Lab 14: Diffraction of Light

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1 Introduction

Diffraction is a phenomenon in which waves deviate without any change to their energy states. While its applications may be more limited, The principle has applications in both everyday devices, several natural phenomena and is essential in certain scientific devices used for measurement and observation. From CD players to the beautiful Godrays you might find on a cloudy day, diffraction appears in many parts of our day to day lives. In this lab we explore some of these applications, investigating the ways in which using the principles of diffraction and interference to measure properties of different objects or the laser itself.

2 Diffraction and Size Measurements

Materials: Laser, single-slit apparatus, whiteboard, ruler, hair, blood slides.

Methods: Place the laser at 140 cm from the whiteboard and shine the laser through the single-slits of different sizes. Measure the central maxima on the whiteboard for the known slit sizes. Measure other objects' central maxima and extrapolate their sizes.

Note that the extrapolation only works if the distance between the laser and the whiteboard is kept constant.

2.1 Data and Extrapolation

To linearize the data, we use the following conversion (where r is the central maxima and s is the slit size):

$$\log r = m \log s + b$$

$$\log r = \log s^m + b$$

$$b = \log C \implies \log r = \log s^m + \log C$$

$$\log r = \log C s^m \implies r = C s^m$$

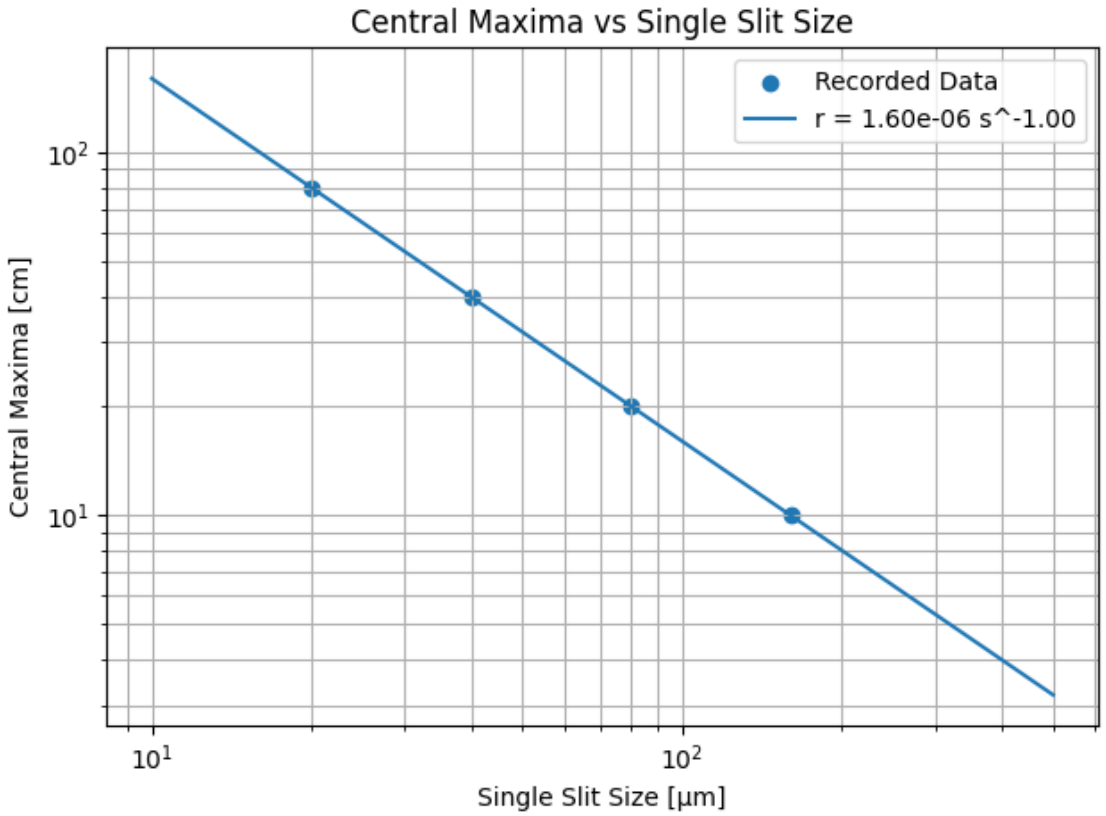
$$\boxed{r = 10^b s^m}$$

Using linear regression on the logarithmic data to find m and b:

[ ]:
```
from math import *

import matplotlib.pyplot as plt
import numpy as np
from si_prefix import si_format
from tabulate import tabulate

# Recorded known data for extrapolation

single_slit_size = np.array([0.02e-3, 0.04e-3, 0.08e-3, 0.16e-3])  # m
single_slit_maxima = np.array([0.08, 0.04, 0.02, 0.01])  # m

# The fringes are not used in the calculations but are recorded anyway
fringes = [4, 12, 20, 80]

# Compute linearization

m, b = np.polyfit(np.log10(single_slit_size), np.log10(single_slit_maxima), 1)
x = np.linspace(1e-5, 5e-4, 256)
f = lambda s: (s**m) * 10**b

# Plot linearization

fig, ax = plt.subplots()

ax.scatter(single_slit_size * 1e6, single_slit_maxima * 1e3, label="Recorded␣
 ↪Data")
ax.plot(x * 1e6, f(x) * 1e3, label=f"r = {10**b:.2e} s^{m:.2f}")
ax.set_yscale("log")
ax.set_xscale("log")
ax.set_title("Central Maxima vs Single Slit Size")
ax.set_xlabel("Single Slit Size [µm]")
ax.set_ylabel("Central Maxima [cm]")
ax.legend()
ax.grid(which="both")

fig.tight_layout()


# Beautifully Pythonic and "functional" code!

print(tabulate(zip(["Jonah's Hair","Alec's Hair","Elias' Hair","Human RBC␣
 ↪(healthy)","Human RBC (sickle)","Frog RBC","Bird RBC",],[s + "m" for s in␣
 ↪map(si_format, map(f, [0.020, 0.015, 0.015, 0.23, 0.19, 0.08, 0.
 ↪15]))],),headers=["Object", "Extrapolated Size"],))
```

```
# Recorded cental maxima sizes for different objects are in the horrible
# one-liner I made below in the *second* input to zip() in meters
```

Object	Extrapolated Size
Jonah's Hair	80.0 µm
Alec's Hair	106.7 µm
Elias' Hair	106.7 µm
Human RBC (healthy)	7.0 µm
Human RBC (sickle)	8.4 µm
Frog RBC	20.0 µm
Bird RBC	10.7 µm



2.2 Analysis

Our extrapolation of the data matches realistic values very closely. For example, real human red blood cells are between 6-9 µm, and out found value was exactly 7.0 µm. Human hair is within 60-120 µm, and all out values are in that range. Another point mentioning is that the sickle cells had a lot of scattering lines within the maxima. The reason that the sickle cell blood had a regular seeming structure, but still had the streaks, is due to the shape of the sickle cells. The thin line

would cause a more slit-like interference pattern hence the streaks.

Also, Elias' shirt is cross-stitched as was evident in the interference pattern. There were two interference patterns in perpendicular directions with the same shape.

3 Measuring the Wavelength of the Laser

Materials: Laser, double-slit apparatus, whiteboard, ruler.

Methods: Place the laser at 140 cm from the whiteboard and shine the laser through the double-slit apparatus. Measure the central maxima on the whiteboard and count the number of anti-nodes.

Data: For a spacing between the slits of 250 µm, the central maxima was 4 cm across with 10 anti-nodes. The slit size was 40 µm and the distance from the laser to the whiteboard was 140 cm.

Calculations: The double-slit interference formula is:

$$\lambda = \frac{xd}{L}$$

where L is the distance from the slits to the whiteboard, d is the distance between the slits, λ is the wavelength of the light, and x is the fringe spacing (distance between bright spots).

We measured the number of nodes in the central maxima and its width, so:

$$x = \frac{W}{n}$$

where n is the number of nodes. Plugging this in and substituting for real values:

$$\lambda = \frac{Wd}{Ln} = \boxed{714\,\text{nm}}$$

Analysis: This wavelength would imply the light is red, but it was green. This is most likely due to measurement error, especially for the distance between the slits and whiteboard, which was measured haphazardly. However, this value is still within the order of magnitude of visible light.

4 Conclusion

Our experimentation allowed us to determine the wavelength of the light to be 714 nm, which is a bit odd, as the laser itself was visibly green. Alongside this, we also used the laser to determine the stitch in Elias's shirt to be a cross stitch, which was visible due to the fact that when the laser was shone through the fabric, we noticed two interference patterns. We also determined that the relationship between the number of fringes and the size of the slit passed through to be inversely proportional. Most notably, we were able to determine the size of red blood cells and hairs with a similar method. We determined that Jonah's hairs to be thinnest of the group at only 80 µm. We measured a human red blood cell to be 7 µm, smaller than those of both frogs and birds at 20.0 µm and 10.7 µm respectively. We got hands-on experience with the applications of diffraction and interference in this lab, allowing us a glimpse into the many interesting applications of physics even though it may not be immediately intuitive, these principles have many uses in engineering and the sciences.