Experiment 11: Holographic Interferometry of a Cantilever using Instant Holographic Film

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May 7, 2024

Abstract

The theoretical and experimental plots for the displacement were created and produced better results for the lighter 2.2g mass than the heavier 5.3g mass. The plots showed a non-linear increasing curve as seen in the figures below for the theoretical curves (and reduced thickness theoretical curves). The experimental plots did not agree with the theoretical more for the heavier weight than the lighter weight.

1 Introduction

Using the interference of two wavefronts, it's possible to create a hologram of a chosen object in a glass plate layered with holographic film. Wavefronts an incident beam of light goes through the holographic film and glass plate to the Cantilever underneath and interferes with the reflected wavefronts, which creates an initial reference hologram. Once this hologram is created, the actual object can then be displaced vertically by a small distance, and this will not affect the reference hologram that was just created. An interference pattern can be observed now with the initial reference hologram and the newly displaced Cantilever, as the light source has remained the same. There is a relationship between the length of the vertical displacement and the number of interference fringes observed, with more fringes for a larger displacement.

$$\Delta y = \frac{N\lambda}{cos\alpha + 1} \tag{1}$$

$$\Delta y = \frac{12F}{Ewt^3}[\frac{L^3}{6} - \frac{(L-x)^3}{6} - \frac{L^2x}{2}] \tag{2}$$

2 Experimental Procedure and Design

This experiment will create a hologram of a Cantilever using a holographic film on a glass plate. This will provide an opportunity to observe interference patterns created with two different weights added to displace the Cantilever vertically by a small distance.

A point by point procedure can be outlined via:

1. The experiment required the use of a 5mW laser, a glass plate layered with holographic film, 2 different weights, and a camera angled above the glass plate. The laser was turned on to warm up for 15 minutes before conducting the experiment. The camera was turned on and ready to record video, and the glass plate with holographic film was ready to be taken out of a darkened environment to be used for light exposure from the laser in a dark room.

2. The first part of the experiment was creating the initial un-displaced Cantilever hologram. To do this, the glass plate with film were taken out of the dark environment into the dark room where the only source of light was the laser (covered), and a small amount of light from the computer screen displaying the video from the camera. The plate was placed carefully against the back wall without touching its surface, with the film side facing up towards the camera and screwed in to be secure.

3. It was placed right underneath the camera and the laser was uncovered to let the light shine over the entire surface of the plate. After a few seconds, light from the Cantilever starts to interfere with the hologram and along with ambient vibrations in the dark room, creates a bit of shimmering. The camera is now recording the process.

4. After a few more seconds, the first light weight was hung on the Cantilever to slightly displace it. This created an interference pattern that could be observed on the top of the plate and on the video. Lastly, the light was taken off and a slightly heavier weight was hung. This created an interference pattern with more fringes.

5. Logger Pro was then used to measure the spacing between fringes acquired from a screenshot of the video recording. Plots for theoretical and experimental curves were created, which are shown below.

3 Images and Plots

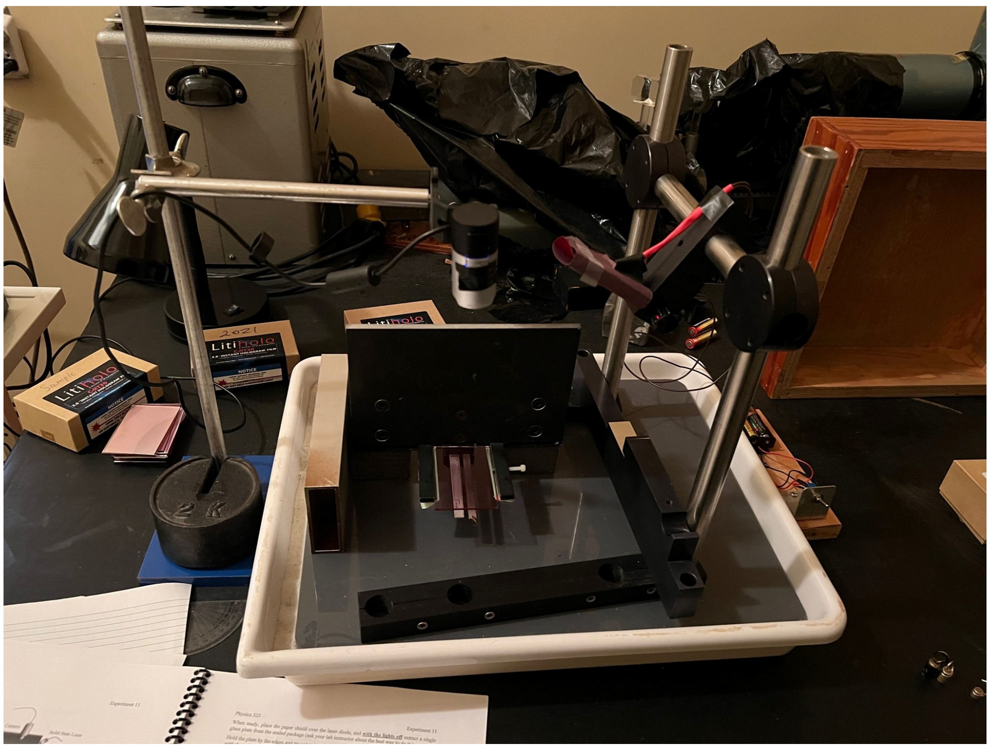

Figure 1: Top-front view of the experimental setup including the laser (top right), camera (top), cantilever (bottom)

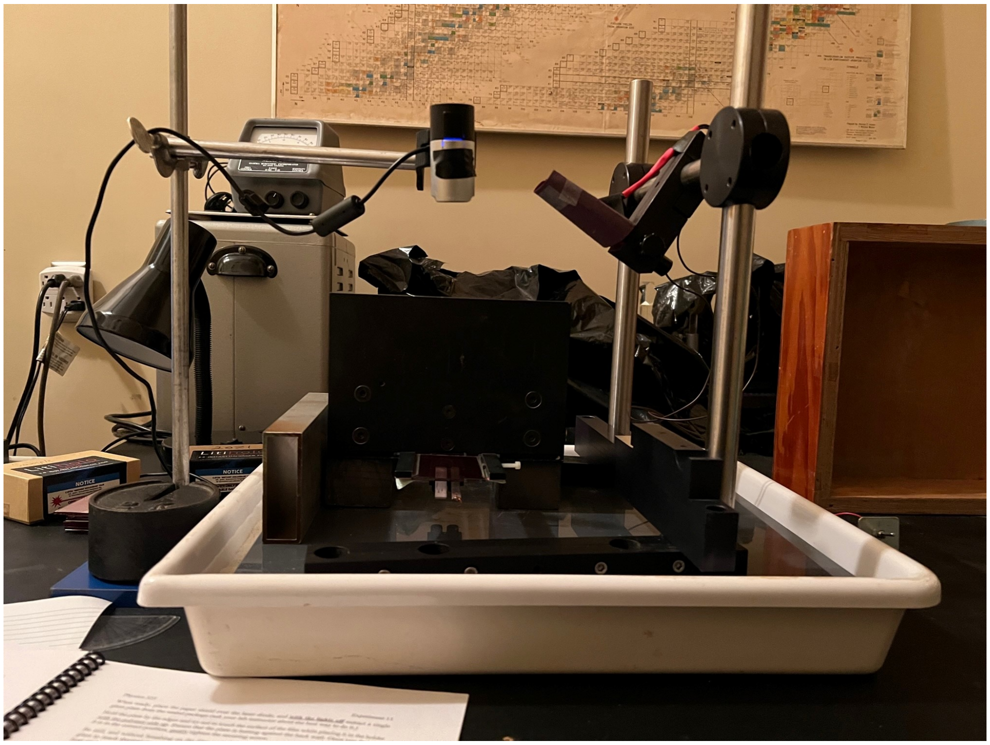

Figure 2: Front-view of the setup

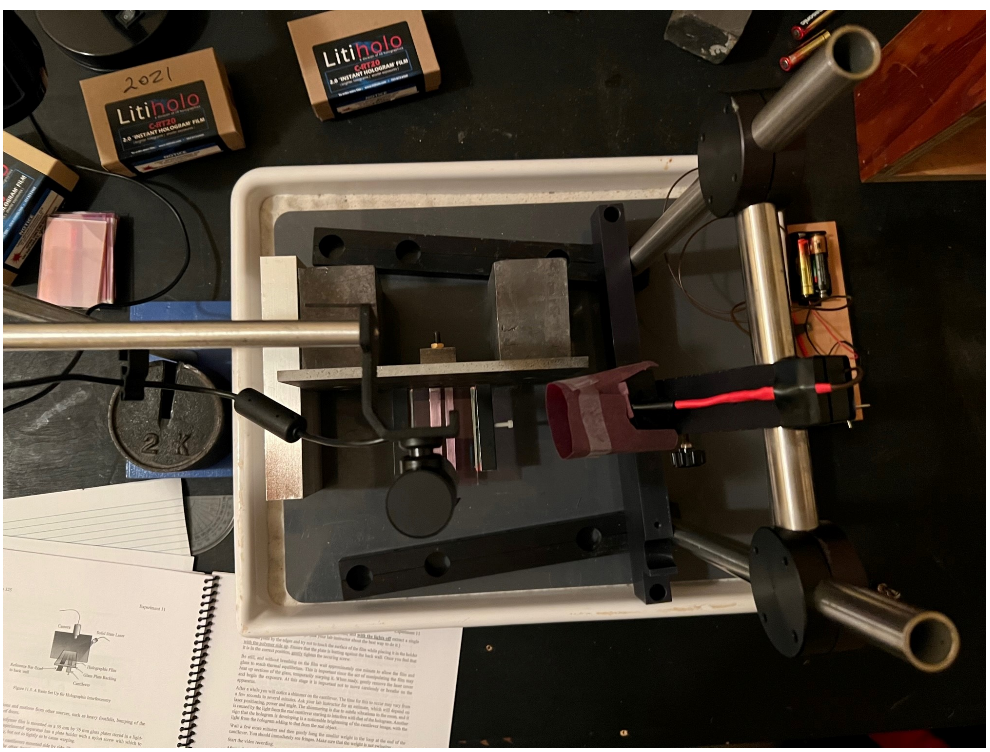

Figure 3: Top-view of the setup

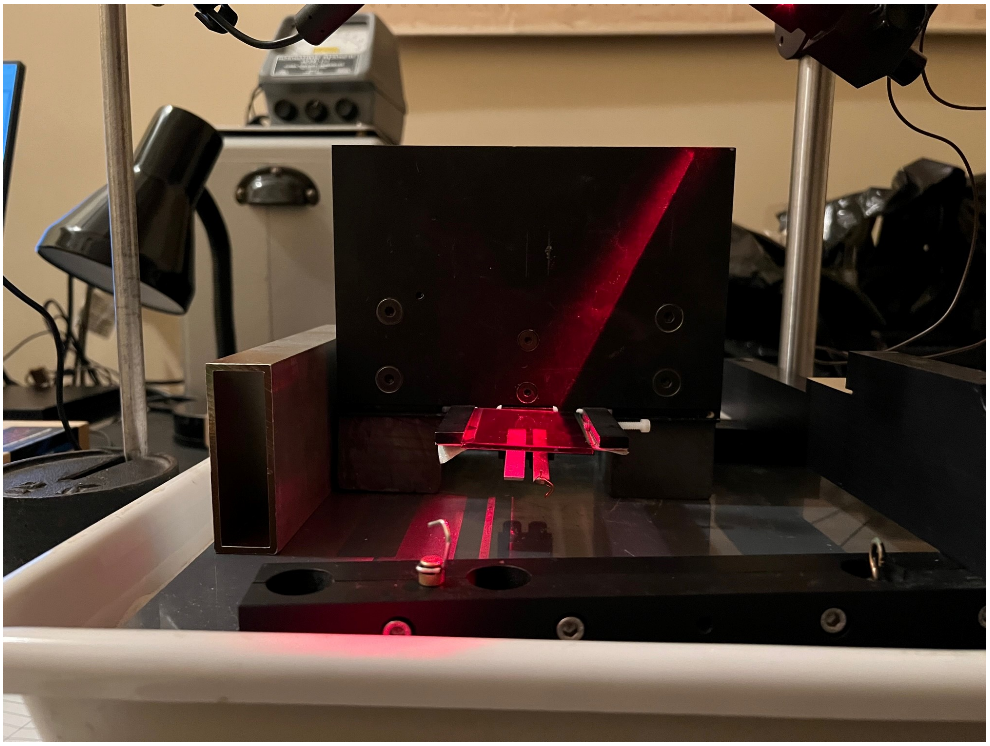

Figure 4: Front-view with laser shining on the plate

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Figure 5: Mass of the lighter weight

Figure 6: Mass of the heavier weight

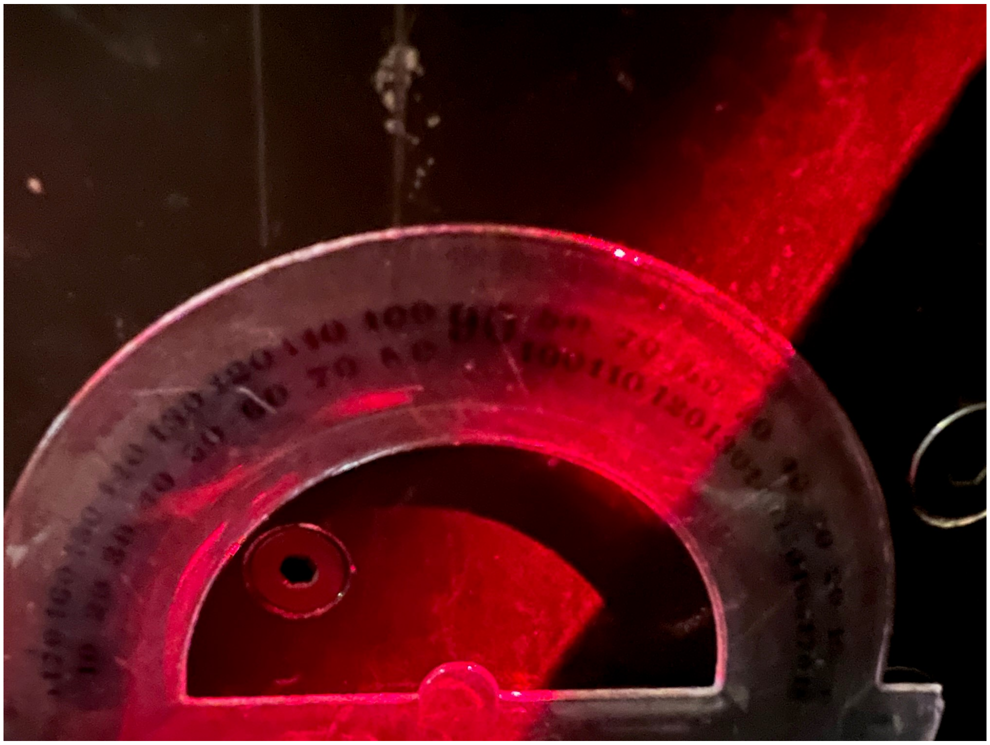

Figure 7: Angle of the incident light

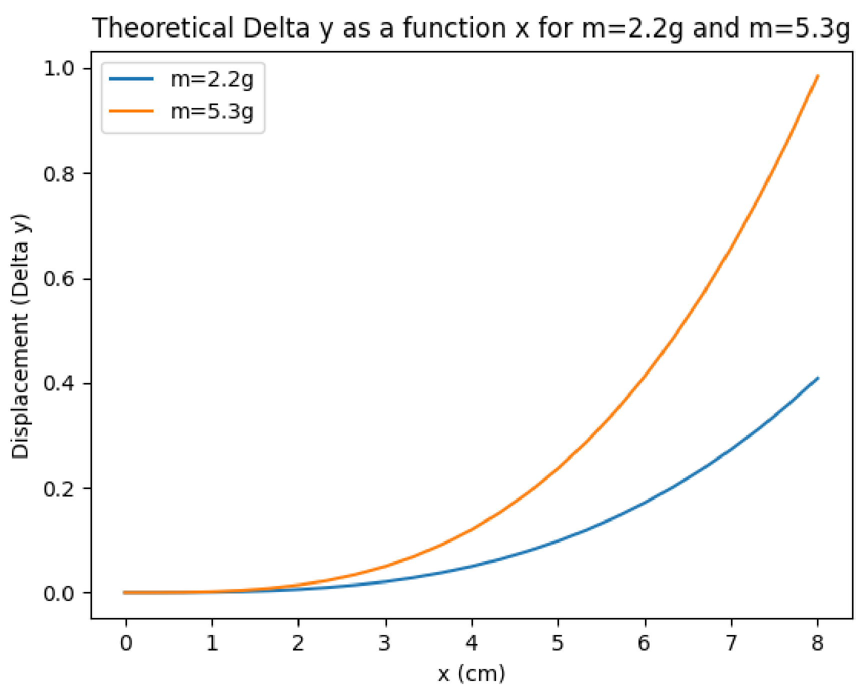

Figure 8: Theoretical plots for displacement using equation 2 for both masses

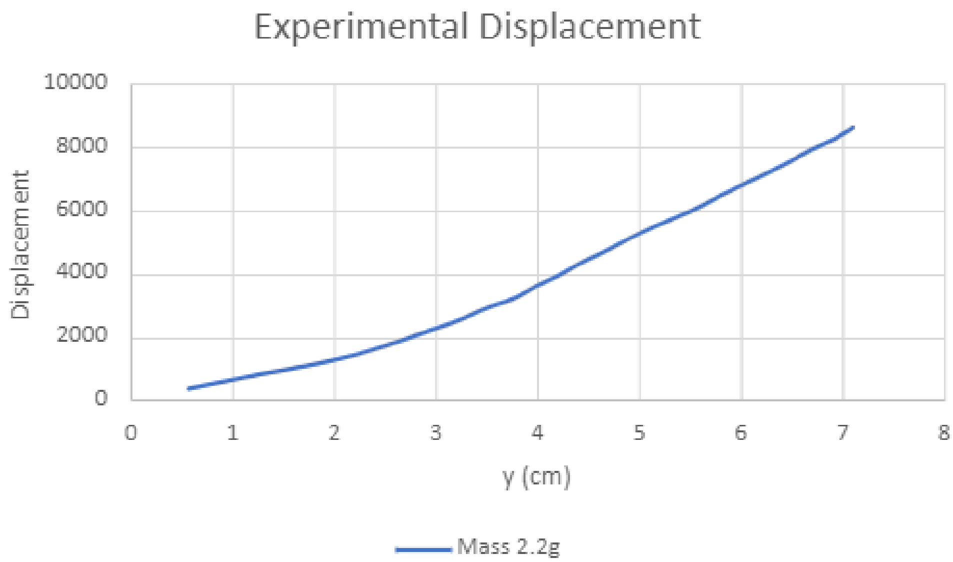

Figure 9: Experimental displacement curve for m=2.2g

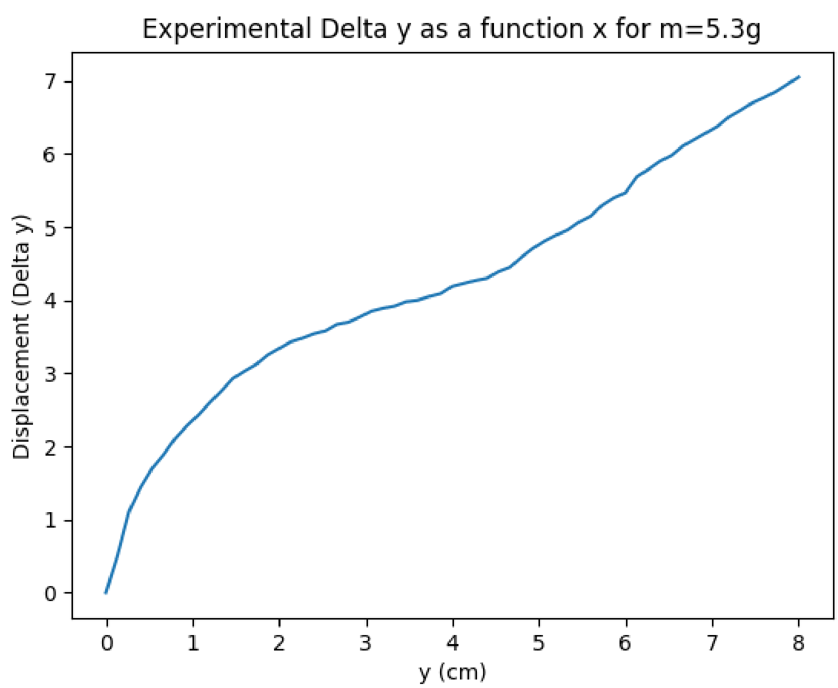

Figure 10: Theoretical plots for displacement using equation 2 for both masses

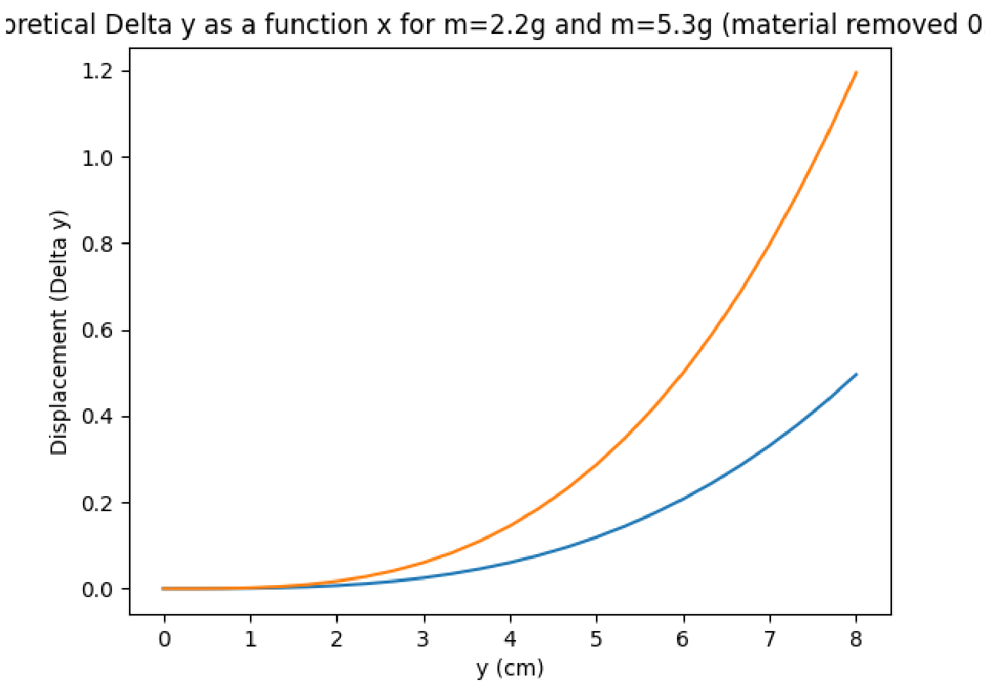

Figure 11: Theoretical plots for displacement for both masses with thickness reduced by 0.1mm

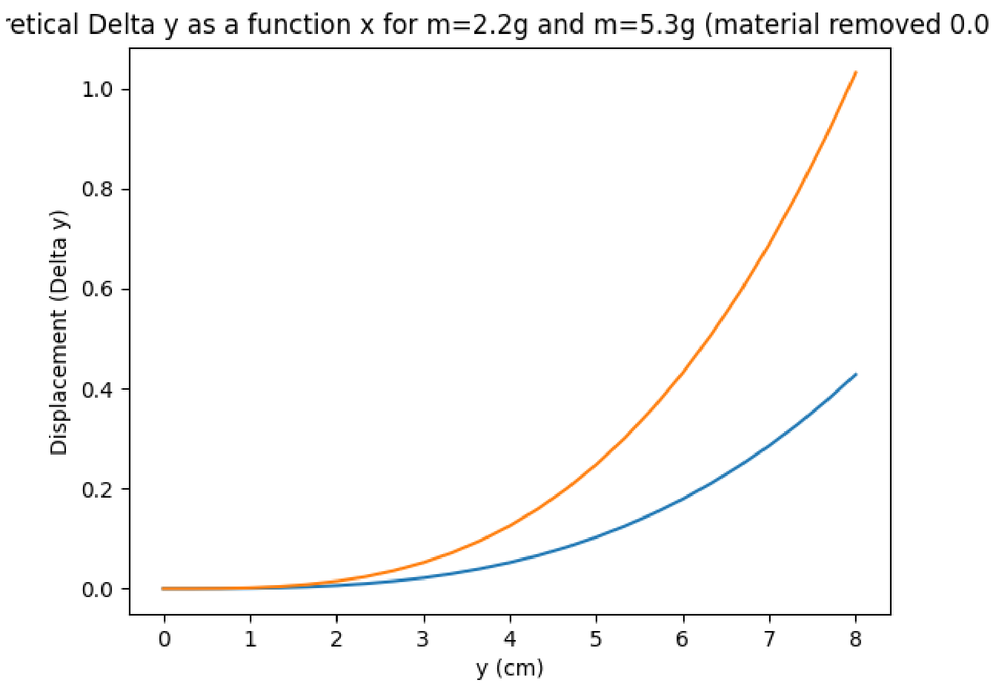

Figure 12: Theoretical plots for displacement for both masses with thickness reduced by 0.025mm

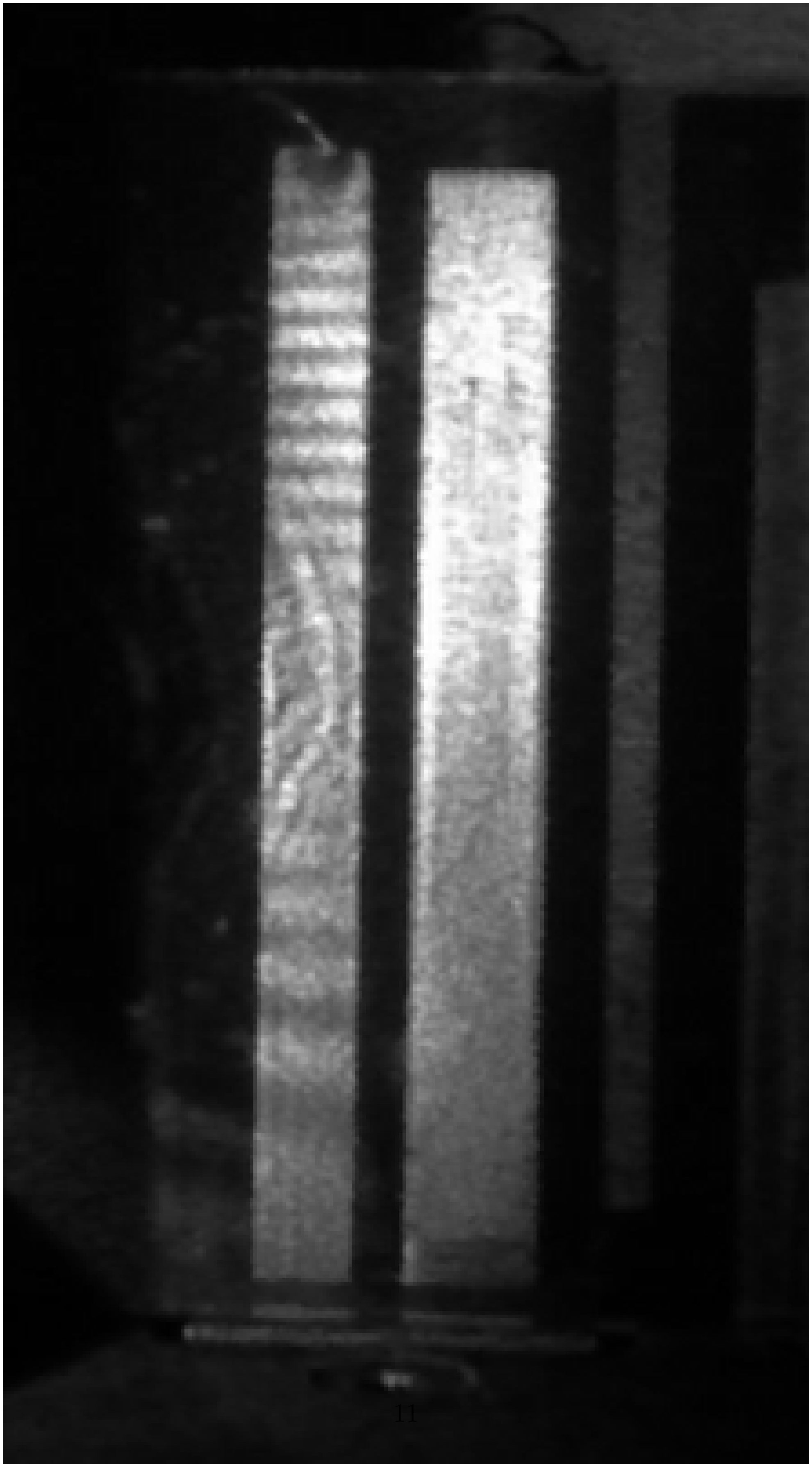

Figure 13: Interference pattern observed for a mass of 2.2g

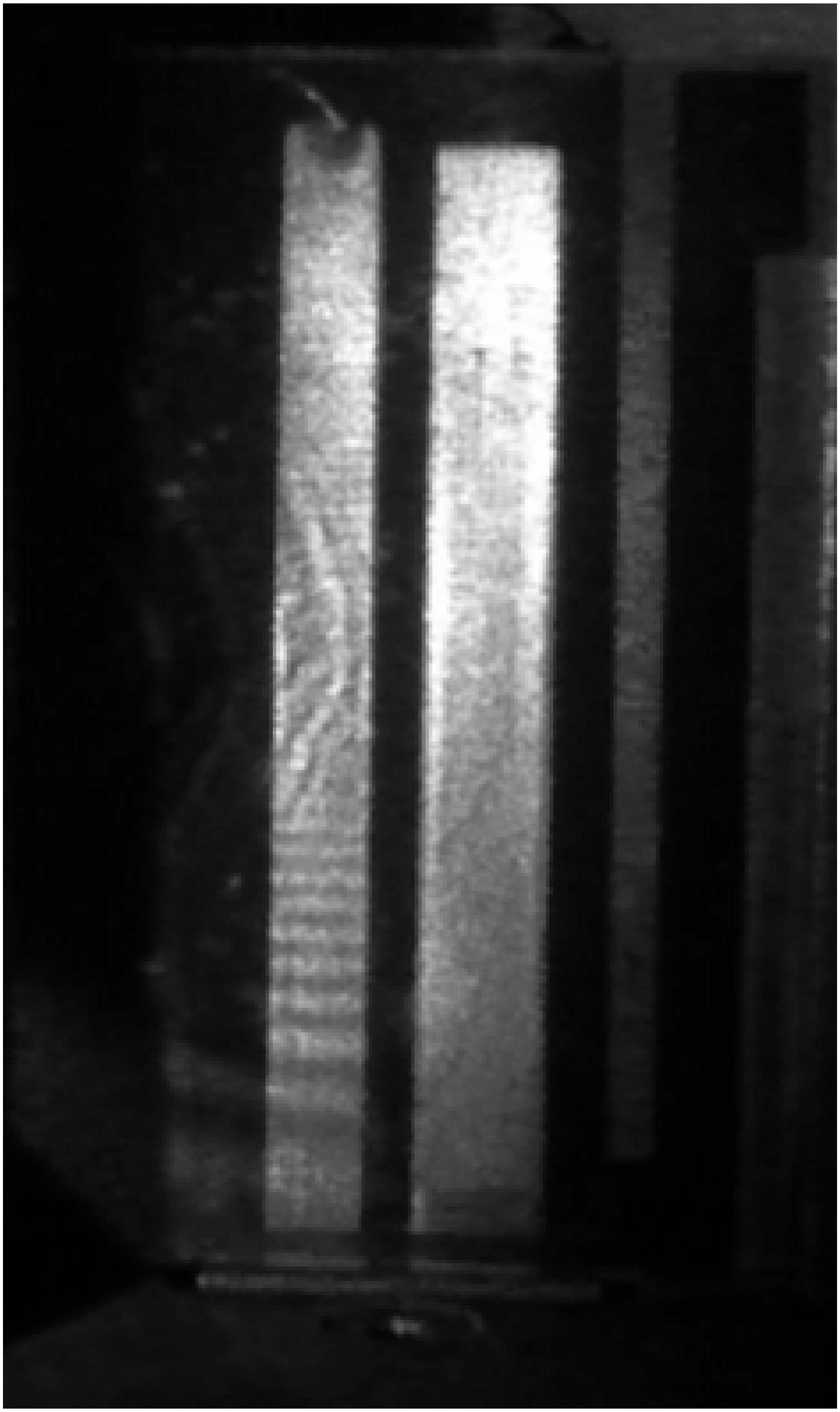

Figure 14: Interference pattern observed for a mass of 5.3g

```python
import matplotlib.pyplot as plt
import numpy as np

def exp_del_y(N,lam,alpha):
    return (N*lam)/(np.cos(alpha)+1)
def theo_del_y(F,E,w,t,L,x):
    return ((12*F)/(E*w*t**3))*((L**3/6) - ((L-x)**3/6) - ((L**2*x)/2))

F_1 = 2.2e-3
F_2 = 5.3e-3
L = 7.17e-2
w = 0.63e-2
t = 0.16e-2
lam = 650e-9
E = 2.08e11
x = np.linspace(0,8,25)
alpha = 36 * (np.pi/180)
N = np.linspace(0,24,25)

exp_x = [0.568052,1.12,1.72,2.21,2.58,2.9,3.22,3.47,3.78,3.98,4.21,4.41,4.64,4.85,5.08,5.34,5.59,5.8,6.02,6.26,6.48,6.68,6.92,7.1]
exp_del_y = [359.31,718.62,1077.93,1437.25,1796.56,2155.87,2515.18,2874.49,3233.8,3593.11,3952.42,4311.73,4671.05,5030.36,5389.67,5748.98,6108.29,6467.6,6826.91,7186.22,7545.53,7904.85,8264.
exp_del_y2 = [1.77e-14,0.51,1.11,1.44,1.7,1.89,2.11,2.28,2.43,2.6,2.76,2.93,3.03,3.12,3.25,3.34,3.43,3.48,3.54,3.58,3.67,3.70,3.77,3.85,3.89,3.92,3.98,4,4.05,4.09,4.19,4.23,4.27,4.3,4.39,4.4
x_y2 = np.linspace(0,8,61)
plt.plot(x,theo_del_y(F_1,E,w,t,L,x),x,theo_del_y(F_2,E,w,t,L,x))

plt.xlabel('x (cm)')
plt.ylabel('Displacement (Delta y)')
plt.title('Theoretical Delta y as a function x for m=2.2g and m=5.3g')
plt.legend(['m=2.2g','m=5.3g'])
#plt.plot(x,exp_del_y(N,lam,alpha))
plt.show()

plt.xlabel('y (cm)')
plt.ylabel('Displacement (Delta y)')
plt.title('Experimental Delta y as a function x for m=5.3g')
plt.plot(x_y2,exp_del_y2)
plt.show()

plt.plot(x,theo_del_y(F_1,E,w,t-.1e-3,L,x),x,theo_del_y(F_2,E,w,t-.1e-3,L,x))
plt.xlabel('y (cm)')
plt.ylabel('Displacement (Delta y)')
plt.title('Theoretical Delta y as a function x for m=2.2g and m=5.3g (material removed 0.1mm)')
plt.show()

plt.plot(x,theo_del_y(F_1,E,w,t-.025e-3,L,x),x,theo_del_y(F_2,E,w,t-.025e-3,L,x))
plt.xlabel('y (cm)')
plt.ylabel('Displacement (Delta y)')
plt.title('Theoretical Delta y as a function x for m=2.2g and m=5.3g (material removed 0.025mm)')
plt.show()
```

Figure 15: Python code to produce the plots

4 Results

The results for the theoretical displacement Δy, can be seen in figure 8, while the experimental results can be seen in figures 9 and 10. The theoretical results both show a non-linear curve that, as expected, varies with the mass. The experimental curve for 2.2g of weight added appears to also be non-linear with a similar shape to the theoretical version, but the experimental curve for the 5.3g of weight seems to have a different shape entirely in comparison to its theoretical counterpart. The reduction of thickness of 0.1mm and 0.025mm is shown in figures 11 and 12, respectively using the theoretical equation. The change does not seem to be very significant as the curves for both the changes are negligible.

Table 1: Values for relevant parameters

Cantilever length (L)	(7.17 $\pm$.05) cm
Width (w)	(0.63 $\pm$.005) cm
Thickness (t)	(0.16 $\pm$.005) cm
Wavelength (λ)	650nm
Young's Modulus of the Cantilever (E)	2.08x10^{12}
Angle (θ)	(36 deg $\pm$.5)
Mass 1 (g) Mass 2 (g)	(2.2g $\pm$.05) (5.3g $\pm$.05)

5 Discussion

When comparing the theoretical and the experimental results for both masses, there are differences in the results. The differences in the curves with respect to the theoretical can be explained by measurement errors accumulating during measuring the interference pattern using Logger Pro. One potential way to improve the results would be to do the measurements on an enlarged image of the interference pattern to more precisely measure the fringes and accommodate for an increase in fringes with a heavier weight. The reduction of thickness did not seem to make significant changes to the curves and the agreement with theory is not improved to any noticeable degree. This is to be expected for the anomalous graph for the experimental curve for the 5.3g mass, but the 2.2g experimental plot is also not more in agreement with the new theoretical. Removing the weight can sometimes leave a remnant of the interference pattern, this might be possible because the film might not have been fully developed without any weights added. If a weight was added too soon then another hologram will also be recorded, and so removing the weight will leave some remnant of an interference pattern.

6 Conclusion

The theoretical curves were non-linear as expected. The experimental curve for 2.2g mass was closer to the theoretical equivalent than the 5.3g mass experimental curve, which showed an oddly shaped curve at the start. The experiment demonstrated the production of holograms and interference patterns with vertical displacements well. The results would be improved with better analysis done on Logger Pro with a larger image of the pattern.

References

[1] D. Rosa. Physics 325, Laboratory Manual. University of Victoria, 2021.