Principles of Physics I (PHY111)

Lab

Experiment no: 8

Name of the experiment: Determination of the wave-length of a monochromatic light by using Newton's rings

YOU HAVE TO BRING A GRAPH PAPER (cm scale) TO DO THIS EXPERIMENT.

Theory

Monochromatic beam of light is a beam where each of the rays has same wave-length.

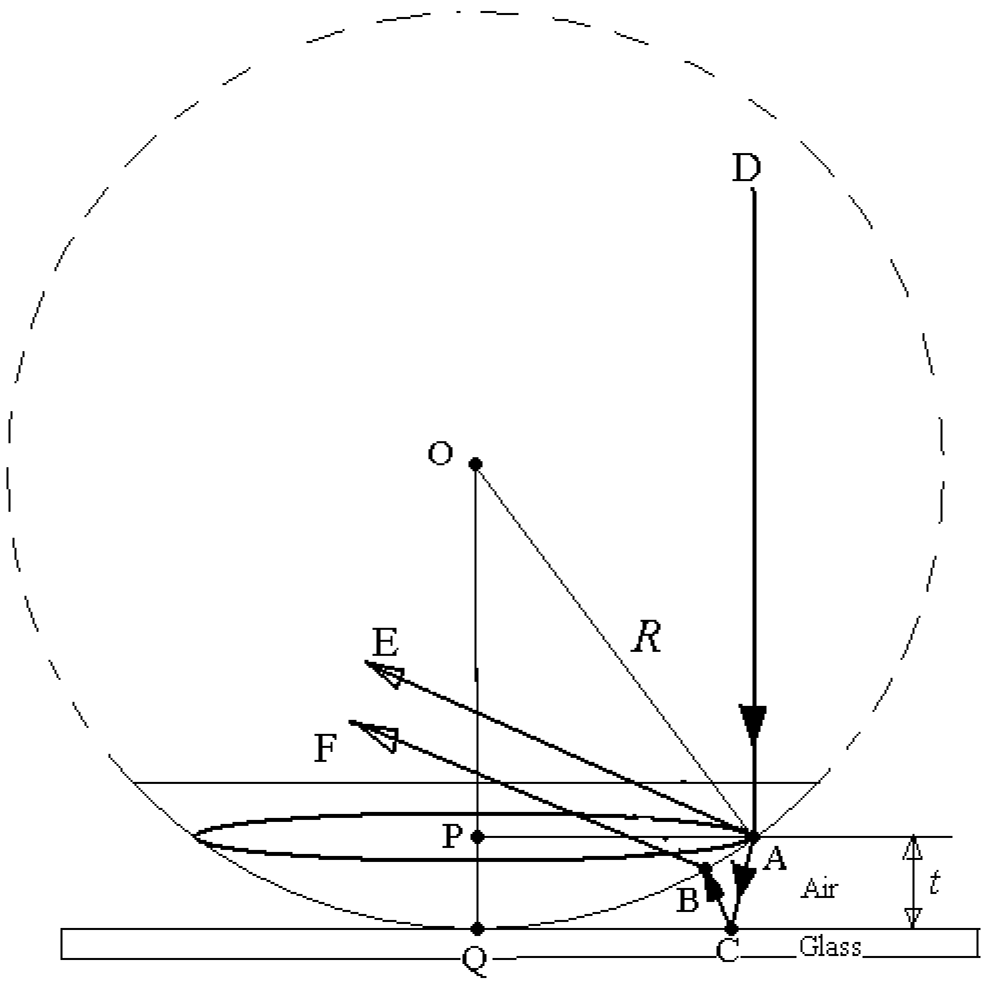

Figure 1: A lens on a plane glass plate

In this experiment we keep a lens on a plane glass. Let the radius of curvature of the lens is OQ = *R*., where O is the centre of curvature. A ray DA is incident on the interface of air and lens at point A. A certain portion of light is reflected along path AE. Another portion of light in refracted to enter air medium along path AC. The ray AC is incident on the interface of air and glass plate at point C. It is reflected along path CB and incident on the interface of air and lens at point B. Then again this ray CB is refracted in lens medium along path BF. Due to the superposition of the rays AE and BF interference occurs. Whether the interference is constructive or destructive depends on the phase shift of two rays. If point A and B are closed to each other we can approximate that $AC \approx BC = t$, where *t* is the thickness of air film between the lens and the glass plate. Obviously the phase shift depends on the *t*.

OQ is normal to the glass plate. AP $\perp$ PQ. Beneath the circle having radius PA and centre P (as shown in figure 1) the thickness, *t* of the air film is same. Therefore, if constructive interference occurs due to the superposition of AE and BF, this circle turns out to be a luminous ring due to the superposition of other pairs of rays originated by other rays like DA which were incident on points along this circle. If the interference is destructive then the circle turns out to be a dark ring

For different values of *t* we find a pattern of successive dark and luminous co-centric rings of different radii which are called Newton's rings.

Now let's see under which condition constrictive and destructive interference occurs.

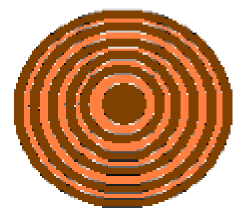

Figure 2: Newton's rings

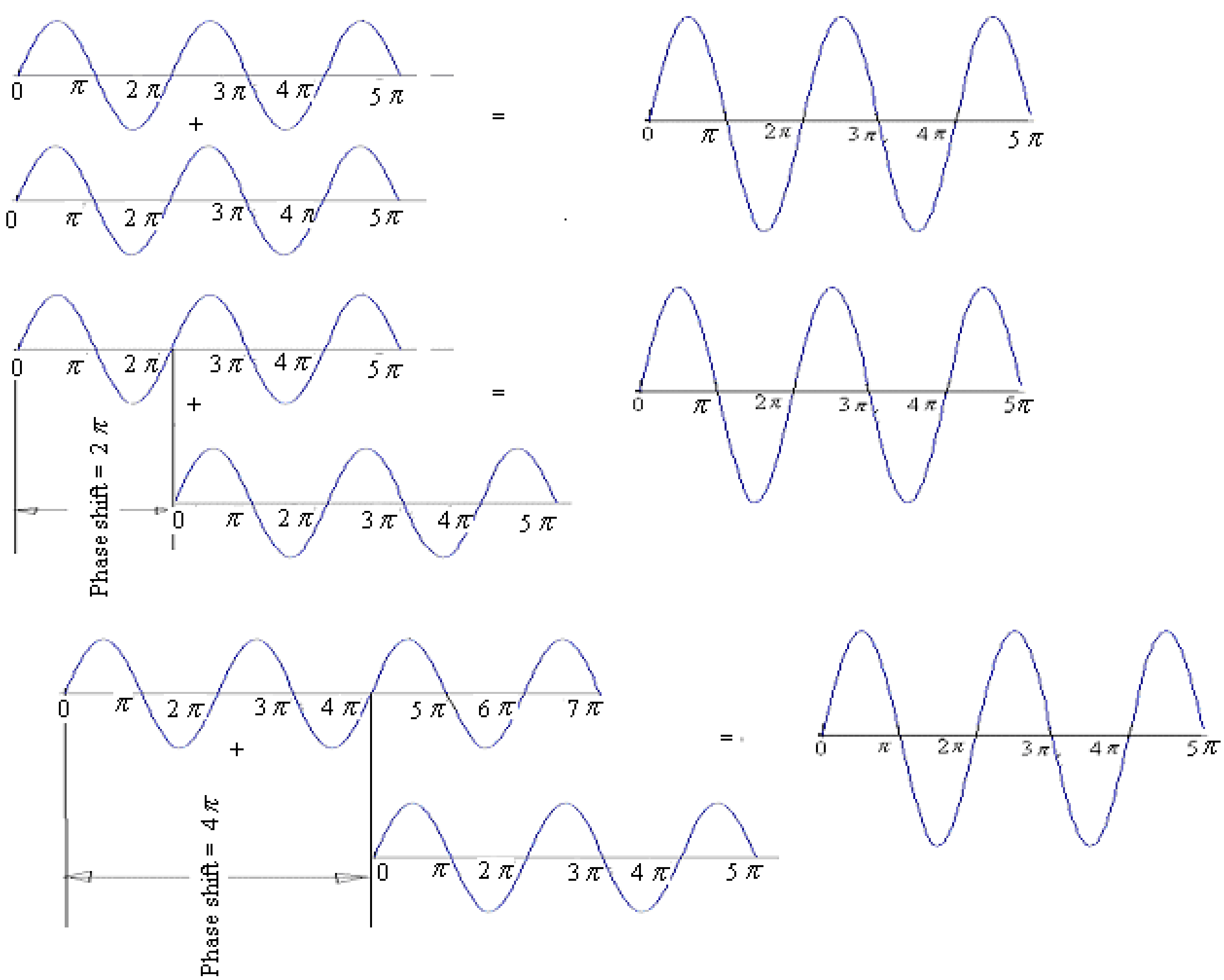

Figure 3: Constructive interference

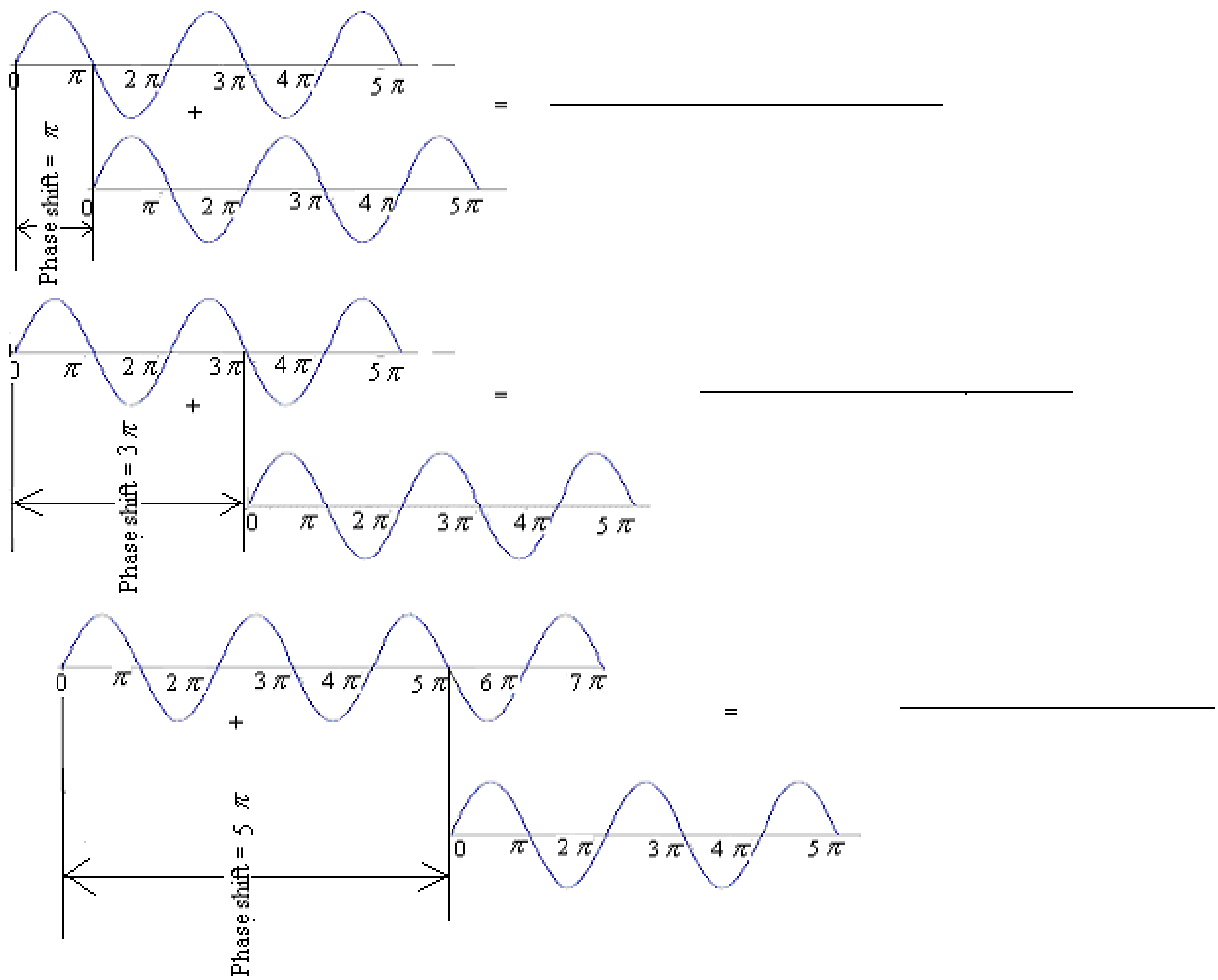

Figure 4: Destructive interference

If the waves which are superimposed are in phase then the amplitude of the resultant wave increases to occur constructive interference. We can easily notice from figure 3 that when the phase shift between the two waves is some even multiple of π (0, 2π , 4π , 6π , etc) then the interference is constructive.

If the waves which are superimposed are out of phase then the amplitude of the resultant wave becomes zero to occur destructive interference. We can easily notice from figure 4 that when the phase shift between the two waves is some odd multiple of π (π , 3π , 5π , etc) then the interference is destructive.

Now the phase shift between two rays of AE and BF occurs due to two reasons:

i) Phase shift due to the path difference between the two rays: From figure 2 we see that the path difference between AE and BF = AC + CB $\approx 2t$ (if A and B are close to each other). Therefore phase shift due to path difference = $\frac{2\pi}{\lambda} \times$ path difference = $\frac{4\pi t}{\lambda}$, here λ = wave length of the light

ii) Phase shift due to the reflection of ray AC on the interface of air and glass: We know that if a ray comes from a media of lower refractive index and moves towards a media of higher refractive index, then a phase sift of π occurs in the reflected ray.

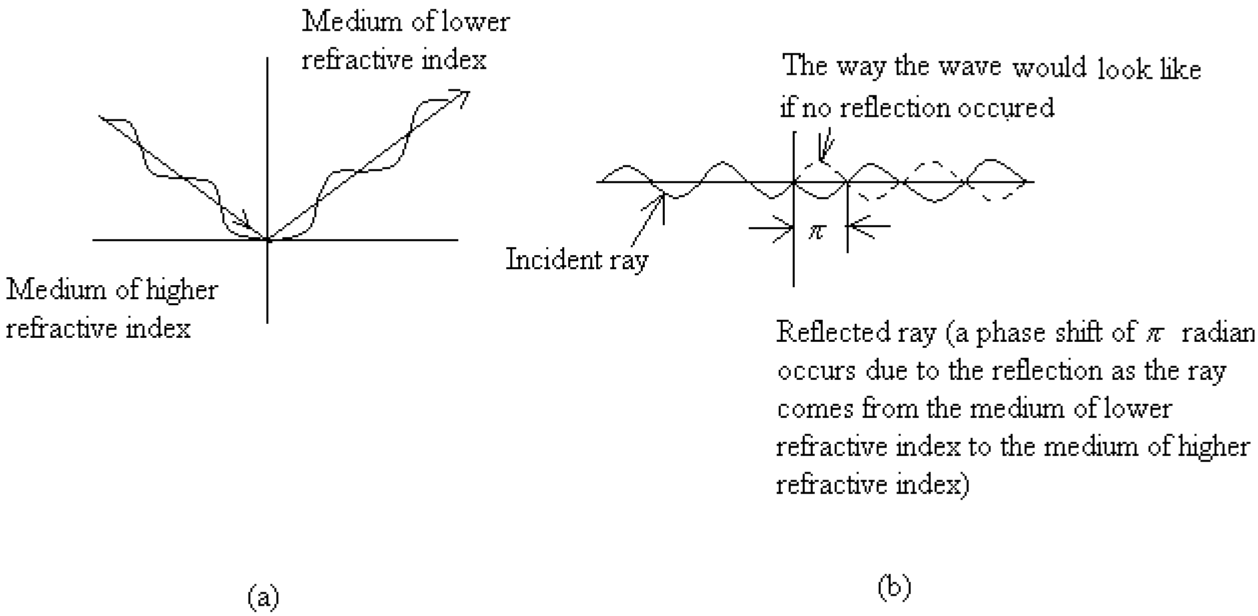

Figure 5: a) A phase shift of π occurs in the reflected ray when the ray comes from a medium of lower refractive index towards a medium of higher refractive index. (b) The incident and the reflected rays are shown on a same line for clarification.

The ray AC comes from air medium and moves towards the glass medium. We know that the refractive index of air is lower than that of the glass. For air refractive index is 1, for glass it is 1.5 (with respect to vacuum). So a phase shift of π radian occurs in the reflected ray CB.

Therefore the total phase difference between AE and BF = $\pi + \dfrac{4\pi t}{\lambda}$ (1)

In figure 1, applying Pythagoras law in triangle OAP:

$OA^2 = OP^2 + PA^2$

=> $R^2 = (R - t)^2 + \left(\dfrac{D}{2}\right)^2 = R^2 - 2Rt + t^2 + D^2/4$

Here D is the diameter of the ring of radius PA and centre P. Now the thickness of air film, t is smaller that R and D. t^2 is much smaller to be negligible. By neglecting t^2 from the above mentioned equation we find, $t = \dfrac{D^2}{8R}$ (2)

Putting it in equation (1)

Total phase difference between AE and BF = $\pi + \dfrac{\pi D^2}{2\lambda R}$ (3)

If the interference is constructive (the ring is bright) then, Total phase difference between AE and BF = 2 $n\ \pi$, where n is an integer (0, 1, 2, 3, 4, etc) (4)

Therefore,

$$\pi + \frac{\pi D^2}{2\lambda R} = 2n\pi$$

$$\Rightarrow \frac{D^2}{2\lambda R} = 2n - 1 \tag{5}$$

For $n = 1$, D represents the diameter of first bright ring, for $n=2$, D represents the diameter of the second bright ring and so on.

To avoid confusion let's put a subscript n at bottom right corner of D to write D_n which means the diameter of n'th bright ring. So for n'th bright ring equation (5) is re written to be:

$$\frac{D_n^2}{2\lambda R} = 2n - 1 \tag{6}$$

Similarly for m'th bright ring ($m \neq n$) we can write

$$\frac{D_m^2}{2\lambda R} = 2m - 1 \tag{7}$$

(7) – (6) →

$$\frac{D_m^2 - D_n^2}{2\lambda R} = 2m - 1 - 2n + 1 = 2(m - n)$$

$$\Rightarrow \lambda = \frac{D_m^2 - D_n^2}{4(m - n)R} \tag{9}$$

If we know the radius of curvature, R of the lens, diameters of two bright rings and the number of the two rings by using equation (9) we can find out the wavelength λ of the monochromatic light.

In this experiment we find out the diameters of different bright rings, and then draw a graph by plotting ring number, n along X axis and corresponding diameter square, D_n^2 along Y axis. It should be a straight line.

The slope of the graph = $\dfrac{D_m^2 - D_n^2}{(m - n)}$

$$\text{So, } \lambda = \frac{slope\ \ of\ \ D_n^2\ \ vs.\ \ n\ \ graph}{4R} \tag{10}$$

Apparatus

Two convex lenses, glass plate, sodium lamp, traveling microscope, etc.

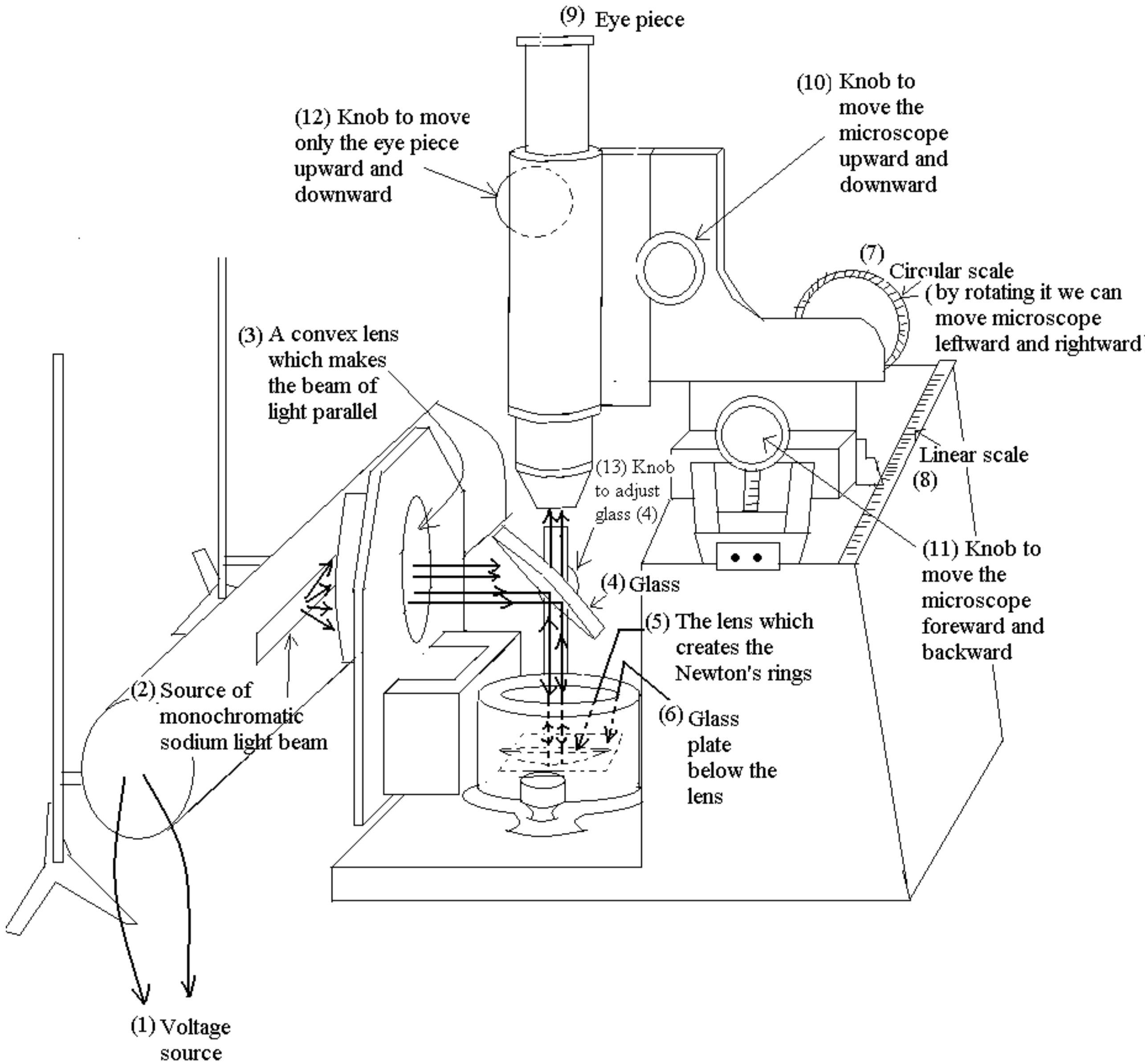

Figure 6: System for the experiment

The arrangement of the apparatus is shown in figure 6. (1) The two wires are connected to a voltage source to illuminate the monochromatic light source (2). (2) is kept at the focus point of a convex lens (3) which makes the beam of light parallel. The parallel beam of light is incident on a plane glass (4) which makes an angle of 45 degree with the horizon. So a portion of the parallel beam of light is reflected along vertically downward. This reflected beam is then again incident on the lens (5) which is kept on plane glass plate (6), and creates Newton's rings. The beams of light along the Newton's rings from (5) again reach the plane glass (4). Some portions of these beams are refracted through (4). Then the beams reach the object-lens of the microscope. Microscope is used to magnify the rings. By keeping our eye on the eye piece we can see the Newton's rings. By adjusting knobs (10), (11), (12) and (13) Newton's rings can be viewed clearly.

Procedure

1. Keep your eye on the eye piece of the microscope. You should see the Newton's rings as shown in figure 2. You should also see a cross-wire. Make sure that initially the two wires intersect at the centre of the central dark circle.

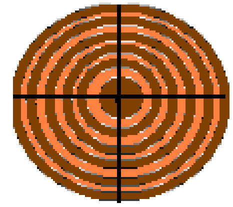

Figure 7

2. By rotating the circular scale (portion (7) in figure 6) you can move the microscope leftward and rightward. See how many numbers of divisions are there in the circular scale. Rotate the circular scale for one complete revolution and see what the displacement of the microscope is along the linear scale for this one revolution. This is the pitch of the system. Write it down in data sheet. Find the least count (L.C.) according to the following equation:

$$L.C. = \frac{Pitch}{No.\ of\ \ divisions\ \ of\ \ circular\ \ scale}$$

. Then write it down in data sheet

3. Rotating the circular scale move the cross-wire leftward of the centre of the rings until the vertical wire comes to a position where it is tangent to the left of the 10^{th} bright ring (as shown in the figure 8). Make sure that the vertical wire passes through the middle of the ring.

4. Now take the measurement of the position of the microscope.

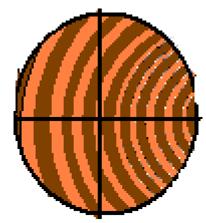

Figure: 8

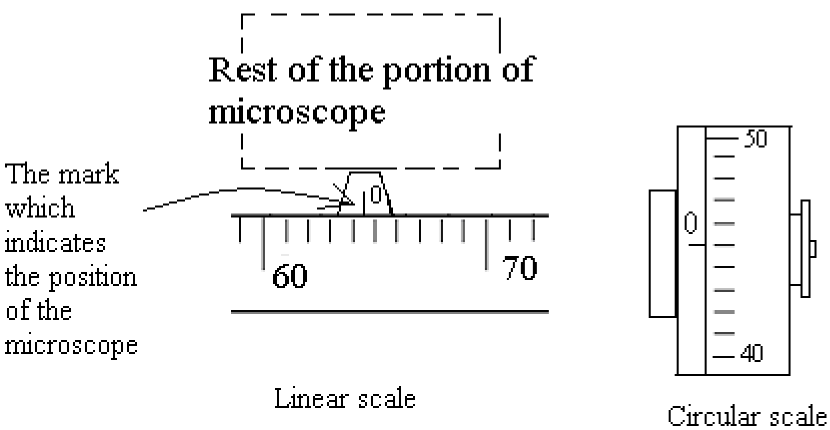

Figure 9

See which mark of the linear scale the microscope has just crossed. The reading of that mark is the linear scale reading. As for example for figure 9 it is 64 mm. Then write it down in the data table. See which mark of the circular scale coincides with the 0 mark adjacent to the circular scale. Multiply least count (L.C.) with the reading of this mark to get circular scale reading. Write it down in the data table. For figure 9, the mark 45 coincides with the 0 mark. So if L.C. is 0.01mm then circular scale reading is 45 $\times$ 0.01 mm = 0.45 mm. Find out the total reading (= linear scale reading + circular scale reading) and write it down in the table. For figure 9: total reading = (64 + 0.45) mm = 64.45 mm

Special case:

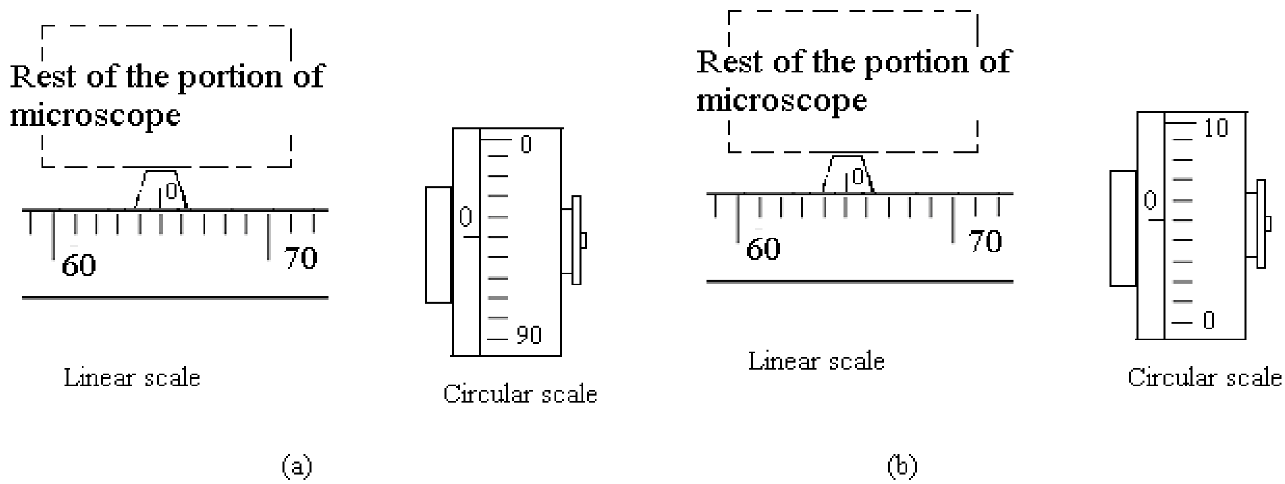

Figure 10

See figure 10. The 0 mark indicating the position of the microscope is very close to mark 65 mm of the linear scale. You can't decide whether the 0 mark has just crossed the 65 mm – mark or it is just about to touch it. In this case see the circular scale. If you see that the circular scale reading is very high (as for example in figure 10 (a) the mark 95 coincides with mark 0), then the microscope has not crossed the 65 mm- mark. So the linear scale reading is 64 mm. On the other hand, if you see that the circular scale reading is very small (as for example in figure 10 (b) the mark 5 coincides with mark 0), then the microscope has crossed the 65 mm-mark. So the linear scale reading is 65 mm.

5. Rotate the circular scale opposite to the previous direction to move the cross-wire right ward of the 10th bright ring and bring the vertical wire to a position where it is tangential to the left side of the 9th bright ring. In the same way as discussed in step 4 measure the position of the microscope and write it down in the table.

6. Rotating the circular scale to the same direction of step 5, gradually move the cross wire right ward, stop where the vertical wire is tangential to the left side of 8th, 7th, 6th, 5th, 4th and 3rd bright ring and take the measurements of the position of the microscope and write them down in the table.

7. Rotate the circular scale to the same direction to move the cross wire right-ward of the rings. Keep rotating until the vertical wire comes to a position tangential to the right side of the 3rd bright ring. Take the measurement of the position of the microscope as discussed in step 4.

8. Rotating the circular scale to the same direction, gradually move the cross wire right ward, stop where the vertical wire is tangential to the right side of 4th, 5th, 6th, 7th, 8th, 9th and 10th bright rings and take the measurements of the position of the microscope and write them down in the table.

9. Find out the diameter, D_n for each bright ring which is the difference between the two measurements of position (at left side and right side of the ring) of the microscope for a certain ring.

10. Draw a D_n^2 vs. n graph which is a straight line. Find out the slope of this line.

11. Know the value of the radius of curvature, R of the lens what you have used.

12. Using equation (10) deduce the wave length of the monochromatic light.

Read carefully and follow the following instructions:

- **Please READ the theory carefully, TAKE printout of the 'Questions on Theory' and ANSWER the questions in the specified space BEFORE you go to the lab class.**
- **To get full marks for the 'Questions on Theory' portion, you must answer ALL of these questions CORRECTLY and with PROPER UNDERSTANDING, BEFORE you go to the lab class. However, to ATTEND the lab class you are REQUIRED to answer AT LEAST the questions with asterisk mark.**
- **Write down your NAME, ID, THEORY SECTION, GROUP, DATE, EXPERIMENT NO AND NAME OF THE EXPERIMENT on the top of the first paper.**
- **If you face difficulties to understand the theory, please meet us BEFORE the lab class. However, you must read the theory first.**
- **DO NOT PLAGIARIZE. Plagiarism will bring ZERO marks in this WHOLE EXPERIMENT. Be sure that you have understood the questions and the answers what you have written, and all of these are your own works. You WILL BE asked questions on these tasks in the class. If you plagiarize for more than once, WHOLE lab marks will be ZERO.**
- **After entering the class, please submit this portion before you start the experiment.**

Name: ______________________ ID: _______________ Sec: ___ Group: __ Date: ___________

Experiment no: ___

Name of the Experiment: ____

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Questions on Theory

*1) Draw the diagram of the lens and the glass plate. Show what happens to a ray of light incident vertically downward on the lens. Explain how the Newton’s rings are formed. [0.5]

Ans:

*2) What is a monochromatic beam of light? [0.5]

Ans:

*3) For which values of phase shift between two superimposing rays does the constructive interference occur? In what condition of this phase shift does the destructive interference occur? [0.5]

Ans:

*4) Mention the reasons which cause the phase shift between the rays AE and BF. [0.5]

Ans:

*5) What is the total phase shift between AE and BF in terms of the thickness of the air, t and the wavelength of the light λ ? [0.5]

Ans:

*6) Find the thickness of the air, t in terms of the radius of curvature of the lens, R and the diameter of the ring, D. [0.5]

Ans:

*7) What is the total phase shift between AE and BF in terms of diameter of the ring, D, wavelength of the light, λ and the radius of curvature of the lens, R? [0.5]

Ans:

*8) Which values can this phase shift have in order to cause constructive interference? [0.5]

Ans:

9) Show that $\lambda = \dfrac{D_m^2 - D_n^2}{4(m-n)R}$ where, D_m and D_n are the diameter of m'th and n'th bright rings respectively. [1]

Ans:

- **Draw the data table(s) and write down the variables to be measured shown below (in the 'Data' section), using pencil and ruler BEFORE you go to the lab class.**

- **Write down your NAME and ID on the top of the page.**
- **This part should be separated from your Answers of "Questions on Theory" part.**
- **Keep it with yourself after coming to the lab.**

Data:

Number of divisions of the circular scale, N = ________________

Pitch = ______________________ mm

Least Count (L.C.) = $\frac{Pitch}{N}$ = ______________ mm

Table 1: Measurement of ring's diameter

Ring number, n	Position of microscope when vertical cross wire is tangent to the left side of the ring			Position of microscope when vertical cross wire is tangent to the right side of the ring			Diameter of the n'th ring, $D_n=\|L-R\|$ (mm)	D_n^2 (mm^2)
	Linear scale reading (mm)	Circular scale reading (mm)	Total reading, L (mm)	Linear scale reading (mm)	Circular scale reading (mm)	Total reading, R (mm)		

Radius of curvature of the lens, R = _________________ mm

Please attach the graph.

- **READ the PROCEDURE carefully and perform the experiment by YOURSELVES. If you need help to understand any specific point draw attention of the instructors.**
- **DO NOT PLAGIARIZE data from other group and/or DO NOT hand in your data to other group. It will bring ZERO mark in this experiment. Repetition of such activities will bring zero mark for the whole lab.**
- **Perform calculations by following the PROCEDURE . Show every step in the Calculations section.**
- **Write down the final result(s).**

Calculations

Result:

- **TAKE printout of the 'Questions for Discussions' BEFORE you go to the lab class. Keep this printout with you during the experiment. ANSWER the questions in the specified space AFTER you have performed the experiment.**
- **Attach Data, Graph, Calculations, Results and the Answers of 'Questions for Discussions' parts to your previously submitted Answers of 'Questions on Theory' part to make the whole lab report.**
- **Finally, submit the lab report before you leave the lab.**

Name: ___________________________ ID: __________________

Questions for Discussions

Discussion

i) Deduce the percentage of error which occurs in the measured value of the wave length of sodium light. The actual value of this wavelength is 5893×10^{-8} cm. [1]

Ans:

ii) What type of difficulty would you face if you tried to measure diameters of the rings of much higher order, say 14^{th} or 15^{th} ring? [0.5]

Ans:

iii) The inner rings (3^{rd} , 4^{th} , etc) are quite thick. Where the vertical wire should be kept while measuring the position of the microscope for these rings? [0.5]

Ans: