**Diffraction Grating**

## Purpose

To understand the diffraction grating and its use in spectroscopy

## Introduction

In the double slit interference we saw that the interference pattern for a monochromatic light (single wavelength) consists of equally spaced bright and dark fringes. The number of slits was 2, we will call this number N. If we use 3 slits (N = 3), we observe that the bright fringes (we will call them primary maxima) are in the same positions on the screen, but they become of larger intensity and smaller width. Also, one secondary maxima of lower intensity appears between the primary bright maxima. See figure 1. If we repeat the experiment with four slits, we observe that the primary maxima are still in same positions but of more intensity and narrower width and also we get two secondary maxima of much lower intensity, between the primary maxima. Notice that for N = 3: the number of secondary maxima = 3 - 2. For N = 4, that number becomes 4 – 2 = 2. The number of secondary maxima for N slits is N - 2. If the number of slits used is very large N, then we get primary maxima of very large intensity and very narrow width (sharp), and the number of N - 2 secondary maxima (of negligible intensity) between the primary maxima. In this case our slits are called a “diffraction grating”. See figure 2. The Distance between the slits, d (slits separation) is given by the Length of the grating, from the first slit to the last slit divided by the number of slits N minus 1, (N is large so we can neglect the -1). The manufacture gives the number of slits (called lines) per Milli-meter. A typical grating could have lines/mm of about 400 lines/mm. The distance between the slits is the reciprocal of that number (for this example d = 1/400 mm).

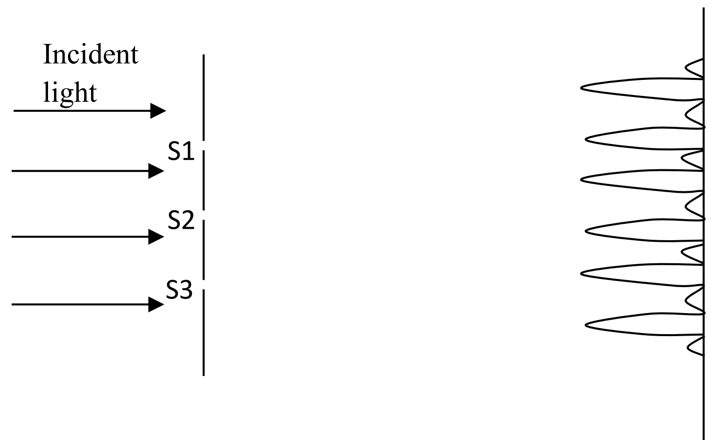


**Fig. 1:** Interference pattern for three slits, N = 3.

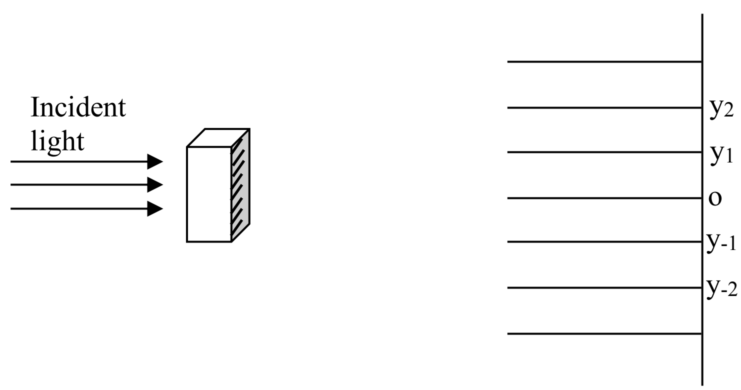


**Fig. 2:** Diffraction pattern for a diffraction grating

Since the positions of the primary maxima are the same as for the double slit interference experiment, the equation for the positions of the maxima on the screen is the same:

$$d sin\theta = m\lambda, \text{ where } m = 0, \pm 1, \pm 2, \ldots \quad \text{eqn. (1).}$$

In the approximation of L >> d,

$$\frac{d\, y_m}{L} = m\lambda$$

Note that for a given grating, d is constant, and if we do not change the position of the screen, then L is also constant. Therefore, for a given m (order of diffraction), the position on the screen $y_m$ depends on the value of λ. So if the incident light is composed of two slightly different wavelengths, each will have a separate position on the screen. Therefore the diffraction grating can resolve light composed of different wavelengths. And using equation 1 we can calculate the value of each wave length.

If we use white light, what color do you expect for the zero order, $m = 0$ at the central point o?

Note that if we use a grating of larger lines/mm, we get a smaller $d$. Using Eq. 1 we can see that this causes a larger separation of the positions $y_m$ on the different λ's on the screen. So the more the lines/mm of the grating the stronger its resolving power. Also, a large number of lines/mm cause a stronger and sharper intensity of the primary maxima for each wavelength. For an illustration open the simulator http://physics.bu.edu/~duffy/HTML5/diffraction_grating.html

Default slit separation for the diffraction grating is 2000 nm; that is 2 μm. Click the Red check box. The center light is the $m = 0$, zero order. The first order above is the $m = 1$. The first one below is the $m = -1$. Now click in addition to the Red, the Green.

a) For the $m = 1$ order why is the green closer to the central point o, than the red? (Hint: See eqn. 1 above). Now click in addition the Blue.

b) What do you notice for the zero order (point o at the center)? Now let's try to increase the grating resolving power, by decreasing the slit separation, d to 1600 nm.

c) What do you notice for the positions of the $y_1$, $y_2$, and $y_{-1}$ and $y_{-2}$?

d) For each order, is the separation between the different λ's greater?

## Running the experiment

When we use a diffraction grating, we use a converging lens in conjunction. The lens is used in order to focus the parallel rays of same θ, to a same $y_m$.

1) If we have a grating with 300 lines/mm, a) calculate d, the slits separation. If the distance to the screen L = 10 m and the light we use have a wavelength λ = 532 nm, b) calculate $y_1$, the position of the first order.

2) Open the simulator [https://ophysics.com/l5b.html](https://ophysics.com/l5b.html)

Notice the default settings are like step 1. Let's check our calculation. Click Grating in place at the top left of the simulator.

> a) What is the value of $y_1$ as measured by the simulator on the ruler at the top (the units for the ruler is in meters)?
>
> b) Was your calculation correct? If not, try again.

3) For the same grating, if we use λ= 600 nm,

> a) do you expect a larger or smaller $y_1$?
>
> b) Calculate $y_1$ in this case. Then check using the simulator, (you can click the dot for λ and then use the arrows on the keyboard for fine adjustment).
>
> c) Was your expectation correct?
>
> d) Was your calculation correct? If not, try again.

4) With the same setting of step 4, if we increase the lines/mm of the grating,

> a) what do you expect to happen to the positions of the orders on the screen? Choose an answer: i) spread out, ii) shrink in, iii) no change.
>
> b) What happens to the zero order? (Choose from the same answer choices). Now let's try it in the simulator, increase the grating lines to 500 lines/mm. Verify your answers.

5) a) What do you expect if we decrease the distance from the grating to the screen, L? Now let's try it. With the same last setting (of step 4) decrease the Lens to Grating Distance to 7 m.

> b) Was your expectation correct?

## Data Sheet

Name: Group: Date experiment performed:

**Introduction exercise:**

Answer to a:

Answer to b:

Answer to c:

Answer to d:

**Experiment:**

Show all your calculations

Step 1) a: b:

Step 2) a: b:

Step 3) a: b:

c: d:

Step 4) a:

b:

Step 5) a:

b: