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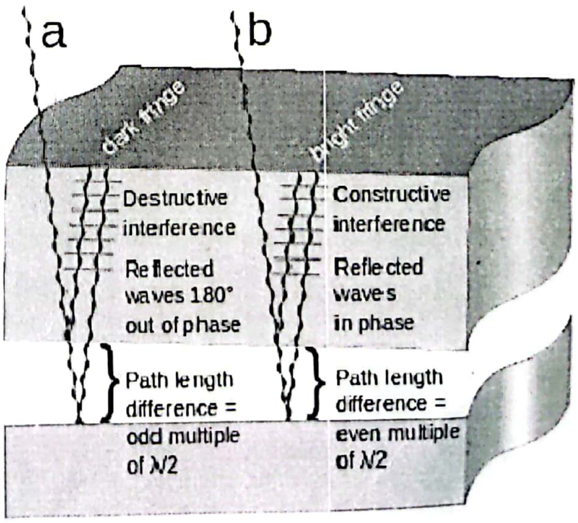
Experiment # 3

Newton's Rings Experiment

Introduction:

Newton's rings is a phenomenon in which an interference pattern is created by the reflection of light between two surfaces, a spherical surface and an adjacent flat surface. It is named after Isaac Newton, who first studied them in 1717. When viewed with monochromatic light, Newton's rings appear as a series of concentric, alternating bright and dark rings centered at the point of contact between the two surfaces. 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.

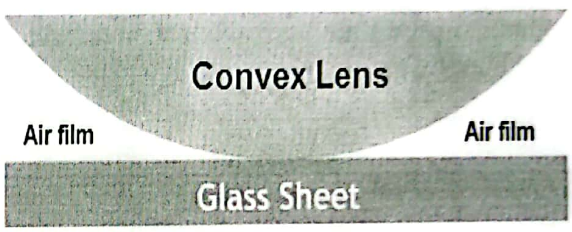
How the interference fringes form. Note that the figure has the sign of the interference backward. There's a sign change in the fields reflected at the second interface but not at the first interface, reversing the interference pattern from that shown. The limiting case, at the center of the pattern, is equivalent to no gap, and hence like a continuous, non-reflecting medium, consistent with the famous dark reflection spot, as seen in the picture on the right.



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. Also, the outer rings are spaced more closely than the inner ones. Moving outwards from one dark ring to the next, for example, increases the path difference by the same amount, λ, corresponding to the same increase of thickness of the air layer, $\lambda/2$. Since the slope of the convex lens surface increases outwards, separation of the rings gets smaller for the outer rings. For surfaces that are not spherical, the fringes will not be rings but will have other shapes.

The production of Newton's rings is fundamentally based on such thin air film interferences. When a Plano-convex lens is placed on a plane glass surface, with its convex surface facing the glass, an air film of increasing thickness is formed between the lower surface of the lens and the upper surface of the glass surface. A air film is considered to be thin when its thickness is of the order of the wavelength of light.

The thickness of the film at the point of contact is zero and increases from the centre towards the edge of the lens. The point at which the thickness of the air film is constant is at the central point of contact.



As a result of this air film, when parallel light is normally incident on the flat side of the convex lens, it is partially reflected from the lower surface of the lens and the upper surface of the glass. The reflections of interest are those involving the surfaces in contact, reflections from top of the lens and bottom of the glass do not contribute to the pattern.

The reflected waves do not experience a change of phase at the lens-air boundary as the light is propagating through a higher refractive index medium to a lower refractive index medium. In contrast, the light that is transmitted past to the air-glass boundary is reflected with a change of phase of 180° as the air has a lower refractive index than the glass.

As a result, both of the reflected waves from the contact boundary travel in the same direction and are coherent because they are derived from the same incident wave by division of amplitude.

The interference between the reflections produces a concentric ring pattern of spectrum colors for white light, or alternate dark and light rings in monochromatic light. The interference rings can be observed both in reflection and in transmitted light. These concentric rings are called Newton's rings. The distances between the interference rings are not constant as the convex boundary is curved.

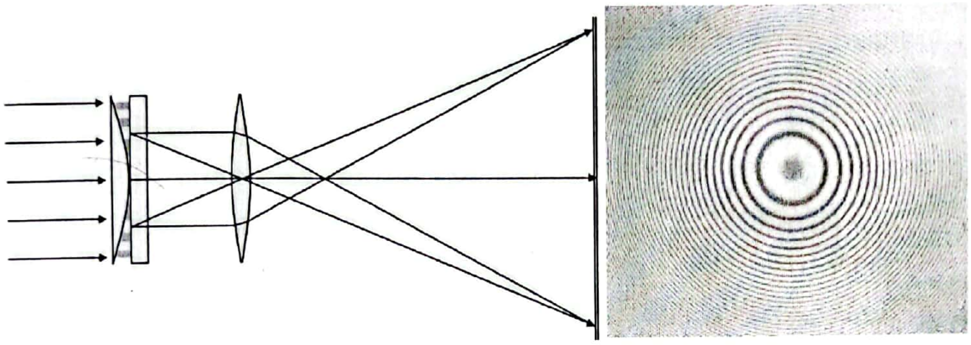


Figure 6: Diagram for formation of Newton's rings through the transmission of light.

The radius of curvature of the convex lens 'R', is related to the radius of the flat surface 'r' and the thickness of the air film 't' by:

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

The radius of the m^{th} bright fringe is given by:

$$r_m = \sqrt{R(2m+1)\frac{\lambda}{2}}$$

The radius of the m^{th} dark fringe is given by:

$$r_m = \sqrt{mR\lambda}$$

The radius of a dark ring is proportional to the square root of the radius of the curvature of the lens.

The diameter , D_m , of the m^{th} fringe from the center is related to the radius of curvature, the refractive index, n_x, of the medium between the lens and glass, and the wavelength λ of the light by:

$$D^2{}_m = \frac{4R\lambda m}{n_x}$$

Central spot is dark in newton's rings experiment because At the point of contact the path difference is zero but one of the rays is reflected so the effective path difference becomes λ/2 thus the condition of minimum intensity is created hence it is a dark spot.

Apparatus:

1 Newton rings apparatus	08550-00
2 Lens, mounted, f = +100 mm	08020-01
1 Interference filters, set of 3	08461-00
1 Screen, translucent, 250 x 250 mm	08064-00
1 Lamp, f. 50 W Hg high press. lamp	08144-00
1 Power supply for Hg CS/50 W lamp	13661-97
2 Lens holder	08012-00
4 Slide mount f. opt. pr.-bench, h = 30 mm	08286-01
1 Slide mount f. opt. pr.-bench, h = 80 mm	08286-02
1 Optical profile-bench, l = 1000 mm	08282-00
2 Base f. opt. profile-bench, adjust.	08284-00
1 Rule, plastic, l = 200 mm	09937-01

Procedure:

The optical setup used to produce a Newton's rings interference pattern, through transmission of light, to find the radius of curvature and the wavelength of the incoming monochromatic light is shown by the optical bench below:

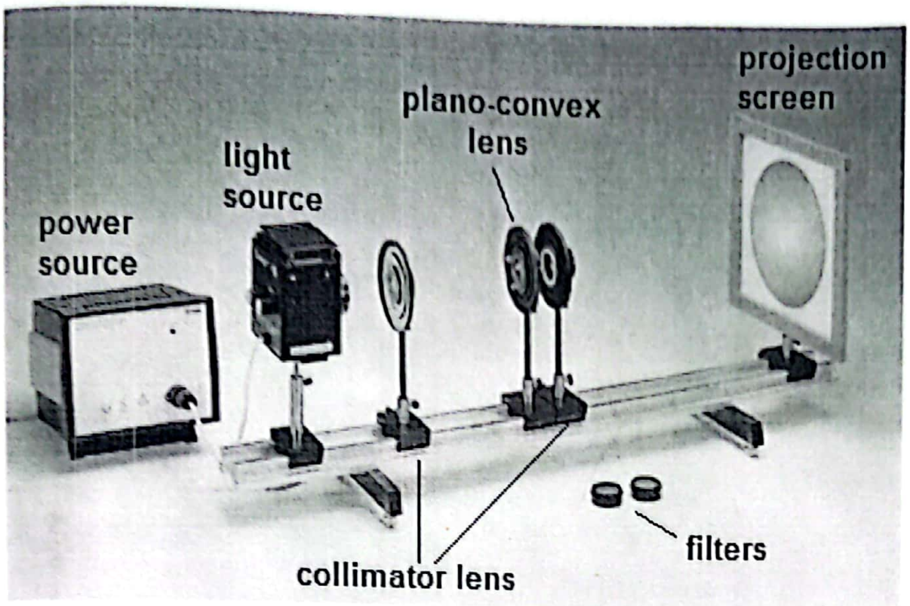


Figure 8: Diagram of set up on optical bench.

The light source is connected to the power supply and fixed on the optical bench, aligned with the three lenses. The Plano-convex lens with the plane glass surface was placed in between two collimator lenses. This lens produced the interference pattern, whilst the collimator lenses either side of it aligned the incident light in order to replicate the source at an infinite distance. This made the incident light parallel, first into the plano-convex lens and then again for the projection screen. The Plano-convex lens has a ruled scale of 20mm printed on it which is also projected.

The projection screen allowed the interference pattern to be observed by viewers. A larger projection screen, such as a plain wall, was not required as rings up to the 10^{th} order fitted within the range of the screen. The experiment was conducted in full covers from external light in order to prevent light attenuation, allowing the projection of light to be as bright as possible.

The experiment used three different colored filters, blue, green and red, with stated wavelengths of 437nm, 546nm and 578nm respectively. The radius of curvature of the Plano-convex lens was stated to be 12.13 ± 0.005m.

R = Radius of curvature

First, the experiment looked to confirm these claimed filter wavelengths with the known radius of curvature value of the lens and the refractive index value of air. Equation was used with λ as the subject:

Dm = Diameter
n_x = Refractive Index

$$\lambda = \frac{n_x D^2{}_m}{4Rm}$$

Each of the three filters was individually tested. They were attached to the first collimating lens by inserting them into the lens bracket. The optical bench allowed the lenses to be moved at varying distances until the projection of the interference pattern was in focus.

The distances had to be adjusted for different filters to achieve a focused projection. However, once the vertical position settings of the lenses were fixed to align them with the optical axis, they were not adjusted in any trials. The screws that tightened the lenses in place were fixed to a limit such that they did not provide excessive contact pressure and risk deformation of the lenses. The filters were allowed to cool from the heat of the light before being handled.

Measurements of the diameters of the dark rings up to the 10th order were recorded for each filter using the ruled scale. The maximum order of rings was measured to 10th as the rings of higher orders were not well defined and thus could not be distinguished adequately. The diameters were measured as opposed to the radii because they are the larger lengths; this reduced the relative instrumental error of the measuring scale. The measurement was taken from the middle of the ring's thickness.

Due to the limited resolution of the scale, a plain sheet was attached to the projection screen and the edges of each ring were marked on to it along with the ruled scale. This allowed the marked diameters to be measured more accurately by a ruler with consideration of the scale conversion. This was repeated for all three filters.

Lastly, the data recorded was then used to calculate the radius of curvature of the lens by assuming that the stated wavelengths of the filters are correct using equation with R as the subject:

$$R = \frac{n_x D^2{}_m}{4\lambda m}$$

Result:

Blue Filter (λ: 436nm)						
Order m	Diameter D_m ± 0.25 (mm)	Theoretical Diameter D_{mT} (mm)	Wavelength λ (nm)	Error in wavelength %	Radius of curvature R (m)	Error in radius %
1						
2						
3						
Green Filter (λ: 546nm)						

Order m	Diameter D_m ± 0.25 (mm)	Theoretical Diameter D_{mT} (mm)	Wavelength λ (nm)	Error in wavelength %	Radius of curvature R (m)	Error in radius %
1						
2						
3						

Red Filter (λ: 578nm)

Order m	Diameter D_m ± 0.25 (mm)	Theoretical Diameter D_{mT} (mm)	Wavelength λ (nm)	Error in wavelength %	Radius of curvature R (m)	Error in radius %
1						
2						
3						