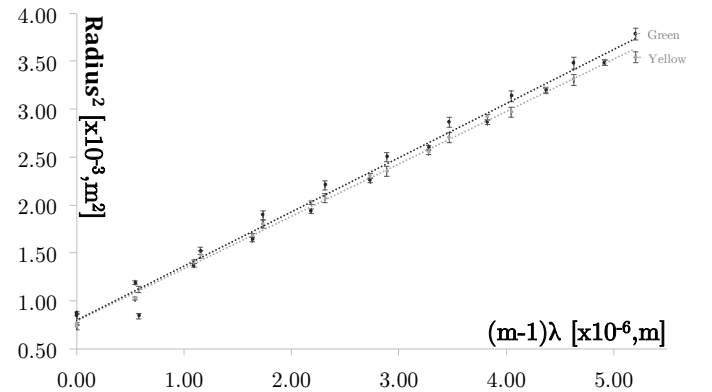


FIG. 2: The fringe radius squared plotted as a function of $(m-1)\lambda$. Horizontal error bars are too small to be seen.

IV. DISCUSSION

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Tube	Radius, a [mm]	η_{water} [mPa]	χ^2_v
<i>Blue</i>	0.55 ± 0.03	$1.49 \pm ??$	19.0
<i>Red</i>	0.47 ± 0.03	$2.47 \pm ??$	6.01
<i>Black</i>	0.46 ± 0.03	$2.47 \pm ??$	27.0

TABLE I: Values for radius of the tube, their respective calculated value for η_{water} , and the reduced χ^2 value for each value.

V. CONCLUSIONS

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- [1] Salvatore P. Sutera and Richard Skalak *The History of Poiseuille's Law*. Annu. Rev. Fluid Mech., 1993.
 - [2] Raymond A. Serway, Chris Vuille, and Jerry S. Faughin *College Physics, 8th Edition*. Brooks/Cole, Belmont, CA, USA, 2009.
 - [3] Hugh D. Young and Roger A. Freedman. *University Physics with Modern Physics, 13th Edition*. Pearson Education Limited, Harlow, Essex, 2015.

Appendix

The uncertainty calculated for the radius of curvature R was found by propagating other uncertainties related to quantities found in equation (3). The majority of those uncertainties are calculated using equations based off formulae found in *Measurements and their Uncertainties* [I. G. Hughes and T. P. A. Hase, *Measurements and their Uncertainties*, Oxford University Press, Oxford, United Kingdom, 2010].

Firstly for the square of the magnified radius of a bright fringe, ρ_m^2 , the error is,

$$\alpha_{r^2} = \alpha_r |2 \times r| \quad (2)$$

where r is the value for the magnified radius of a bright fringe, and α_r is it's respective uncertainty. In our experiment this value arises due to a 30 cm ruler being used to measure the diameter, so the highest precision achievable would have been limited at half a division, therefore $\alpha_r = 0.5$ cm.

The uncertainty on the magnification squared, M^2 , is found by,

$$\alpha_{M^2} = M^2 \left| 2 \times \frac{\alpha_M}{M} \right| \quad (3)$$

with α_M as the error on the magnification. For the initial and repeated experiment this value was taken to be 0.5 due to the difficulties in measuring the width of one of the tick-marks with a 30cm ruler. In the Travelling Microscope experiment $\alpha_M = 0.005$ due to the precision to which we could measure with the vernier scale.

To calculate the uncertainty on the radius of curvature R , the following equation is thus used,

$$\alpha_R = R \times \sqrt{\left(\frac{\alpha_n}{n}\right)^2 + \left(\frac{\alpha_{M^2}}{M^2}\right)^2}, \quad (4)$$

where the term $n = (m - 1)\lambda$, and the uncertainty on that, α_n , was found by using a least squares fitting function in the software Microsoft® Excel. M^2 is again, the magnification squared with it's uncertainty α_{M^2} found above in equation (5).

The uncertainty on d_0 is found by further propagating the uncertainties found above, the resulting equation is,

$$\alpha_{d_0} = d_0 \times \sqrt{\left(\frac{\alpha_c}{c}\right)^2 + \left(\frac{\alpha_{M^2}}{M^2}\right)^2 + \left(\frac{\alpha_R}{R}\right)^2} \quad (5)$$

where c is the intercept of the least squares fitting, and α_c is it's respective uncertainty.

With the case of the Travelling Microscope there is also the uncertainty on the vernier scale used, we shall take the highest precision it can measure to be $\alpha_{vernier} = 0.5$ mm.