PHYSICS EXPERIMENT

Fresnel Biprism

GENERATING INTERFERENCE BETWEEN TWO BEAMS USING A FRESNEL BIPRISM

- Use a Fresnel biprism to create two virtual coherent sources of light from a single point light source.
- Observation of the interference between the two split beams from the virtual light sources.
- Determine the wavelength of light from an He-Ne laser from the separation between interference bands.

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10/15 MEC/UD

Fig. 1: Measurement set-up.

GENERAL PRINCIPLES

In one of his experiments on interference, *August Jean Fresnel* used a biprism to induce interference between two beams. He split a diverging beam of light into two parts by using the biprism to refract them. This resulted in two split beams which acted as if they were from two coherent sources and which therefore interfered with each other. By observing on a screen, he was able to see a series of peaks in the light intensity with a constant distance between them.

Whether a peak occurs in the intensity or not depends on the difference Δ in the path travelled by each of the split beams. If the light source is a long distance L from the screen, the following is true to a good approximation:

(1) $\Delta = A \cdot \frac{x}{L}$.

Here, x refers to the coordinate of the point observed on the screen which is perpendicular to the axis of symmetry. A is the distance between the two virtual light sources, which is yet to be determined Peaks in intensity occur at the precise points where the difference in the path travelled is a multiple of the wavelength λ:

(2) $\Delta_n = n \cdot \lambda$, mit n = 0, 1, 2, …

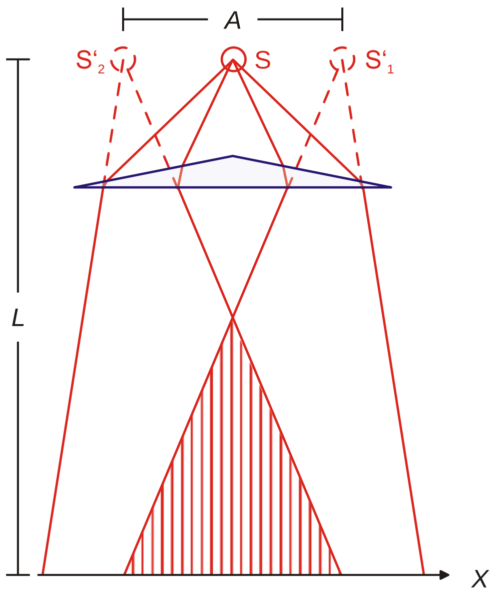

Fig. 2: Schematic diagram of light passing through a biprism.

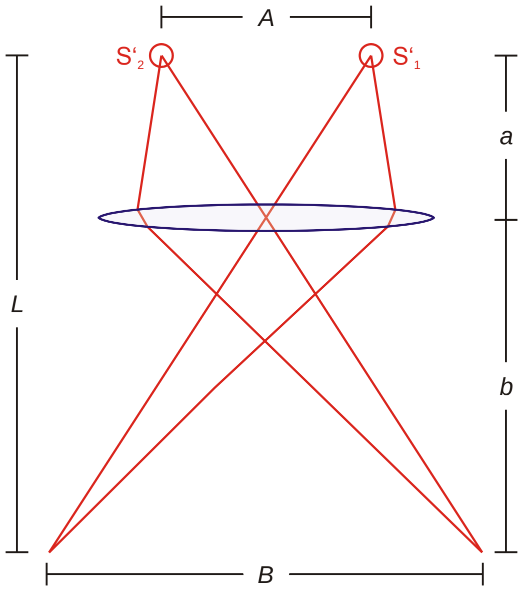

Fig. 3 Ray diagram for obtaining an image of the two virtual sources on the screen.

A comparison between (1) and (2) shows that the peaks will be at the following coordinates:

(3) $x_n = n \cdot D$

They should also be at a constant distance D apart. The following relationship is also true:

(4) $\lambda = A \cdot \frac{D}{L}$.

Equation (4) can be seen as an expression for determining the wavelength λ of the light being used. It is always applicable for interference between two beams.

Nevertheless, it is still to be established how the distance between the two virtual sources A can be measured. This can be assisted by a simple optical set-up, in which in image of both sources is obtained on the screen with the help of a converging lens so that the distance B between the images of the two sources can be measured (see Fig. 3). The following then applies:

(5) $A = B \cdot \frac{a}{b}$

a: Object distance, *b*: Image distance.

LIST OF EQUIPMENT

1	Fresnel Biprism	U14053	1008652
1	Prism Table on Stem	U17020	1003019
1	He-Ne Laser	U21840	1003165
1	Achromatic Objective 10x / 0,25	W30614	1005408
1	Convex Lens on Stem *f* = 200 mm	U17104	1003025
3	Optical Rider D, 90/50	U103111	1002635
1	Optical Bench D, 50 cm	U10302	1002630
1	Projection Screen	U17130	1000608
1	Barrel Foot, 1000 g	U13265	1002834
1	Pocket Measuring Tape, 2 m	U10073	1002603

Additionally required:

1 Sheet of graph paper, 20 x 30 cm^2 approx.

1 Pencil

SAFETY INSTRUCTIONS

The He-Ne laser, U21840 (1003165), emits visible radiation at a wavelength of 630-680 nm with a maximum power of less than 1 mW, thus conforming to class 2 regulations as specified in DIN EN 60825-1 “Safety of lasers”, i.e. the human eye can be protected by the instinctive reaction to turn away and blink.

- Do not look straight into the laser beam or any reflected beam.
- Lasers should only be operated by trained and authorised personnel.
- All those people participating in or observing an experiment must have been informed of the dangers inherent in laser radiation and educated regarding protective measures.
- Experiments may only be performed using the minimum power output required in each specific instance.
- Ensure that the beam is not directed at eye level.
- Use suitable screening to isolate the area around the laser and avoid unwanted reflections.
- Any rooms in which laser experiments take place should be labelled with warning signs.
- Observe the regulations valid in the respective country where the experiment is being performed, e.g. Germany’s health and safety regulations BGV B2 “Laser radiation”, and any stipulations set by the relevant ministry.
- Keys should be carefully stored so that they cannot be accessed by unauthorised persons.

Safe operation of the He-Ne laser is guaranteed, provided it is used correctly. However, there is no guarantee of safety if the equipment is used in an inappropriate or careless manner. If it is deemed that the equipment can no longer be operated without risk (e.g. visible damage has occurred), the laser should be switched off immediately and secured against any unintended use.

- Before putting the equipment into operation, check for any signs of damage. In the event of any malfunction or visible damage, turn off the laser and put it away so that it cannot be used unintentionally.
- Due to internal operating and triggering voltages which can be hazardous to life, never open the housing.

SET-UP

- Set up the apparatus as shown in Fig. 4 but initially omitting the converging lens of focal length f = 200 mm.
- Position the screen at a distance > 4 m from the end of the optical bench and attach some mm square graph paper to it.
- In order to spread out the laser beam, screw the achromatic objective to the beam exit opening of the laser.
- Position the biprism in the middle of the prism table and fix it in place with spring clips.

Note:
Be careful handling the biprism since it is made of very brittle glass.

- Adjust the laser in such a way that the laser beam strikes the biprism right in the middle and interference bands can be seen on the screen.
- You may need to turn the laser slightly to the left or right for fine adjustment to ensure that the interference pattern on the screen is symmetrical either side of the central maximum.

PROCEDURE

Observation of interference

- Increase and decrease the object distance by moving the prism table along the optical bench and observe the interference bands on the screen as you do so.
- Select an object distance which results in at least 5 interference bands being easy to identify on the screen either side of the central intensity maximum. Do not change the position of the prism table after this.

Separation of intensity minima

Note:
Because of the contrast between light and dark, it is easier to measure the distance between adjacent minima in the light intensity rather than between the maxima.

- Use a pencil to mark on the millimetre-squared graph paper the positions $x_{n+1/2}$ (n = 0, 1, 2, …) of minimum light intensity in the interference pattern up to the 5th order band (Fig. 5).
- Measure the distances $D_n = x_{n+1/2} - x_{n-1/2}$ between each adjacent pair of intensity minima.
- Determine the average separation of minima D by taking the arithmetic mean of the individual distances between them D_n.

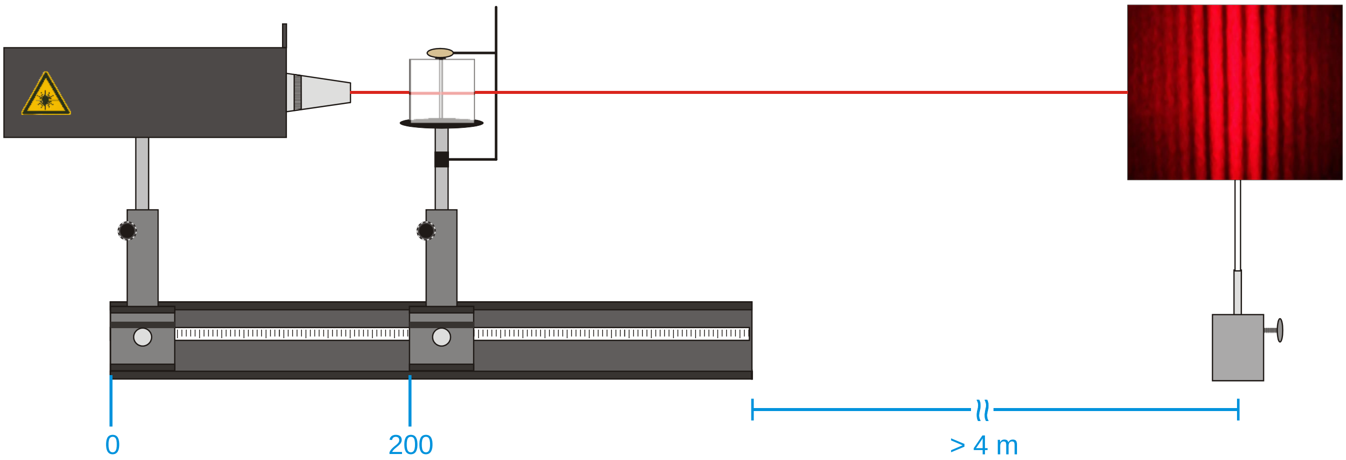

Fig. 4: Sketch of measurement set-up.

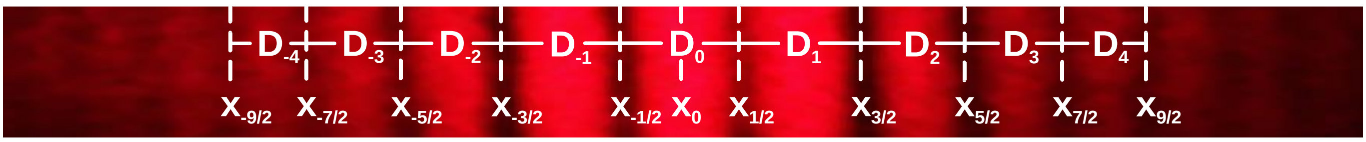

Fig. 5: Locations $x_{n+1/2}$ of minimum light intensity in interference pattern and distances $D_n = x_{n+1/2} - x_{n-1/2}$ between adjacent pairs of intensity minima.

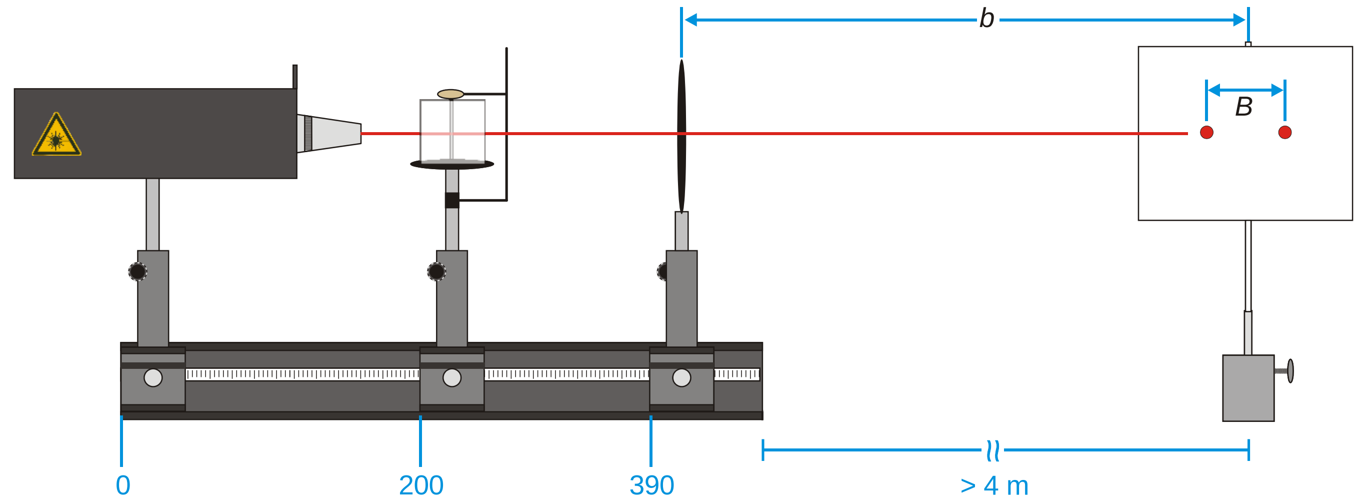

Fig. 6: Set-up featuring converging lens to determine the separation *A* between the two virtual light sources from the distance *B* between the images of the two virtual sources and the image distance *b* (see Fig. 3).

Distance between images of the two virtual light sources

- Position a converging lens of focal length f = 200 mm at the 390-mm mark on the optical bench (see Fig. 6).
- Move the lens until two bright points can be seen in good focus on the screen.

Note:
These bright points of light are the images of the two virtual light sources. In order to see them more clearly, you may wish to turn down the power of the laser beam.

- Mark the positions of the images of the virtual light sources on the screen with a pencil.
- Measure the distance *B* between the images of the two virtual light sources as well as the distance *b* of the image from the lens.

SAMPLE MEASUREMENT

Average separation of intensity minima *D*:	8.1 mm
Distance between images of virtual light sources *B*:	7.7 mm
Image distance *b*:	4480 mm
Focal length of converging lens *f*:	200 mm

EVALUATION

The interference pattern on the screen consists of vertical interference bands. The relative distance *D* between these bands decreases as the biprism is moved further away from the laser because this causes the separation A between the virtual light sources to increase.

The position of the laser (the source of the light) and therefore the object distance *a* are not precisely known. The object distance therefore needs to be calculated using the law for the formation of images by lenses. This allows the object distance to be calculated from the focal length *f* of the converging lens and the distance *b* measured between the lens and the image:

$$\text{(6)}\quad \frac{1}{f} = \frac{1}{a} + \frac{1}{b} \Rightarrow \quad a = \frac{f \cdot b}{b - f} = \frac{200\ \text{mm} \cdot 4480\ \text{mm}}{4480\ \text{mm} - 200\ \text{mm}} = 209\ \text{mm}.$$

Solving equation (6) for *a* and substituting it into equation (5) gives the following result:

$$\text{(7)}\quad A = a \cdot \frac{B}{b} = \frac{f \cdot B}{b - f} = \frac{200\ \text{mm} \cdot 7.7\ \text{mm}}{4480\ \text{mm} - 200\ \text{mm}} = 0.36\ \text{mm}.$$

The distance between the light source and the plane of observation *L* is simply the sum of *a* and *b*:

$$\text{(8)}\quad L = a + b = 209\ \text{mm} + 4480\ \text{mm} = 4689\ \text{mm}.$$

For a wavelength λ, equation (4) gives the following result:

$$\text{(9)}\quad \lambda = A \cdot \frac{D}{L} = 0.36\ \text{mm} \cdot \frac{8.1\ \text{mm}}{4689\ \text{mm}} = 622\ \text{nm}$$

The value for the wavelength determined by measurement is within about 2% of the value quoted in literature for the He-Ne laser, λ = 632.8 nm.