How does varying distance between the two gratings influence the distance between the successive peaks and the central maximum?

IB Physics IA

1 Introduction

In physics class, we learned about the diffraction grating, the diffraction grating is a device which can separate light according to its wavelength. The teacher told us that diffraction gratings can form many constructive interferences and destructive intereferences which are very bright when a beam of light passes through it. Figure 1 shows how a beam of light will travel and appear on the screen:

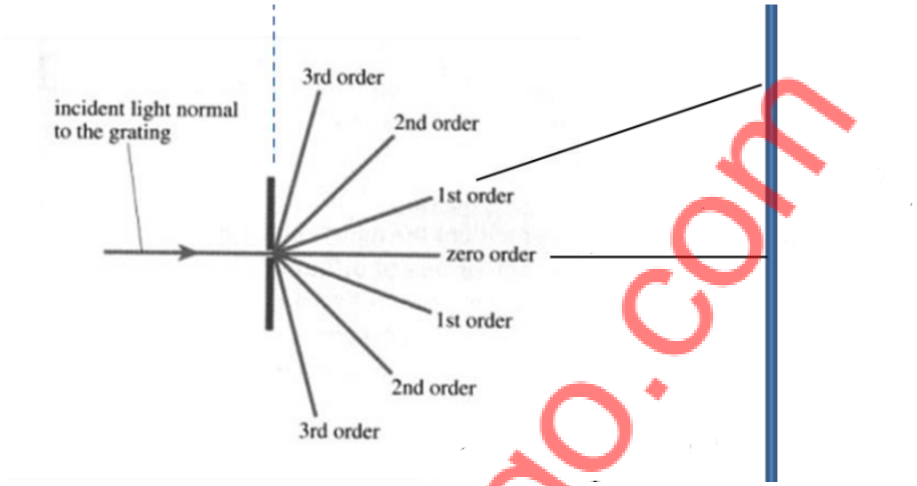

Figure1: Diffraction grating experiment

During all of the experiments and the information searched on the internet, there are very few labs done with two diffraction gratings being used together, which brings up my curiosity about what will happen when I use two diffraction gratings simultaneously. I want to determine the pattern of the light on the screen when there are two diffraction gratings when the distances between them very.

2 Research Question

How does varying distance between the two gratings influence the distance between the successive peaks and the central maximum?

3 Hypothesis

3.1 The Effects of Two Diffraction Gratings

When there is only one diffraction grating, we can see many "bright dots" which present constructive interference and destructive interference on the screen. If we put another diffraction grating between the original diffraction grating and the screen, the light will be diffracted again on the new diffraction grating, making there are n^2 "bright dots" if we assume the original number of them are n.

I assume that only 0 and 1 order maximum are visible in this experiment.

In the experiment, the light beam is travelling in this pattern. The graph is shown in Figure 2 below.

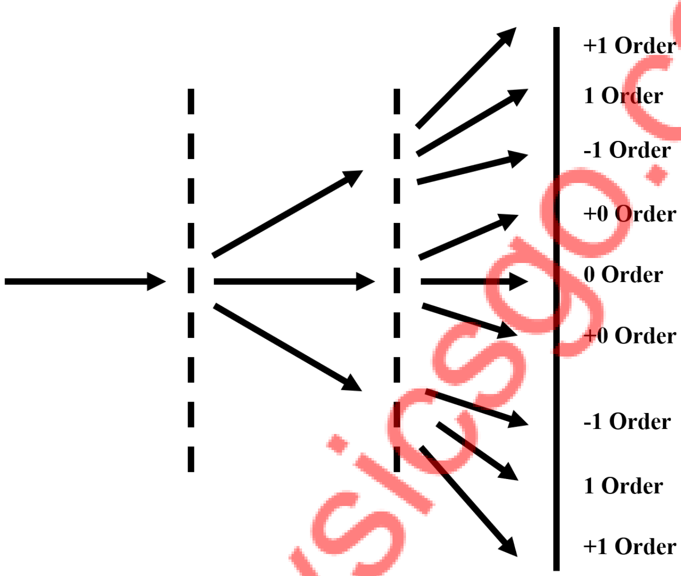

Figure 2: Successive Peaks

There are only 9 successive peaks. The different names of these peaks are labelled on Figure 2.

According to the equation:

$$d \times \sin\theta = n_0 \times \lambda \ (1)$$

d presents the distances between the slits, θ represents the diffraction angle, n_0 represents the diffraction order on the first diffraction grating, and λ represents the wavelength of the wave.

We can divide d from both sides, to determine the following equation:

$$\sin\theta = \frac{n_0 \times \lambda}{d}$$

We can determine the distance between the central maximum and the position with the position of the first-order constructive interference on the second diffraction grating by using the following trigonometric equation:

$$\sin\theta = \frac{n_0 \times \lambda}{d}$$

In the equation below, S represents the distances between the central maximum on the diffraction grating and the locators of constructive interference and destructive interference, since it is the first order. L represents the distances between two diffraction gratings.

$$\sin\theta = \frac{S}{D-L}$$

$$\frac{S}{D-L} = \frac{n_0 \times \lambda}{d}$$

$$S = \frac{n_0 \times \lambda \times (D-L)}{d} \quad (2)$$

3.2 The Effect of the Angle of the Light the Diffraction Grating

Since the two diffraction gratings are parallel to each other the angle between the normal to the light beam is π - θ. From equation 1, we can obtain the value of θ by using the arcsin function

$$\theta = \arcsin\frac{n_0 \times \lambda}{d} (3)$$

If there is an angle between the normal and the light beam, since we assume the light beam is infinitely thin then the distances between the slits could be seen as only the y component of the length of the slits as seen in Figure 3 below:

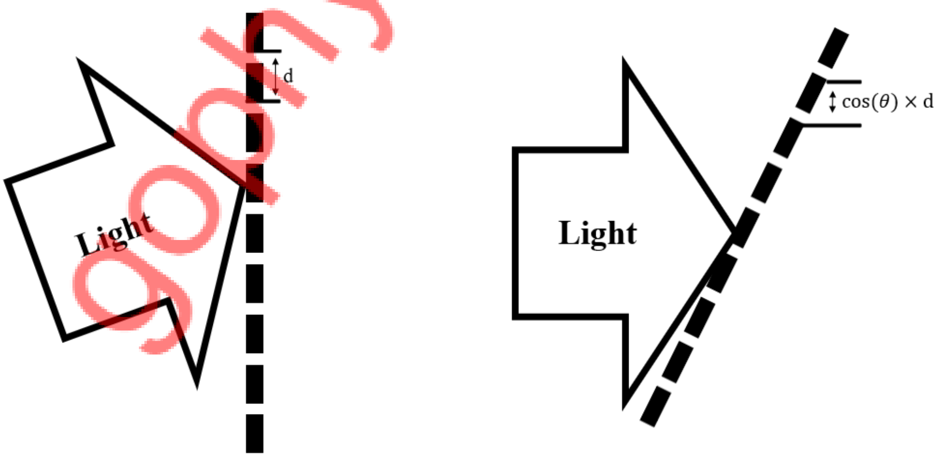

Figure3: Assumption

The new slit distances concerning the angle of the light beam becomes:

$$s = \cos\left(\arcsin\frac{n_0 \times \lambda}{d}\right) \times d (4)$$

We can now obtain the following equation:

$$\sin\beta = \frac{n_1\times\lambda}{\cos{(\arcsin{\frac{n_0\times\lambda}{d}})}\times d}(5)$$

β represents the angle between the light beam and the refracted light beam The angle relative to the screen (α) is:

$$\beta = \arcsin{(\frac{n_1\times\lambda}{\cos{(\arcsin{\frac{n_0\times\lambda}{d}})}\times d})}$$

$$\alpha = \arcsin{\frac{n_0\times\lambda}{d}} \pm \arcsin{(\frac{n_1\times\lambda}{\cos{(\arcsin{\frac{n_0\times\lambda}{d}})}\times d})}$$

With α we can calculate the distance between the central maximum and the next maxima.

$$l = L\times\tan\arcsin{\frac{n_0\times\lambda}{d}} \pm \arcsin{(\frac{n_1\times\lambda}{\cos{(\arcsin{\frac{n_0\times\lambda}{d}})}\times d})}$$

For the whole constructive interference, we need to add equation (2) to obtain the following equation:

$$l = L\times\tan{(\arcsin{\frac{n_0\times\lambda}{d}} \pm \arcsin{(\frac{n_1\times\lambda}{\cos{(\arcsin{\frac{n_0\times\lambda}{d}})}\times d})})} + \frac{n_0\times\lambda\times(D-L)}{d}(7)$$

4 Experiment

Investigating how relationship between the distance between diffraction gratings and the distance from the different visible successive peaks to the central maximum.

4.1 Method

In the experiment, I will use two diffraction gratings. The diffraction gratings are 100 silts per millimetre. The first diffraction grating is at a fixed position: 20 centimetres away from the screen. The second diffraction grating moves between 19 centimetres to 10 centimetres from the screen. I used a red laser to create a beam of light to pass through the diffraction grating. Constructive interference will be shown on the screen with different patterns.

4.2 Variables

The independent variables, dependent variables and controlled variables are listed below:

Independent Variables: The distance between the 2nd diffraction grating to the screen (L)

Dependent Variables: The distance between the visible successive peaks (l)

Controlled Variables: The distance between the slits (d), The distance between the first diffraction grating with the screen (D), The wavelength of the light (λ)

4.3 Materials

The following materials will be used to conduct the investigation:

1. Two diffraction gratings which are 100 slits per millimetre
2. A laser
2. Two rulers
4. Tape

The materials of the lab are shown in Figure 4 below:

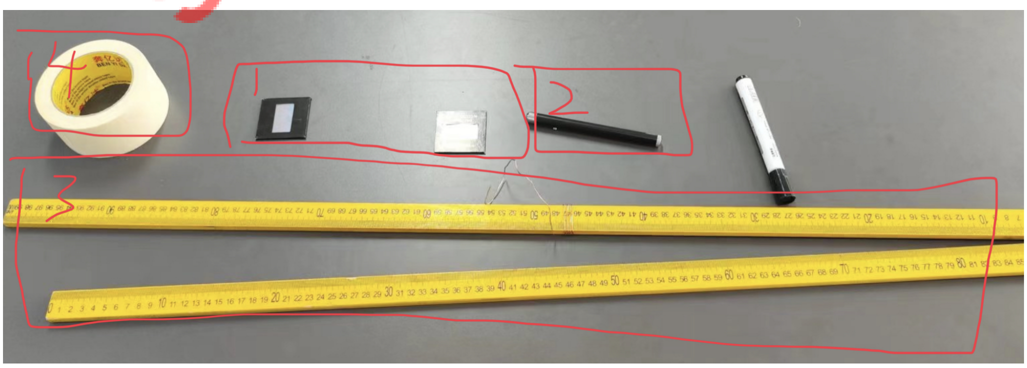

Figure4: lab materials

4.4 Procedure of collecting the data

The following steps are take to collect data collection in the first experiment
1. Stick one of the rulers on the whiteboard perpendicular to the ground by using the tape
2. Place the other ruler parallel to the ground, one side meets the other ruler at 0 cm, another side is put on the podium to fix the ruler
3. Place one of the diffraction gratings at 20 cm of the second ruler
4. Place the second diffraction grating at 19 cm of the second ruler
5. Move the second diffraction grating 1 cm towards the screen
6. Take a photo of the screen and the light spots (Areas of constructive interference and destructive interference), with the first ruler on the picture to analyze the distance between the different light spots
7. Repeat steps 5 to 6 5 times
8. Repeat step 7 5 times

Figure 5 below shows the lab set-up

Figure5: lab setup

4.5 Ethical and safety concerns

The laser can produce a very sharp light beam, which can harm our eyes. Wear safety glasses.

The diffraction grating is put on the ruler which is very thin. The diffraction grating has a high possibility to fall on the ground and break.

5 Analyze

5.1 Raw data

Table 1 below shows the raw data collected from the experiments

Trials	Distance between diffraction gratings ±0.5 mm	Raw distance $n_0 = 0$, $n_1 = 0$	Raw distance $n_0 = 0$, $n_1 = 1$	Raw distance $n_0 = 1$, $n_1 = 0$	Raw distance $n_0 = 1$, $n_1 = 1$
1	17.0	15.0	25.0	25.5	38.0
	16.0	25.0	36.0	38.0	46.0
	15.0	21.0	31.0	29.0	40.0
	14.0	20.0	30.0	27.0	35.5
	13.0	17.5	29.0	25.0	48.5
2	17.0	40.0	50.0	51.0	63.0
	16.0	40.5	50.0	53.0	67.0
	15.0	50.0	60.0	63.0	70.0
	14.0	30.0	38.0	43.0	60.0
	13.0	30.0	38.0	45.0	58.0
3	17.0	40.0	51.0	53.0	63.0
	16.0	30.0	40.0	43.0	56.0
	15.0	30.0	39.0	41.0	65.0
	14.0	30.0	38.0	43.0	60.0
	13.0	30.0	38.0	45.0	58.0
4	17.0	30.0	40.0	40.5	48.0
	16.0	30.0	40.0	43.0	56.0
	15.0	30.0	39.0	41.0	65.0
	14.0	30.0	40.0	42.0	57.0
	13.0	30.0	38.0	40.0	60.0
5	17.0	40.0	51.0	53.0	63.0
	16.0	30.0	30.0	32.0	45.0
	15.0	50.0	60.0	63.0	70.0
	14.0	45.0	53.0	55.0	60.0
	13.0	30.0	38.0	42.0	50.0

Table 1: Raw Data

By subtracting the value from the line in the third column, we can obtain the distance between the peaks and the central maximum.

The data subtracted by the third column is shown in appendix A.

By calculating the mean of the distance between the peaks and the central maximum, we can obtain the value in Table 2.

Distance between diffraction gratings ±0.5mm	Average distance from the central maxium			
	$n_0 = 0$		$n_0 = 1$	
	$n_1 = 0$	$n_1 = 1$	$n_1 = 0$	$n_1 = 1$
17.0	0.0	10.4	11.6	22.0
16.0	0.0	8.1	10.7	22.9
15.0	0.0	9.6	11.2	25.8
14.0	0.0	8.8	11.0	23.5
13.0	0.0	8.7	11.9	27.4

Table 2: Processed Data

5.2 Theoritical Number

According to equation (7), we have the constant variable in the table below:

Variables	Explanation	Figure
d	Distance between slits	$1.00 \times 10^{-5} \pm 5 \times 10^{-7}$ m
D	First diffraction grating to the screen	$2.00 \times 10^{-2} \pm 5 \times 10^{-4}$ m
λ	Wavelength	$7 \times 10^{-7} \pm 1 \times 10^{-7}$ m

Table 3: Constants

By subtracting the values into equation 7, we can obtain the theoritical values in Table 4:

Distance between diffraction gratings ±0.5 mm	Average distance from the center			
	$n_0 = 0$		$n_0 = 1$	
	$n_1 = 0$	$n_1 = 1$	$n_1 = 0$	$n_1 = 1$
17.0	0.0	11.9	15.4	27.5
16.0	0.0	11.2	14.7	26.1
15.0	0.0	10.5	14.0	24.7
14.0	0.0	9.8	13.3	23.2
13.0	0.0	9.1	12.6	21.9

Table 4: Theoretical Data

In the Figure 6 below we can obtain the relationship between those two variables, by using both the theoretical value and the and values.

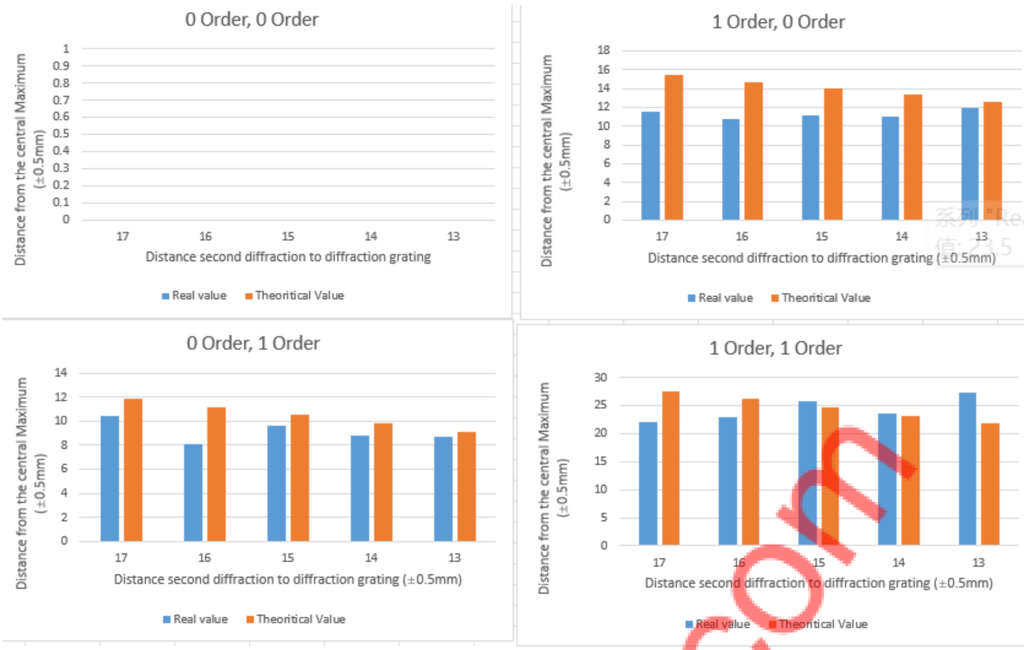

Figure6: Relationship

From the theoretical data, we can see a clear relationship of linear proportionality.

If we insert all of our controlled variables into equation, we can obtain different equations about different distance of constructive interference and destructive interference between the central maximum.

When both n_0 and n_1 is 0,

$$l = 0$$

When $n_0 = 0$ and $n_1 = 1$, $l =$

$$L \times \tan\left(\arcsin \frac{0\times700\times10^{-9}}{1.00\times10^{-5}} + \arcsin\left(\frac{1\times700\times10^{-9}}{\cos\left(\arcsin \frac{0\times700\times10^{-9}}{1.00\times10^{-5}}\right)\times1.00\times10^{-9}}\right)\right) + \frac{0\times700\times10^{-9}\times(20-L)}{1.00\times10^{-5}}$$

We obtain the following linear equation:

$$l = 0.070172L$$

When $n_0 = 1$ and $n_1 = 0$, $l =$

$$L \times \tan\left(\arcsin \frac{1\times700\times10^{-9}}{1.00\times10^{-5}} + \arcsin\left(\frac{0\times700\times10^{-9}}{\cos\left(\arcsin \frac{1\times700\times10^{-9}}{1.00\times10^{-5}}\right)\times1.00\times10^{-9}}\right)\right) + \frac{1\times700\times10^{-9}\times(20-L)}{1.00\times10^{-5}}$$

We obtain the following linear equation:

$$l = 0.070172L + 0.0035$$

When $n_0 = 1$ and $n_1 = 1$, $l =$

$$L \times \tan\left(\arcsin \frac{1\times700\times10^{-9}}{1.00\times10^{-5}} + \arcsin\left(\frac{1\times700\times10^{-9}}{\cos\left(\arcsin \frac{1\times700\times10^{-9}}{1.00\times10^{-5}}\right)\times1.00\times10^{-9}}\right)\right) + \frac{1\times700\times10^{-9}\times(20-L)}{1.00\times10^{-5}}$$

We obtain the following linear equation:

$$l = 0.141215 + 0.0035$$

There are still differences between the theoretical and the real values. However the real value is close to the theoretical value and has the same trend.

6 Conclusion

The final relationship between L and l is a linear relationship when the other variables are the same. The equation is shown below:

$$l = L \times \tan\left(\arcsin \frac{n_0 \times \lambda}{d} \pm \arcsin\left(\frac{n_1 \times \lambda}{\cos\left(\arcsin \frac{n_0 \times \lambda}{d}\right) \times d}\right)\right) + \frac{n_0 \times \lambda \times (D-L)}{d}$$

While as explained in section 3, all of other letters presents a constant

The random error is different in each experiment. But for all of the experiments, it isn't greater than 20%

If we check the difference between the theoretical value and the actual value, then I found that some of these values having a large error. A few of the values have an error greater than the theoretical value.

6.1 Limitations and improvement

There are some systematic errors in this lab because of the limitations in the equipment and fault made by humans as well as because of the complicated equation. This makes the errors more obvious in the form of the inaccurate outcome of the experiment. I list some of them below:

6.1.1 Difficulities for the human eye to find the constructive interference and destructive interference

In this experiment, I assumed that there are only 9 locations of constructive interference and destructive interference are visible. In reality, there are many dots of light I can see which makes it more difficult to find out which point is the point I want to look for.

This can't be improved.

6.1.2 Difficulities to put two diffraction gratings parallel and perpendicular to the ground by hand

In the experiment we used one hand to hold the diffraction grating while using another hand to hold the laser. It is very difficult to hold all of the experiment materials properly. This may be leads to some errors in the data collection.

This can be improved by using some equipment to hold the lab materials.

6.1.3 The light beam is not a point

The light beam is not a theoretical line which means that the light beam has a width. This may cause some difficulties to read the locations of constructive interference and destructive interference. This can be improved by using a light-intensity measuring instrument to measure the actual peak instead of reading it manually

7 References

https://www.physics.louisville.edu/sbmendes/phys%20356%20fall%2016/Diffraction%20Gratings.pdf

"Introduction to Diffraction Gratings." Shimadzu.com, www.shimadzu.com/opt/guide/diffraction/02.html.

Tsokos, K. A. Physics for the IB Diploma. 1998. 6th ed., Cambridge, Cambridge University Press, 2014.

A Raw data

On the table below, it shows the data subtracted by the third column

Trails	Distance between diffraction gratings $\pm 0.5mm$	Distance between central maximum and the peaks ($\pm 0.5 mm$)			
		$n_0 = 0$		$n_0 = 1$	
		$n_1 = 0$	$n_1 = 1$	$n_1 = 0$	$n_1 = 1$
1	17	0	10	10.5	23
	16	0	11	13	21
	15	0	10	8	19
	14	0	10	7	15.5
	13	0	11.5	7.5	31
2	17	0	10	11	23
	16	0	9.5	12.5	26.5
	15	0	10	13	20
	14	0	8	13	30
	13	0	8	15	28
3	17	0	11	13	23
	16	0	10	13	26
	15	0	9	11	35
	14	0	8	13	30
	13	0	8	15	28
4	17	0	10	10.5	18
	16	0	10	13	26
	15	0	9	11	35
	14	0	10	12	27
	13	0	8	10	30
5	17	0	11	13	23
	16	0	0	2	15
	15	0	10	13	20
	14	0	8	10	15
	13	0	8	12	20

Appendix A: Data