Interference and Diffraction of Light

When two or more waves overlap at some point, they can add together so that the combined amplitude could be either greater or less than the amplitudes of the constituent waves. This effect is known as *interference*. In most general terms, the interference can be either *constructive* (the resulting amplitude is greater than the individual amplitudes) or *destructive* (the resulting amplitude is less than the individual amplitudes).

To observe sustained optical interference phenomena, several conditions must be present:

1. The sources of interfering waves must be coherent, that is, they must maintain a constant phase with respect to each other.

2. The sources should be monochromatic (single wavelength) or quasi-monochromatic.

3. It is possible that on occasion the source may be non-monochromatic. If this is so, then the path difference for two interfering waves must be small (e.g. thin film interference).

In this experiment, a helium-neon (He-Ne) laser of wavelength 632.8 nm will be used as a source of coherent monochromatic light to illuminate single, double, and multiple slits, and circular apertures. Using only an ordinary ruler, the wavelength of the laser light will also be measured.

Experiment:

Apparatus:

- optical bench with holders and mounts
- helium-neon laser
- slide with four single slit apertures of different widths.
- slide with four double slit apertures of different widths and separations
- slide with multiple slit apertures
- short ruler with millimeter gradations
- circular table mount for short ruler
- viewing screen with millimeter graduations
- two-meter stick
- one-meter stick

CAUTION

Laser radiation can cause retinal damage and blindness if allowed to be focused into the eye

DO NOT LOOK DIRECTLY INTO THE LASER!!

Viewing the beam from the side or a pattern on the wall is not harmful

1. Single Slit Diffraction.

Turn on the He-Ne laser, and position the screen so that it is a bit more than 2.5 m from the laser, and so that the laser beam strikes the screen normally near its center. Mount the slide with the single slits in the holder, and position it so that the laser beam falls on the narrowest slit, and a clear diffraction pattern can be seen on the screen. The clearest pattern will result when the narrow beam fully covers the width of the slit. Carefully adjust the position of the slit to obtain the best image.

* By measuring the distance of the slit from the screen, and the position of the minima of the diffraction pattern on the screen,

  i) verify that the minima occur as predicted by the theory, and
  ii) determine the width of the slit (Note that, as in every experimental measurement, your determination of the width must include a value and its error).

For the He-Ne laser is $\lambda = 632.8$ nm.

* Determine in the same way the widths of the other three slits in the slide.

* As you changed slits, did the patterns you obtained agree with the theoretical predictions?

* Did your experimental measurements of the widths agree (within error bounds) with those reported on the slide's label? Would you conclude that this is a good method for measuring the width of slits? Of any size? What changes would you make to measure a much narrower slit if the present setup is inappropriate? What about a much wider slit?

Optional: If your measurements do not agree with those on the label, you may want to measure the width of one or more slits using a travelling microscope. There will be one such microscope with an accuracy of 10 μm available in the laboratory. Suitable illumination with a desk lamp will make the slit easily visible in the microscope.

2. Double Slit Interference and Diffraction

Young's classic double slit experiment is very simple: a monochromatic beam of light is split into two beams by slits. The split beams are allowed to overlap and the two waves interfere – constructively in some places, destructively in others.

Thomas Young (1773-1829) was an English linguist, physician, and expert in many fields of science. At the age of fourteen he was familiar with Latin, Greek, Hebrew, Arabic, Persian, French and Italian, and later was one of the first scholars successful at decoding inscriptions on the Rosetta Stone. His was one of the most brilliant minds of the late eighteenth-century. At Cambridge he was called 'Phenomenon Young'. While still in medical school he made original studies of the human eye and developed the first version of what is now known as the three-colour theory of vision. While studying the human voice mechanism, he became interested in the physics of sound and sound waves. Then he turned to optics and developed a wave theory of light that was successful in explaining many of Newton's experiments on light. This interpretation was attacked by some in England who were upset by the implication that Newton's original particle or corpuscular theory of light might be wrong.

Method

Mount the slide with the four sets of double slits in the holder. Position it so that the laser beam falls on the narrowest, closest pair of slits, and a clear diffraction pattern can be seen on the screen. The clearest pattern will result when the narrow beam fully covers the width of both slits. Carefully adjust the position of the slide to obtain the best image. (Hint: notice that the best image will occur when you see the brightest spot of light while looking at the slide from the side, from your position besides the table).

* See how the pattern on the screen changes when the slit spacing is changed and also when the slit width is changed. Do your observations agree with the theoretical predictions?

* Determine the width of the slits and their separation for each of the four double-slits. Did your experimental measurements agree within error bounds with those reported on the slide's label? Would you conclude that this is a good method for measuring the width and separation of double slits?

3. Multiple Slits

Mount the slide with the multiple slit systems in the holder. Successively position it so that a clear diffraction pattern can be seen on the screen for each of the systems on the slide. Recall that the clearest pattern will result when the narrow beam fully covers the width of the slits. Carefully adjust the position of the slide to obtain the best image.

* Make a rough sketch of the variation of intensity across the screen for each of the diffraction patterns (i.e. for each of the slit systems).

4. Measuring the Wavelength of Light with a Ruler (after A.L. Schawlow)

A logical extension of Young's double-slit interference experiment is to increase the number of slits from two to a larger number *N*. An arrangement like this, usually involving many more slits – as many as 1000/mm is not uncommon – is called a *diffraction grating*. Actually a grating of the type just described, in which light passed *through* the slits, is called a *transmission grating*. Sometimes gratings are ruled on a surface and the interference effects are viewed in reflected rather than in transmitted light. These are called *reflection gratings*. It is this second type of grating that will be used in this experiment.

In this exercise we are going to use the fine rulings on a ruler as a reflection diffraction grating. The diffraction pattern will be obtained by reflecting the laser beam off the ruler. This is shown schematically in Figure 1. Notice that the angles α and β for the incident and reflected beams respectively are defined differently to the normal convention – in this case they are defined *with respect to the surface of the ruler* rather than with respect to the normal to the surface. This is done because it simplifies the subsequent analysis.

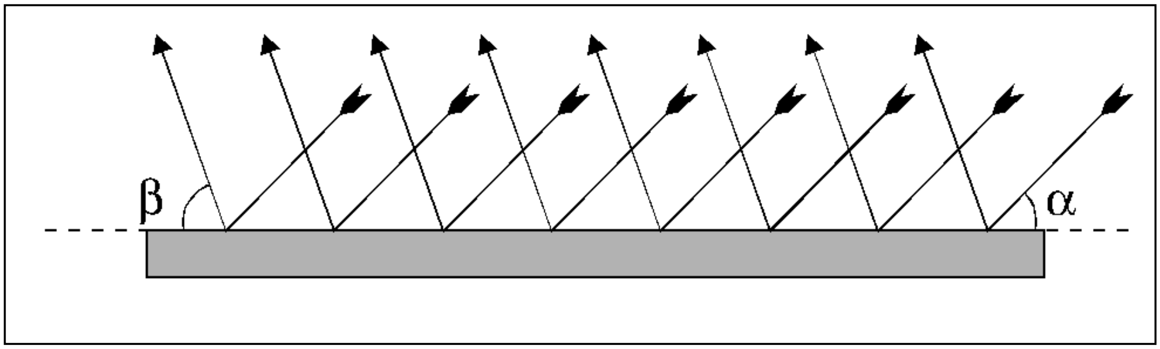

Figure 1. A ruler used as a diffraction grating. $\boldsymbol{\alpha}$ is the incidence angle and $\boldsymbol{\beta}$ is the reflection angle. Note that in this case the angles are measured from the reflecting surface.

It is easy to derive the path difference for adjacent rulings following the diagrams of Figure 2, shown below.

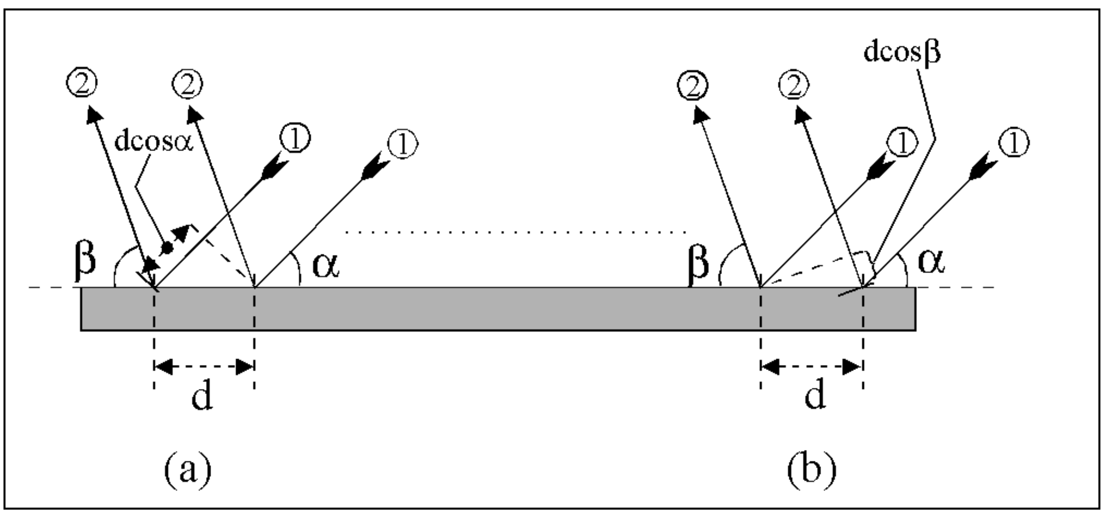

Figure 2. Extra length travelled by (a) the incoming portion of beam "2", and (b) the outgoing portion of beam "1".

Figure 2(a) shows the extra length travelled by the incoming portion of beam "2", while Figure 2(b) shows the extra length travelled by the outgoing portion of beam "1". From these we obtain that the path difference for adjacent rulings is $d\cos\alpha - d\cos\beta$, where α and β are shown in the diagrams.

The condition for maxima is then $n\lambda = d\left(\cos\alpha - \cos\beta_n\right) \quad n = 0,1,2...$

where β_n is the value of β corresponding to the n^{th} order diffraction. If α and β_n are very small, as they will be as the light just grazes the ruler, then

$$\cos\alpha \approx 1 - \alpha^2/2$$

and similarly for $\cos\beta_n$, so that we can write $\quad n\lambda \approx (d/2)\left(\beta_n^2 - \alpha^2\right)$

For $n = 0$, the light is just reflected off the ruler with the reflection angle equal to the incident angle: $\beta_o = \alpha$.

Method:

The short ruler is placed on the circular table on the optical bench, parallel to the direction of the laser beam and just beside it. The ruler is then slightly displaced and rotated on the table, until the laser beam passes along the ruler and grazes the millimeter divisions over the last centimeter or so of the ruler.

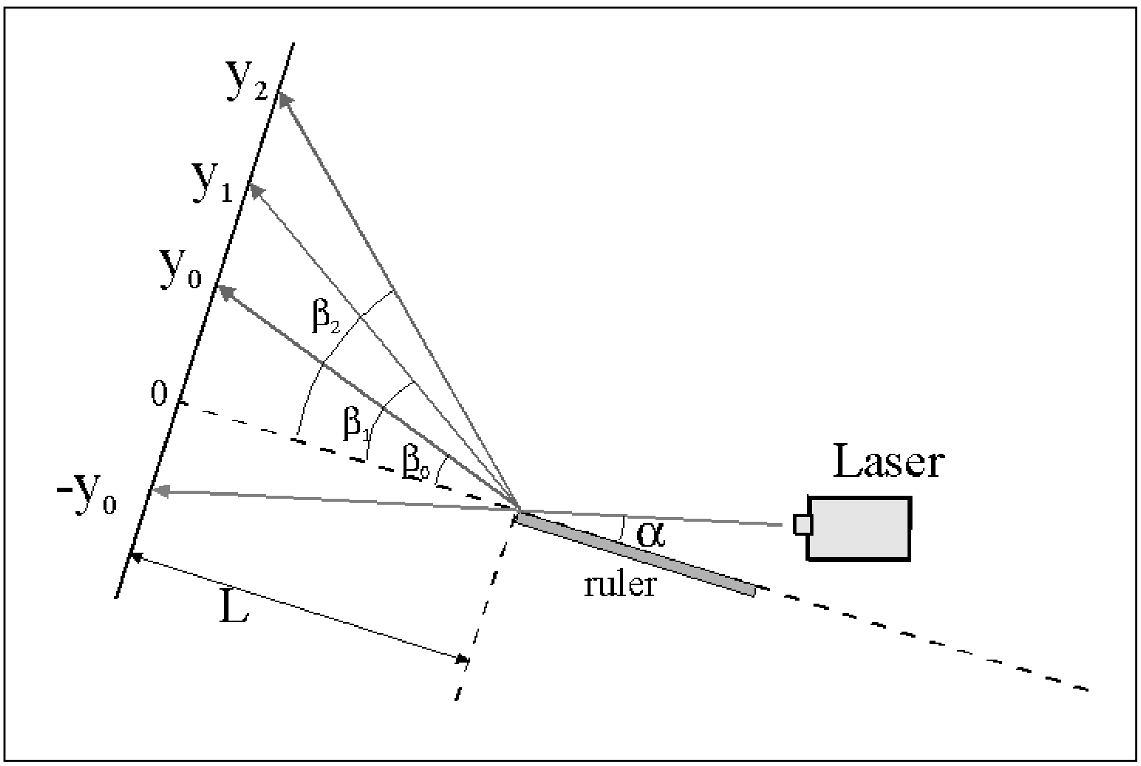

Figure 3. Measuring the wavelength of light with a ruler.

As shown in Fig. 3, some of the beam passes over the end of the ruler directly striking the screen at position $-y_o$. Several sharp diffraction orders will be seen on the screen, labelled y_o, y_1, y_2, ... in Figure 3.

The angle of incidence $\alpha = \beta_o$ is defined by the spots y_o and $-y_o$. All the other diffraction angles can be derived from the other spots on the screen. Let $-y_o$, y_1, y_1, y_2... be the distances of the spots on the screen *from the point O*, *midway between $-y_o$ and y_o*, and let L be the distance from the screen to the edge of the ruler. Then, *for small angles*:

$$\alpha = \beta = y_o/L\text{ , and } \beta_n = y_n/L$$

so that
$$n\lambda = \left(d/2L^2\right)\left(y_n^2 - y_0^2\right)$$

By measuring these quantities it is possible to estimate λ to within 1% or 2%.

* Measure the values of y_n with their uncertainties.

* Draw a plot of y^2_n against n. If possible within the scale you are using, draw the error bars for the values of y^2_n. From the graph, estimate λ and its error.

* Estimate the value of λ and its error using linear regression (see Appendix B – but you should be able to find a linear regression package on a computer or on your calculator).