Measuring Thinning Rate of Thin Films With Interferometry

Connor Brandt, Owen Crowley, Ben Jacob
Advised by Yorick Andeweg
Schibli-Lab

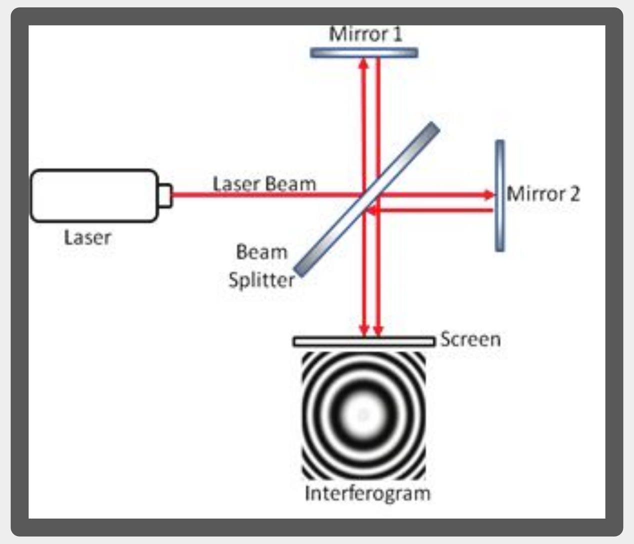
Introduction:

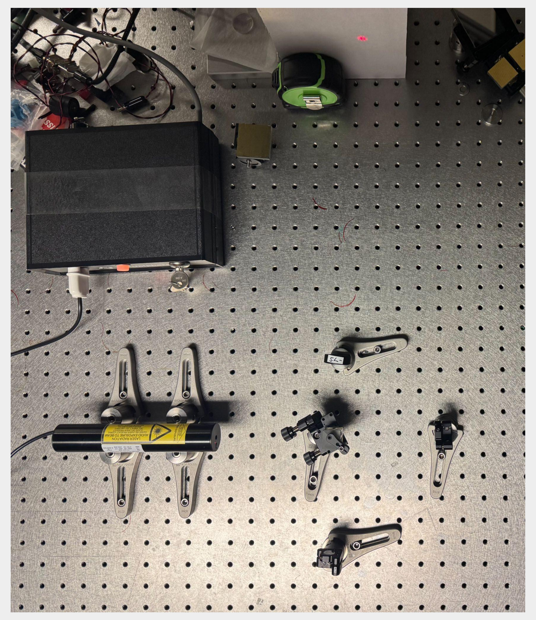
Overview: Bubbles from a bubble wand do not last forever, and their thinning rate over time is influenced by several factors. This project aims to measure the rate at which a thin film thins with a Michelson Interferometer and determine whether this rate follows a logarithmic, linear, or exponential trend.

Hypothesis: The bubble thins as surface tension stretches it, and evaporation removes liquid exponentially, causing a gradually slowing exponential decay in thickness, measurable by the interferometer.

Interferometry (Michelson)

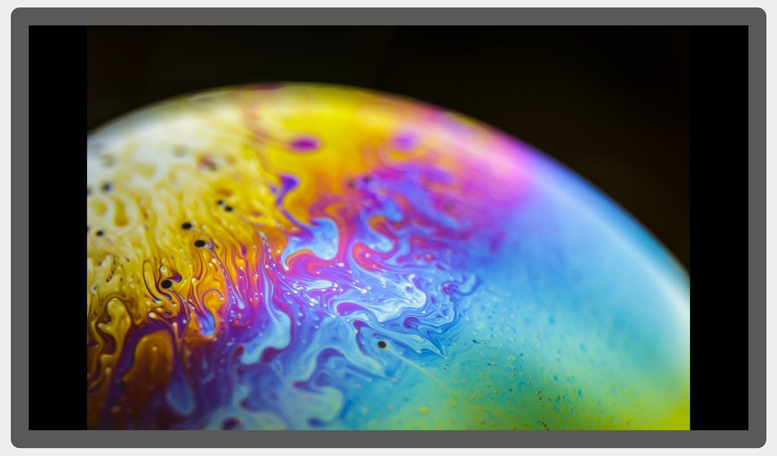
- An interferometer can measure the phase shift of light caused by changes in optical path length in a partially transparent object.
- A laser first hits a beam splitter, which sends about 50% of the light straight through and reflects the other 50% at a right angle.
- One of the two beams passes through the semi-transparent object, creating a phase shift due to the objects refractive index and thickness.
- Both beams then bounce off separate mirrors and return to the beam splitter, where they recombine.
- The recombined beams produce constructive or destructive interference, forming fringes on the interferogram.
- The motion of these fringes shows how the optical path length — and therefore the film's thickness — changes over time.





Thin films

- Thin films are films with a thickness ranging from fractions of a nanometer to a few micrometers
- They are so thin that they have interactions with light
- Their thinning rate is measurable using light with an interferometer due to their refractive index.



Theory Behind Equation

- The equation below is used in our Python script to measure the thickness (t) of a transparent film by counting the number of fringe shifts that occur.
- The laser wavelength (λ) determines how much optical path change corresponds to one fringe, the index of refraction (n) determines how much the film slows the light compared to air
- The factor of 4 accounts for the fact that the light passes through the two films twice, once going to the mirror and once returning.
- By measuring (m) and knowing (λ) and (n), the physical thickness (t) of the film can be calculated.

$$\text{thickness}(t) = (\text{fringes counted}) \times \frac{\lambda}{4n}$$

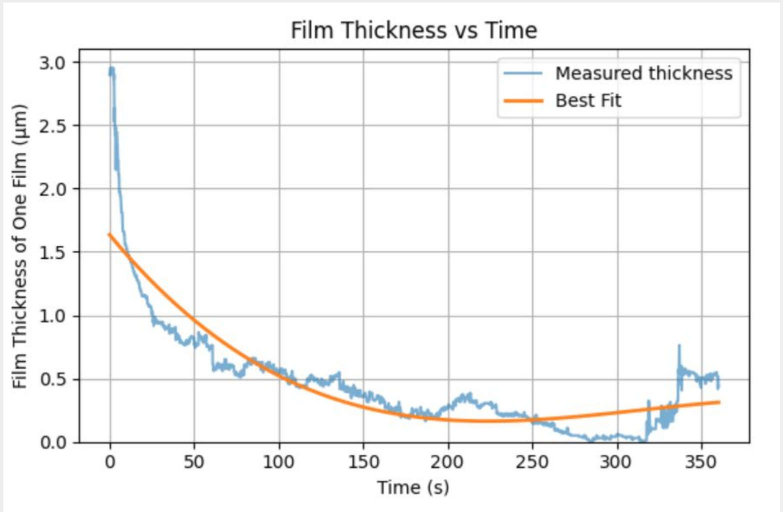
References:

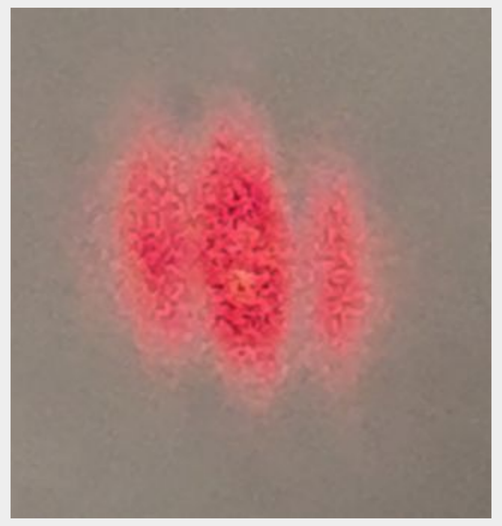
LIGO. Build Your Own Michelson Interferometer.

Boulogne, F., Restagno, F., & Rio, E. (2022). Measurement of the Temperature Decrease in Evaporating Soap Films. Phys. Rev. Lett., 129, 268001.

Experiment/Data

- Mixed various solutions of glycerol, water, and soap with varying percentages of glycerol for longevity
- Placed two soap films into one arm of our interferometer to disrupt the path the light travels through
- As the films thinned, the interference pattern began to shift right as the light spent more of it's path traveling through the air and less traveling through the films
- We cropped our videos to just the fringe, ran them through a large python script, and extracted how many fringes passed as a function of time
- Using our equations we translated that into the thickness of the film over time to get our data
- The uptick at the end of the graph is the film thickening slightly right before popping also known as the marangoni effect





Conclusion:

Regardless of glycerol concentration, all data sets show exponential decay with varying starting thicknesses. The rate of exponential decay is largely similar between trials regardless of glycerol content, showing that rate of decay is independent of the ratio of glycerol.

Future Work

To expand our knowledge on thin films, we would like to add the independent variable pressure by putting thin films inside a vacuum chamber.