PHY221: Resolving Power of Telescope

1 Introduction

The following discussion and figures have been adapted from Ref. [1].

The resolution of any viewing instrument (a telescope, our eyes) refers to the ability of being able to distinguish between two closely spaced objects. Common experience tells us that bringing an object closer to our eyes usually allows us to say if the object is singular or has multiple components (such as an intertwined string). By bringing the object closer to our eyes, we increase the angle subtended by the two separate components allowing us to "resolve" them.

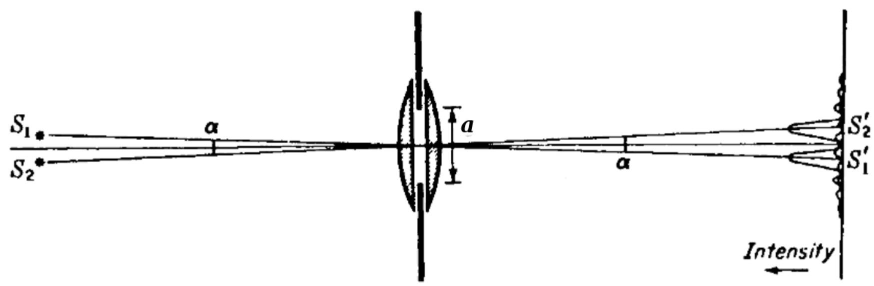


Figure 1: Diffraction images of two sources formed by a rectangular aperture

A telescope is an instrument which aids in the viewing of remote objects. Telescopes are designed to give an image of a point source which is as small as possible. When parallel light passes through the aperture, it gives a diffraction pattern with a central maximum of fixed width. This diffraction pattern limits the resolving power of the telescope.

Figure 1 shows a double-convex lens limited by a rectangular aperture of vertical dimension a. Two sources S_1 and S_2 form real images S_1' and S_2' on a screen. Each image consists of a single-slit diffraction pattern. The angular separation α between the sources is equal to the angular separation between the central maxima. The condition shown here is when the principal maximum of one source falls exactly on the second minimum of the adjacent pattern. This is the smallest value of α which will give zero intensity between the two maxima.

The angular separation from the center to the second minimum corresponds to $\sin\theta \approx \theta = 2\lambda/a = 2\theta_1$, where θ is the angle made by the line joining the center of the aperture and the position of one maximum with the horizontal. Figure 2 shows the diffraction images of the two sources for different choices of α. Figure 2:(a) shows the case that is illustrated in Fig. 1.

As the angular separation α reduces, the two maxima merge, and the resultant intensity (shown as the heavy line) changes its shape. At $\alpha = \theta_1$, the two sources are barely resolved with a small dip in intensities still visible. At smaller α, at no point does the intensity become zero and it is not possible to resolve the two sources as separate. Rayleigh arbitrarily fixed the separation $\alpha = \theta_1 = \lambda/a$ as the criterion for resolution of two diffraction patterns; this is known as *Rayleigh's criterion*. The angle θ_1 is sometimes called the *resolving power* of the aperture a, or it is also called as the *minimum angle of resolution*.

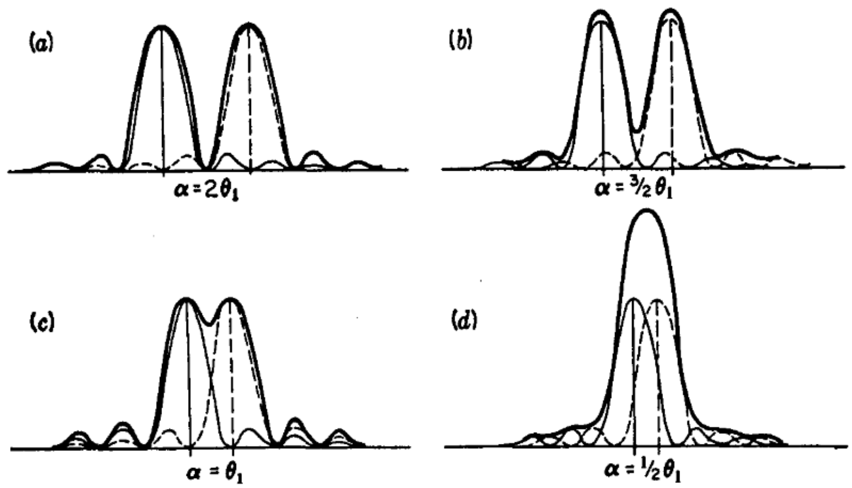
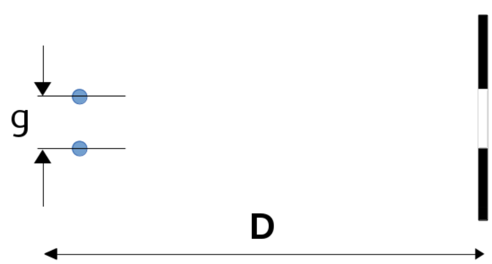


Figure 2: Diffraction images of two sources:(a) and (b) well resolved; (c) just resolved; (d) not resolved.

2 Purpose

The objective of this experiment is to use a rectangular slit to examine the resolving power of a telescope and demonstrate Rayleigh's criterion by examining the relationship between g/D and λ/a; where g is the distance between the two sources, D is the distance between the plane containing the sources and the plane of the objective of the telescope, λ is the wavelength of light for the two sources, and a is the width of the slit in front of the objective of the telescope. Reproduce the left part of Fig. 1 (upto the aperture) in your notebook and show that the angle subtended by the sources at the aperture may be approximated by g/D, i.e. $\alpha \approx g/D$.



3 Procedure

- Turn on the lamp. (*What source is the lamp? What is its typical frequency?*)
- Obtain a card from the laboratory assistant with slits etched on it (source card). Make a note of the different pairs of slits, each pair has a different separation between them. By placing these slits in front of the lamp, you will be able to obtain two distinct sources of light. The separation between the slits is g, the distance between the two sources.
- Examine the telescope. (*Does it look horizontal? Does it matter if it is not perfectly horizontal?*). Note the rectangular slit apparatus mounted on the front, near the objective of the telescope. Learn to use the screw to open and close the rectangular slit. Determine the least count of the scale etched on the rectangular slit apparatus, and its zero error. Note both in your lab handbook.
- Mount the source card near the lamp using sticky-tape. Using black card paper strips, darken all pairs of sources except the one you are examining at the moment. Note the g for the source slits you are considering.
- Place the telescope at a distance D from the sources. (A suggested starting value is $D = 1.0$ m.) Open the rectangular slit on the telescope completely, and observe the image of the two sources through the eyepiece. Focus the telescope till you obtain a sharp image of the source(s) in your eyepiece.
- Now the values of g, D, and λ are fixed[1]. Proceed to determining a in two ways as follows:
  - Start with the rectangular slit wide open, such that the two sources are completely resolved. Reduce the width of the rectangular slit slowly while observing through the telescope. As the slit gets narrower, diffraction patterns from the two sources will appear and start to spread. As the slit gets narrower, the dark region between the two sources becomes blurred and tends to vanish. At this stage the two sources are just resolved and the angle subtended by the sources is the minimum angle of resolution. Take a measurement of the width of the rectangular slit.
  - Now reduce the width of the rectangular slit till the two sources are completely unresolved. Now proceed to slowly increase the width while observing through the telescope. At some point, the slits will appear just resolved. Measure the width of the rectangular slit again.

  Repeat the above two steps, thus obtaining four measurements of a. Use the arithmetic mean of the four measurements of a (let us call it A) for further steps.
- Repeat the measurement of A, for different values of D, such that a total of three values of D are examined. Make a table as follows, filling in the boxes with measured A values.:

D	g_1	g_2	g_3
D_1			
D_2			
D_3			

[1]The wavelength of the sodium lamp is 5893Å.

- For each value of A in the above table, calculate λ/A and g/D. Draw a graph (using Excel or any other preferred software) of g/D vs λ/A and determine the slope, thus verifying if λ/A and g/D are equal. Paste the graph (along with fit) in your lab notebook.
- *What would you say are the largest sources of uncertainty in your experiment? Are they systematic or random? How would you quantify the largest one?*

References

[1] Francis A. Jenkins and Harvey E. White, "Fundamentals of Optics", 4th Ed.