PX2505 - Optics Lab Report - Newton Rings

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Sidney Pauly
52104132
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University of Aberdeen
Scotland
UK

https://github.com/sidney-pauly/papers

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1 Aims

The aim of this experiment was to examine light interference at thin-film interfaces. This sort of interference can happen between curved surface (like a lens) on top of a flat surface with a small gap between them. Due to the produced rings (caused by the interference minima and maxima) this phenomena is called "Newton Rings".

Beyond studying the phenomena itself further aims of the experiment are:

1. Comparing the accuracy of different measurement procedures (manual vs. image based)
2. Analyzing the geometry of the produced pattern to measure the curvature of the used lens
3. Measuring the refractive index of a different material (water). This can be done by placing it into the gap and using the obtained curvature measurement to calculate the refractive index.

2 Theory

2.1 Interference

The newton rings experiment is an experiment on interference. What is special about the interference that can be observed is that it does not require a coherent light source (like a laser). Instead it creates the interference by splitting the light (partly reflecting it and partly letting it through) and thereby letting it travel different distances (within the range of one wavelength).

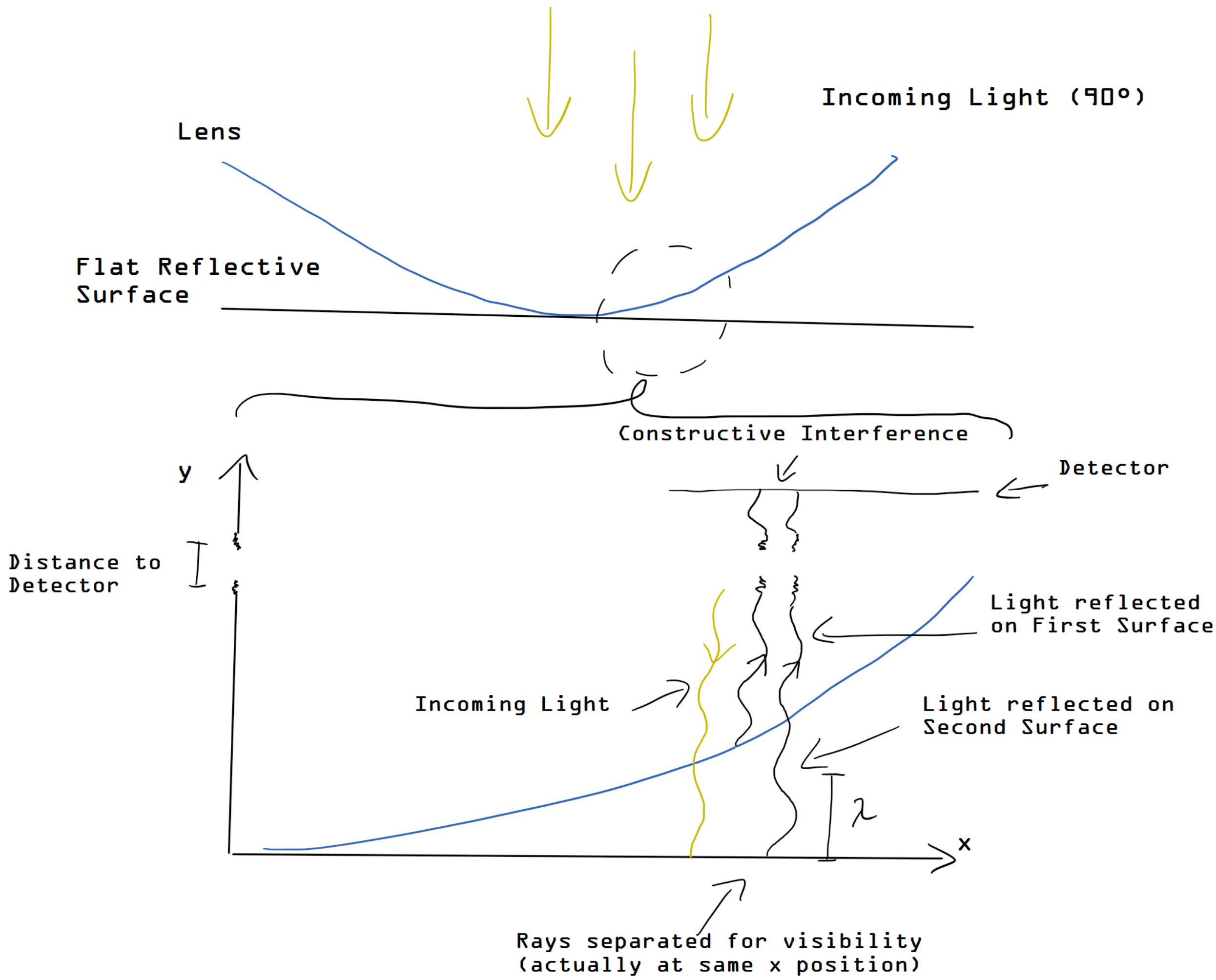

Figure 1: Light path through the Lens and Reflective surface resulting in interference

To get a single light beam to travel different distances, a semi reflecting surface is used. Some light travels through the reflective surface and while other light gets transmitted the transmitted light is then reflected back at a further reflecting surface within a few wavelength in distance. If the reflective surface is exactly an integer multiple of $\frac{1}{2}$ the wavelength away, the light will interfere constructively (as it has to go back and forth thereby covering an integer multiple of the wavelength). Conversely for values of $\frac{1}{4}$ integer multiple of the wavelength the light will interfere destructively as it now is shifted half a wavelength. This works with non-coherent light, as each packet of light is interfering with itself, rather than with other light beams. This also means that this interference can only happen, if the distance between the half reflecting surface and the reflective surface is small enough, as otherwise the light with the longer path length will take too long as each packet of light is limited in length.

It should also be noted that different materials between the surfaces will alter the effective path length the light has to take and will thus alter at what distances destructive and constructive interference happens. This fact will later be used to measure the refractive index of water.

In the actual experiment a lens is used, as the semi reflective surface. This has the advantage of directing the light only exactly downwards, preventing any transverse components to affect the result. Additionally using a lens means that the distance between semi reflective surface and substrate starts from 0 and progressively gets bigger away from the contact point. Therefore at different distances form the center there is different amounts of interference. If the light is monochromatic this will create a clear interference pattern, which can be measured and used to infer the refractive index in the gap (if the refractive index is known other properties could of course also be inferred)

Furthermore it is important that the lens reflects and transmits close to 50% of the light. This is because the visibility of any interference pattern is best if the relative intensity of the two beams involved is equal [1].

2.2 Geometry

As previously mentioned the it is possible to derive the curvature of the lens from the produced interference pattern. The Lab Manual[1] provides the following formula:

$$R = \frac{r^2}{m}\frac{n}{\lambda} \tag{1}$$

Here R stands for the radius of the lens. λ is the wavelength of the light and n the refractive index of the material between the lens and the substrate. $\frac{r^2}{n}$ as the ratio between the number of the maxima (n) and the radius of that maxima (r). The maximas are rings in the interference patterns with the fewest light. Figure 2 shows an interference pattern. The maximas appear as bright rings around the center.

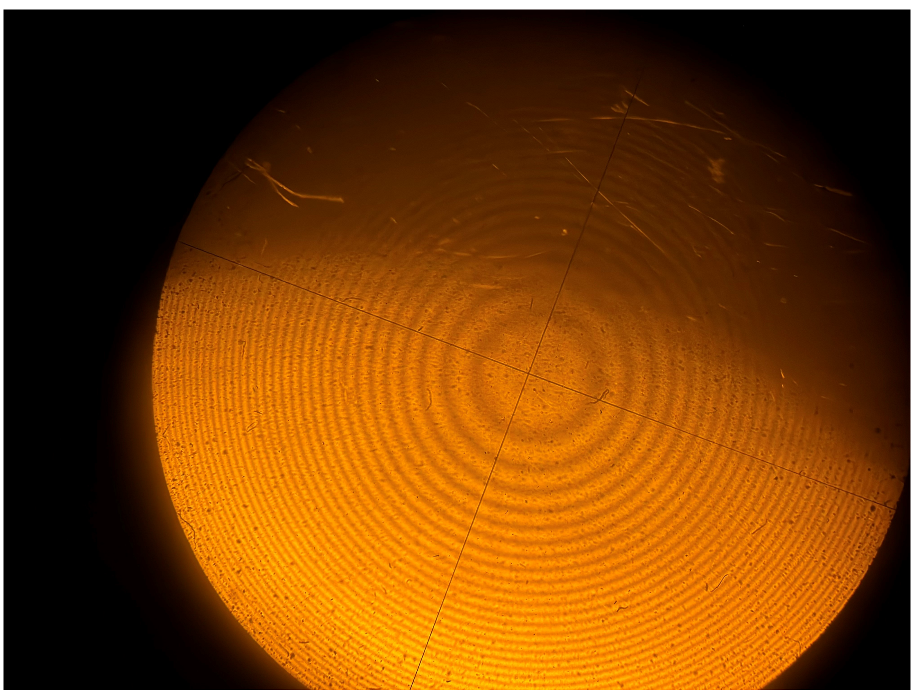

Figure 2: Fringes produced in the experiment

In a first step the experiment is run with air in the gap. As air has a known refractive index of

$n = 1$. Furthermore a monochromatic sodium light source is used, which has a known wavelength of $\lambda = 589.3nm$[1] the curvature can be calculated. Now if a different material is to be examined it is possible to solve the formula based on the known curvature:

$$n = R\lambda \frac{m}{r^2} \tag{2}$$

3 Method

3.1 Overall setup

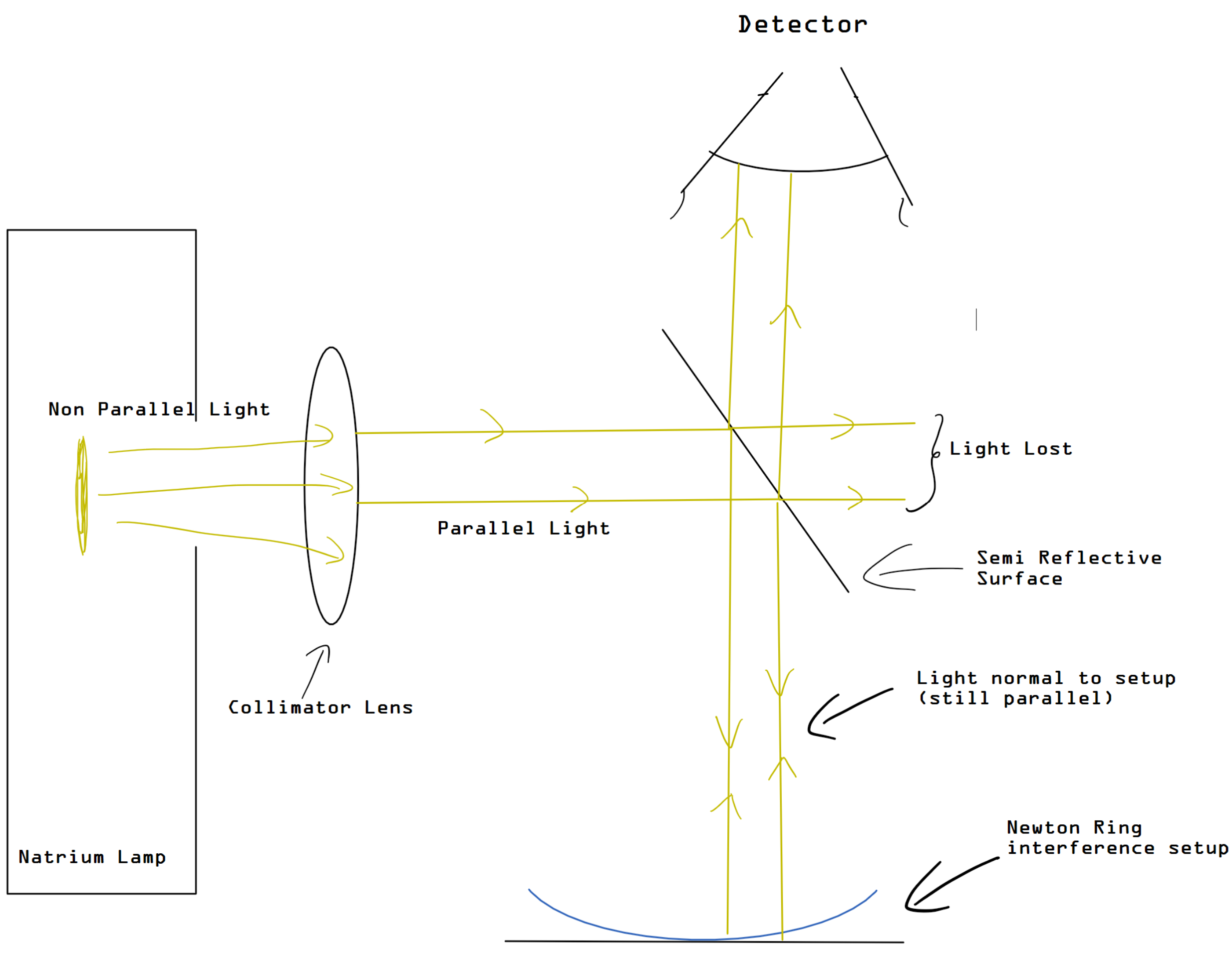

Figure 3: The experimental setup

As described for such interference to happen it is not necessary to have coherent light. Therefore in the experiment a "normal" sodium lamp can be used. On the other hand it is important that the light comes from exactly above and that all light rays are parallel to ensure that the resulting interference can be clearly related back to the geometry of the lens. In other words it is important to ensure that light that did not experience the same amount of interference does not end on top of each other on the detector. To ensure that the light is parallel a collimator lens is used. Getting the light to shine onto the lens at 90 degrees is a bit more complicated, as that would usually result in the resulting interference pattern to be reflected directly back into the light source. To sperate light source and detection spot an additional semi-reflecting surface is used at 45 degrees. It first reflects the light from the lamp downwards onto the lens. The resulting interfering light then travels back upwards and is partially transmitted through to the detector (some of it, is still reflected into the source, but this just reduces the overall brightness).

3.2 Manual measurements

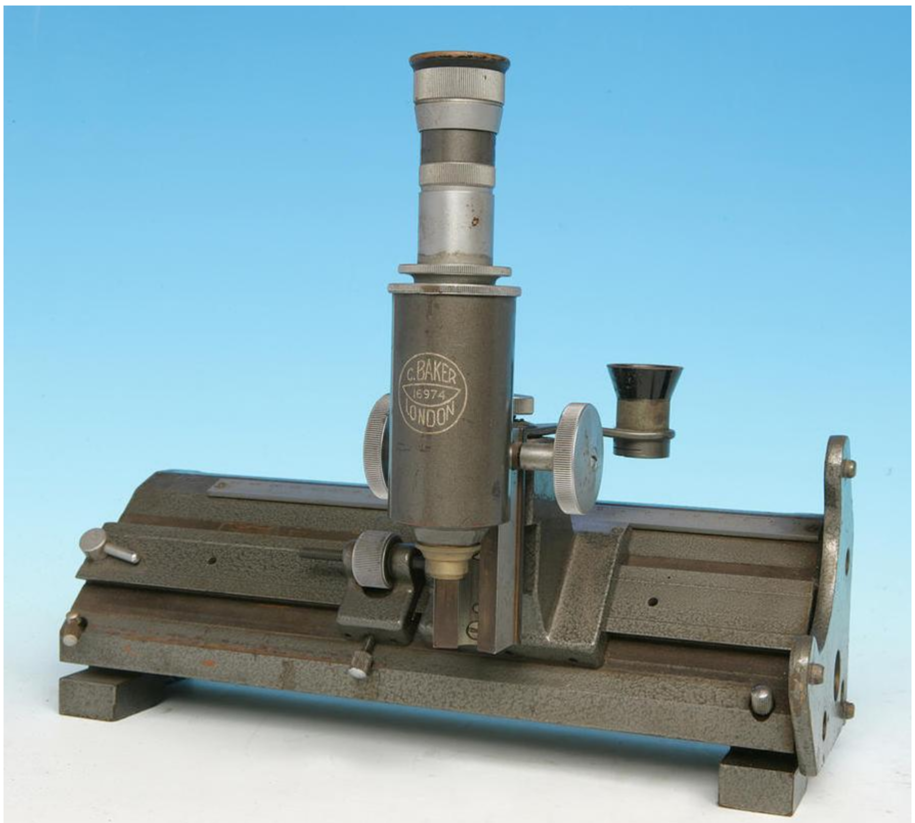

Figure 4: A traveling microscope[2]

The first method to determine the radius of the produced maxima rings is manual measurement. It can be done through the use of a traveling microscope (See Figure 4). A traveling microscope can be finely adjusted along its axis. These microscopes also include a vernier scale, thus the current position can be read to a hight accuracy.

To position the microscope exactly over an image feature the microscope has a build in crosshair. It can be seen in Figure 2.

3.3 Image based measurements

The second method to get the measurements is to take a picture of the interference pattern. The size of different features in the picture can then be related to their physical size.

Taking these measurements is made easier through the utilization fo digital software like ImageJ[3]

The software allows to load a digital image and then measure length within the image. In order to relate these distances to physical distance a known length within the image needs to be provided first. This can be done by taking a picture of a ruler at the exact same spot as the lens[1]:

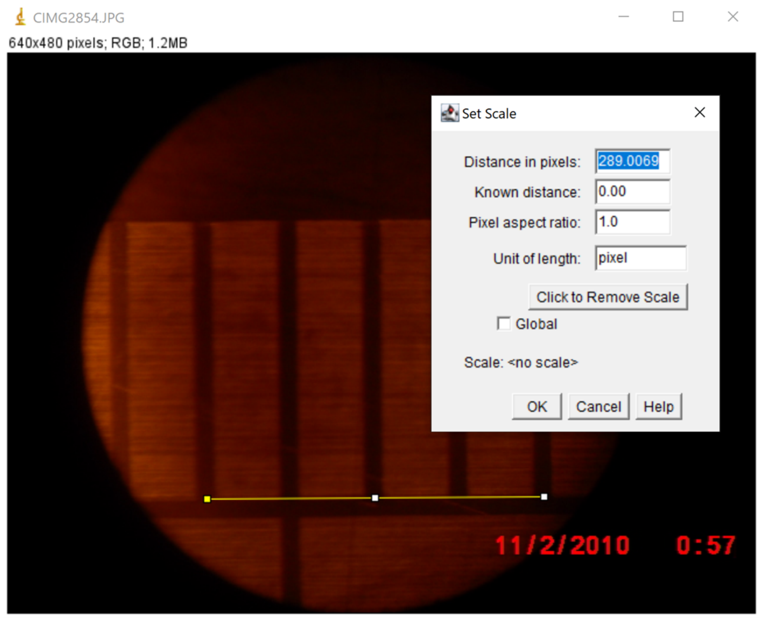

Figure 5: Providing a known physical distance within ImageJ

As shown in Figure 5 a distance on the ruler can then be measured and the known distance value (here 4mm) can be provided to the software.

Now the image to be analyzed can be loaded into the software. One way of then measuring the size of features would be to find them on the screen and use the distance tool. However it is faster and more precise to use the "Plot profile" feature. It produces a graph of the brightness of each pixel along a drawn line:

[1] A helping characteristic of microscopes is that only objects at a narrow distance interval are in focus. Thus if the ruler is in focus it is very close to the height that the lens was at.

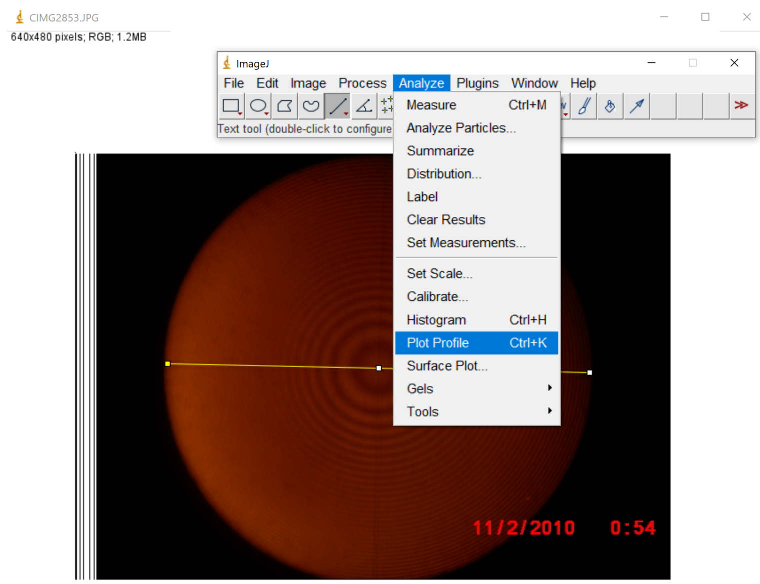

Figure 6: ImageJ's "Plot Profile" feature

4 Results

4.1 White light

In addition to examining the fringes produced by a sodium lamp the setup was tested with a white light source. The resulting fringes looked like this:

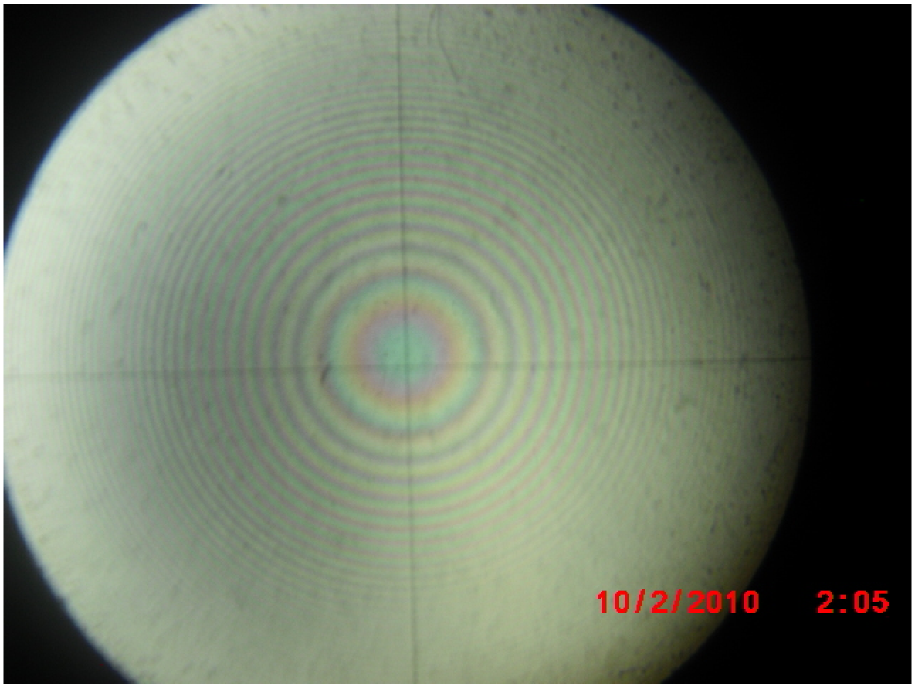

Figure 7: Interference pattern produced by a white light source

4.2 Manual measurements

Through measuring the distances between different maxima of the interference pattern it is possible to determine the refractive index of the material in between the gap or the curvature of the lens used (depending on which of the two is unknown). The following measurements where taken by moving the traveling microscope over the different features:

Ring Number	Left Hand Side (mm)	Right Hand Side (mm)	Diameter 2y (mm)	y^2 (mm^2)
2	92.46	91.42	1.04	0.2704
4	92.94	90.92	2.02	1.0201
6	93.24	90.62	2.62	1.7161
8	93.48	90.38	3.1	2.4025
10	93.72	90.16	3.56	3.1684
12	93.9	89.96	3.94	3.8809
14	94	89.8	4.2	4.41
16	94.22	89.62	4.6	5.29
18	94.4	89.48	4.92	6.0516
20	94.54	89.3	5.24	6.8644

The ring number denotes the interference maxima that was measured. "Left Hand Side" is the traveling microscope reading on the left side of the ring, "Right Hand Side" the reading of the right side of the maxima. Through this the diameter of the maxima can be determined and thereby its radius r, which is basically its distance from the contact point of lens and reflecting substrate. Through the use of excel the following fit can then be done find $\frac{r^2}{m}$:

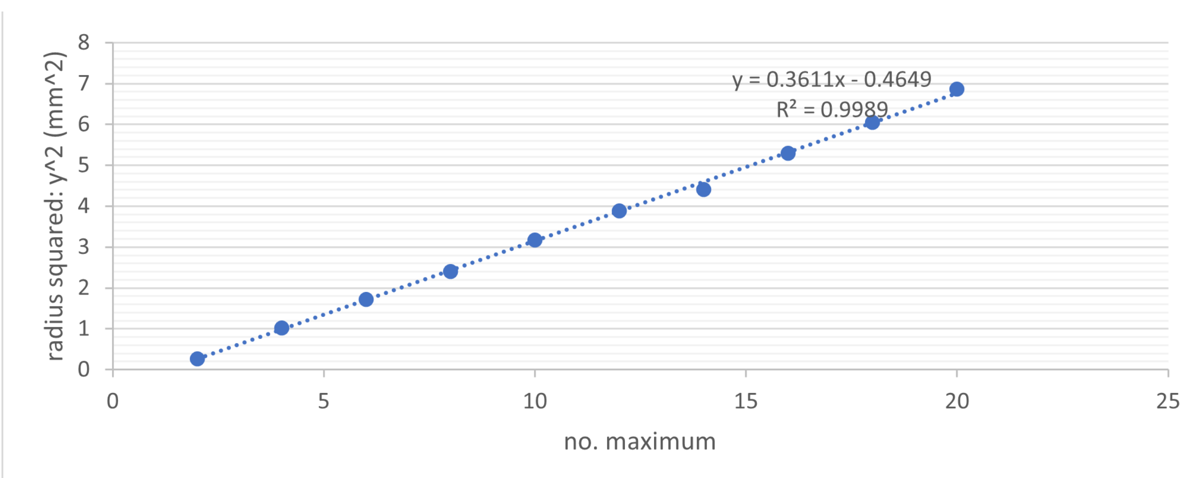

Figure 8: m vs. r^2 and slope fit obtained through manual measurements

The values of the resulting trend line can be seen directly on the graph. An R^2 value of 0.9989 is high and is indicative precise measurements (For statistically perfect data the value would be 1).

The gradient of the slope ($\frac{r^2}{m} = 0.3611mm^2$) can then be plugged into Formula 1 to obtain a radius of the lens R of $61.3cm$.

4.3 Image analysis

As described this analysis can also be done by utilizing the ImageJ software. The previously mentioned "Plot Profile" tool provided us with a brightness graph that looked like this:

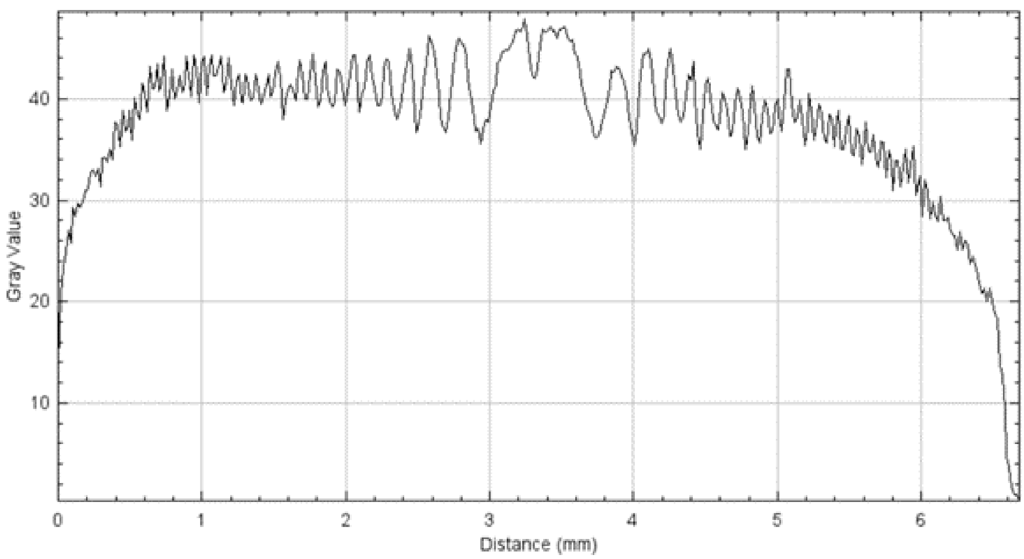

Figure 9: Brightness values across the interference pattern

Measuring the distances between the different peaks the following values where obtained:

Ring Number	Left Hand Side (mm)	Right Hand Side (mm)	Diameter 2y (mm)	y^2 (mm^2)
2	2.8200	3.5110	0.6910	0.11937025
4	2.253	4.092	1.8390	0.84548025
6	1.908	4.424	2.5160	1.582564
8	1.645	4.673	3.0280	2.292196
10	1.424	4.908	3.4840	3.034564
12	1.244	5.101	3.8570	3.71911225
14	1.051	5.267	4.2160	4.443664
16	0.885	5.433	4.5480	5.171076
18	0.719	5.585	4.8660	5.919489
20	0.581	5.783	5.2020	6.765201

Plotting these values leads to the following best fit:

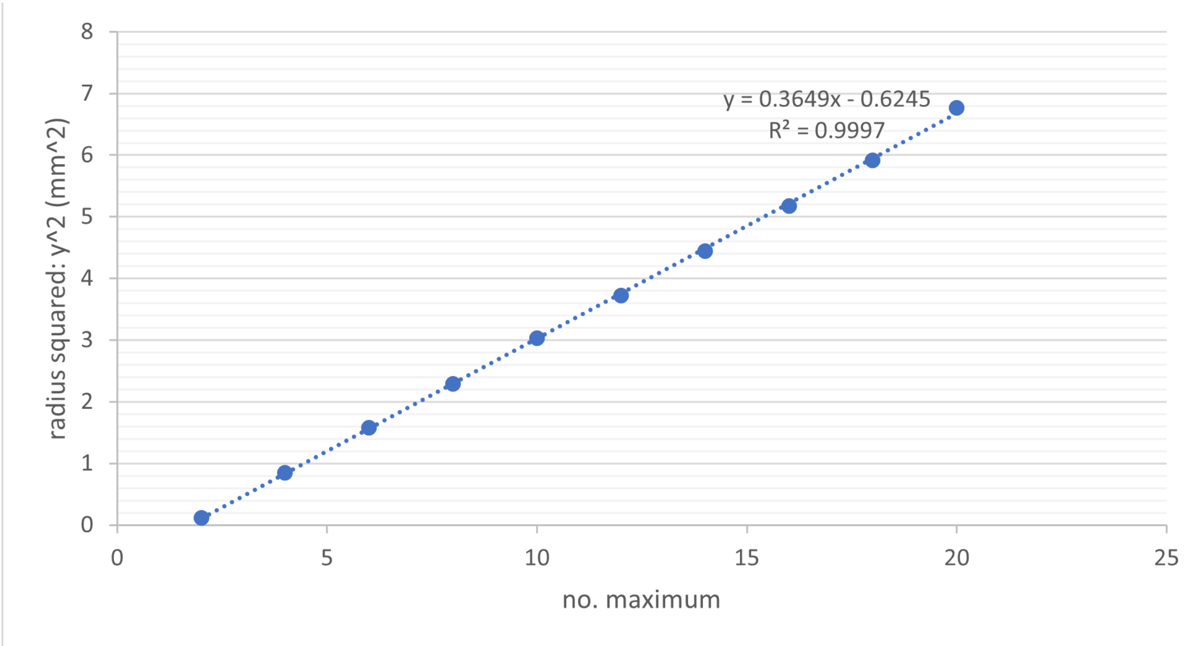

Figure 10: m vs. r^2 and slope fit obtained through ImageJ analysis

Note that the R^2 value is even lower with this method. Again plugging in the numbers leads to a radius of curvature of the lens of $61.9cm$. The difference between the methods is just $6mm$, thus the both of the measurements seem to agree.

4.4 Refractive index of water

To obtain the $\frac{r^2}{m}$ values for water ImageJ was used again, as it was faster. The obtained values looked like this:

Ring Number	Left Hand Side (mm)	Right Hand Side (mm)	Diameter 2y (mm)	y^2 (mm^2)
2	2.9710	3.7781	0.8071	0.162852603
4	2.524	4.224	1.7000	0.7225
6	2.267	4.5	2.2330	1.24657225
8	2.026	4.723	2.6970	1.81845225
10	1.838	4.994	3.1560	2.490084
12	1.683	5.066	3.3830	2.86117225
14	1.511	5.22	3.7090	3.43917025
16	1.374	5.375	4.0010	4.00200025
18	1.254	5.495	4.2410	4.49652025
20	1.133	5.616	4.4830	5.02432225

using regression analysis a value of $\frac{m}{r^2}$ of 3,696721 was obtained. The R^2 value was 0.999 which was again very high.

Using equation 2 and the previously obtained curvature of the lens $R = 61.9cm$ (ImageJ result) the refractive index of the water can be calculated.
The resulting value was of 1.349.

5 Conclusions

Newton rings could successfully be produced with the setup. Both of the applied measurement techniques were accurate. They lead to results with a high R^2 values. As neither of the two methods is clearly better it comes down to preference and ease of access/use.

The obtained refractive index for water of 1.349 seems plausible when compared to online sources, which provide a value of 1.33[4]. However the obtained value seems to be quite a bit off the value given online. This could be due to the water used having a slightly different refractive index than pure water (maybe due to impurities, etc.).
As the difference is quite big it is also likely that there where some systematic errors within in the expirement.
One problem could be the that the camera was slightly moved between photographing the ruler and the fringe pattern, which would through all measurements off by the same amount. A different option could be that the the light is not perfectly parallel, which would distort the image. Similarly distortions could be caused by the different parts of the expiriment not being aligned properly with each other.
If this method was used to determine the refractive index of a material it would help if the radius of the lens was known beforehand through other means. It prevent errors from the the subsequent experiments to stack up. Furthermore it would also allow the verification of the setup by examining the calculated refractive index vs. a known one (e.g. air).

6 Declaration

I certify that this report has been written by myself, except where otherwise indicated

References

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4. Polyanskiy MN. Refractive index database. Available from: `https://refractiveindex.info` [Accessed on: 2023 May 18]