Experiment 233: Fresnel Biprism

Aim

To study the interference pattern produced by the Fresnel Biprism and to determine the wavelength of the light source.

References

1. Halliday and Resnick, "Fundamentals of Physics" 4th Ed., pages 1054 – 1056, McGraw-Hill.
2. Kaye and Laby, "Physical and Chemical Constants"

Introduction

This experiment is a fascinating introduction to the interference of light — the phenomenon where two coherent light beams pass through the same region of space and combine to produce periodic patterns in intensity known as interference fringes. The positions of the fringes in space depend critically on the relative distances travelled by the interfering beams, and so most interference systems are very vibration sensitive because microscopic movements of the components affect the distance travelled. The elegance of this experiment lies in the fact that the optical system is arranged so that vibrations affect both beams identically so that the *relative* distances travelled are not altered and the fringes are very stable.

In this experiment you will:

(i) Extend the knowledge of interference phenomena that you already have from your understanding of Young's Experiment. (You should be familiar with this.)

(ii) Learn how to set up a simple optical system

(iii) Measure the wavelength of sodium light

(iv) Learn about imaging relationships in optical systems

Theory

If you are not familiar with Young's Experiment, you should read up about this **now**! You will find a good explanation in Reference 1.

In Young's Experiment, coherent light beams from two slits interfere in the plane of a screen to produce a pattern of light and dark lines known as *interference fringes.* The spacing of the interference fringes is governed by the distance of the slits from the screen, their spacing, and the wavelength of the light. It can be shown easily that, in the centre of the pattern, the fringe spacing is given (to a very good approximation) by:

$$\Delta x = \frac{\lambda\, l}{d} \qquad (1)$$

where Δx is the fringe spacing at the screen, d is the slit spacing, l is the distance between slits and screen and λ is the wavelength of the light.

Exercise: Derive equation (1) and include the derivation in your report.

In Young's experiment, the light illuminating the two slits comes from the same source, by diffraction from a single slit placed in front of the light source. In the Fresnel Biprism experiment, a single slit is also used over the light source, but following this is a biprism which consists of two prisms of acute apex angle glued together at their bases (see Figure 1). Light diverging from the single slit is refracted by the two halves of the prism to produce two overlapping, diverging beams which interfere to produce a fringe pattern.

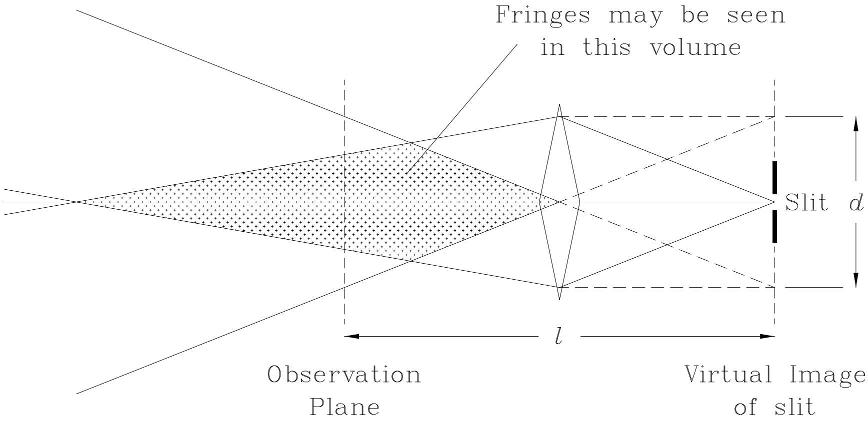

Figure 1: Fresnel biprism experiment.

The fringe pattern may be observed anywhere in the space in front of the biprism in which the two beams overlap. It may be thought of as interference between light from two virtual sources which arise from refraction of the two halves of the beam from the single slit, by the biprism. This is indicated by the dotted lines in Figure 1. Equation (1) therefore holds where d is now the spacing between the *virtual sources* which appear to be in the plane of the single slit behind the biprism. If the fringe spacing Δx , the virtual source spacing d, and the distance between the plane of observation and the single slit l are measured it is possible to calculate the wavelength of the light.

Setting up the apparatus

You are provided with the following:

(i) an optical bench

(ii) a sodium discharge lamp

(iii) a narrow adjustable slit

(iv) a Fresnel biprism

(v) a viewing eyepiece

(vi) a lens for determining the spacing of the virtual sources

(1) First check that the centres of **ALL** components in the system are set to be the same height above the optical bench. That is, the centre of the hole in the lamp housing should be the same height as the centre of the slit, which should be the same height as the centre of the lens, etc. (see Figure 2). You should try to achieve this to 5 mm accuracy or better. Now remove all components from the optical bench. (Note: You cannot mount the lamp on the optical bench itself, it has to stand on the wooden lab bench top.)

(2) Next, place the sodium lamp on its stand at one end of the optical bench facing down the track.

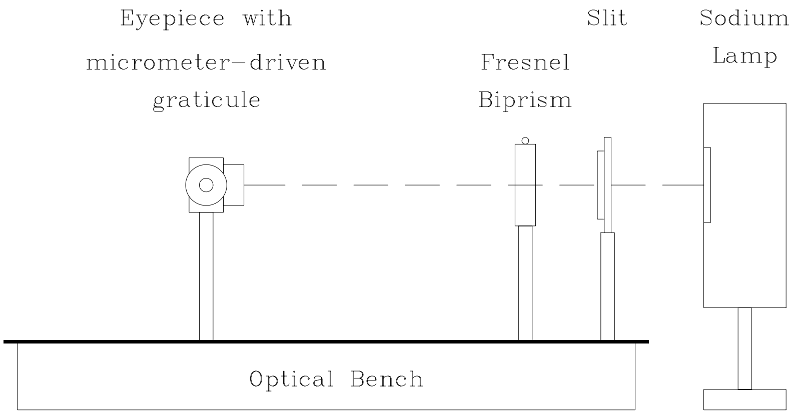

Figure 2: Sketch of experimental setup.

(3) Now place the adjustable slit on the optical bench track, directly in front of the sodium lamp, and adjust both it and the lamp so it is as uniformly illuminated as possible. Adjust the slit width to be equal to about 5 thicknesses of ordinary paper (you can hold slivers of paper between the jaws of the slit while making this adjustment) using the lever. Rotate the slit using the large knurled ring so it is as close to vertical as possible, using your best judgement.

(4) Next place the Fresnel biprism on the optical bench track about 75 mm in front of the slit. You must now adjust the slit so it is parallel with the line between the two prisms of the biprism. **This is a critical adjustment which must be done very carefully!**

To do this, look at the slit through the biprism from a distance of about 300 mm in front of the biprism holder. If you get your head in the correct position you will actually see two images of the slit — one from each half of the biprism. Now move your head slightly from side to side. If the biprism and slit are not parallel you will see the slit images disappear in turn, being cut off by a "line" that appears to move up or down that slit image as you move your head. Rotate the slit **slowly and gently**, using the knurled ring and still moving your head, until a "cut-off" line moving up and down each slit image does not occur but rather the whole slit image appears and disappears at once. The biprism and slit are now very nearly parallel.

(5) Final adjustment is made by looking for fringes through the eyepiece. Place the eyepiece on the optical bench track, looking towards the biprism, about 300 mm from the biprism holder. If you are lucky and the parallelism is good enough, you will see vertical fringes. If you don't, then **gently** adjust the slit angle again using the knurled ring. As you go through the position of parallelism you will see high contrast fringes appear like magic out of the yellow background, and then disappear again. Adjust for the maximum contrast.

Note: Many people have trouble getting fringes. There are two main causes: (a) the slit is too wide, and (b) the biprism and slit are not parallel. If you cannot get fringes try decreasing the slit width, if you darken the room you can still actually see faint light through the eyepiece even when the slit is nominally "completely closed". The jaws don't match perfectly and enough light leaks through to see a very dim fringe pattern. The fringe *contrast* increases as the slit is made narrower, but of course the fringe *brightness* decreases. A compromise is called for!

If, after 15 minutes effort or so you still can't get fringes, then ask your supervisor for help.

Measurements

You are now ready to start making measurements which will enable you to calculate the wavelength of the light source. You need to measure three things:

(i) the spacing of the fringes at the observation plane

(ii) the distance of the observation plane from the slit plane (The biprism has no magnification so this is also the plane in which the two virtual images of the slit are located)

(iii) the separation of the virtual images of the slit.

Fringe spacing

(6) The eyepiece is equipped with a micrometer-driven hairline graticule which you will use to measure the fringe spacing. If you look in the *front* of the eyepiece you will see this moving across the aperture as you adjust the micrometer. You must first adjust the focus of the eyepiece for your eyes so that you can see the hairline clearly.

Switch the room lights on and hold a piece of white paper about 100 mm in front of the eyepiece while looking through it. Twist the knurled focus ring around the eyepiece lens until you can see the moving hairline clearly. You will also see a fixed graticule. When you put the eyepiece back in the biprism setup, note that you will measure the fringe pattern *in the plane of the graticule* because the eyepiece is now adjusted to bring anything in that plane into focus.

Replace the eyepiece on the optical bench, switch the room lights off, move the hairline across the fringe pattern, and measure the fringe spacing. Aim to measure the spacing to an accuracy of 5% or better. **It is up to you to devise a strategy for doing this, and show in your report that it achieves the required accuracy.**

Distance from the observation plane to the slit plane

(7) You can measure this with a metre rule. Once again, aim for an accuracy of better than 5% and show in your report that you achieved this. Be sure that you measure as close as possible to the actual observation plane. Remember that this is the plane of the graticule in the eyepiece, so you will have to measure or estimate where this is. Again, it is up to you to devise a strategy that will give you the required accuracy and describe it in your report.

The separation of the virtual sources

(8) This can be measured using a trick with the aid of the lens. Note that, when using a lens to form an image of an object on a screen, if the object and screen are far enough apart there are two positions of the lens which will give an in-focus image as shown in Figure 3.

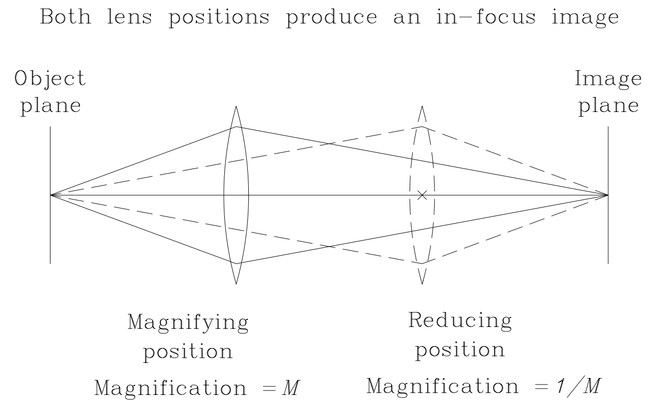

Figure 3: Method for determing d.

A back of the envelope sketch and some thought about the basic imaging properties of converging lenses will show you that the object and screen should be separated by more than 4× the focal length of the lens. In one position the lens magnifies, whereas in the other position it reduces. If the magnification with the lens in one position is M, then with the lens in the other position it is $1/M$. Now imagine that the object is the two virtual images of the slit as seen through the Fresnel biprism. If the separation of the virtual images is d, the separation of the images produced by the lens will be:

$$D_1 = Md$$

with the lens in one in-focus position, and

$$D_2 = d/M$$

with the lens in the other in-focus position. Combining these two equations, it is easy to see that $M = \sqrt{D_1/D_2}$, and once this has been calculated d can be obtained from $d = D_1/M$ or directly from $d = \sqrt{D_1 D_2}$.

Use this to measure the separation of the virtual images of the slit. First roughly measure the focal length of the lens by projecting an image of a distant bright window (this is a good approximation to an object located at infinity if you use a window at a distance at least equal to the width of the main laboratory) onto a wall and measuring the spacing between the lens and wall when you have a focused image. Now move the eyepiece back along the optical bench so that it and the slit are separated by about 5× the focal length of the lens, and place the lens in between the eyepiece and biprism. Adjust the longitudinal position of the lens on the track **with the eyepiece fixed in the same position** until you see an in-focus image of the two virtual slit images through the eyepiece. Measure the image spacing using the micrometer graticule. This is D_1. Now move the lens up or down the track (still with the eyepiece in the same position) until you find another in-focus image. Again measure the spacing of the slit images using the micrometer graticule. This is D_2. You can now calculate d.

Estimate the errors in this procedure and include an explanation of the estimate in your report.

You are now in a position to calculate the wavelength of the sodium lamp. Do so, and also estimate the error on the result. Compare your value with the mean wavelength of the two yellow sodium lines as given in Reference 2 which is available in the laboratory.

Write-up

In your write-up, be sure to include the following:

1. A derivation of equation (1).
2. A brief description of the experimental method.
3. Descriptions of your strategies for measuring the parameters required for calculation of the wavelength, and error estimates.
4. The final result, a comparison with the known value, and an estimate of the measurement error.

List of Equipment

1. Optical bench
2. Sodium light source
3. Variable aperture slit
4. Biprism

5. Thin lens
6. Eyepiece graticule
7. Large set-square
8. Meter rule

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