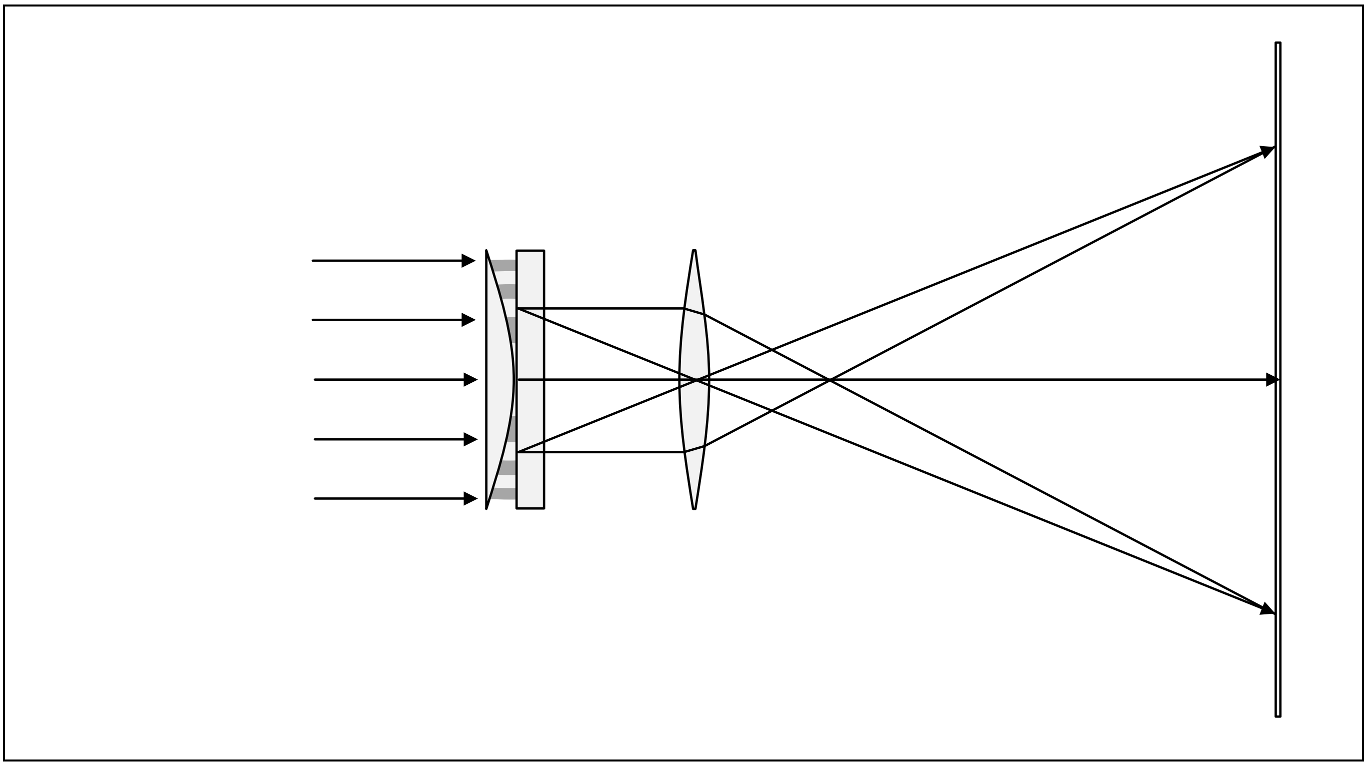
Newton's Rings in Transmitted Monochromatic Light

Objects of the experiment

- To demonstrate Newton's rings in transmitted light as a system of interference rings between a flat glass plate and a planoconvex lens.
- To determine the bending radius of the planoconvex lens by measuring the Newton's rings when illuminating with the yellow light of the sodium spectrum.
- To investigate the dependency of the Newton's rings on the wavelength of the light by illuminating with monochromatic light from the mercury spectrum.

Principles

In creating Newton's rings, a very slightly curved convex lens is placed so that it touches a flat glass plate. This forms a wedge of air with one spherically curved boundary surface. When this arrangement is illuminated with normally incident parallel light, concentric interference rings are formed around the point at which the two surfaces touch. We can observe these interference rings both in reflection and in transmitted light The distances between the interference rings are not constant, as one of the boundary surfaces of the "air wedge" is curved.



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Apparatus

1 Glass plates for Newton's rings	471 11
2 Lenses in holder, f = + 100 mm	460 03
1 Iris diaphragm in holder	460 26
1 Holder with spring clips	460 22
1 Optical bench, 1 m, standard cross-section	460 32
6 Optics riders, H = 60 mm, W = 36 mm	460 353
1 Spectral lamp, Na	451 111
1 Spectral lamp, Hg	451 062
1 Housing for spectral lamp	451 16
1 Universal choke	451 30
1 Mercury light filter, yellow	468 30
1 Mercury light filter, green	468 31
1 Mercury light filter, blue	468 32
1 Translucent screen	441 53
1 Saddle base	300 11

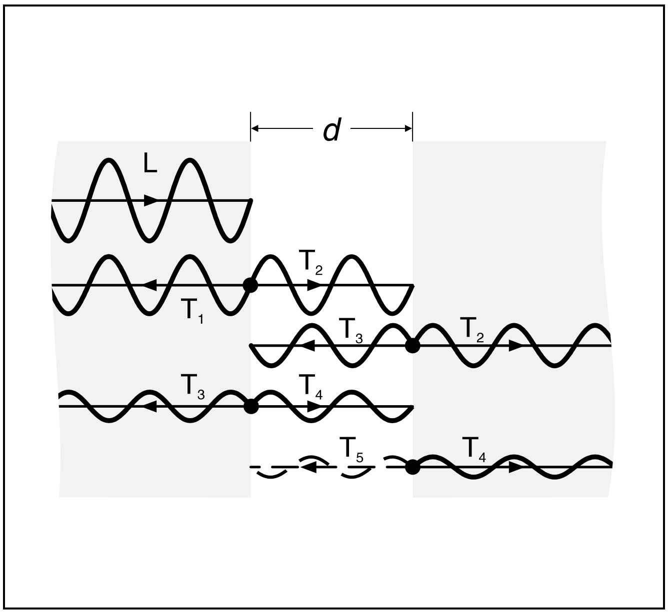


Fig. 1: Schematic representation of the interference at a wedge of air

In Fig. 1, a light wave L coming from the left strikes an air wedge with the thickness d between two glass plates. The partial wave T_1 is reflected at the left-hand boundary surface between the glass plate and the air wedge. The partial wave T_2 passes through the air wedge. The reflection of partial wave T_3 at the right-hand boundary surface occurs in conjunction with a phase shift, as this involves reflection at a medium with a higher refractive index. Partial wave T_4 is first reflected at the right-hand boundary surface and then at the left-hand boundary surface, and its phase shifts each time. Additional partial waves, here represented with T_5, are created by multiple reflection in the air wedge, with the corresponding phase shifts. We can now observe the interference of the partial waves T_1, T_3 and further partial waves in reflection, and T_2, T_4 and further partial waves in transmitted light.

The path difference Δ between T_2 and T_4 is

$$\Delta = 2\,d + 2 \cdot \frac{\lambda}{2} \qquad \text{(I).}$$

The condition for constructive interference

$\Delta = n \cdot \lambda$ where n = 1,2,3 …

is thus fulfilled when

$$d = (n-1) \cdot \frac{\lambda}{2} \quad \text{where n = 1,2,3 …} \qquad \text{(II)}$$

When the two glass plates are touching, i.e. for $d = 0$, constructive interference always occurs in the direction of propagation, regardless of the wavelength of the incident light. In reflection, we always observe extinction in this case due to the simple phase shift of T_3. At a finite distance, the interference depends on the thickness d of the air wedge and the wavelength λ of the light. For the air wedge bounded by a convex lens, and for transmitted light, the situation is as follows:

The thickness d is dependent on the distance r from the point of contact between the convex lens and the glass plate, as well as on the bending radius R of the convex lens. Fig. 2 illustrates the relationship

$R^2 = r^2 + (r - d)^2$,

from which we derive the relationship

$$d = \frac{r^2}{2\,R} \qquad \text{(III)}$$

for small thicknesses d. The rings of constructive interference, i.e. the bright rings, can thus be calculated from

$$r_n^2 = (n-1) \cdot R \cdot \lambda \quad \text{where } n = 1, 2, 3 \ldots \qquad \text{(IV)}$$

As the planoconvex lens is compressed slightly at the point of contact due to the contact pressure, we must modify equation (III) accordingly. A better approximation of the actual relationships is

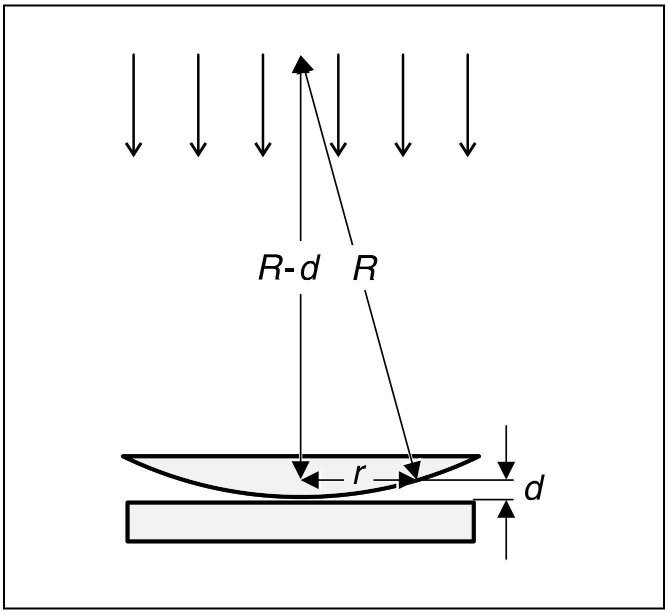
$$d = \frac{r^2}{2\,R} - d_0 \quad \text{for} \quad r \geq \sqrt{2\,Rd_0}\ . \qquad \text{(V)}$$

For the radii r_n of the bright interference rings, the relationship

$$r_n^2 = (n-1)\,R\,\lambda + 2\,R\,d_0 \quad \text{where } n = 2, 3 \ldots\ . \qquad \text{(VI)}$$

applies.

Fig. 2: Schematic representation of the “air wedge” between the glass plate and the planoconvex lens



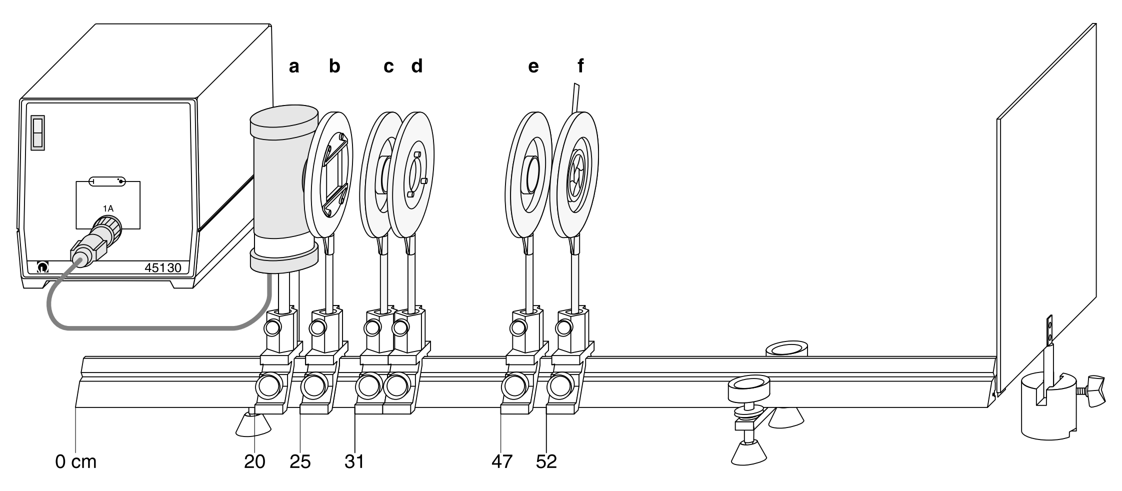


Fig. 3: Experiment setup on the optical bench with positioning specifications in cm for the left-hand edge of each optics rider

(a) Na (or Hg) spectral lamp
(b) Object holder
(c) Lens, f = 100 mm
(d) Plates for Newton’s rings
(e) Lens, f = 100 mm
(f) Iris diaphragm

Setup

Note: darken the room as much as possible when carrying out measurements.

Plates for Newton’s rings:

- Hold the “plates for Newton’s rings” in front of a bright background and observe them in reflected light. Completely loosen the three knurled screws first.
- Carefully tighten the knurled screws until
  a) the glass plates touch (i.e. no more interference rings emerge from the center and the innermost interference ring is dark);
  b) the ring system is precisely in the middle of the scale (the ring system always moves toward the knurled screw that is being tightened).

Note: increasing the contact pressure further will deform the plates.

Setting up the optical bench

Fig. 3 shows the experiment setup.

- Mount the optical components on the optical bench; observe the positioning specifications for the left edge of the optics riders.
- Place the translucent screen at a distance of 1 to 2 m.
- Set up the holder for the “plates for Newton’s rings” **(d)** so that the adjusting screws face the translucent screen. Slide the optics rider as close as possible to the lens **(c)**.
- Place the Na-spectral lamp in the setup. Connect the universal choke and switch it on. After a warm-up phase of a few minutes, move the optics rider until the “plates for Newton’s rings” are optimally illuminated.
- Vary the position of lens **(e)** or the translucent screen until a sharp image of the Newton’s rings appears and the scale is clearly recognizable.
- You may need to check and readjust the “plates for Newton’s rings” using the knurled screws (the innermost ring is now bright!).

Carrying out the experiment:

Note:
Once you have adjusted the plates for Newton’s rings, do not change their settings. In particular, avoid touching the adjusting screws.

a) Measuring with the Na-spectral lamp:

- Optimize the bright-dark contrast of the Newton’s rings using the iris diaphragm **(f)**.
- Measure and record the left-hand intersection point r_L and the right-hand intersection point r_R of the bright rings with the scale.

b) Measuring with the Hg-spectral lamp:

Attention:
Allow the spectral lamps to cool down before removing them, or handle them with a cloth.

- Replace the Na spectral lamp with the Hg lamp.
- Switch on the universal choke and wait for the warm-up phase of a few minutes to elapse.
- Observe the Newton’s rings with colored fringes.
- Clamp the yellow filter in the object holder. Optimize the bright-dark contrast of the Newton’s rings using the iris diaphragm **(f)**.
- Measure and record the left-hand intersection point r_L and the right-hand intersection point r_R of the bright rings with the scale.
- Repeat the measurement with the green and blue color filters.

Measuring example

Table 1: Left and right scale intersections of the Newton's rings for illumination with yellow Na-spectral light

No.	$\frac{r_L}{\text{mm}}$	$\frac{r_R}{\text{mm}}$
2	3.9	3.8
3	5.3	5.1
4	6.3	6.0
5	7.2	6.8
6	8.0	7.4
7	8.7	8.1
8	9.2	8.7
9	9.9	9.3
10	10.3	9.9
11	10.8	10.2
12	11.2	10.8

Table 2: Left and right scale intersections of the Newton's rings for illumination with yellow, green and blue Hg-spectral light

	Yellow		Green		Blue	
No.	$\frac{r_L}{\text{mm}}$	$\frac{r_R}{\text{mm}}$	$\frac{r_L}{\text{mm}}$	$\frac{r_R}{\text{mm}}$	$\frac{r_L}{\text{mm}}$	$\frac{r_R}{\text{mm}}$
2	3.9	3.9	3.7	3.6	3.5	3.4
3	5.2	5.0	5.3	5.0	4.6	4.5
4	6.3	6.0	6.2	5.9	5.5	5.4
5	7.1	6.8	7.0	6.7	6.2	6.0
6	8.0	7.4	7.6	7.3	7.1	6.7
7	8.7	8.0	8.3	7.8	7.5	7.2
8	9.2	8.7	8.9	8.4	8.1	7.8
9	9.8	9.2	9.5	9.0	8.7	8.2

Evaluation

a) Measuring with the Na-spectral lamp:

The measurement results from Table 1 are shown in graph form in Fig. 4. Each radius *r* is determined as the mean value of the respective measurements for r_L and r_R.

The line through the measurement points has the slope:

$$\frac{\Delta r^2}{\Delta\,(n-1)} = 10.7\ \text{mm}^2.$$

Using equation (VI) and the wavelength of the Na-D line λ = 589 nm, we can calculate the bending radius of the convex lens as the value

R = 18.3 m

The axis section

$r^2(n = 1) = 5.0\ \text{mm}^2$

corresponds to a flattening of the lens on contact by the value

$d_0 = 0.14\ \mu\text{m}$

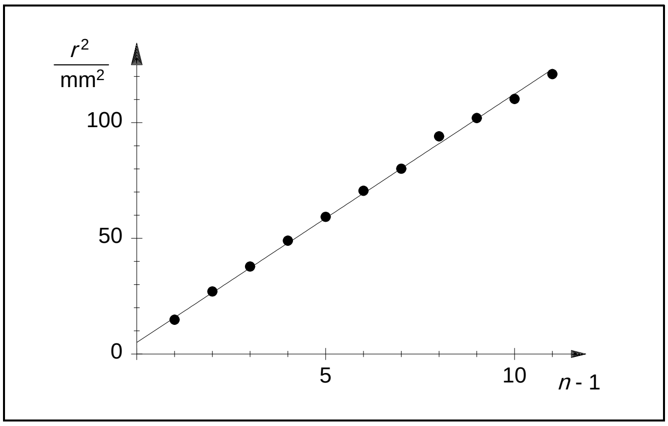


Fig. 4: Relationship between the radii *r* of the bright interference rings and their consecutive number *n* for illumination with the light of the Na-D line

b) Measuring with the Hg-spectral lamp:

Fig. 5 illustrates the relationship between r_n^2 and *n* for the spectral lines of the Hg lamp. The slope of the drawn straight lines increases proportionately with the wavelength of the Hg lines, in close agreement with equation (VI) (see Table 3).

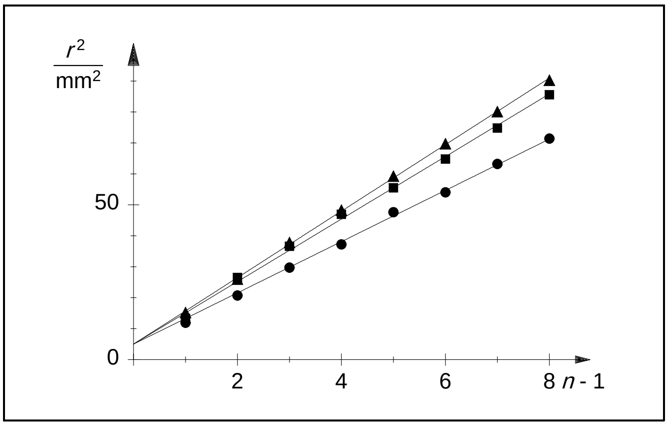


Fig. 5: Relationship between the radii *r* of the bright interference rings and their consecutive number *n* for illumination with the yellow (triangles), green (squares) and blue (circles) light of the Hg spectrum.

Table 3: Slope *a* of the graphs from Fig. 5

Color	$\frac{\lambda}{\text{nm}}$	$\frac{a}{\text{mm}^2}$
Blue	436	8.3
Green	546	10.1
Yellow	579	10,7

Result

The concentric structure and the change in the distance between the Newton's rings can be explained in terms of the spherical curvature of the convex lens which forms one of the boundaries of the air wedge.

When the setup is illuminated with white light the interference rings are surrounded by colored fringes, because the diameter of the interference rings increases with the wavelength (see (IV) and (VI)).