EXERCISE 81	DETERMINING THE LENS CURVATURE RADIUS AND THE LIGHT WAVELENGTH USING NEWTON'S RINGS

Exercise Objective: Observation of interference fringes of equal thickness, using this phenomenon for measurement purposes.
Topics: The phenomenon of light interference, interference fringes of equal thickness, Newton's rings.

1. Introduction

Light has a dual particle-wave nature. The wave nature of light manifests itself in the phenomenon of interference. Light waves, like any electromagnetic waves, can overlap according to the principle of superposition. According to this principle, the total effect of several independent influences is the sum of the effects caused by each influence separately.

The principle of superposition, as well as the term "interference", was introduced in 1801 by Thomas Young. When waves with the same frequency and constant path difference (coherent waves) overlap, a characteristic interference pattern is observed: alternation of light (maxima) and dark (minima) fringes. This spatial redistribution of light flux as a result of the superposition of coherent waves, with maxima occurring in some places and minima in others, is called light interference.

More information about wave interference can be found in https://phys.libretexts.org/Courses/Muhlenberg_College/Physics_122%3A_General_Physics_II_(Collett)/12%3A_Waves/12.06%3A_Interference_of_Waves

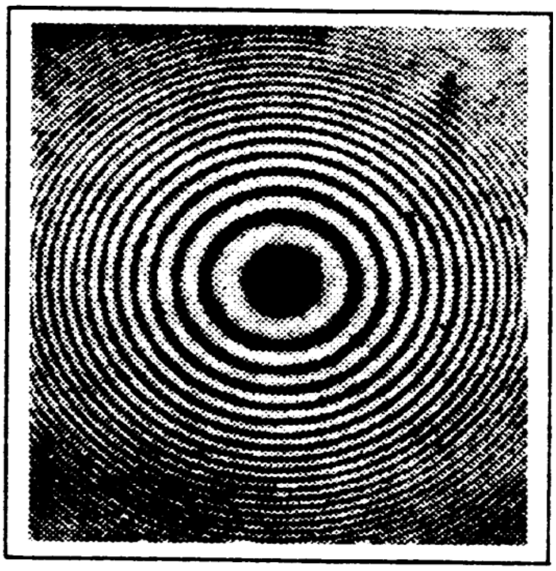

Fig. 1. Image of Newton's fringes.

A special case of interference is so-called Newton's rings. They can be easily observed if a plano-convex lens is placed on a flat glass plate, called an optical flat (as in Fig.2). An air wedge of varying angle is created between the flat surface of the gauge and the spherical lens. The interference fringes of equal thickness formed in such a wedge are circular (Fig.1). As the distance from the central, dark fringe (or rather, disk) formed at the point of contact between the two surfaces increases, the subsequent fringes become closer and closer together until they are no longer distinguishable.

Note: Sometimes the zero line may be light, indicating that the two surfaces are not adhering. This is usually caused by surface contamination, such as traces of grease or dust, which must be removed.

2. Principle of measurement and measurement system

The principle of measuring the radius of curvature of a lens R_s (or the wavelength of light λ) is based on the direct measurement of the diameter of a specific circular interference fringe. In practice, only the dark fringes are measured. They are narrower than the bright fringes, which improves the accuracy of the measurement. Relationship for the ordinal number of the fringes is:

$$h_K = \frac{K\lambda}{2}, \qquad K = 0,\ 1,\ 2\ , \tag{1}$$

where h_k is the wedge height for the K^{th} dark fringe, and λ is the wavelength in air. The height difference $\Delta h = h_{K+1} - h_K$ between successive fringes K+1 and K is $\lambda/2$. The interference fringes are therefore contour lines defining the height increase by λ/2. Using Fig. 2, we can write

$$(R_s - h_K)^2 + r_K^2 = R_s^2.$$

Hence

$$R_s = \frac{r_K^2 + h_K^2}{2h_K}\ ,$$

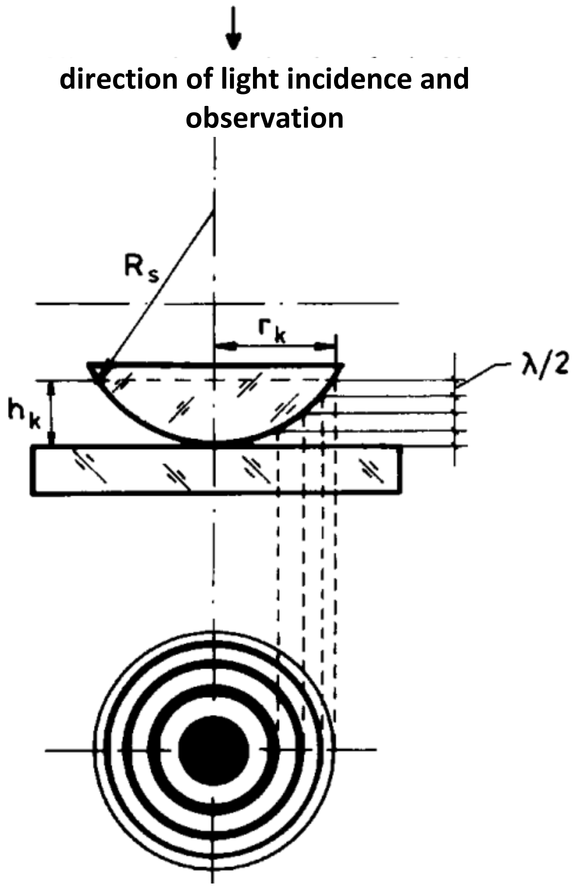

Fig.2. Interference fringes are arranged in a contour pattern.

and after substitution (1)

$$R_s = \frac{r_K^2 + h_K^2}{K\lambda}\ .$$

The value r_K^2 is generally several million times larger than h_K^2, so without making any appreciable error one can finally write in approximate form

$$R_s = \frac{r_K^2}{K\lambda}\ , \qquad K = 0,\ 1,\ 2 \tag{2}$$

Knowing the radius r_K of the K^{th} circular fringe, the radius of curvature of the lens R_s can be calculated. To do this, use an appropriate device that allows the convenient observation of the fringes and measurement of their diameters.

In the simplest case, when the fringes are not dense, a simple millimeter scale placed on the top surface of the plate can be used to measure the diameter. Of course, with such a simple device, high measurement accuracy should not be expected. This accuracy can be significantly improved by adapting a suitable microscope for the measurements. The optical diagram of one possible solution is shown in Fig. 3.

We will use such a device during laboratory exercises. It is a microscope with a plane-parallel glass plate P placed on a table. A plano-convex lens to be measured is placed on this plate. Both elements are illuminated by a parallel beam of monochromatic light through the microscope objective using an illuminator O with a monochromatizing filter F, a lens, and a semi-transparent mirror Z placed above the microscope objective.

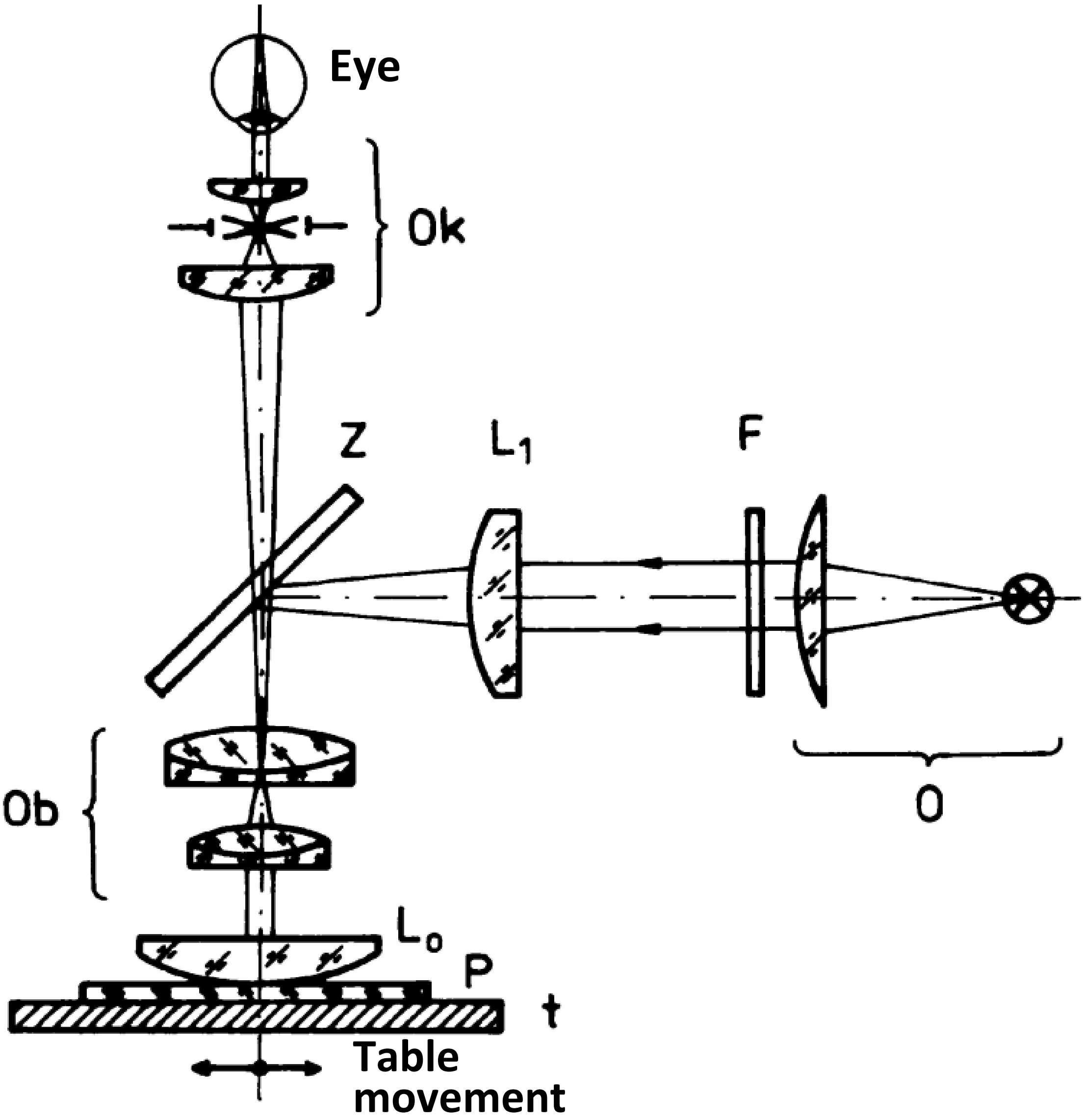

Fig. 3. Schematic diagram of a microscope for measuring Newton's rings: t – sliding microscope stage, P – glass plane-parallel plate, L_0 – measured lens, Ob – microscope objective, Z – semi-transparent mirror dividing the light, Ok – eyepiece, O – illuminator, F – replaceable filter, L_1– lens.

The Ok microscope eyepiece is equipped with a crosshair. An image of Newton's interference fringes is formed in the plane of this crosshair.

In Fig. 3, arrows indicate the direction of movement of the microscope stage. The amount of movement is measured with a dial gauge.

3. Tasks to be performed

A) Measurements

In this exercise, determine the radius of curvature R_s of the lens indicated by the teacher and the wavelength λ of light transmitted through the monochromatic filter indicated by the teacher. To do this, you must:

– Set the microscope on its stand so that the illuminator is approximately on the condenser axis L (Fig.3).

– Wash the surfaces of the lens and the plane-parallel plate with alcohol, wipe them dry with a clean flannel, and blow them with a rubber bulb.
– Place the lens to be measured on the plate so that its convex side is in contact with the plate and place them on the microscope stage.

The stage should be set in the center position. Try to direct the lens so that the central (zero) dark fringe falls approximately in the center of the microscope's field of view. Adjust the microscope to focus on the fringe image.

Determining the lens curvature radius R

Measure the diameters of at least five dark bands with the largest possible diameters. This can be done as follows:
– By turning the stage screw, count the number of successive dark fringes moving (e.g., to the left) across the vertical line of the cross. Each fringe corresponds to a specific interference order K.
– Align the center of the K^{th} selected fringe with the vertical arm of the cross and read the sensor reading a_1. By moving the stage in the opposite direction, read the reading a_2 for the same fringe. The difference between the two readings gives the diameter of this fringe; its radius is $r_K = 0{,}5\ |a_1 - a_2|$. Calculate the lens curvature radius R_s. Repeat the measurement r_K of the given fringe several times and determine the accuracy of this measurement.
– Present the results of the measurements, calculations, and error determinations in a table.

Determining the wavelength of light

Knowing the R_s value of the lens's radius of curvature, it can be used to measure the wavelength λ of the interference filter. To do this:
– Place the interference filter under test on the microscope illuminator and measure (as above) the diameter of the K^{th} dark fringe. Determine the measurement error for the radius r_K. Repeat the measurement several times for different values of K.
– Using the already known value of R_s, calculate (from 2) the wavelength λ for different values of r_K
– Present the measurement and calculation results in a table. Provide sample calculations separately.

B) Error Assessment

When discussing errors, the accuracy of the readings should first be assessed, then the relative and absolute error in determining the radius R_s should be calculated. When calculating the error $\Delta\lambda$, the error ΔR_s should also be taken into account.

Prepared by A. Kubica

Translated to English by Liudmyla Filevska