Student's name ____

Experiment O2

DETERMINATION OF LIGHT WAVELENGTH USING NEWTON'S RINGS

Objective: determination of light wavelength from interference phenomenon.

1 EQUIPMENT:

1) photographic enlarger;
2) object-glass;
3) Newton's apparatus;
4) screen;
5) sheet of white paper;
6) pencil.

2 THEORY

Interference is the phenomenon which takes place at light waves superposition. As a result of interference, intensity of the resulting wave can be greater or less than the sum of individual waves, depending on the phase shift of the superposed waves. The waves must be coherent to enhance each other in some points (constructive interference) and cancel in other points (destructive interference). Coherent waves have the same frequency, constant phase shift and the same polarization. Throughout the interference pattern, energy of the wave is redistributed.

Phase shift of two waves created by the same source can be caused by the geometrical difference of paths passed by rays

$$\Delta r = r_2 - r_1,$$

where r_1 and r_2 are path lengthes of the first and the second waves, respectively. Optical difference of paths in a medium with refraction index (n>1)

$$\delta = \Delta r n = (r_2 - r_1)n = r_2 n - r_1 n,$$

where $r_1 n$ and $r_2 n$ are optical paths in the medium (the greater is refraction index, the slower the wave propagates through the medium and, effectively, the greater is the phase shift).

Passing from the less optically dense medium to the more optically dense one, in process of refraction on the boundary the wave accuires additional phase shift, equivalent to the loss of halfwavelength $\lambda/2$. This loss may be interpreted as the increase of the optical path by $\lambda/2$ and must be taken into account in calculation of optical difference δ.

Using the notion of path difference, we can find conditions for constructive and destructive interference. If the path difference is any even multiple of $\lambda/2$, then the phase angle is a multiple of 2π, phases of the waves coincide and the interference is constructive. For path differences of odd multiples of $\lambda/2$ the phases of the waves are shifted by $\pi/2$ and the interference is destructive.

Thus, we have the conditions for constructive interference (***maximum intensity***):

$$\delta = \pm m\lambda = 2m\lambda / 2$$

and for destructive interference (***minimum intensity***):

$$\delta = \pm(m + 1/2)\lambda = \pm(2m + 1)\lambda / 2$$

where δ is the optical path difference of the interfering beams of light; m=0,1,2... is a fringe order of interference for ***max*** or ***min***; λ is the wavelength.

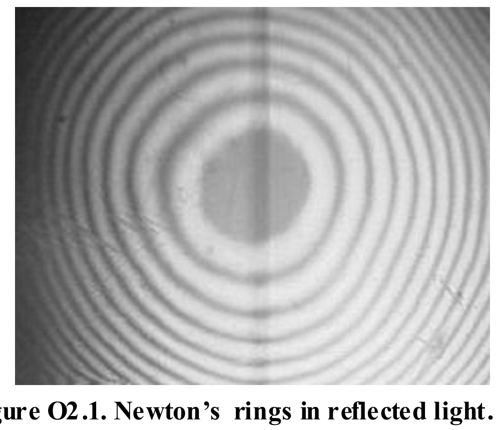

Figure O2.1. Newton's rings in reflected light.

In nature, interference is observed on thin films of soap, oil or petroleum on the surface of water. Newton's rings appear as a series of concentric, alternating light and dark rings formed due to interference between the light waves reflected from the top and bottom surfaces of the air film formed between the convex lens of large curvature and adjacent glass plate (Fig. O2.1). The light rings are caused by constructive interference between the light rays reflected from both surfaces, while the dark rings are caused by destructive interference. One can observe the Newton's rings in incident or reflected light. In our laboratory the interference pattern in incident light is realized.

Dark region can be observed in center of the interference pattern in reflected light (see Fig.O2.1). To explain this fact, one must take into account that one of two interfering waves has the phase shift of π due to reflection from plane of glass, though the geometric difference of paths is absent. Then, total optical path difference is $\delta=\lambda/2$. The pattern in incident light is always reverse to that of reflected light.

Let us consider a convex lens placed on top of a flat surface as an experimental setup and derive the formula for wavelength calculation from interference maximum condition.

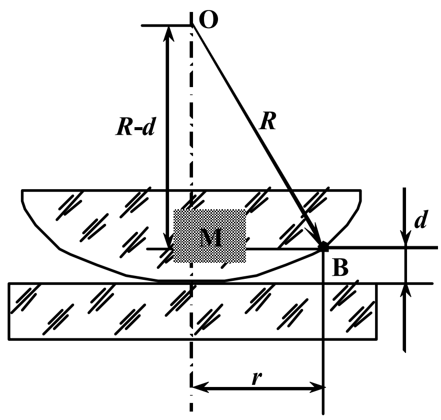

Figure O2.2

Difference of optical paths for *maximum* of intensity in reflected light is

$$\delta = 2d + \lambda/2,$$

and for incident light is

$$\delta = 2d + 2\lambda/2, \qquad \text{(O2.1)}$$

where d is the thickness of the air film between the lens and the plate (see Fig. O2.2.). In our experiment we have incident light, so condition (O2.1) is fulfilled for light rings. Consider triangle **OBM** where **OB**=$\boldsymbol{R}$ is the radius of curvature of the convex lens and **MB**=$\boldsymbol{r}$ is the radius of ring. For this triangle

$$\mathbf{OB}^2 = \mathbf{BM}^2 + \mathbf{MO}^2,$$

or

$$\boldsymbol{R}^2 = \boldsymbol{r}^2 + (\boldsymbol{R} - \boldsymbol{d})^2,$$

$$\boldsymbol{R}^2 = \boldsymbol{r}^2 + \boldsymbol{R}^2 - 2\boldsymbol{dR} + \boldsymbol{d}^2.$$

As we choose the lens of large curvature, $\boldsymbol{d} \ll \boldsymbol{R}$ and one may neglect $\boldsymbol{d}^2$. Then

$$2dR = r^2,$$

and

$$d = r^2/2R.$$

Now the value of $\boldsymbol{d}$ can be substituted into formula (O2.1) to obtain

$$\delta = r^2/R + 2\lambda/2.$$

From the interference condition we have for the maximum intensity:

$$\delta = (2m+1)\lambda/2,$$

so that

$$r^2/R + 2\lambda/2 = (2m+1)\lambda/2.$$

Simplifying the above equation we obtain

$$r^2/R = m\lambda - \lambda/2. \qquad \text{(O2.2)}$$

It is convenient to measure radii of two different rings $\boldsymbol{r_i}$ and $\boldsymbol{r_k}$ of the same color to calculate the wavelength. Then formula (O2.2) for $\boldsymbol{i}^{\text{th}}$ and $\boldsymbol{k}^{\text{th}}$ rings is written as:

$$r_i^2/R = (i - 1/2)\lambda, \qquad \text{(O2.3)}$$

$$r_k^2/R = (k - 1/2)\lambda. \qquad \text{(O2.4)}$$

From equations (O2.3) and (O2.4) one has

$$r_i^2 - r_k^2 = (i-k)\lambda R,$$

and, finally

$$\lambda = \frac{(r_i - r_k)(r_i + r_k)}{(i-k)R}. \qquad \text{(O2.5)}$$

3 DESCRIPTION OF EXPERIMENTAL APPARATUS

In the experimental setup a photo-enhancer is used. Optical arrangement is shown in Fig. O2.3. Light from the bulb lamp **L** passes through condensor **C** to the Newton' apparatus **A**. Condensor forms a parallel light beam. Newton's apparatus includes a convex lens of large curvature placed on top of a glass plate. Object-lens **O** projects the obtained Newton's rings onto screen **S**. Distance between the Newton's apparatus and object-lens is ***a***, ***b*** is the distance between the object-glass and screen.

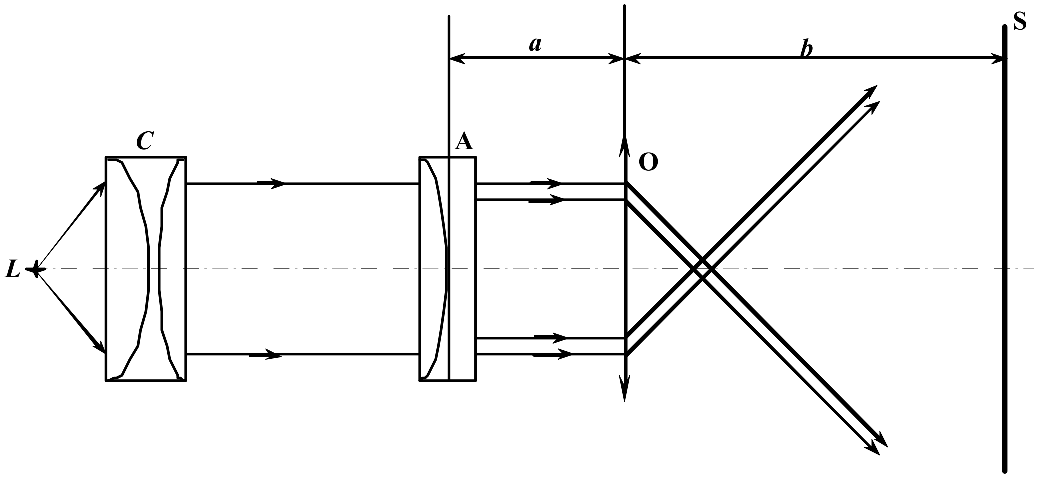

Figure O2.3

4 PROCEDURE AND ANALYSIS

4.1 Turn on the experimental apparatus. Obtain a clear image of Newton's rings on the screen. Place a sheet of paper onto the screen and mark positions of intensity maxima of some color (red, for example) for a few rings (not less then five).

4.2 Measure the radii of marked rings (note that these are observed rings, enlarged by the object-lens, but not actual ones).

4.3 Calculate the radii r' of the actual rings by formula

$$r' = \frac{a}{b} r_n$$

where r_n is the radius of the ring observed on the screen, ***a*** is distance between the Newton's apparatus and object-lens, ***b*** is distance between the object-lens and screen.

Calculate the radii of four or five actual rings. Take pairs of r values and calculate 3 values of λ by formula (2.5). To attain an exact result it is reasonable to take r for rings as far one from another, as possible, for example, r_1 and r_5; r_2 and r_5; r_1 and r_4.

4.4 Fill the tables O2.1 and O2.2 with the results of measurements and calculations.

Table O2.1

N	1	2	3	4	5
r_n, mm					
r'_n, mm					

Table O2.2

i	k	r_1, mm	r_k, mm	λ, nm	$\Delta\lambda$, nm	ε, %
Mean values						

4.5 Estimate the absolute and relative errors.

4.6 Represent the final result as

$$\lambda = (\lambda_{mean} \pm \Delta\lambda_{mean})\ \text{nm}.$$

4 CONTROL QUESTIONS

1. What is light interference?
2. What are conditions for minimum and maximum of interference?
3. What is called the Newton's interference apparatus?
4. Explain the construction of experimental apparatus?
5. What is difference between interference patterns in monochromatic and white light?