## Lab #5 Physical Optics:Interference and Diffraction

**A. Complete this:**

Your Name Neil Sawhney Slot _____

Partner's Name N/A

Please check the circle next to your lab section:

- ◯ A, Prof Yecko, Mon 1–3 PM
- ◯ B, Prof Webb-Mack, Tue 2–4 PM
- ● C, Prof Yecko, Wed 10 AM–12
- ◯ D, Prof Corn-Agostini, Thu 9 AM–11 AM
- ◯ E, Prof Webb-Mack, Tue 9–11 AM
- ◯ F, Prof Yecko, Fri 1 PM–3 PM

**B. Read and sign Academic Integrity Statement:**

*I hereby attest that I have not given or received any unauthorized assistance on this assignment.*

Neil Sawhney

Sign here

**C. Grading rubric:**

| Category and very brief grading comments..... | Pts Available | Pts earned |
|---|---|---|
| Purpose | 1 | |
| Data | 2 | |
| Explanation of Errors | 3 | |
| Calculations | 3 | |
| Results & Analysis | 3 | |
| Conclusion + Questions | 1+2 | |
| *Total* | 15 | |

# Lab #5: Diffraction & Interference

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# Contents

# 1. Purpose

The purpose of this lab is to determine the wavelength of a red laser pointer and the thickness of a human hair by using the interference pattern created due to the wave like nature of light.

# 2. Data

| Grating Slits (lines/mm) | D, Distance from Grating To Screen (cm) | x+1 (mm) | x-1 (mm) |
|---|---|---|---|
| 500 | 36.8 | 131.05 | 128.55 |
| x,D Instrumental Error | 0.71 | | |
| X1 Range Uncertainty | 1.25 | | |

Table 2.1: Diffraction Grating

| a, Slit Width (mm) | D, Distance from Slit To Screen (cm) | x+1 (mm) | x-1 (mm) | x+2 (mm) | x-2 (mm) |
|---|---|---|---|---|---|
| 0.2 | 79 | 4.1 | 3.52 | 7.5 | 9.95 |
| 0.3 | 79.3 | 2.39 | 2.77 | 5.19 | 5.35 |
| 0.4 | 82 | 2.5 | 1.58 | 4.51 | 4.5 |
| a Instrumental Error | 0.02 | | | | |
| x,D Instrumental Error | 0.71 | | | | |
| X1 Range Uncertainty | 0.19 | | | | |
| X2 Range Uncertainty | 0.43 | | | | |

Table 2.2: Single Slit

| D, Distance from Hair to Screen (cm) | x+1 (mm) | x-1 (mm) | x+2 (mm) | x-2 (mm) | x+3 (mm) | x-3 (mm) |
|---|---|---|---|---|---|---|
| 59.6 | 6.1 | 5.4 | 11.43 | 10.89 | 17 | 16.95 |
| x,D Instrumental Error | 0.71 | | | | | |
| X1 Range Uncertainty | 0.35 | | | | | |
| X2 Range Uncertainty | 0.27 | | | | | |
| X3 Range Uncertainty | 0.03 | | | | | |

Table 2.3: Hair Reverse Slit

# 3. Sources of uncertainty

- center of dots were roughly estimated, since the edges were fuzzy and the circles were large
- center of lines were roughly estimated, since the edges were fuzzy and the lines were long
- center of lines were roughly estimated, since the edges were fuzzy and the lines were long

# 4. Calculations

## 4.1 Wavelength Calculations

### Part A

#### Value

$$I(\delta) = I_0 \left[ \frac{\sin\left(\frac{N\delta}{2}\right)}{\sin\left(\frac{\delta}{2}\right)} \right]^2 \text{ where } \delta \equiv \frac{2\pi}{\lambda} d \sin\theta \tag{4.1}$$

#### Question

$$\lim_{\sin\theta = \frac{m\lambda}{d} \quad m = 0, \pm 1, \pm 2, \ldots}$$

$$\tan\theta = \frac{\text{Average of } x_m}{D}$$

$$\theta = \arctan\left(\frac{\text{Average of } x_m}{D}\right)$$

$$\lambda = \frac{d}{m} \sin\left(\arctan\left(\frac{\text{Average of } x_m}{D}\right)\right)$$

$$d = \frac{1\ mm}{500\ lines} * 1\ lines = 0.002mm$$

$$\lambda = 0.002 * 10^{-3} \sin\left(\arctan\left(\frac{(131.05 * 10^{-3} + 128.55 * 10^{-3})/2}{36.8 * 10^{-2}}\right)\right) \quad \text{where m} = \pm 1$$

$$\lambda = 0.002 * 10^{-3} \sin\left(\arctan\left(\frac{(131.05 * 10^{-3} + 128.55 * 10^{-3})/2}{36.8 * 10^{-2}}\right)\right)$$

$$\lambda = 6.6526 * 10^{-7} \text{ m} = 665.26 \text{ nm}$$

**Error**

$$\lambda = \frac{d}{m} \sin\left(\arctan\left(\frac{(x_{+1} + x_{-1})/2}{D}\right)\right)$$

$$\delta\lambda = \left|\frac{\partial\lambda}{\partial D} * \delta D\right| + \left|\frac{\partial\lambda}{\partial x_{+1}} * \delta x_{+1}\right| + \left|\frac{\partial\lambda}{\partial x_{-1}} * \delta x_{-1}\right|$$

$$\delta\lambda = \left|-\frac{4dD\,(x_{+1} + x_{-1})}{m\left((x_{+1} + x_{-1})^2 + 4D^2\right)\sqrt{4D^2 + (x_{+1} + x_{-1})^2}} * \delta D\right| +$$
$$\left|\frac{4dD^2}{m\left((x_{+1} + x_{-1})^2 + 4D^2\right)\sqrt{4D^2 + (x_{+1} + x_{-1})^2}} * \delta x_{+1}\right| +$$
$$\left|\frac{4dD^2}{m\left((x_{-1} + x_{+1})^2 + 4D^2\right)\sqrt{4D^2 + (x_{+1} + x_{-1})^2}} * \delta x_{-1}\right|$$

$$\delta\lambda = \left|-\frac{(0.008)(0.368)\,(131.05 + 128.55)}{\left((131.05 + 128.55)^2 + 4(0.368)^2\right)\sqrt{4(0.368)^2 + (131.05 + 128.55)^2}} * 0.71\right| +$$
$$\left|\frac{(0.008)(0.368)^2}{\left((131.05 + 128.55)^2 + 4(0.368)^2\right)\sqrt{4(0.368)^2 + (131.05 + 128.55)^2}} * 1.25\right| +$$
$$\left|\frac{(0.008)(0.368)^2}{\left((128.55 + 131.05)^2 + 4(0.368)^2\right)\sqrt{4(0.368)^2 + (131.05 + 128.55)^2}} * 1.25\right|$$

$$\delta\lambda = \frac{1065107\sqrt{263252741}}{5544160451521046 48} = \pm 3.1170 * 10^{-8}\ \text{m} = \pm 30\ \text{nm}$$

## Part B

### Value

$$I(\beta) = I_0 \left( \frac{\sin \beta}{\beta} \right)^2 \quad \text{where } \beta \equiv \frac{\pi}{\lambda} a \sin \theta$$

$$\sin \theta = \frac{p\lambda}{a} \quad p = \pm 1, \pm 2, \ldots$$

$$\sin \theta = \frac{p\lambda}{a}$$

$$\lambda_n = \frac{\sin(\theta)\, a}{p}$$

$$\lambda_n = \frac{\sin\left(\arctan\left(\frac{\text{Average of } x_p}{D}\right)\right) a}{p}$$

$$\lambda_1 = \frac{\sin\left(\arctan\left(\frac{(4.1(10^{-3}) + 3.52(10^{-3}))/2}{79(10^{-2})}\right)\right) 0.2(10^{-3})}{1} 9.6454(10^{-}7) \text{ m} = 964.54 \text{ nm}$$

$$\lambda = \frac{1}{6} \sum_{n=1}^{n=6} \lambda_n$$

$$\lambda = \frac{1}{6}(964.54 + 1104.36 + 976.04 + 996.83 + 995.12 + 1098.76) = 1022.608 \text{ nm}$$

**Error**

$$\lambda_n = \frac{\sin\left(\arctan\left(\frac{(x_{+p}+x_{-p})/2}{D}\right)\right)a}{P}$$

$$\delta\lambda = \left|\frac{\partial\lambda}{\partial D} * \delta D\right| + \left|\frac{\partial\lambda}{\partial x_{+p}} * \delta x_{+p}\right| + \left|\frac{\partial\lambda}{\partial x_{-p}} * \delta x_{-p}\right| + \left|\frac{\partial\lambda}{\partial a} * \delta a\right|$$

$$\delta\lambda = \left|-\frac{4aD\left(x_{+p}+x_{-p}\right)}{P\left(\left(x_{+p}+x_{-p}\right)^2+4D^2\right)\sqrt{4D^2+\left(x_{+p}+x_{-p}\right)^2}} * \delta D\right| +$$

$$\left|\frac{4aD^2}{P\left(\left(x_{+p}+x_{-p}\right)^2+4D^2\right)\sqrt{4D^2+\left(x_{+p}+x_{-p}\right)^2}} * \delta x_{+p}\right| +$$

$$\left|\frac{4aD^2}{P\left(\left(x_{-p}+x_{+p}\right)^2+4D^2\right)\sqrt{4D^2+\left(x_{+p}+x_{-p}\right)^2}} * \delta x_{-p}\right| +$$

$$\left|\frac{x_{+p}+x_{-p}}{P\sqrt{4D^2+\left(x_{+p}+x_{-p}\right)^2}} * \delta a\right|$$

$$\delta\lambda = \left|-\frac{4(0.2)(790)\left(4.1+3.52\right)}{1\left(\left(4.1+3.52\right)^2+4(790)^2\right)\sqrt{4(790)^2+\left(4.1+3.52\right)^2}} * 0.71\right| +$$

$$\left|\frac{4(0.2)(790)^2}{1\left(\left(4.1+3.52\right)^2+4(790)^2\right)\sqrt{4(790)^2+\left(4.1+3.52\right)^2}} * 0.71\right| +$$

$$\left|\frac{4(0.2)(790)^2}{1\left(\left(3.52+4.1\right)^2+4(790)^2\right)\sqrt{4(790)^2+\left(4.1+3.52\right)^2}} * 0.71\right| +$$

$$\left|\frac{4.1+3.52}{1\sqrt{4(790)^2+\left(4.1+3.52\right)^2}} * 0.02\right| = 2.770 * 10^{-7}\ \text{m}$$

$$\delta\lambda = \pm 277\ \text{nm}$$

## 4.2 Hair Thickness Calculations

**Value**

$$\lambda_n = \frac{\sin\left(\arctan\left(\frac{(x_{+p}+x_{-p})/2}{D}\right)\right)a}{P}$$

$$a_1 = \frac{\lambda_n P}{\sin\left(\arctan\left(\frac{(x_{+p}+x_{-p})/2}{D}\right)\right)}$$

$$a_1 = \frac{(660*10^{-9})(1)}{\sin\left(\arctan\left(\frac{(6.1*10^{-3}+5.4*10^{-3})/2}{59.6*10^{-2}}\right)\right)}$$

$$= 6.84*10{-}5 \text{ m} = 68.4\ \mu\text{m}$$

$$a_2 = \frac{(660*10^{-9})(2)}{\sin\left(\arctan\left(\frac{(11.43*10^{-3}+10.89*10^{-3})/2}{59.6*10^{-2}}\right)\right)} = 7.050*10^{-5} \text{ m} = 70.5\ \mu\text{m}$$

$$a_3 = \frac{(660*10^{-9})(2)}{\sin\left(\arctan\left(\frac{(17*10^{-3}+16.95*10^{-3})/2}{59.6*10^{-2}}\right)\right)} = 4.636*10^{-5} \text{ m} = 46.4\ \mu\text{m}$$

$$a = (a_1 + a_2 + a_3)/3 = (68.4 + 70.5 + 46.4)/3 = 61.76$$

**Error**

$$a = \frac{\lambda_n P}{\sin\left(\arctan\left(\frac{(x_{+p}+x_{-p})/2}{D}\right)\right)}$$

$$\delta a = \left|\frac{\partial a}{\partial D} * \delta D\right| + \left|\frac{\partial a}{\partial x_{+p}} * \delta x_{+p}\right| + \left|\frac{\partial a}{\partial x_{-p}} * \delta x_{-p}\right| + \left|\frac{\partial a}{\partial \lambda} * \delta \lambda\right|$$

$$\delta a = \left|\frac{4\lambda PD}{(x_1+x_2)\sqrt{4D^2+(x_1+x_2)^2}} * \delta D\right| +$$

$$\left|-\frac{4\lambda PD^2}{(x_1+x_2)^2\sqrt{4D^2+(x_1+x_2)^2}} * \delta x_{+p}\right| +$$

$$\left|-\frac{4\lambda PD^2}{(x_1+x_2)^2\sqrt{4D^2+(x_1+x_2)^2}} * \delta x_{-p}\right| +$$

$$\left|\frac{P\sqrt{4D^2+(x_1+x_2)^2}}{x_1+x_2} * \delta \lambda\right|$$

$$\delta a = \left|\frac{4(660*10^{-9})1(59.6*10^{-2})}{(6.1+5.4)\sqrt{4(59.6*10^{-2})^2+(6.1+5.4)^2}} * (0.71)\right| +$$

$$\left|-\frac{4(660*10^{-9})1(59.6*10^{-2})^2}{(6.1+5.4)^2\sqrt{4(59.6*10^{-2})^2+(6.1+5.4)^2}} * (0.71)\right| +$$

$$\left|-\frac{4(660*10^{-9})1(59.6*10^{-2})^2}{(6.1+5.4)^2\sqrt{4(59.6*10^{-2})^2+(6.1+5.4)^2}} * (0.71)\right| +$$

$$\left|\frac{1\sqrt{4(59.6*10^{-2})^2+(6.1+5.4)^2}}{6.1+5.4} * (30*10^{-9})\right|$$

$$= 3.94338174505277*10^{-8}\text{ m} = .04\ \mu\text{m}$$

# 5. Results

## Wavelength

### Part A

$$\text{Calculated Wavelength} = 660 \pm 30 \text{ nm}$$

### Part B

$$\text{Calculated Wavelength} = 1000 \pm 300 \text{ nm}$$

## Hair Thickness

$$\text{Calculated Hair Thickness} = 61.76 \pm 0.04 \ \mu\text{m}$$

# 6. Conclusions

By using the interference and wave like nature of light, the diffraction pattern created by a laser hitting a hair was used to determine the thickness of the hair. The error bounds of the calculated value agrees with literature values.

# 7. Answered Questions

Click the question to be brought to the location where the question is answered.

## 7.1 Question

Derivation for Principal Maxima