Advanced Spectrometer Experiment

Experiment Findings · February 2020

1 author:

Ekin Bircan Boşdurmaz
Bilkent University

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Grating Interference & Dispersion Prism

Ekin Bircan Boşdurmaz [1], Görkem Bozkurt[1], İlke Atasoy[1]
[1]Department of Physics, Bilkent University.
Çankaya, 06800 Ankara, Turkey.
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Optics is always an interesting topic for Physicists. It is almost impossible to find a physics book which does not include some words about Isaac Newton and his prism. In this experiment, we studied geometrical optics to calculate the wavelength of specific colors. Also, we calculated the refractive index of a dispersion prism as a function of wavelength. The results obtained from these studies presented with tables and figures.

I. INTRODUCTION

A. Double Slit

In a double slit experiment the slits should be smaller than the wavelength of the light that is coming in. Lets consider a double slit as shown in Figure 1a and 1b.

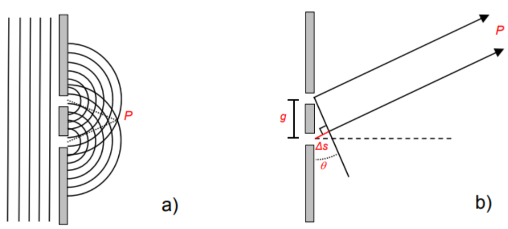

Figure 1. Double Slit[1]

It can be seen that the light hits the double slit in form of a wave. Thus each slit becomes an origin of an spherical wave. These two spherical waves spread out and then create constructive and destructive interference. Any point P is considered which where we can observe the wave trains as parallel[1]. The path difference Δs is:

$$\Delta s = g \sin\theta_n \tag{1}$$

For the maxima:

$$\Delta s = g \sin\theta_n = n\lambda, \tag{2}$$

where $n = 0, 1, 2, 3, ...$
and for the minima:

$$\Delta s = g \sin\theta_n = \left(n + \frac{1}{2}\right)\lambda, \tag{3}$$

where $n = 0, 1, 2, 3, ...$ must be true.

B. Grating Interference

A grating is defined as multiple number of slits, N, as shown on Figure 2 [1].

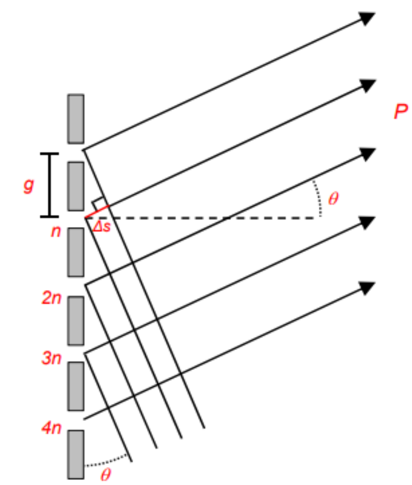

Figure 2. The path length differences of grating slits[1]

1. *Intensity:*

The intensity of the interference pattern,I_0, grows as the slit number N increases. The intensity is defined as:

$$I = (NA)^2 \tag{4}$$

Where A is the electric field vector.

2. *Interference:*

As shown in the double slit, the differences of the pathways should be an multiple of the wave length of the light that is shining through the slits.
For the maxima:

$$\sin\theta = \frac{n\lambda}{g} \tag{5}$$

where $n = 0, 1, 2, 3, ...$ and g is the grating spacing. the separation at the gratings results from the diffraction.

C. Dispersing Prisms

In physics, dispersion is defined as a material where the angle of reflection of light is highly depending on the wavelength. In this case we will be using a dispersion prism, which has a equilateral triangle as its cross-sectional area [1]. Where different wavelength of light will be refracted at different angles as shown on figure 3.

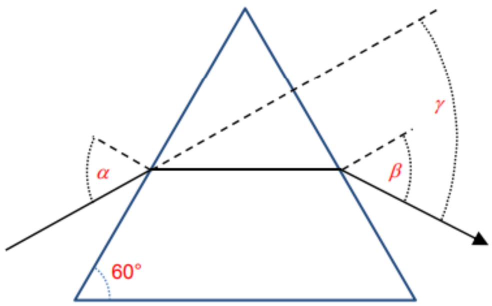

Figure 3. Angle of refraction in an Equilateral prism[1]

In this case, the refraction index n can be found with simple geometry as:

$$n = \frac{\sin \frac{\gamma + 60^\circ}{2}}{\sin 30^\circ} \tag{6}$$

Thus if the deflection angle is known, one can calculate the refractive index of a prism.

1. *Refraction in a Prism*

Various wavelength are separated in the prism due to the fact that refractive index increases while the wavelength of light decreases[1]. This phenomena can be seen on Figure 4 more clearly.

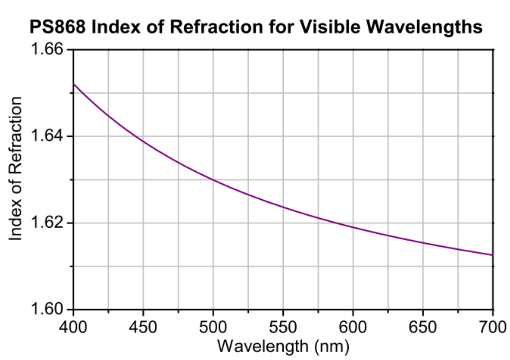

Figure 4. Index of refraction vs wavelength for the prism[1]

D. Experiment 1: Wavelength Measurement of Three Lines in the Mercury Spectrum

The grating equation that was shown previously on eq. 3 can be used on this experiment if the setup is done as shown in figure 5.

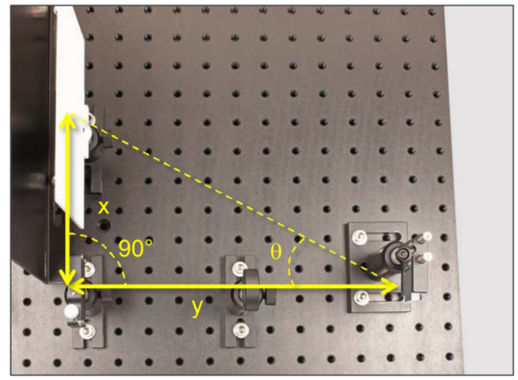

Figure 5. Experiment 1[1]

θ has to be known in order to calculate the wavelength[1]. And with this setup and simple geometry, it can be seen that:

$$\theta = \arctan \frac{y}{x} \tag{7}$$

and thus the wavelength can be calculated.

E. Experiment 2: Measuring the Index of Refraction of the Prism Using a Known Spectral Line

In order to determine the refractive index shown in eq. 6, the smallest deflection angle in the prism γ has to be measured.

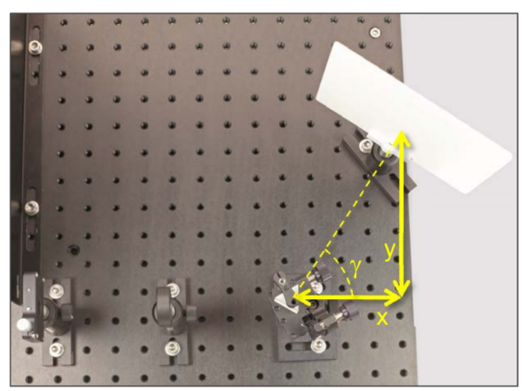

Figure 6. Experiment 2[1]

With the setup shown in Figure 6. we can easily measure the values x,y and calculate γ by:

$$\gamma = \arctan \frac{y}{x} \tag{8}$$

and thus the refractive index can be calculated.

II. SETUP

As for the setup, the Thor Labs' Advanced Spectrometer Kit (EDU-SPEB1, EDU-SPEB1/M) was used. Flashlight of a cellphone was used for the source of light and fixed at the proper level.

To focus maximum amount of light possible, two condenser lenses were used in the path of light from source to slit. To prevent stray light exposure, TPS5 laser safety screen was mounted. A diffraction grating (1200 lines/mm) was used to calculate the wavelengths of different colors in first part. In the second part, a glass dispersion prism with an unknown refractive index was used. The the complete setup with the equipment is shown in the figure below.

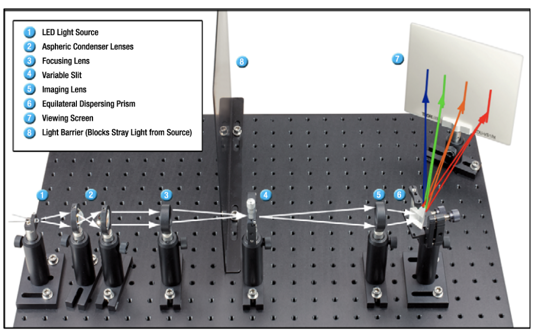

Figure 7. Setup [1]

III. RESULTS AND DISCUSSION

In this week's assignment, we have two experiments to accomplish. It will be convenient to separate the results too. We used MATLAB to analyze the data and generate the plots. The code that we used cab be found at Appendix section.

A. Experiment 1: Wavelength Measurement using Diffraction Grating

For this part of the experiment, we arranged the grating, light source and screen according to figure 5. After some fine adjustments, we acquired the following color pattern on the screen.

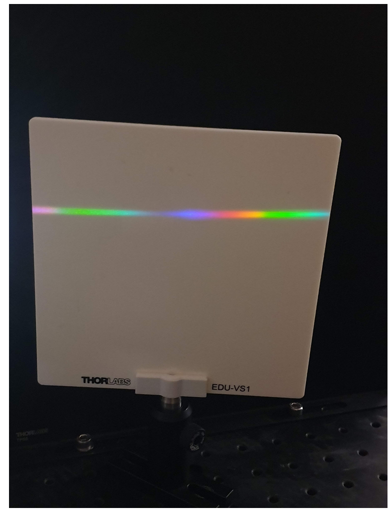

Figure 8. Grating Refraction of White Light on Screen

We adjusted the y distance as 25 cm and measured the x distance for each color. Then using the equations 5 and 7, we calculated the wavelength of each color. In the rightmost column you can see the typical λ range for that specific color.

Color	x (cm)	y (cm)	λ_{exp} (nm)	$\lambda_{typical}$ (nm) [2]
Red	20	25	650.7	700-635
Orange	22.5	25	619.4	635-590
Yellow	23.5	25	607.2	590-560
Green	24.5	25	595.2	560-520
Cyan	26	25	577.6	520-490
Blue	29.5	25	538.8	490-450
Violet	32.5	25	509.1	450-400

Table I. Calculated Wavelengths vs. Typical Wavelength Ranges

As you can see from table I, there is the expected trend in measured wavelengths which is similar to the typical wavelengths. The maximum error in our measurements is around 25 %. Since we did not have the proper light source and a steady measure for distance, this error can be acceptable.

B. Experiment 2: Refraction Index of Dispersion Prism

For this experiment, we used a dispersion prism with unknown index of refraction. Again, we adjusted the screen so that the colors can be seen clearly. After this, we took measurements for x and y values from the center line of each color. The screen can be seen from the following picture.

Figure 9. Separated Colors from Dispersion Prism

We used the calculated wavelengths (from table I) with the equations 5 and 8 in order to find the refractive index of dispersion prism for different wavelengths. The measured y and x distances and corresponding wavelength can be found in the following table.

Color	x (cm)	y (cm)	γ (degrees)	n_{calc}
Red	12	17.5	55.56	1.36
Orange	11.75	17.25	55.74	1.36
Yellow	11.5	18	57.4,	1.38
Green	11	18.1	58.71	1.4
Cyan	10.75	18.4	59.7	1.41
Blue	10	18.9	62.12	1.44
Violet	9.75	19.3	63.2	1.45

Table II. Calculated Wavelengths vs. Typical Wavelength Ranges

We also plotted this calculated refractive index values with respect to wavelength to see that our experiments are consistent with fig. 4 or not.

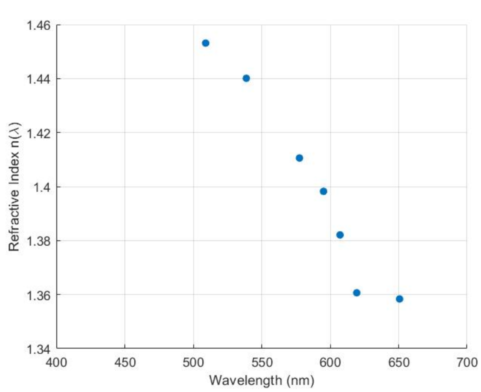

Figure 10. Calculated Refractive Index (n(λ)) vs. Wavelength

There is a ± 0.2 difference between our refractive index measurements and the values given in the manual. One should also point that our dispersion prism has some cracks that can alter the homogeneity of the material thus change the refractive index.

IV. CONCLUSION

In this experiment some concepts related to nature of light were studied. These concepts include constructive and destructive interference, dispersion, refraction. With the first experiment, refraction of white light by a diffraction grating was obtained, and by that, wavelengths of visible colors were calculated. It was satisfying to be able to see the results were not in a conflict with the typical ranges. For the second experiment refractive index of dispersion prism for different wavelengths was calculated by using wavelength values from first part. As for the results, they were not as precise as the theoretical data because an iPhone 4S flashlight was used instead of the LED light, also the the environment was not hundred percent dark and the measurements were done by hand with a ruler. But yet, the results that were obtained were satisfying.

REFERENCES

[1] Thor Labs. *Thor Labs Advanced Spectrometer Kit*.

[2] Craig F. Bohren and Eugene Clothiaux. *Fundamentals of Atmospheric Radiation: An Introduction with 400 Problems*. 2008.

[3] Eugene Hecht. *Optics, 2nd Edition*. Addison-Wesley, 1987.

V. APPENDIX

MATLAB Code used for calculations and figures

```
%First Experiment with Diffraction Grating
g = 1/ 12000; %grating lines per cm
y1 = 25; %slit to grating center distance
%x distances for red,
%orange, yellow, green, cyan, blue, violet
x1 = [20 22.5 23.5 24.5 26 29.5 32.4];
theta1 = atand(y1./x1);
lambda1 = g*sind(theta1)* 10^7;
%since its in cm, we should multiply by 10^7

%Second Experiment with Prism
%Distances in cm
%(red, orange, yellow, green, cyan, blue, violet)
x2 = [12 11.75 11.5 11.0 10.75 10 9.75];
y2 = [17.5 17.25 18 18.1 18.4 18.9 19.3];
theta2 = atand(y2./x2);
nlambda = sind((theta2+30)/2)./sind(30);


figure;
scatter(lambda1,nlambda,'fill');
xlim([400 700]);
```

```
grid on;
xlabel('Wavelength (nm)');
ylabel('Refractive Index n(\lambda)');
```