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A Novel Approach to Determine Dispersive Power of Diffraction Grating Using Diode Lasers

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Abstract - Diffraction gratings are used in many fields in physics, especially effectively used in astronomical applications. There are many equations that govern the physics of these gratings, including the resolving power equation and dispersive power equation. In order to introduce the concept of dispersive power of the grating, most of the physics undergraduate courses contain this experiment in the laboratory courses. This paper discusses an all-together new approach to determine the dispersive power of the grating using lasers..

***Key Words*:** Diffraction grating, Dispersive power, Under-graduate experiment, semiconductor Lasers.

1.INTRODUCTION

Diffraction gratings are used in many fields in physics, especially astronomy [1]. In astronomy, diffraction gratings are used in spectrographs to analyze the light of astronomical objects that is gathered by telescopes. These gratings use the principles of constructive and destructive interference of light to spread the different wavelengths out based on the wave nature of light and the diffraction grating equation,

$$d\sin\,\theta = n\lambda$$

where d is the grating spacing, θ is the angle of the incoming light, n is diffraction order, and λ is the wavelength of light.

The path length of light is related to wavelength of light and the structure of grating. This allows for the analysis of the elemental makeup of the objects in question based on the resulting spectra.

1.1. Angular dispersion

This angular dispersion is characterized by the dispersive power equation . The resolving power is equal to the total aperture of the grating times this dispersive power.

$$\frac{\mathrm{d}\theta}{\mathrm{d}\lambda} = \frac{n}{\mathrm{d}\ \cos\,\theta}$$

This shows that the dispersion of the light is based on the wavelength λ, the order of diffraction n, and the grating spacing d. In addition that means that the resolving power is dependent on the wavelength, which is also shown in the resolving power equation itself.

1.2. Dispersive Power of a Plane Diffraction Grating

The dispersive power of a diffraction grating is defined as the rate of change of the angle of diffraction with the change in the wavelength of light used. Thus, if the wavelength changes from λ to $(\lambda + d\lambda)$ and corresponding angle of diffraction changes from θ to $(\theta + d\theta)$, then the ratio $d\theta/d\lambda$ is called the dispersive power of the grating. For plane diffraction grating, we have the grating equation for normal incidence as

$$(a+b)\sin\,\theta = n\lambda$$

where $(a+b)$ is the grating element and θ the angle of diffraction for n^{th} order spectrum.
Differentiating eqn. (1) with respect to λ, we get
$(a+b)\cos\ \theta \frac{d\theta}{d\lambda} = n$
Therefore, the dispersive power, $\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\ \theta}$
or

$$\frac{d\theta}{d\lambda} = \frac{n}{(a+b)(1-\sin^2\ \theta)^{1/2}}$$

$$\sin\ \theta = \frac{n\lambda}{(a+b)}$$

$$\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\sqrt{1-\left(\frac{n\lambda}{a+b}\right)^2}} \text{ or } \frac{d\theta}{d\lambda} = \frac{1}{\sqrt{\left(\frac{\mathrm{a}+\mathbf{b}}{\mathrm{n}}\right)^2 - \lambda^2}}$$

In the above equation $d\theta$ is the angular separation between the two spectral lines with difference in wavelengths as $d\lambda$. The above expression shows that the angular separation is independent of the width of the spectral lines and the total number of rulings on the ruled surface.

The above equation indicates that

(i) the dispersive power is directly proportional to the order of the spectrum n, that is, higher is the order greater is the dispersive power.

(ii) the dispersive power is inversely proportional the grating element, that is, the dispersive power of is greater for a grating having larger number of lines per **cm**. That is, dispersive power increases with the closeness of rulings.

(iii) the dispersive power is inversely proportional to $\cos\ \theta$, that is, larger the value of θ higher is the dispersive power.

If θ is small, $\cos\ \theta \simeq 1$ and hence the influence of the factor $\cos\ \theta$ on dispersive power may be taken as negligible, then $(d\theta \propto d\lambda)$ the angular dispersion of two spectral lines in a particular order is directly proportional to the difference in wavelength between the two spectral lines. Such a spectrum is called normal spectrum.

1.3. Linear Dispersive Power of A Grating

The above equation expresses the angular separation per unit wavelength in the given order of spectrum or angular dispersive power. Sometimes it is necessary to know the linear separation of the two spectral lines in given order of spectrum. If dx represents the linear separation of two spectral lines along the screen differing in wavelength by $d\lambda$,

$$dx = f d\theta$$

where f is the focal length of the lens. Hence, linear dispersion,

$$\frac{dx}{d\lambda} = f\frac{d\theta}{d\lambda} = \frac{nf}{(a+b)\cos\ \theta}$$

The linear dispersive power of the grating can be increased by using a lens of large focal length.

2. Experimental

2.1 Light source for dispersive power

As the dispersive power involves a minimum of two wavelengths, it is conventional to use a sodium vapour lamp whose spectrum contains D1 and D2 lines at 5890 and 5896 angstroms. However, this experiment is also being performed in many under-graduate laboratories with mercury source whose spectral lines are well defined. However, it is not a practice to use laser beams for these experiments as lasers are highly monochromatic and does not contain multiple wavelengths.

An attempt is made in this laboratory to mix two laser beams in order to use the mixture as the source for determining the resolving power and dispersive power of a diffracting grating and the procedure adopted and the results obtained were presented in this paper.

Two commercial laser diode modules were procured from EGISMOS Technology corporation, Taiwan, with model numbers H-8-3-515-1/5-D/R and H-8-3-520-1/5-D/R . These two diode modules give the light with 515nm and 520nm with nearly 5mW power. The two modules were chosen as the difference in wavelengths is only 5 nm. The diode modules were used as procured without making any modifications.

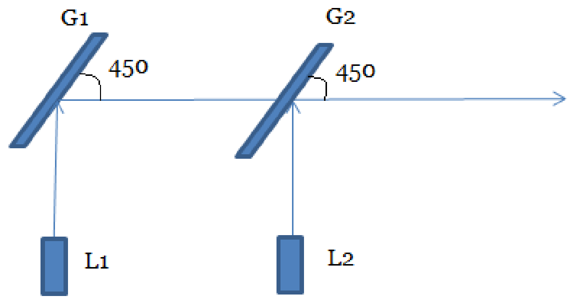

Fig.1. Block diagram of experimental setup used to mix two laser beams

Two thin glass plates G1 and G2 of size 3cm x 9cm were used to effectively combine these two wavelengths using the optics as shown in the fig.1. The glass plates were fixed to a solid rectangular metal base such that the glass plates are at right angle to the surface to which they are mounted upon. These mounts were supported by three screws and springs such that the horizontal plane on which the glass plates were fixed can be adjusted according to the requirement. The Laser L1 and Laser L2 are mounted to a fixed base and the optical output from these lasers are arranged such that the reflected beam makes 90^0 with the incident beam after reflection at the glass plates. The vertical heights of the incident beams and reflected beams were made to coincide after careful adjustments of the experimental setup. As the present experimental setup uses only commercially available undergraduate laboratory equipment, it needs to take utmost care for adjusting the angles, distances and heights.

In order to test the two beams to follow a single straight line, a screen was placed before the beam at 3 meters and by moving the screen further away from the beam, the vertical and horizontal separations were tested. In the present experiment the adjustments were made up to a distance of 20 meters. After confirming that there is no vertical and horizontal separation of the two beams up to 20 meters, it is once again verified that the two beams are on same line by moving the screen close to the source. Then the experiment was carried out without disturbing the setup.

A variable vertical slit along with the telescope, taken from the student spectrometer, was introduced in the beam. The width of the slit was adjusted such that it is very narrow and allows sufficient light to form an image.

A commercial students grating with 15000 lines per inch was kept using grating holder such that the grating was perpendicular to the beam. A white wall which was at distance of 10 meters was used as a screen to observe the grating spectrum. Only first and second order spectra were observed in this case.

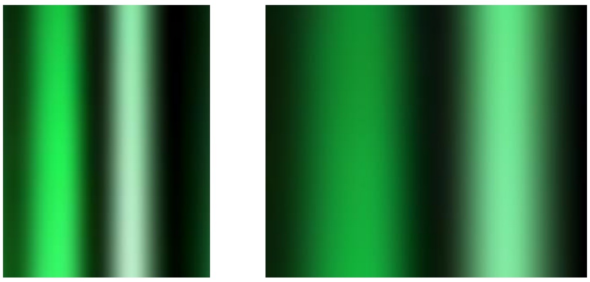

Fig.2. Magnified view of diffraction images of First order and Second order

With Laser L1 ON and Laser L2 OFF, the spectrum corresponding to Laser L1 is noted, by marking the slit image positions on the wall corresponding to first and second order on left and right sides of the incident beams. Later with laser L1 OFF and Laser L2 ON, the diffracted slit image positions of first order and second order were noted on the wall. With both the Lasers ON, the diffracted slit image

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positions of first order and second order were noted on the wall. These diffracted slit image positions were marked with a find pencil on the continuous graph paper attached to the wall for accurate measurements involved. These diffracted slit image positions were used for final calculations.

Fig.2. shows the separation of the first order and second order diffracted images obtained at a distance of 6.4 meters from the grating. The left images are due to 520nm and right images are due to 515nm respectively in both first and second order. The individual positions of diffraction images due to Laser L1 and Laser L2 were identified using the corresponding laser individually. The diffracting angles were calculated from the geometry assuming the condition of small angles.

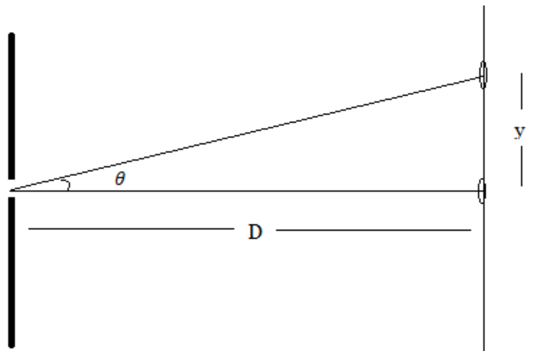

Fig 3. Geometry used for diffraction calculations

From the geometry, tan θ = y / D . As y<< D, and using small-angle approximation, tan θ = sin θ = y / D for any n th order minimum, the angles were estimated, where D is the distance between the grating and screen / wall and the y is the position of the diffracted image from the un-diffracted position. However, as it is difficult to identify the exact position of the un-diffracted position accurately, in order to reduce the error involved, the positions of the diffracted patterns on left and right sides of the centre were taken into consideration and half of the distance between these two was taken as y.

3. RESULTS AND DISCUSSION

From the positions of the diffracted patterns on left and right sides of the centre, the diffracting angle θ_1 for laser light of wavelength λ_1 from laser L_1 is calculated as described above. Similarly the diffracting angle θ_2 for laser light of wavelength λ_2 from laser L_2 is calculated. The difference between these two diffracting angles $d\theta$ and the difference between the two wavelengths of the lasers L_1 and L_2 , $d\lambda$ is calculated. The ratio $\frac{d\theta}{d\lambda}$, is calculated. The value of the $\frac{d\theta}{d\lambda}$ thus obtained for various grating was found to be in good agreement with the values obtained through conventional laboratory experiment methods. From the separation between the diffracted images of the first order slit images, for a fixed distance, for a particular order, the linear dispersion $\frac{dx}{d\lambda}$ is calculated, for different student gratings. Even though no focussing lens was used in this method, the values of the linear dispersive power are found to be following the proportionality relations as defined by the theoretical derivations of the formula for liner dispersive power[2,3].

4. CONCLUSIONS

The use of two different lasers with wavelengths separated by 5 nm can be effectively used to determine the dispersive power of a diffracting grating instead of conventional sources. This method can also be used for demonstration of the concept for a class room of any size as this method uses lasers as source. First order diffraction pattern can be demonstrated in an ordinary class room without the use of dark conditions. Efforts to bring out the combined, simplified, all-packed built-in module of the laser sources with two wavelengths is under progress and will be reported and patented very soon.

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