

Interference at Fresnel's biprism with an He-Ne laser

Objects of the experiment

- Observing the two-beam interference of two virtual light sources created at a biprism.
- Observation of the images of the virtual light sources and measuring their distance B.
- Determination of the wavelength of the laser from measuring the distance of the interference pattern.
- Determination of the prism angle

Principles

The nature of light was a controversial issue for a long time. In 1690, Christiaan Huygens interpreted light as a wave phenomenon; in 1704, Isaac Newton described the light beam as a current of particles. This contradiction was resolved by quantum mechanics, and the idea of wave-particle duality came up.

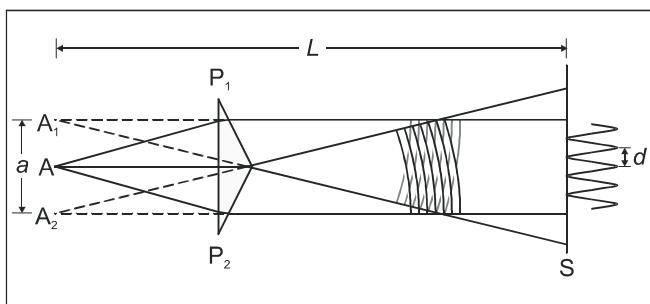


Fig. 1 Schematic representation of the beam path at *Fresnel's* biprism
 A: light source (He-Ne laser)
 A': virtual light sources
 P₁, P₂: prism halves
 S: translucent screen
 a: distance between the two virtual light sources
 α: prism angle (radian measure)
 d: distance between two neighbouring intensity maxima (or minima)

In the 18th and 19th centuries, interference experiments contributed a lot to the decision regarding the nature of light. According to the common principle which characterizes these experiments, wave-optical methods – such as reflection, refraction, blocking and beam spitting – allow the creation of two interfering light bundles from the light emitted by a source. Therefore this method of superimposing light is called two-beam interference.

Following a method of A. Fresnel (1826), the light bundle from a laser which is made divergent by means of a lens can be refracted at two prisms with a common base so that two coherent partial bundles arise. These two partial bundles superimpose in certain areas and exhibit interference phenomena.

According to Fig. 1, two virtual images of the approximately point-like light source A are created by refraction in the two prism halves (P₁, P₂). The superposition of the two coherent partial bundles from the two virtual light sources A' results in interference patterns on the translucent screen in certain directions. Intensity maxima always occur at positions where the path difference Δs between the partial bundles from A' is an integer multiple of the wavelength λ. At great distances L₁, the following relation for the distance d between two neighbouring maxima (or minima) holds:

$$\frac{d}{L_1} = \frac{\lambda}{a} \quad \text{or} \quad \lambda = \frac{a \cdot d}{L_1} \quad (I)$$

- a: distance between the two virtual light sources A'
 d: distance between two intensity maxima (or minima)
 L₁: distance between the plane of the light sources and the plane of observation
 λ: wavelength

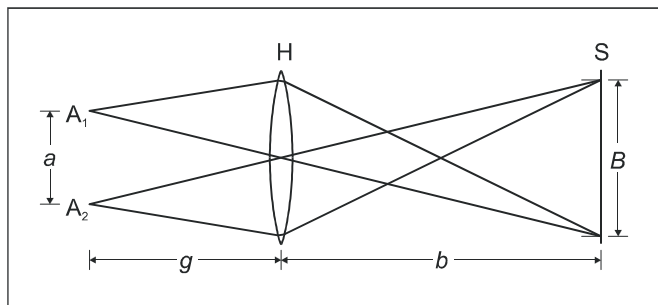


Fig. 2 Determining the distance a between the virtual light sources A' from the imaging equation
 A' : virtual light source
 H : imaging lens
 S : translucent screen
 a : distance between the two virtual light sources A'
 B : distance between the two virtual light sources A' on the screen
 g : object distance = distance between A' and the lens
 b : distance between the lens H and the screen

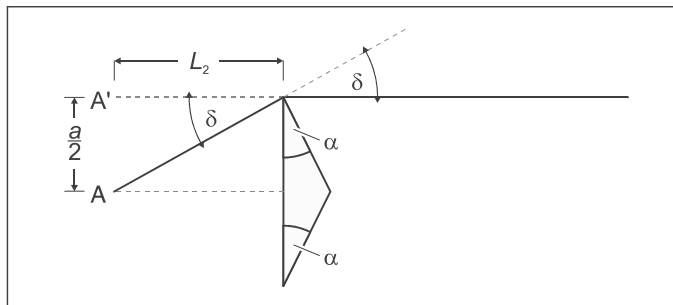


Fig. 3 Deflection of a beam in a biprism
 A : light source (He-Ne laser)
 A' : virtual light source
 α : prism angle (radian measure)
 δ : total deflection (radian measure)
 L_2 : distance between the light source A or A' and the biprism

The distance a between the two virtual light sources A' is determined by means of a simple optical setup. For this the two virtual light sources A' are sharply imaged on the translucent screen S by means of a lens H . From Fig. 2 the imaging equation can be read immediately:

$$\frac{a}{g} = \frac{B}{b} \quad \text{or} \quad a = \frac{B \cdot g}{b} \quad \text{(II)}$$

- a : distance between the two virtual light sources A'
- B : distance between the two virtual light sources A' on the screen
- g : object distance = distance between A' and the lens H
- b : image distance = distance between the lens H and the screen

If the focal length f of the imaging lens is known, the object distance g can be obtained with the aid of the imaging equation:

$$\frac{1}{g} = \frac{1}{f} - \frac{1}{b} \quad \text{or} \quad g = \frac{f \cdot b}{b - f} \quad \text{(III)}$$

The distance a between the virtual light sources occurring in equation (I) can also be calculated from the prism specifications (prism angle α and the refractive index n). At small refracting angles α , the deflection δ of rays by a prism is given by

$$\delta = \alpha \cdot (n - 1) \quad \text{(IV)}$$

- δ : total deflection (radian measure)
- α : prism angle (radian measure)
- n : refractive index

For small angles of deflection δ we can write (see Fig. 3):

$$\frac{a}{2L_2} = \tan \delta \approx \delta \quad \text{(V)}$$

Together with equation (III) this gives

$$a = 2L_2(n - 1) \cdot \alpha$$

for the distance a or

$$\alpha = \frac{a}{2L_2(n - 1)} \quad \text{(VI)}$$

for the prism angle α . For the wavelength λ , equations. (I), (III) and (IV) lead to the following relation:

$$\lambda = \frac{2L_2 \alpha d(n - 1)}{L_1} \quad \text{(VII)}$$

with $L_1 = g + b$ and $L_2 = g$.

Apparatus

1 He-Ne laser, linearly polarized	471 830
1 Biprism	471 09
1 Prism table	460 25
1 Lens in frame, $f = +5$ mm	460 01
1 Lens in frame, $f = +200$ mm	460 04
1 precision optical bench, 1 m	460 32
3 Optics rider 60/34	460 370
1 Optics rider 60/50	460 373
1 Translucent screen	441 53
1 Saddle base	300 11
1 Vernier callipers	311 53
1 Steel tape measure, $l = 2$ m/78"	311 77

Safety notes

The He-Ne laser meets the requirements according to class 2 of EN 60825-1 "Safety of laser equipment". If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe.

- Never look into the direct or reflected laser beam.
- No observer must feel dazzled.

Setup

Remark: the adjustment should be carried out in a slightly darkened room.

The entire setup is illustrated in Fig. 4. The spherical lens K with a focal length f of +5 mm expands the laser beam, which then impinges on the biprism P. The lens H is only placed in the beam path for determining the distance between the two light sources A' .

- Using a rider, mount the He-Ne laser to the optical bench as shown in Fig. 4.
- Set up the screen at a distance of approx. 1.80 m from the laser.
- Direct the laser towards the screen, connect the plug-in power supply to the laser, and switch the laser on.
- Place the spherical lens with the focal length $f = +5$ mm at a distance of approx. 2 cm in front of the laser. (The laser beam is expanded by the lens and should have a beam diameter of approx. 15 cm on the screen.)
- Put the prism table on the optical bench at a distance of approx. 15 cm from the spherical lens.
- Fix the biprism using the adjustable spring clamp. (If necessary, readjust the height of the laser and of the spherical lens so that the laser beam passes through the centre of the biprism.)
- The interference fringes appear vertically in the centre of the translucent screen.

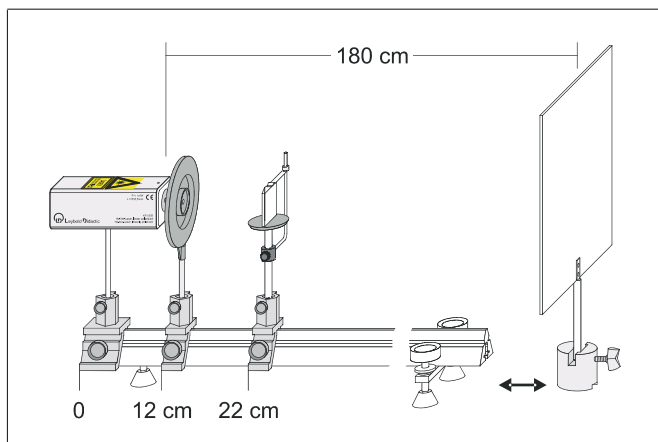


Fig. 4 Experimental setup for observing interference phenomena created by means of *Fresnel's* biprism.

- K lens for expanding the laser beam
- P prism table with biprism
- H lens for imaging the two light sources A' (Fig. 1)
- S screen

Carrying out the experiment

- It is recommendable to observe the interference phenomenon at first.
- In order to determine the distances d between the intensity maxima, put a sheet of paper on the screen and mark the locations of maximum light intensity (or, alternatively, minimum light intensity) using a soft pencil.
- Position the lens H ($f = +200$ mm) between the screen and the prism table as shown in Fig. 5, and create a sharp image of the two virtual light sources A' .
- For this displace the lens H towards the prism table until two intensive luminous spots are seen (typically the distance is approx. 8 mm).
- Measure the distance B, i.e. distance of the images of the light sources A' .
- Measure the image distance b .

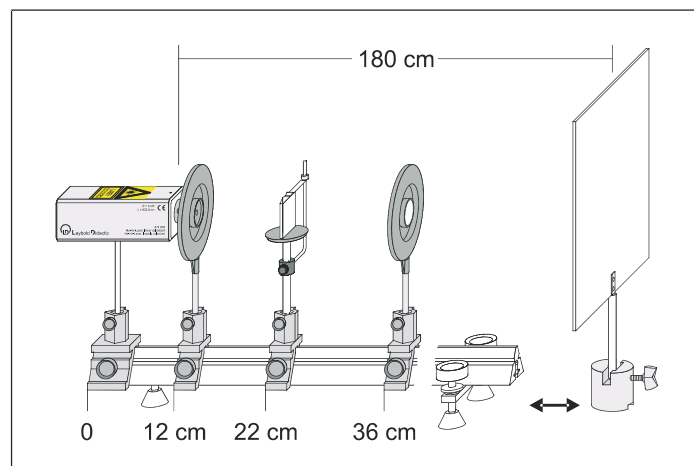


Fig. 5 Modified experimental setup for determining the distance of the two virtual light sources.

Measuring example

Table. 1: Distances d between the intensity maxima.

Measured value	$\frac{d}{\text{mm}}$
1	0.8
2	0.8
3	0.8
4	0.75
5	0.8
6	0.8

Mean value: $d = 0.79 \text{ mm}$

Image distance: $b = 1.46 \text{ m}$

Distance between the images of A'
on the screen: $B = 0.85 \text{ mm}$

Evaluation

a) Determining the wavelength

The angle of incidence α is the angle the incident ray of light makes with the normal to the reflecting surface at the point of incidence.

With the measured quantities

$b = 1.46 \text{ m}$

$d = 0.79 \text{ mm}$

$B = 0.85 \text{ mm}$

and the focal length of the imaging lens $f = 200 \text{ mm}$, equation. (III) leads to the object distance:

$g = 0.23 \text{ m}$.

Now the distance a between the virtual light sources can be determined using Eq. (II):

$a = 1.45 \text{ mm}$.

With the aid of Eq. (I), this intermediate result enables the wavelength λ of the He-Ne laser to be determined:

$\lambda = 635 \text{ nm}$.

b) Determining the prism angle

With the measured quantities

$b = 1.46 \text{ m}$

$d = 0.79 \text{ mm}$

$B = 0.85 \text{ mm}$

and the quantities derived from them

$g = 0.23 \text{ m}$ (Eq. (III))

$a = 1.45 \text{ mm}$ (Eq. (II))

the prism angle α of the biprism can be determined from equation (VI) ($n = 1.5231$):

$\alpha = 0.0056$ (0.32°)

Results

Refraction of the light in the two prism halves leads to two virtual light sources which are coherent with respect to each other. The superposition of these light bundles results in interference fringes.

Supplementary information

In order that visible interference phenomena arise at a biprism, the angle of deflection δ has to be very small in each of the prism halves (P_1, P_2) for beams that fall in almost perpendicularly. For a prism made of glass ($n = 1.52$), that means that the refracting angle α has to be very small, too (see equation (IV)). Manufacturing prisms that acute is difficult. According to a proposal by Winkelmann and Abbe a glass trough can be used whose side is a biprism with a greater refracting angle (e.g. 8.5°). The stronger deflection can be diminished by a liquid with a suitable refractive index n_F . The total deflection is then given by a modified equation:

$$\delta = \alpha \cdot (n - n_F) \quad (\text{VIII})$$

A liquid with a suitable refractive index ($n_F \approx 1.46 \dots 1.50$) is easily found by mixing appropriate components.