Lab Report 2
NEWTON'S RINGS

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Abstract

This investigation was performed to understand the concepts of constructive and destructive interference and its relation with fringe widths and refractive index of a material by measuring the wavelength of a monochromatic light. This was done using the patterns of newton's rings. A graph was plotted between the square of the diameter of the rings and the number of the rings. The value of the wavelength was observed to be 499.90±9.71 nm which is 13.9% deviated from the literature value.

Introduction

This experiment was conducted to understand the constructive and destructive interference patterns of light waves and find the wavelength (λ) of the monochromatic light.

This used the principle of refraction of light, refractive index of a material and wave interference. Refraction is the redirection of a light wave as it passes from one medium to another. The redirection can be caused by the light wave's change in speed or by a change in the medium. refraction follows Snell's law, which states that, for a given pair of media, the ratio of the sines of the angle of incidence θ_1 and angle of refraction θ_2 is equal to the ratio of phase velocities $\frac{v_1}{v_2}$ in the two media, or equivalently, to the refractive indices $\frac{n_2}{n_1}$ of the media. The refractive index of the optical medium determines how much the path of light is bent, or refracted, when entering a material. The literal values of the refractive index of common materials used in this experiment like air and water are 1 and 1.33 respectively

Wave interference is a phenomenon in which two coherent waves are combined by adding their intensities or displacements with due consideration for their phase difference. The resultant wave may have greater intensity (constructive interference) or lower amplitude (destructive interference) if the two waves are in phase or out of phase, respectively.

This particular experiment was done using Newton's Rings which are produced by the path difference induced in light rays when passing through different mediums of varying thickness. When viewed with monochromatic light (in this case sodium lamp), Newton's rings appear as a series of concentric, alternating bright and dark rings centered at the point of contact between the two surfaces. An ordinary lamp is not used as, when viewed with white light, it forms a concentric ring pattern of rainbow colors, because the different wavelengths of light interfere at different thicknesses of the air layer between the surfaces, which makes it difficult to measure the radius of the rings.
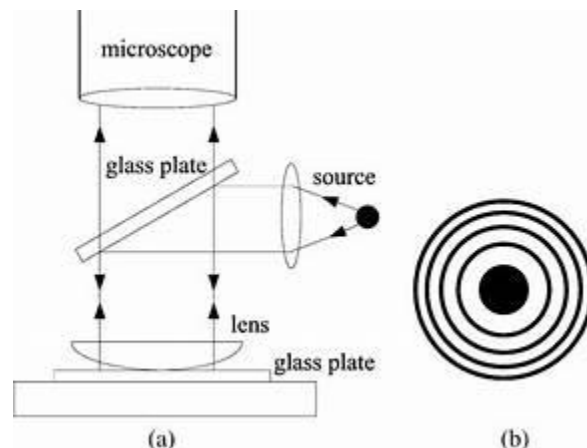

Figure 1 newton's rings apparatus

The formula used for deriving the diameter of the consecutive dark fringes is given by –

$$D_n{}^2 = \frac{4R\lambda n}{n_x}$$

(1)

Where D is the diameter of the rings, λ is the wavelength of the sodium lamp, n_x is the refractive index of the material in which the experiment takes place (in this case air), n is the number of the ring and R is the radius of curvature.

Another principle used in this experiment was uncertainties and errors. There were three types of errors involved –
Instrumental error – Errors that occur due to the minimum scaling of the non–digital instrument where, it may be possible to estimate additional figures. Hence, the instrumental error can be taken as ± half of the smallest unit.

Systematic error – Common mistakes constant throughout the entire experiment, such as incorrect calibration of instrument or human error such as reaction time, etc.
Random error – Small and unpredicted fluctuations in either the technique or the environment that alter the results of the experiment.

To express the error of data sets, two methods were used, described in detail in subsequent pages of this report -
Statistical analysis of large data sets
Linest function in excel

The final principle used was error propagation. The error of the quantities, which were combined in a formula to get the result, gave rise to new errors. Therefore, to work out these new errors, the formulas, listed below, were used –

Addition and Subtraction	$z = x \pm y$	$\Delta z = \sqrt{(\Delta x)^2 + (\Delta y)^2}$	(2)
Multiplication and Division	$z = xy$ or $\frac{x}{y}$	$\Delta z = \|z\|\sqrt{\left(\frac{\Delta x}{x}\right)^2 + \left(\frac{\Delta y}{y}\right)^2}$	(3)
Powers	$z = x^n$	$\Delta z = \|n\|x^{n-1}\Delta x$	(4)
Constant	$z = Cx$	$\Delta z = \|C\|\Delta x$	(5)

To minimize the error on the readings, repeated readings were taken. This minimized the systematic and random errors

Method

Setup Alignment

At the start, it was ensured that all lenses and glasses were clean of any fingerprints so that there were no disruptions in the pattern made.
The apparatus consisted of a planoconvex lens L, a monochromatic lamp (in this case a sodium lamp), flat glass surface G, reflecting surface P, microscope and Perspex housing. Lens L was placed on G inside the Perspex housing containing both G and P.
Once the sodium lamp was warmed up, its light was directed onto plate P by keeping it as close to it as possible. Once this was done, the microscope was used to focus and find the rings

Ring's Radius

Once the rings were found, the microscope was aligned in a way that the crosshairs were centered on the rings. The position of the microscope, on the vernier scale, was measured. This was the first reading, the center of the rings.
Following this, the position of the microscope was adjusted, using the position adjustment wheel, till the crosshair was aligned to the first dark ring. This was the measurement of the position of the first ring.
This process was repeated till the position of the 20th ring was determined.

Radius of Curvature of the Lens

The Radius of curvature of the lens (R) was measured using the spherometer.
To measure the height (h), the screw and the legs were placed in such a way that the screw was on the center of the lens and the legs at the corner
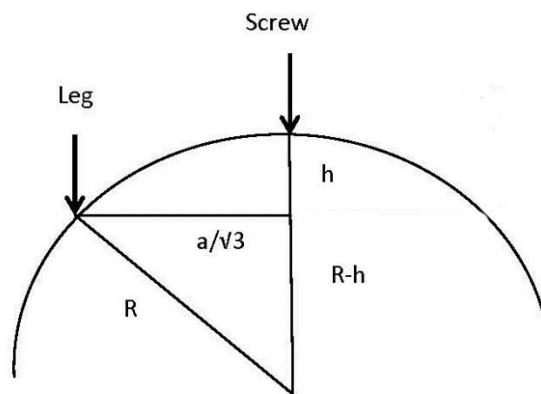The method used to for the derivation of R is as follows –

Figure 2 measurement of R

$$R = \sqrt{\left(\frac{a}{\sqrt{3}}\right)^2 + (R - h)^2} \qquad (6)$$

Results

The results of the experiment conducted are as follows –

Δposition(m*10^{-4})	position(m*10-4)	n(no of ring)
0.005	7.367	0
0.005	7.409	1
0.005	7.445	2
0.005	7.459	3
0.005	7.468	4
0.005	7.475	5
0.005	7.487	6
0.005	7.503	7
0.005	7.514	8
0.005	7.523	9
0.005	7.531	10
0.005	7.541	11
0.005	7.549	12
0.005	7.555	13
0.005	7.559	14
0.005	7.563	15
0.005	7.566	16
0.005	7.567	17
0.005	7.568	18
0.005	7.568	19
0.005	7.569	20

Figure 3 results of the experiment

The errors on the radius, diameter and D^2 were derived using formula (4) and (5) of error propagation. The results are as follows –

Δposition(m*10^{-4})	position(m*10-4)	radius	Δradius	Δdiameter	diameter	n(no of ring)	D²	ΔD²
0.005	7.367	0	0.007071	0.014142	0	0	0	0.005
0.005	7.409	0.042	0.007071	0.014142	0.084	1	0.007056	0.002376
0.005	7.445	0.078	0.007071	0.014142	0.156	2	0.024336	0.004412
0.005	7.459	0.092	0.007071	0.014142	0.184	3	0.033856	0.005204
0.005	7.468	0.101	0.007071	0.014142	0.202	4	0.040804	0.005713
0.005	7.475	0.108	0.007071	0.014142	0.216	5	0.046656	0.006109
0.005	7.487	0.12	0.007071	0.014142	0.24	6	0.0576	0.006788
0.005	7.503	0.136	0.007071	0.014142	0.272	7	0.073984	0.007693
0.005	7.514	0.147	0.007071	0.014142	0.294	8	0.086436	0.008316
0.005	7.523	0.156	0.007071	0.014142	0.312	9	0.097344	0.008825
0.005	7.531	0.164	0.007071	0.014142	0.328	10	0.107584	0.009277
0.005	7.541	0.174	0.007071	0.014142	0.348	11	0.121104	0.009843
0.005	7.549	0.182	0.007071	0.014142	0.364	12	0.132496	0.010295
0.005	7.555	0.188	0.007071	0.014142	0.376	13	0.141376	0.010635
0.005	7.559	0.192	0.007071	0.014142	0.384	14	0.147456	0.010861
0.005	7.563	0.196	0.007071	0.014142	0.392	15	0.153664	0.011087
0.005	7.566	0.199	0.007071	0.014142	0.398	16	0.158404	0.011257
0.005	7.567	0.2	0.007071	0.014142	0.4	17	0.16	0.011314
0.005	7.568	0.201	0.007071	0.014142	0.402	18	0.161604	0.01137
0.005	7.568	0.201	0.007071	0.014142	0.402	19	0.161604	0.01137
0.005	7.569	0.202	0.007071	0.014142	0.404	20	0.163216	0.011427

Figure 4 results with errors

Using this data, a graph of D^2 was plotted against number of rings. This is given as follow –
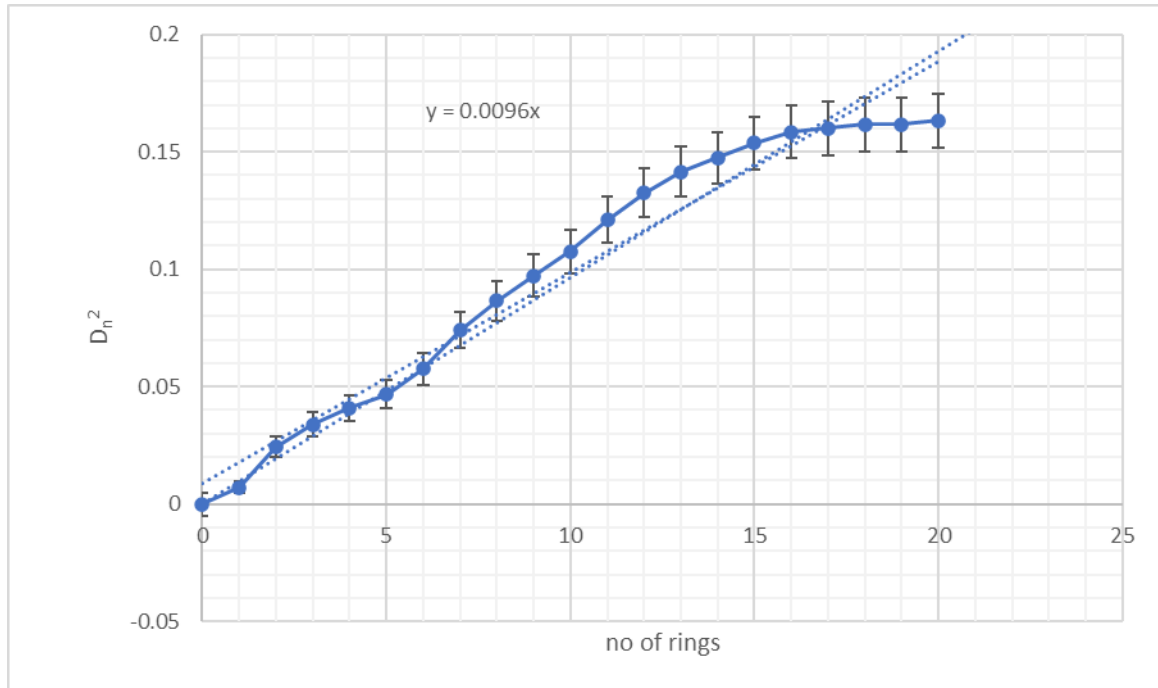

y = 0.0096x

Figure 5 graph of D² vs n

Using the LINEST function in MS-Excel, the gradient of the graph and the error on it was calculated as 0.0103 ± 0.0002 cm^2. Using equation (1), the gradient (m) was derived as follows –

$$m = \frac{4\lambda R}{n_x}$$

This was manipulated as –

$$\lambda = \frac{mn_x}{4R} \qquad (7)$$

The value of the terms used in the above formula are given as follows –

m = $(0.0103\pm0.0002) *10^{-4}$ m^2
n_x = 1.0000 ± 0.0005
The value of R, derived from the spherometer (equation (6)), = 0.5151 ± 0.0005 m

$\therefore$ The value of $\lambda \approx 4.9990\times10^{-6}$ m

The error of λ was derived using the error propagation formula (3)

$$\therefore \qquad \Delta\lambda = |\lambda|\sqrt{\left(\frac{\Delta m}{|m|}\right)^2 + \left(\frac{\Delta n_x}{|n_x|}\right)^2 + \left(\frac{\Delta R}{|R|}\right)^2}$$

$\Rightarrow \qquad \Delta\lambda \approx 9.71$ nm

$\therefore$ Reported value of λ = 499.90 ± 9.71 nm

Literature value of λ = 580 nm

Deviation = $\frac{\lambda_{literature}-\lambda_{observed}}{\lambda_{literature}} \times 100 \approx 13.9\%$

Discussion

The greatest source of error, that persisted throughout the experiment, was the parallax of the human eye. It is a form of systematic human error. This error could not be accounted for as it is a human error. It could only be minimized by taking multiple readings.

This was seen in two different places, one of them being aligning the crosshair of the microscope to the alternate dark fringes. This could have been minimized by taking multiple readings, as stated above. Another error faced in this part was focusing on the rings. Unfortunately, this error could only have been reduced by getting as clear image of the patterns as possible.

The other part where parallax error came into play was the measurement of the radius using the vernier scale. Since the divisions were so small, the human eye could have made an error in aligning the vernier scale. This part also consisted of instrumental error like the resolution of the vernier scale which was given as ±0.0005 m or ±0.5 mm. this error persisted throughout the readings, escalated to ±0.0002 m for the gradient and then finally propagated through equation (7) to become ±9.17 nm for the wavelength

Using the line of best fit method, the value of gradient was calculated which was reframed for, then, calculating the wavelength. For the error, the formulas for error propagation were used. The final Reported value of λ was equal to 499.90 ± 9.71 nm, which deviates 13.9%, approximately, from the literature value of

the wavelength. For all future investigations, multiple readings would be taken to minimize the error on the observations

Conclusion

This investigation shows that formula (1) could be broadly validated. The value of λ was calculated using the patterns of newton's rings given by the alternate constructive and destructive wave interference. This was derived using the known values of n_x and n, and the experimentally derived values of D^2 and R. The final Reported value of λ was equal to 499.90±9.71 nm, which deviates 13.9%, approximately, from the literature value of the wavelength.

This investigation also validated the inverse relation between the square of the diameter of the rings and the refractive index and the direct relation between the square of the diameter of the rings and the wavelength of the monochromatic light.

References

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