BS 192: Undergraduate Science Laboratory (Physics)

A
Laboratory Report
on

Newton's Rings

by

Jaskirat Singh Maskeen
Nishchay Bhutoria
Kavya Lavti
Kanhaiyalal

Indian Institute of Technology Gandhinagar

Index

Experiment No. 3

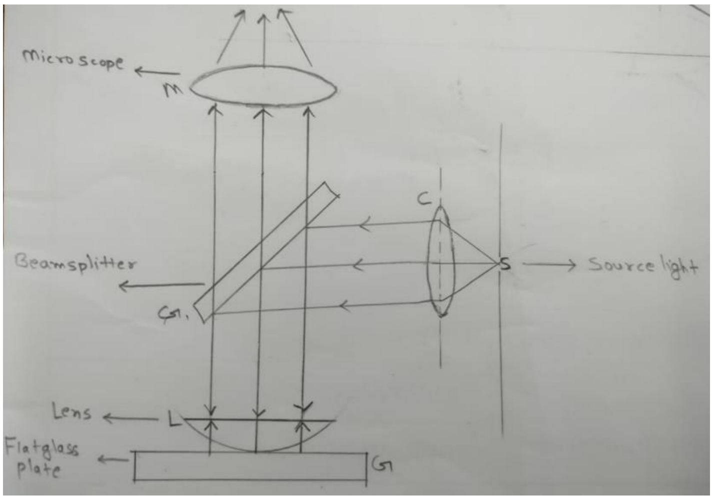
Newton's Rings

I. Aim:

To determine the radius of curvature of a lens by Newton's rings method.

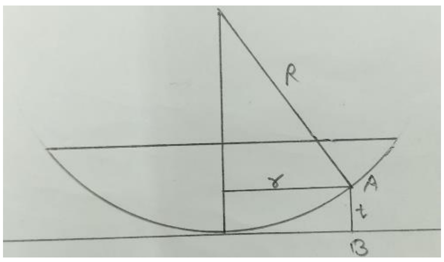
II. Apparatus:

Microscope with XY stage, power supply for sodium lamp, sodium vapour lamp, plano-convex lens and its holder, beam splitter with holder.



III. Theory:

Newton's ring is an optical phenomenon, first observed by Robert Hooke and later studied by Isaac Newton. This phenomenon can only be explained by constructive and destructive interference of monochromatic light, which requires wave theory of light. The purpose of this experiment is to measure the radius of curvature of a convex surface (plano-convex lens) and, in doing so, test the theoretical analysis of this phenomenon. The plano-convex lens is placed on the top of a flat glass plate in a holder, with screws to accurately position the height of the lens so that there is only one contact point between the lens and the plate. The monochromatic light is made incident on the beam splitter, and the rays fall normally on the lens. Some rays reflect from the curved part of the lens, while some transmit through and get reflected from the flat glass plate beneath the lens. The two rays interfere constructively or destructively, depending on the thickness of the air column between the lens and the flat glass plate.



Path difference between the two rays, is given by,

$$\Delta x = 2 \times (R + t) - 2 \times R$$

$$\Delta x = 2t$$

If we see a bright ring above the line AB, then the two rays are interfering constructively. Light reflected at A undergoes no phase change and light reflected at B undergoes one phase change, therefore the condition for constructive interference is,

$$2t = \left(m + \frac{1}{2}\right)\lambda$$

Where m, has an integer value. Since t must be positive, m can have values 0, 1, 2, ...

Applying Pythagoras theorem,

$$R^2 = r^2 + (R - t)^2$$

$$r^2 = 2Rt - t^2$$

Since t is very small, $t^2 \rightarrow 0$.

$$t = \frac{r^2}{2R} = \frac{d^2}{8R}$$

Where d is the diameter of the ring.

Considering the m^{th} bright ring,

$$t_m = \frac{d_m^2}{8R} \text{ and } 2t_m = \left(m + \frac{1}{2}\right)\lambda$$

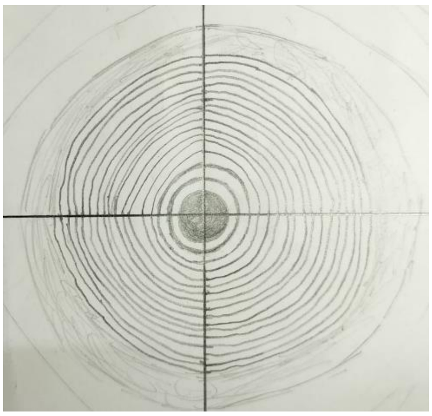
Considering $m = m_1$ and $m = m_2$,

$$t_{m_2} - t_{m_1} = \frac{d_{m2}^2 - d_{m_1}^2}{8R} \text{ and } 2t_{m_2} - 2t_{m_1} = (m_2 - m_1)\lambda$$

Using these equations,

$$R = \frac{d_{\mathrm{m}_2}^2 - d_{m_1}^2}{4\lambda(m_2 - m_1)}$$

Same can also be obtained by taking two dark rings. Note that only the value of $m_2 - m_1$ matters, not the values of m_2 and m_1 themselves.



- Using micrometre to position the XY stage:

The micrometre on the XY stage consists of a main scale and a circular scale. The circular scale is divided into fixed divisions, and the rotation of the circular scale moves the platform either left or right. The pitch of the micrometre is defined as the distance moved by the platform when the circular scale undergoes one full rotation. The least count will be the distance moved by the platform by turning the circular scale through its one division.

Let us say the circular scale is divided into k divisions, and the pitch of the micrometre is p units.

So, the least l count will be:

$$l = \frac{\mathrm{p}}{\mathrm{k}}$$

The reading given by micrometre is:

$$reading \ = \ main\ scale\ reading \ + \ l \ \times circular\ scale\ reading$$

IV. Procedure:

1. Clean all the optics with isopropyl alcohol provided and turn on the sodium vapour lamp so that it reaches its maximum intensity.
2. Place the flat disk near the depression region of the microscope and place a plano-convex lens on top of it such that there should be a point of contact between them.
3. Tilt the beam-splitter to 45 degrees, so we get maximum brightness.
4. Adjust the distance between the microscope tube and the object using that focus knob until our image is clear and sharp, and we see many circular fringes.
5. Now, using micrometre screws, coincide cross wire intersection with the center of circular fringes.
6. Now, set up the microscope so that one crosswire tangentially touches the rings, making sure we can move through 20 rings by turning the micrometre screw in one direction only.
7. Position the crosswire at the center of a clear and larger ring (let's call it the "m^{th}" ring), noting its position (X_m) using the micrometre.
8. Turn the fine movement knob, moving the microscope toward the center of the ring system. Adjust the crosshairs so that they are at tangent to every other ring as we move, noting down their positions (X_{m-1}, X_{m-2}, ..., X_2, X_1).
9. After crossing the center of the ring system, continue placing the crosswire tangent to the corresponding rings, diametrically opposite from the first set. Note down their positions (Y_1, Y_2, Y_3, ..., Y_{m-2}, Y_{m-1}).
10. Now, repeat the same for dark fringes.

V. Observations and Graphs:

Bright Fringes Reading 1								
X = MSR + 0.01 x CSR					Xm		Ym	
Ring no.	Xm (mm)	Ym (mm)	Dm (Xm-Ym) (mm)	Dm^2 (Xm-Ym)^2 (mm^2)	MSR	CSR	MSR	CSR
20	9.40	4.49	4.91	24.11	9.0	40	4.0	49
19	9.34	4.55	4.79	22.94	9.0	34	4.5	5
18	9.27	4.61	4.66	21.72	9.0	27	4.5	11
17	9.21	4.68	4.53	20.52	9.0	21	4.5	18
16	9.14	4.74	4.40	19.36	9.0	14	4.5	24
15	9.07	4.82	4.25	18.06	9.0	7	4.5	32
14	9.00	4.90	4.10	16.81	9.0	0	4.5	40
13	8.93	4.98	3.95	15.60	8.5	43	4.5	48
12	8.85	5.06	3.79	14.36	8.5	35	5.0	6
11	8.77	5.14	3.63	13.18	8.5	27	5.0	14
10	8.68	5.23	3.45	11.90	8.5	18	5.0	23
9	8.59	5.31	3.28	10.76	8.5	9	5.0	31
8	8.49	5.41	3.08	9.49	8.0	49	5.0	41
7	8.39	5.52	2.87	8.24	8.0	39	5.5	2
6	8.28	5.62	2.66	7.08	8.0	28	5.5	12
5	8.17	5.76	2.41	5.81	8.0	17	5.5	26
4	8.03	5.90	2.13	4.54	8.0	3	5.5	40
3	7.89	6.05	1.84	3.39	7.5	39	6.0	5
2	7.70	6.24	1.46	2.13	7.5	20	6.0	24
1	7.42	6.50	0.92	0.85	7.0	42	6.5	0

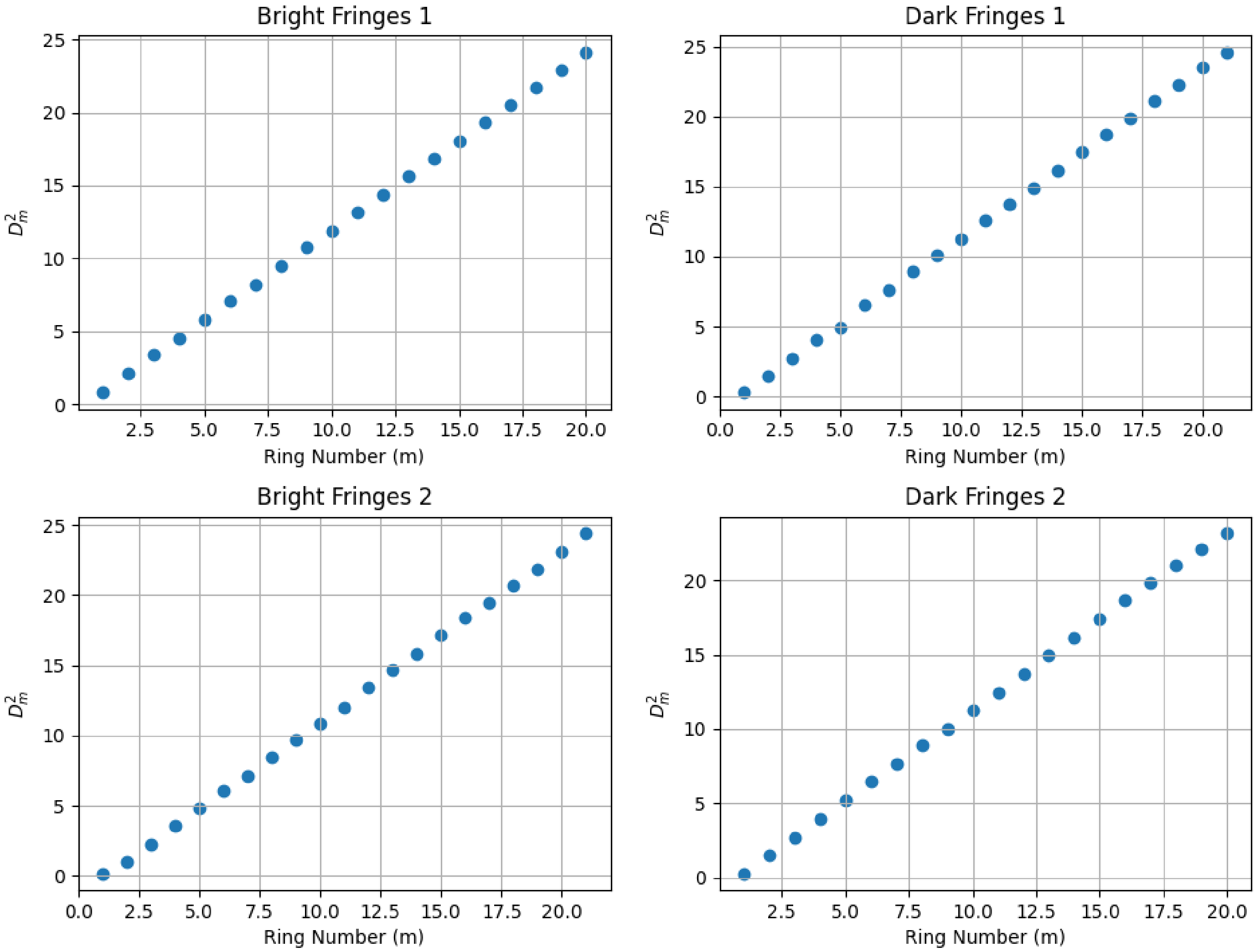
Dark Fringes Reading 1								
X = MSR + 0.01 x CSR					Xm		Ym	
Ring no.	Xm (mm)	Ym (mm)	Dm (Xm-Ym) (mm)	Dm^2 (Xm-Ym)^2 (mm^2)	MSR	CSR	MSR	CSR
21	9.42	4.46	4.96	24.60	9.0	42	4.0	46
20	9.37	4.52	4.85	23.52	9.0	37	4.5	2
19	9.31	4.59	4.72	22.28	9.0	31	4.5	9
18	9.25	4.65	4.60	21.16	9.0	25	4.5	15
17	9.18	4.72	4.46	19.89	9.0	18	4.5	22
16	9.11	4.78	4.33	18.75	9.0	11	4.5	28
15	9.04	4.86	4.18	17.47	9.0	4	4.5	36
14	8.96	4.94	4.02	16.16	8.5	46	4.5	44
13	8.89	5.03	3.86	14.90	8.5	39	5.0	3
12	8.81	5.10	3.71	13.76	8.5	31	5.0	10
11	8.73	5.18	3.55	12.60	8.5	23	5.0	18
10	8.63	5.27	3.36	11.29	8.5	13	5.0	27
9	8.54	5.36	3.18	10.11	8.5	4	5.0	36
8	8.44	5.45	2.99	8.94	8.0	44	5.0	45
7	8.33	5.57	2.76	7.62	8.0	33	5.5	7
6	8.23	5.68	2.55	6.50	8.0	23	5.5	18
5	8.04	5.82	2.22	4.93	8.0	4	5.5	32
4	7.95	5.95	2.00	4.00	7.5	45	5.5	45
3	7.79	6.14	1.65	2.72	7.5	29	6.0	14
2	7.58	6.36	1.22	1.49	7.5	8	6.0	36
1	7.26	6.70	0.56	0.31	7.0	26	6.5	20

Bright Fringes Reading 2								
X = MSR + 0.01 x CSR					Xm		Ym	
Ring no.	Xm (mm)	Ym (mm)	Dm (Xm-Ym) (mm)	Dm^2 (Xm-Ym)^2 (mm^2)	MSR	CSR	MSR	CSR
21	9.05	4.11	4.94	24.40	9.00	5	4.00	11
20	8.99	4.18	4.81	23.14	8.50	49	4.00	18
19	8.92	4.24	4.68	21.90	8.50	42	4.00	24
18	8.86	4.31	4.55	20.70	8.50	36	4.00	31
17	8.79	4.38	4.41	19.45	8.50	29	4.00	38
16	8.72	4.43	4.29	18.40	8.50	22	4.00	43
15	8.65	4.51	4.14	17.14	8.50	15	4.50	1
14	8.57	4.59	3.98	15.84	8.50	7	4.50	9
13	8.49	4.66	3.83	14.67	8.00	49	4.50	16
12	8.41	4.75	3.66	13.40	8.00	41	4.50	25
11	8.32	4.85	3.47	12.04	8.00	32	4.50	35
10	8.24	4.94	3.30	10.89	8.00	24	4.50	44
9	8.15	5.04	3.11	9.67	8.00	15	5.00	4
8	8.04	5.13	2.91	8.47	8.00	4	5.00	13
7	7.92	5.25	2.67	7.13	7.50	42	5.00	25
6	7.82	5.36	2.46	6.05	7.50	32	5.00	36
5	7.68	5.49	2.19	4.80	7.50	18	5.00	49
4	7.54	5.65	1.89	3.57	7.50	4	5.50	15
3	7.35	5.85	1.50	2.25	7.00	35	5.50	35
2	7.12	6.10	1.02	1.04	7.00	12	6.00	10
1	6.82	6.40	0.42	0.18	6.50	32	6.00	40

Dark Fringes Reading 2								
X = MSR + 0.01 x CSR					Xm		Ym	
Ring no.	Xm (mm)	Ym (mm)	Dm (Xm-Ym) (mm)	Dm^2 (Xm-Ym)^2 (mm^2)	MSR	CSR	MSR	CSR
20	9.01	4.20	4.81	23.14	9.0	1	4.0	20
19	8.95	4.25	4.70	22.09	8.5	45	4.0	25
18	8.89	4.31	4.58	20.98	8.5	39	4.0	31
17	8.82	4.37	4.45	19.80	8.5	32	4.0	37
16	8.76	4.44	4.32	18.66	8.5	26	4.0	44
15	8.68	4.51	4.17	17.39	8.5	18	4.5	1
14	8.60	4.58	4.02	16.16	8.5	10	4.5	8
13	8.53	4.66	3.87	14.98	8.5	3	4.5	16
12	8.45	4.75	3.70	13.69	8.0	45	4.5	25
11	8.36	4.84	3.52	12.39	8.0	36	4.5	34
10	8.28	4.93	3.35	11.22	8.0	28	4.5	43
9	8.19	5.03	3.16	9.99	8.0	19	5.0	3
8	8.10	5.12	2.98	8.88	8.0	10	5.0	12
7	7.99	5.23	2.76	7.62	7.5	49	5.0	23
6	7.88	5.34	2.54	6.45	7.5	38	5.0	34
5	7.76	5.47	2.29	5.24	7.5	26	5.0	47
4	7.60	5.61	1.99	3.96	7.5	10	5.5	11
3	7.43	5.78	1.65	2.72	7.0	43	5.5	28
2	7.24	6.01	1.23	1.51	7.0	24	6.0	1
1	6.88	6.35	0.53	0.28	6.5	38	6.0	35

(Images of these readings are in Section IX)

Plotting D_m^2 against m, we get the following graphs,



VI. Calculations:

To get slope, we use the following formula,

$$S = \frac{D_m^2 - D_{m\text{-}2}^2}{(m-(m-2))}$$

The error in slope is,

$$\frac{\Delta S}{S} = 2\frac{\Delta D_m}{D_m} + 2\frac{\Delta D_{m-2}}{D_{m-2}}$$

ΔD_m and ΔD_{m-2} have the value 0.01 mm (which is the least count of screw gauge attached to the XY plate of the microscope)

Applying these to the observations, we get the following tables,

Bright Fringes Reading 1		
m	Slope (S)	Error (ΔS)
20	1.20	0.00
19	1.21	0.00
18	1.18	0.00
17	1.23	0.00
16	1.28	0.00
15	1.23	0.00
14	1.22	0.00
13	1.21	0.00
12	1.23	0.00
11	1.21	0.00
10	1.21	0.00
9	1.26	0.01
8	1.21	0.01
7	1.21	0.01
6	1.27	0.01
5	1.21	0.01
4	1.20	0.02
3	1.27	0.04
Average slope	1.22	
Average error	0.01	

Dark Fringes Reading 1		
m	Slope (S)	Error (ΔS)
21	1.16	0.00
20	1.18	0.00
19	1.19	0.00
18	1.21	0.00
17	1.21	0.00
16	1.29	0.00
15	1.29	0.00
14	1.20	0.00
13	1.15	0.00
12	1.24	0.00
11	1.25	0.00
10	1.17	0.00
9	1.25	0.01
8	1.22	0.01
7	1.34	0.01
6	1.25	0.01
5	1.10	0.01
4	1.26	0.02
3	1.20	0.09
Average slope	1.22	
Average error	0.01	

Bright Fringes Reading 2		
m	Slope (S)	Error (ΔS)
21	1.25	0.00
20	1.22	0.00
19	1.23	0.00
18	1.15	0.00
17	1.15	0.00
16	1.28	0.00
15	1.24	0.00
14	1.22	0.00
13	1.31	0.00
12	1.25	0.00
11	1.18	0.00
10	1.21	0.01
9	1.27	0.01
8	1.21	0.01
7	1.17	0.01
6	1.24	0.01
5	1.27	0.02
4	1.27	0.03
3	1.04	0.13
Average slope	1.23	
Average error	0.01	

Dark Fringes Reading 2		
m	Slope (S)	Error (ΔS)
20	1.08	0.00
19	1.14	0.00
18	1.16	0.00
17	1.21	0.00
16	1.25	0.00
15	1.21	0.00
14	1.24	0.00
13	1.29	0.00
12	1.23	0.00
11	1.20	0.00
10	1.17	0.00
9	1.18	0.01
8	1.21	0.01
7	1.19	0.01
6	1.25	0.01
5	1.26	0.01
4	1.22	0.02
3	1.22	0.10
Average slope	1.21	
Average error	0.01	

Taking average, and getting the final value of slope and error using the four readings, we get,

$$S = 1.22 \text{ mm}^2 \text{ / ring number}$$

$$\Delta S = 0.01 \text{ mm}^2 \text{ / ring number}$$

VII. Result, Discussion and Error Analysis:

To calculate the radius of curvature of lens, we have the following equation,

$$R = \frac{S}{4\lambda}$$

$$(\lambda = 5893 \text{ Å})$$

$$R = 517.53 \text{ mm}$$

To calculate the error,

$$\frac{\Delta R}{R} = \frac{\Delta S}{S} + \frac{\Delta \lambda}{\lambda}$$

Assuming $\frac{\Delta\lambda}{\lambda} = 0$ (i.e., There is no error in the wavelength of monochromatic light),

$$\Delta R = R \times \frac{\Delta S}{S}$$

$$\Delta R = 3.23 \text{ mm}$$

Or,

$$\boldsymbol{R = 517.53 \pm 3.23} \text{ mm}$$

Standard deviation ($\sigma = \sqrt{\left(\frac{\sum(x_i-\mu)^2}{N}\right)}$) across all readings for the radius of curvature comes out to be,

$$\boldsymbol{\sigma = 21.19} \text{ mm}$$

Another way in which we can estimate the error in R is to let ΔS equal half of maximum S minus the minimum S,

$$\Delta S = \frac{|S_{max} - S_{min}|}{2}$$

And then use the formula $\Delta R = R \times \frac{\Delta S}{S}$ to estimate the error in R

Reading	R (mm)	ΔR (mm)
Bright Fringes Reading 1	519.38	20.62
Dark Fringes Reading 1	517.48	51.26
Bright Fringes Reading 2	521.44	58.80
Dark Fringes Reading 2	511.82	45.27

Taking average of these, we get

$$\boldsymbol{R} = \mathbf{517.53} \pm \mathbf{43.98}\ \mathrm{mm}$$

- Possible sources of errors:
  1. We must choose such fringes whose width are more than the width of crosshair present on the microscope or else we might overshoot or undershoot the reading.
  2. The screw should be turned only in one direction, to avoid the possible backlash error.
  3. The radius of curvature of lens might be small which would not ensure near normal incidence of light.
  4. The monochromatic light source might not be perfect. That would result in multi coloured fringes, and it would be difficult to estimate the tangent position to place the crosshairs on.

If we use white light instead of monochromatic light, we will see the visible spectrum of light in circular fringes, as lights of different wavelengths would interfere at different thicknesses of the air column. Another interesting thing to note is that shape of fringes depends on the shape of the air column. In case of plano-convex lens, its circular, while if we keep a wedge-shaped prism on the glass plate, we will get straight fringes.

VIII. Conclusion:

We conducted this experiment to determine the value of the radius of curvature of a plano-convex lens, which comes out to be $R = 517.53 \pm 43.98$ mm, with a standard deviation of 21.19 mm. We observed the interference of light rays due to reflection from two surfaces and got circular fringes, due to radial symmetry of the air column about the point of contact. Also, the fringes got closer to each other with increase in their order, because, as we move away from the contact point, the thickness of air column increases, so the difference between the radius of two consecutive fringes decreases.

We can also use this experiment to find unknown wavelength of a monochromatic light, by using a plano-convex lens of known radius of curvature or measuring the curvature using spherometer and then conducting this experiment using a monochromatic light of unknown wavelength.

IX. Readings Images:

Bright - 1

Page No.:
Date: / /

Ring No.	X_m (mm)	Y_m (mm)
20	9.40	4.49
19	9.34	4.55
18	9.27	4.61
17	9.21	4.68
16	9.14	4.74
15	9.07	4.82
14	9.00	4.90
13	8.93	4.98
12	8.85	5.06
11	8.77	5.14
10	8.68	5.23
9	8.59	5.31
8	8.49	5.41
7	8.39	5.52
6	8.28	5.62
5	8.17	5.76
4	8.03	5.90
3	7.89	6.05
2	7.70	6.24
1	7.42	6.50

Verified [illegible]

Dark - 1

Ring No.	X_m (mm)	Y_m (mm)
21	9.42	4.46
20	9.37	4.52
19	9.31	4.59
18	9.25	4.65
17	9.18	4.72
16	9.11	4.78
15	9.04	4.86
14	8.96	4.94
13	8.89	5.03
12	8.81	5.1
11	8.73	5.18
10	8.63	5.27
9	8.54	5.36
8	8.44	5.45
7	8.33	5.57
6	8.23	5.68
5	8.04	5.82
4	7.95	5.95
3	7.79	6.14
2	7.58	6.36
1	6.98	6.98

Page No.: Date: / /

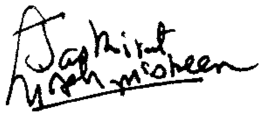
Bright - 2

Ring No	X_m (mm)	Y_m (mm)
21	9.05	4.07
20	8.99	4.18
19	8.92	4.24
18	8.86	4.31
17	8.79	4.38
16	8.72	4.43
15	8.65	4.51
14	8.57	4.59
13	8.49	4.66
12	8.41	4.75
11	8.32	4.85
10	8.24	4.94
9	8.15	5.04
8	8.04	5.13
7	7.92	5.25
6	7.82	5.36
5	7.68	5.49
4	7.54	5.65
3	7.35	5.85
2	7.12	6.10
1	6.50	6.40

Dark - 2.

Ring No	X_m (mm)	Y_m (mm)
20	9.01	4.20
19	8.95	4.25
18	8.89	4.31
17	8.82	4.37
16	8.76	4.44
15	8.68	4.51
14	8.60	4.58
13	8.53	4.66
12	8.45	4.75
11	8.36	4.84
10	8.28	4.93
9	8.19	5.03
8	8.10	5.12
7	7.99	5.23
6	7.88	5.34
5	7.76	5.47
4	7.60	5.61
3	7.43	5.78
2	7.24	6.01
1	6.88	6.35

X. Author Contribution:

Name	Roll Number	Contribution	Signature
Jaskirat Singh Maskeen	23110146	Reading screw gauge, Theory, Error analysis (mathematical part), Finding possible sources of error and conclusion.	
Nishchay Bhutoria	23110222	Index, Aim, Taking readings in lab, Error analysis (computational part), plotting graph using Matplotlib, Cover page.	
Kavya Lavti	23110164	Document structure, Taking readings in lab, Procedure, Theory (screw gauge)	
Kanhaiyalal	23110155	Noting readings, Apparatus Diagrams.