

## Newton's rings in transmitted and reflected white light

### Objects of the experiments

- Observing Newton's coloured rings in transmitted and reflected white light
- Comparing the bright rings in transmitted light with the dark rings in reflected light
- Explaining the complementarity of the interference patterns with the aid of the phase jump that occurs in reflection at a medium of higher optical density
- Comparing the contrast of the two interference patterns

### Principles

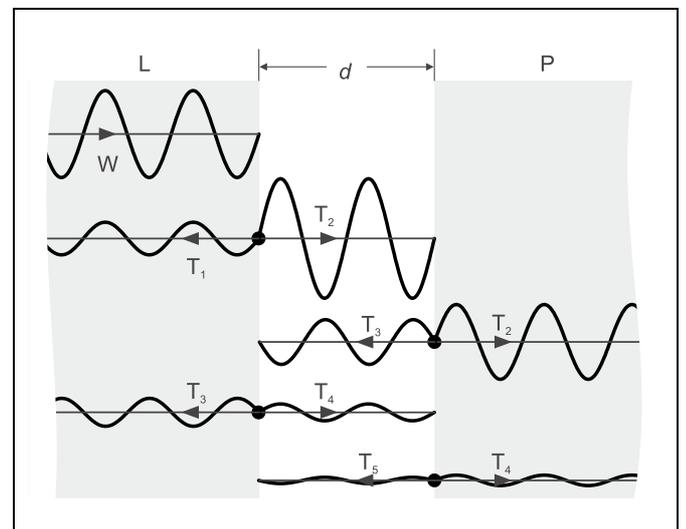
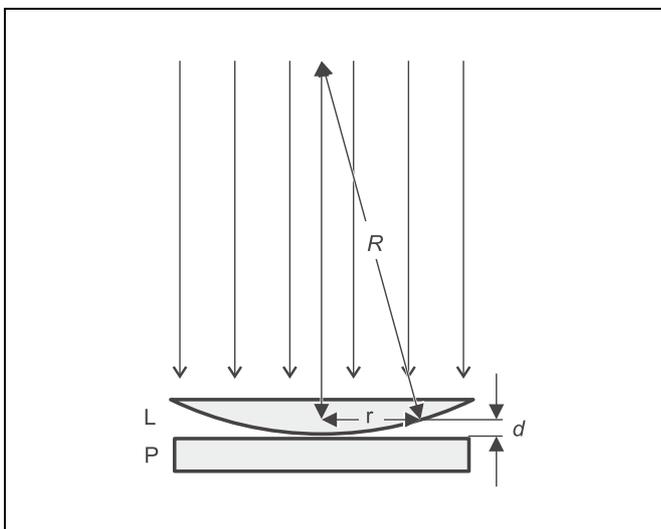
Colour phenomena at thin oil layers on water, at very thin soap films and at thin layers of air are due to interference of light waves. Today interference phenomena of light at thin layers are used to produce reflection reducing layers on glass surfaces (antireflection coating, e.g., of spectacle lenses).

Newton's rings arise as a result of reflection and refraction of light at two refracting surfaces which are very close to one another. In this experiment, Newton's rings are generated by means of a plano-convex lens with a large radius of curvature whose very weakly convex side is in contact with a plane glass plate. If this arrangement is illuminated with perpendicularly incoming, parallel white light, concentric rings with coloured edges form around the contact point of the two surfaces. The interference rings can be observed in both the reflected and the transmitted light. The distances between the interference rings are not constant because one boundary surface is curved.

In Fig. 2 the interference at an air wedge of thickness  $d$  between two glass surfaces is illustrated: the light wave  $W$  incident from the left impinges on the boundary surface of the lens  $L$  and is reflected as partial wave  $T_1$ . The non-reflected part passes through the air wedge as partial wave  $T_2$  and is reflected at the surface of the glass plate  $P$ . As the reflection at

Fig. 1 Schematic representation of the plane glass plate and the plano-convex lens with large radius of curvature.  
P: glass plate  
L: plano-convex lens  
 $R$ : radius of curvature  
 $r$ : distance from the contact point of the lens and the glass plate

Fig. 2 Diagram for explaining the interference at an air wedge  
L: plano-convex lens, P: glass plate  
 $T_1 \dots T_5$  partial waves that arise as a result of reflection and transmission of the light wave  $W$  at the interfaces L and P;  $d$ : distance between the glass surfaces of the lens and of the glass plate



**Apparatus**

1 glass plates for Newton's rings . . . . .	471 111
2 beam splitters . . . . .	471 88
2 lenses in frame $f = +200$ mm . . . . .	460 04
1 precision optical bench, 1 m . . . . .	460 32
5 riders, $H = 60$ mm/ $B = 36$ mm . . . . .	460 353
1 rider, $H = 60$ mm/ $B = 50$ mm . . . . .	460 351
1 cantilever arm 100 . . . . .	460 356
1 halogen lamp housing 12 V, 50/90 W . . . . .	450 64
1 incandescent lamp 12 V/90 W, G6.35 . . . . .	450 63
1 transformer 2 ... 12 V . . . . .	521 25
2 connecting leads, 100 cm, black . . . . .	501 33

the interface P takes place at the medium of higher optical density, the reflected partial wave  $T_3$ , in contrast to the partial wave  $T_1$ , experiences a phase jump of  $\pi$  (corresponding to the reflection of a wave in a rope at a fixed end).

The part which is not reflected penetrates the glass plate, which has a greater optical density, as partial wave  $T_2$ . The partial wave  $T_3$  falls back on the lens L and is reflected at the lens with a phase jump of  $\pi$  as partial wave  $T_4$ . The non-reflected part again penetrates the glass plate, which has a higher optical density, without phase jump. Further partial waves, which are indicated by  $T_5$ , arise as a result of multiple reflections.

In the reflected light, interference of the partial waves  $T_1$  and  $T_3$  is observed. The path difference  $\Delta_R$  between  $T_1$  and  $T_3$  is

$$\Delta_R = 2 \cdot d + \frac{\lambda}{2} \quad (I),$$

and the interference pattern, which forms due to reflection and refraction, consists of concentric dark rings around a dark centre. The condition for destructive interference is fulfilled if the path difference  $\Delta_R$  is an odd multiple of half the wavelength  $\lambda$ :

$$(2 \cdot k - 1) \cdot \frac{\lambda}{2} = 2 \cdot d + \frac{\lambda}{2} \quad k = 1, 2, 3, \dots$$

or

$$d = (k - 1) \cdot \frac{\lambda}{2} \quad (II).$$

In the transmitted light, interference of the partial waves  $T_2$  and  $T_4$  is observed. The path difference  $\Delta_T$  between  $T_2$  and  $T_4$  is

$$\Delta_T = 2 \cdot d + 2 \cdot \frac{\lambda}{2} \quad (III).$$

If Newton's rings are observed in the transmitted light, the interference pattern is complementary to that in the reflected light. The centre of the set of circles is bright in the transmitted light. Therefore the bright rings are measured instead of the dark ones. After two reflections at the medium of higher optical density, the partial wave  $T_4$  has experienced two phase jumps of  $\pi$  thus being in phase with the original wave train  $T_2$  when  $T_4$  and  $T_2$  superimpose.

The condition for constructive interference is fulfilled if the path difference  $\Delta_T$  is an integer multiple of the wavelength  $\lambda$ ,

$$k \cdot \lambda = 2 \cdot d + 2 \cdot \frac{\lambda}{2} \quad k = 1, 2, 3, \dots$$

or

$$d = (k - 1) \cdot \frac{\lambda}{2} \quad (IV).$$

This condition corresponds exactly to the condition (II) for destructive interference in reflected light. Therefore the interference patterns observed are complementary.

According to Fig. 2, the amplitudes of the partial waves  $T_1$  and  $T_3$  are approximately equal as both partial waves are generated by a single reflection. The partial wave  $T_4$  is generated by two reflections and therefore is considerably weaker than the partial wave  $T_2$ , which is generated without reflection. Therefore the contrast, i.e., the relative difference in intensity between the bright and dark rings is much weaker in the case of transmitted light than in the case of reflected light.

According to Fig. 1, the thickness  $d$  in (II) and (IV) depends on the distance  $r$  from the contact point between the convex lens and the glass plate and on the radius of curvature  $R$  of the convex lens. For small values of the thickness  $d$  we have

$$d = \frac{r^2}{2R} \quad (V).$$

For the diameters

$$D_k = 2 \cdot r_k$$

of neighbouring Newton rings, the following relation is obtained from (II) or (IV), respectively, and (V):

$$D_{k+1}^2 - D_k^2 = 4 \cdot R \cdot \lambda \quad (VI).$$

Thus, if the radius of curvature  $R$  of the lens is known, a medium wavelength  $\lambda$  of white light can be determined by measuring the diameters.

**Setup**

*Note:*

*If the pressure acting on the glass plates for Newton's rings is too high or asymmetric, the glass plates may be permanently deformed or damaged.*

*Be very careful when turning the knurled screws for adjusting the glass plates for Newton's rings.*

*The experimental setup is illustrated in Fig. 3. With the aid of the two beam splitters  $S_1$  and  $S_2$ , the Newton rings are projected on the wall side by side. This enables the interference phenomena to be observed simultaneously and thus to be compared with each other.*

- Set up the optical bench at a distance of approx. 2.0 m parallel to the wall.
- Mount the halogen lamp H to the optical bench as shown in Fig. 3.
- Set up the beam splitter  $S_1$  on the optical bench at a distance of 30 cm from the halogen lamp, and align it at an angle of 45°.
- Switch the halogen lamp H on, and direct it towards the beam splitter.
- Position the lens  $L_1$  by means of a rider and the cantilever arm on the optical bench immediately in front of the beam splitter  $S_1$  as shown in Fig. 3.

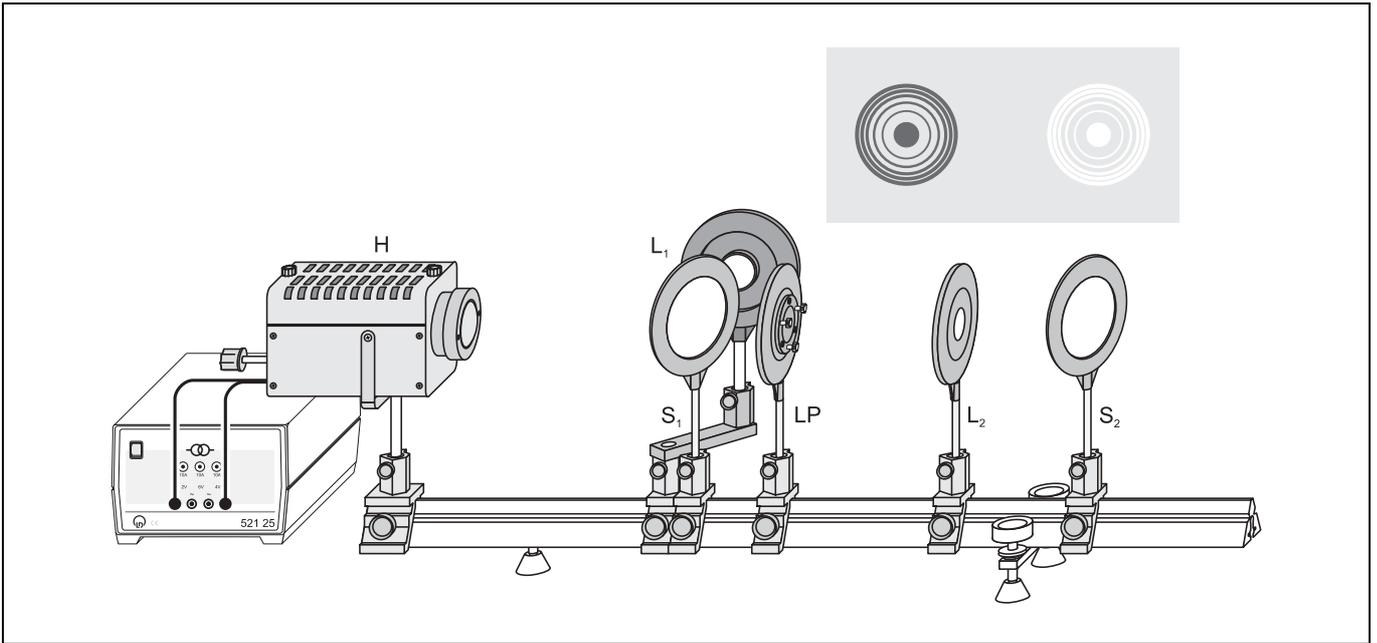


Fig. 3 Experimental setup for simultaneously observing Newton's rings in transmitted and reflected light.  
 H halogen lamp  
 LP plano-convex lens and glass plate  
 S<sub>1</sub>, S<sub>2</sub> beam splitters  
 L<sub>1</sub>, L<sub>2</sub> lenses for imaging the rings

- Put the glass plates for Newton's rings on the optical bench at a distance of approx. 16 cm from the beam splitter S<sub>1</sub> (The scale on the plates should point in the direction of the beam splitter S<sub>1</sub>.)
- Displace the rider with the glass plates for Newton's rings towards the beam splitter until the ring pattern is imaged on the wall via the lens L<sub>1</sub>.
- For this first loosen the knurled screws of the glass plates for Newton's rings completely and then tighten them cautiously until
  - a) the glass plates get into contact (i.e. until no further interference rings come out of the centre and the innermost ring of the reflected light is dark.)
  - b) the ring system is exactly in the centre of the scale (The ring system always moves in the direction of the knurled screw which is being turned.)
- If necessary, displace the lens L<sub>1</sub> somewhat until the image of the ring pattern on the wall is sharp.
- Set up the lens L<sub>2</sub> at a distance of approx. 20 cm from the rider with the glass plates for Newton's rings.
- Put the beam splitter S<sub>2</sub> on the optical bench at a distance of approx. 35 cm from the glass plates for Newton's rings.
- Align the beam splitter at an angle of 45° relative to the optical axis so that the light from the lamp is seen near the interference pattern of the reflected light.
- Displace the lens L<sub>2</sub> towards the beam splitter S<sub>2</sub> until the image of the ring pattern (and the scale) of the transmitted light is sharp.

### Carrying out the experiment

- Observe the interference phenomena, and compare the concentric ring patterns of the transmitted and of the reflected light with respect to the succession of bright and dark rings.
- Measure the diameter of the bright and of the dark centre by means of the projected scale.
- Measure the diameters of the bright and of the dark rings by means of the projected scale.
- Compare the contrast of the two interference patterns.

### Measuring example

Interference pattern observed in transmitted light: small contrast  
 The centre is dark and surrounded by concentric dark rings. The boundaries of the rings are coloured.

Interference pattern observed in reflected light: larger contrast  
 The centre is bright and surrounded by concentric bright rings. The boundaries of the rings are coloured.

Table 1: Ring diameter  $D$  of the intensity maxima for reflected light or minima for transmitted light, respectively

	$\frac{D'_k}{\text{mm}}$	
	Reflection	Transmission
Centre	3.2	3.3
ring 1	6.2	6.3
ring 2	8.4	8.6
ring 3	10.2	10.4
ring 4	11.5	11.6
ring 5	12.8	13.0

The distance between neighbouring rings decreases with increasing radius.

## Evaluation

According to Table 1, the centres and the ring diameters of the two interference patterns are equal for the observations in reflected and transmitted light.

Fig. 4 shows the relation between the squares of the diameters  $D_k^2$  and the running index  $k'$  of the rings. For the slope  $a = 31.6 \text{ mm}^2$  of the straight line drawn in the figure, we have because of (VI)

$$a = D_{k'+1}^2 - D_k^2 = 4 \cdot R \cdot \lambda.$$

The radius of curvature  $R$  is given in the instruction sheet of the glass plates for Newton's rings. It is  $R = 12.144 \text{ m}$ .

From this  $\lambda = 650 \text{ nm}$  is obtained, which is in agreement with the fact that for measuring the diameters the reddish colour fringes were used.

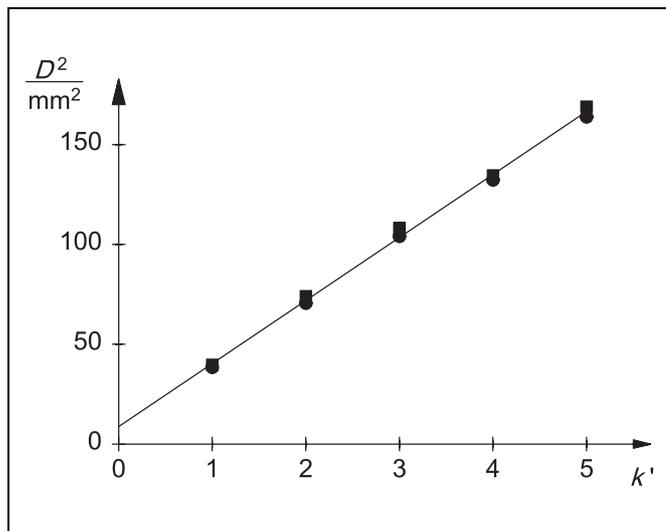


Fig. 4 Square of the ring diameter plotted against the running index of the interference ring  
● reflected light, ■ transmitted light

## Results

Newton's rings in transmitted and reflected light appear to be complementary to each other. The complementarity results from the additional path difference of  $\lambda/2$ , which is due to a phase jump of  $\pi$  at the medium with higher optical density.

In transmitted light, the contrast between bright and dark is clearly weaker than in reflected light.

## Supplementary information

The occurrence of a dark centre in the interference pattern is a direct proof of the light experiencing a phase jump of  $\lambda/2$  when it is reflected at a medium of higher optical density. As for a thickness  $d \ll \lambda$  the path difference – without phase jump – would be zero, the interference should lead to maximum brightness rather than darkness. Only by taking into account  $\lambda/2$ , the result of the experiment can be explained.

However, as has been pointed out by *T. Young*, if a lens made of crown glass and a plate made of flint glass are used to generate Newton's rings, a bright spot is seen in the centre in the observation of the reflected light if the space between the glass plate and the plano-convex lens is filled with China oil instead of air. As the refractive index of the oil lies between that of crown glass and that of flint glass, reflection takes place at the medium with higher optical density both above and below so that for a very thin layer with  $d \ll \lambda$  an intensity maximum arises in the centre in the case of reflected light.