VIVEKANANDA COLLEGE
THAKURPUKUR
KOLKATA-700063

NAAC ACCREDITED ‘A’ GRADE

Topic: Diffraction in a multislit (diffraction by grating)

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Name of the Teacher: SUBHAYAN BISWAS

Name of the Department: PHYSICS

Double, redouble . . . more than that: N slit diffraction pattern: Grating

In case of single and double slit Fraunhofer diffraction pattern we find a similarity. Both the patterns contain one principal maxima and other secondary maxima. *In the double slit pattern secondary maxima are enhanced compared to the secondary maxima of single pattern due to presence of the factor 4 = 22, where 2 is the number of the slits*. It is true that the principal maxima is also improved by the same factor. But the secondary maxima are more visible in case of the double slit pattern. Double slit pattern is textured by the interference pattern. The number of the equispaced interference maxima inside a diffraction maxima is already discussed in the previous section. Now the presence of one principal maxima becomes obvious to any person due to which we prefer the name 'principal'. However, we get some resemblance between the two diffraction patterns. What will be the nature of the fringe if someone wants to increase the number of slits? So we are interested to introduce the theory of N slit diffraction pattern. This can be referred as a general treatment and that should be reducible to the hitherto discussed two cases: single slit and double slit if we put N = 1 and N = 2. Such collection of large number of slits is referred as **grating**. If we look at the arrangement of double slits we get that these are parallel and aligned in a plane. We here discuss the diffraction pattern by a arrangement with plane parallel N slits.

An arrangement consisting of large number of parallel slits of the same width separated by equal opaque spaces is known as diffraction grating or transmission grating. Grating always shows strong diffraction pattern. Hence the word diffraction is generally omitted from the description of the grating. Rather the arrangement and the nature of producing the diffraction pattern is referred with the grating. According to our proposal we are now going to discuss the diffraction pattern by plane transmission grating.

Plane diffraction grating consists of a number of parallel slits and equidistant lines ruled on an optically plane parallel glass plate by a fine diamond point. To make a resemblance with the matter discussed in the previous section we chose the transparent space between two consecutive ruled lines as **e**, slit width and the width of the ruled lines (controlled by the dimension of the diamond tip) as **b**. The quantity (**e + b**) is called grating element (the separation between two sources). Following the same logic as the previous section we can easily comment that for such collection of N -1 grating elements there should be N sources in the arrangement. The midpoint of each slit is considered as point diffracting source.

Note: That does not mean that it is mandatory to arrange the parallel slits in same plane. The plane may be a curved one with spherical or parabolic revolution.

Because light is transmitted through the slits and we observe the pattern from the opposite side of the existence of the main source. This actually refers another possibility where we may have regularly spaced source which are created by the reflection and can be referred as reflection grating. The common example is the surface of a CD.

a scratch behaves like an opaque space. The transparent portion between two scratches becomes a siit.

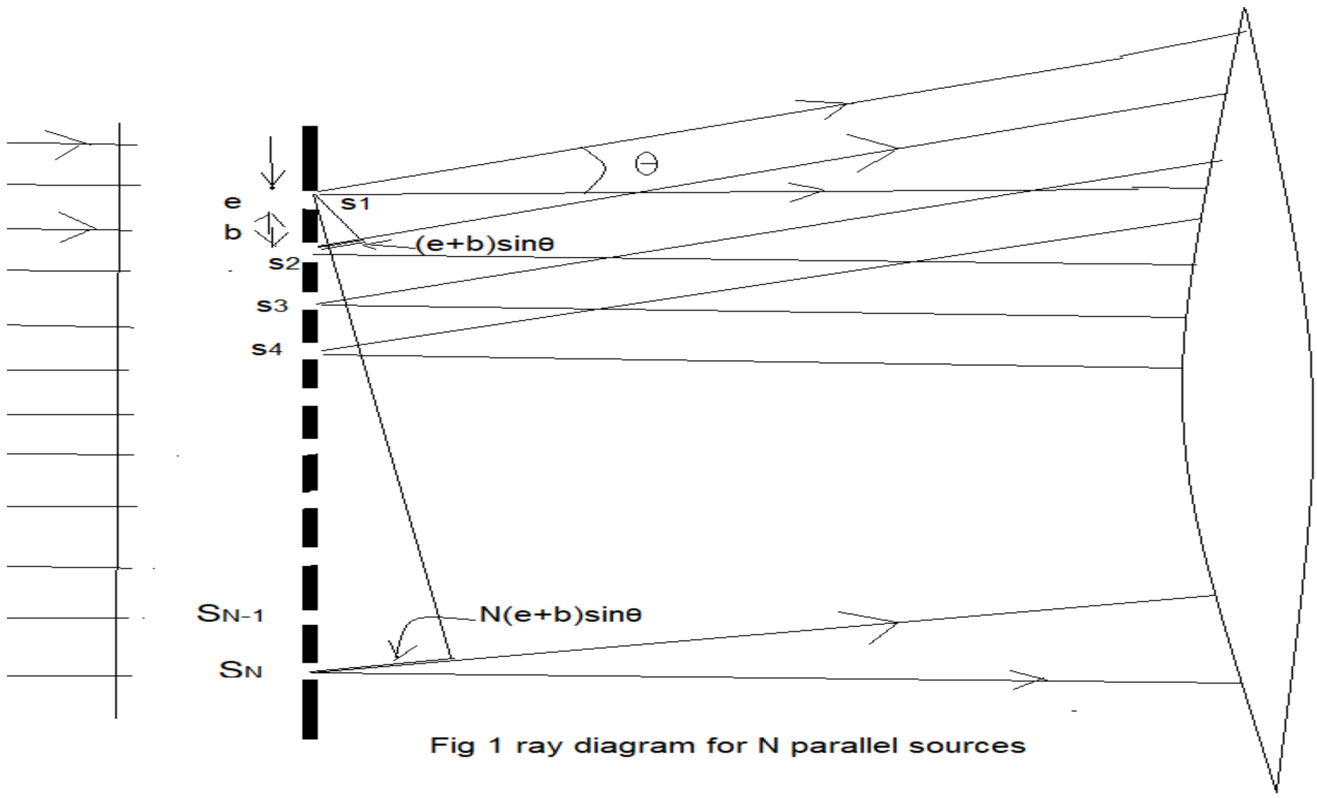


Fig 1 ray diagram for N parallel sources

The ray diagram is shown in the fig. 1. The amplitude of the light emanating from each source in a direction can be considered as **R**. The value of **R** is modulated by diffraction and its magnitude is **R** = **A**$\frac{\sin\alpha}{\alpha}$. α is related to the angle of deviation (θ) of the ray from the normal by the relation **α =** $\frac{\pi e\sin\theta}{\lambda}$. Since the source to source distance is (e+b), the path difference between two sources S_i and S_{i+1} is (e + b) sinθ. So the corresponding phase difference is $\frac{2\pi(e+b)\sin\theta}{\lambda}$. We consider the phase difference as **2β**, as was considered in the case of the double slit pattern. If we count from S1 then the phase difference increases like **2β**, 4**β**, 6**β**...... 2N**β**. So phase difference increases in arithmetic progression with common difference 2**β**. The intensity at any point P is resultant of the N sources with amplitude 'a' and phase difference 2**β**. We can refer the expression of amplitude due to superposition of N waves from the equation → $R = ae^{-i(\omega t+\Phi av)}\frac{\sin\frac{N\Phi}{2}}{\sin\frac{\Phi}{2}}$ Here R = **A**$\frac{\sin\alpha}{\alpha}$ and ϕ = **2β**. (for detail calculation see single slit diffraction note) Excluding the time varying part and the overall average phase the amplitude becomes

$$y = \mathbf{R}\frac{\sin N\boldsymbol{\beta}}{\sin\boldsymbol{\beta}} = \mathbf{A}\frac{\sin\alpha}{\alpha}\frac{\sin N\boldsymbol{\beta}}{\sin\boldsymbol{\beta}} \text{ ----------------------(2)}$$

Therefore the intensity becomes

$$\mathbf{I = I_0}\frac{\sin^2\alpha}{\alpha^2}\frac{\sin^2 N\beta}{\sin^2\beta} \text{ -------------------------(3)}$$

The effect of the factor $\frac{\sin^2\alpha}{\alpha^2}$ was discussed in details for single slit diffraction pattern. We also observed that, for same value of **α** the angular separation. θ changes different values of e/λ. This factor as usual makes an envelope. The factor $\frac{\sin^2 N\beta}{\sin^2\beta}$ is new to us.

We have to analyse this term, which carries the information of the grating, collection of N sources. In equation (3) the first term is diffraction pattern produced by a single slit and the second term represents the interference pattern produced by N equally spaced point sources. For comparison we can replace N = 2 and expression (3) will be reduced to the expression **$4.A^2.(\frac{\sin\alpha}{\alpha})^2.(\cos\beta)^2$** . The **$\cos^2\beta$** represents the intensity distribution of interference of two sources with which we were familiar. But we are not familiar with the intensity distribution of interference between N sources.

Principal maxima

The maximum intensity can be observed if the denominator of $\frac{\sin^2 N\beta}{\sin^2\beta}$, vanishes. We can call such maxima as principal maxima. So the condition for principal maxima is

$$\sin\beta = 0$$

$$\beta = \pm m\pi$$

But both the denominator and numerator vanish under such condition and the expression $\frac{\sin^2 N\beta}{\sin^2\beta}$ apparently becomes in-determinant. It may be evaluated by finding the limit (using L,hospital rule) $\lim_{\beta\to\pm m\pi}\frac{\sin N\beta}{\sin\beta} = \lim_{\beta\to\pm m\pi}\frac{N\cos N\beta}{\cos\beta} = \pm N$ ----------------(4)

These maxima positions are called as principal maxima. The intensity of the principal maxima is proportional to N^2. Thus the intensity of the principal maxima increases with increment of number of slits. In general the intensity is very high unless since itself is becomes very small. Therefore the intensity of principal maxima can be written as

$$I = \mathbf{N^2A^2}\frac{\sin^2\alpha}{\alpha^2} \text{ ------------------------------------}\mathbf{(5)}$$

From the expression of the phase difference between two consecutive sources we get

$$\beta = \frac{\pi(e+b)\sin\theta}{\lambda} = \pm m\pi$$

So the condition for principal maxima is $(e+b)\sin\theta = \pm m\lambda$ -------------------(6)

From the expression (6) we have

$$\sin\theta = \frac{\pm m\lambda}{(e+b)} \text{ ---------------------(7)}$$

Since **$\alpha = \frac{\pi e\sin\theta}{\lambda}$** , we can replace the value of sinθ from this expression in to it and thus α becomes:

$$\alpha = \frac{\pi e\sin\theta}{\lambda} = \frac{\pi e\frac{\pm m\lambda}{(e+b)}}{\lambda} = \frac{\pi em}{(e+b)}$$

Expression (7) helps us to realise the angular deviation of the maxima from the normal. Since $|\sin\theta| <= 1$, m can not be greater than $\frac{\lambda}{(e+b)}$. In reality we have a good number of principal maxima inside the principal maxima of the diffraction pattern produced by the factor $\frac{\sin^2\alpha}{\alpha^2}$**.** This expression (6) is independent of N which indicates that the position oí tbe principa maxima does not depend on the number of sources or in practical sense region of the grating exposed under radiation.

One can find the similarity of the expression (6) with the maximum of the intensity produced by interference in the double slits. But we never uttered the word like principal maxima or a number of maxima though the equation (7) can also be applicable there.there are two reasons

Firstly the value of (e+b) in double slit is greater than the value of grating element (e + b). In real space the θ value will be much larger in the case of grating than the pattern produced in double slit. The large value of e also invites minima of the diffraction pattern at too earlier value of θ which offers us several missing orders of interference maxima. In case of grating we observe the pattern produced inside the diffraction principal maxima and the first minima on either side and so apart due to smallness of (e + b) the angular width covers almost all the field of view.

Secondly the scale factor were $2^2 = 4$ for double slits but in case of grating it becomes N^2 where N 1000. So the intensity is modified enormously. Since there is no other maxima (we are inside the pm of diffraction pattern which cannot be identified separately) we have no other choice to call it as principal maxima.

Minima

The minimum intensity will be provided when the numerator of the factor $\frac{\sin^2 N\beta}{\sin^2\beta}$ becomes zero but denominator gives non zero value. i.e.

sinNβ = 0 but sinβ ≠ 0

.

To get sinNβ= 0 we choose **Nβ = ±sπ**. '**s**' are integer but should not be equal to 0, N, 2N... because those value generate β = 0, π, 2π etc which are reserved for principal maxima. As a condition we can say

s is any integer ≠ pN

where p is an integer: order number of principal maxima. From the expression of β we can write

$$N\beta = N\frac{\pi(e+b)\sin\theta}{\lambda} = \pm s\pi \text{ --------------------(8)}$$

Or $(e+b)\sin\theta = \pm s\pi/N$ ----------------------(9)

Since left hand side of the equation (6) and (9) is same the condition of the minimum intensity can be expressed as:

$$(e+b)\sin\theta = X, \pm\frac{\lambda}{N}, \pm\frac{2\lambda}{N}, \pm\frac{3\lambda}{N}, \ldots\ldots, \pm\frac{(N-1)\lambda}{N}, X, \pm\frac{(N+1)\lambda}{N}., \pm\frac{(N+2)\lambda}{N}., \pm\frac{(N+3)\lambda}{N}, \ldots$$
$$., \pm\frac{(2N-1)\lambda}{N}, X, \frac{(2N+1)\lambda}{N}, \frac{(2N+2)\lambda}{N}, \frac{(2N+3)\lambda}{N}, \ldots., \frac{(3N-1)\lambda}{N}, X, \frac{(3N+1)\lambda}{N}, \frac{32N+2)\lambda}{N}, \ldots \text{etc.}$$

The omitted values are referred by X, which are 0, λ, 2λ, 3λ etc. i.e., position of central (0^{th}) and first, second, third principal maxima on either side.

We can also represent the condition in term of β using the equation (8) as:

$\beta = X, \pm\frac{\pi}{N}, \pm\frac{2\pi}{N}, \pm\frac{3\pi}{N}, \ldots\ldots, \pm\frac{(N-1)\pi}{N}, X, \pm\frac{(N+1)\pi}{N}, \pm\frac{(N+2)\pi}{N}, \pm\frac{(N+3)\pi}{N}, \ldots, \pm\frac{(2N-1)\pi}{N}, X, \pm\frac{(2N+1)\pi}{N}, \pm\frac{(2N+2)\pi}{N}, \pm\frac{(2N+3)\pi}{N}, \ldots, \pm\frac{(3N-1)\pi}{N}, X, \pm\frac{(3N+1)\pi}{N}, \pm\frac{(3N+2)\pi}{N}, \pm\frac{(3N+3)\pi}{N}$..... etc.

Secondary maxima

When the condition for the minima is expanded it shows that a good number of minima exist between two principal maxima. The series of minima indicates existence of other type of maxima between them. These maxima are referred as secondary maxima. Before going to discuss this it is better to mention that this is only for academic interest. They are too weak to detect besides the highly intense principal maxima.

The first two principal maxima occur for s = N and s = 2N = N + N. Minima presents for s values from N + 1 to N + (N - 1). So in between two adjacent principal maxima there are (N-1) minima. Secondary maxima appear in between the minima. Therefore the number of secondary maxima becomes (N-2).

To get the condition for the secondary maxima we have to differentiate the expression of amplitude; i.e., we must have

$$\frac{d}{d\beta}\left(\frac{\sin N\beta}{\sin\beta}\right) = 0$$

$$\frac{N\cos N\beta\sin\beta - \cos\beta\sin N\beta}{\sin^2\beta} = 0$$

$$N\cos N\beta\sin\beta - \cos\beta\sin N\beta = 0$$

$$N\cos N\beta\sin\beta = \cos\beta\sin N\beta$$

$$N\frac{\sin\beta}{\cos\beta} = \frac{\sin N\beta}{\cos N\beta}$$

$$N\tan\beta = \tan N\beta$$

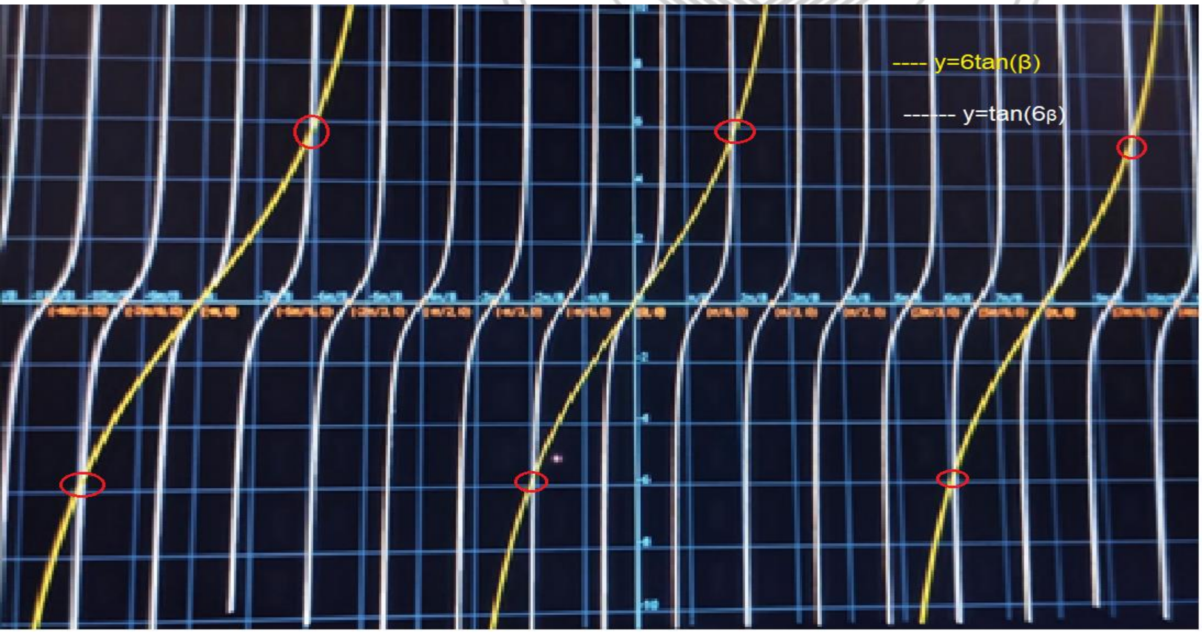


Figure: 2 Graphical solution of the equation N tanβ = tan Nβ.

The white lines are showing y=tan(6β) and yellow lines are y= 6tan(β)

This is again a transcendental equation which can be solved by graphical method. And to plot the graph one has to assume some value of N. In the previous figure we represent the variation of tan (6β) and 6 tanβ with respect to β. The two graphs always cut at integral value of π on β axis. But integral value of π are reserved for either principal maxima or minima. The intersection points other than those values of β will give the position of secondary maxima. Since number N is taken as 6 we are considering a grating with six sources. Thus between two consecutive principal maxima there will be (6 – 1) = 5 minima and (6-2) = 4 maxima. The first order principal maxima will occur for this case at β = π and 0^{th} order maxima or central maxima will appear at β = 0. So within the β value 0 to π there should be four secondary maxima or four intersection points of the graphs of tan (6β) and 6 tanβ.

Position of secondary maxima(SM) can be calculated from the graph as given in the table.

Value of β	0	0.756240	1.30133	1.84026	2.34536	3.14159(π)
Status	CM	1^{st} SM	2^{nd} SM	3^{rd} SM	4^{th} SM	1^{st} PM

CM=Central maxima; nth SM=nth Secondary maxima; nth PM=nth Principal maxima

Intensity distribution of the interference pattern

The existence of the principal maxima and the secondary maxima can be directly observed from the graphical variation of the factor governing the interference. This is the factor $\frac{\sin^2 N\beta}{\sin^2 \beta}$.

We again show the variation with β. The variation will be again in the β space. The angular separation in real space is somewhat different, which can be retrieved from the relation of β.

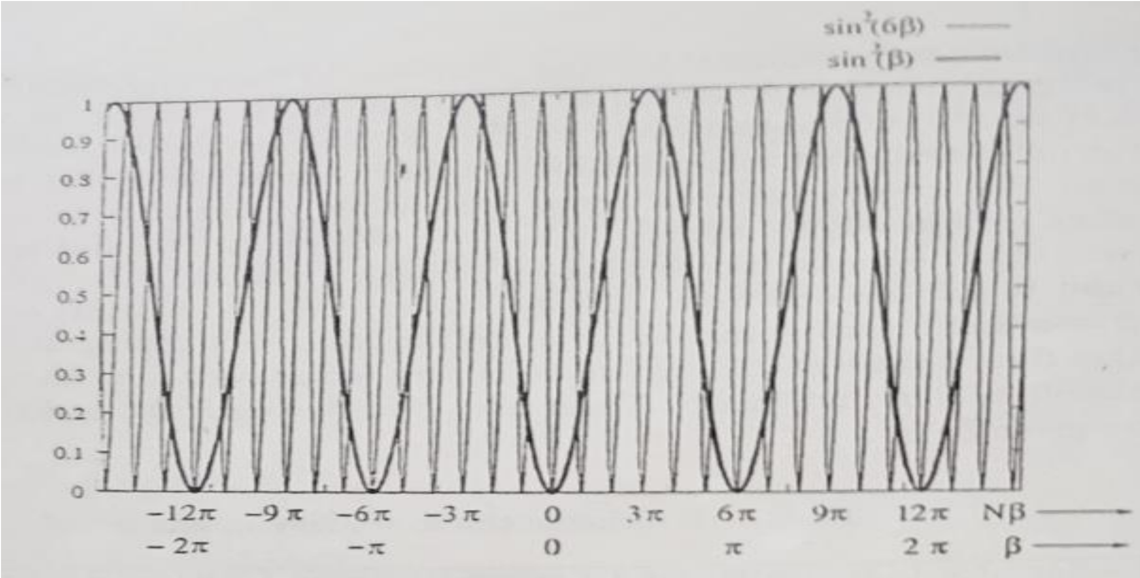
For large N values secondary maxima becomes insignificant so we choose smaller value of N to demonstrate the variation. We seek for the value of β as [equation (8)]

$\beta = \pm\frac{s\pi}{N}$

let us consider N=6. So $\beta = \pm\frac{s\pi}{6}$

For s = 0, 6, 12 both sinβ and sinNβ becomes zero and produces maximum intensity. Thus s = 0 is central maxima, s = 6 or $\beta = \pm\pi$ is first principal maxima and s = 12 or $\beta = \pm 2\pi$ is second principal maxima and so on.

s = 1, 2, 3, 4, 5 give the condition for five minima between 0^{th} and first principal maxima s = 1 and s = 5 are the minima which bounds the principal maxima. So between 1 and 2, 2 and 3, 3 and 4, 4 and 5 four secondary maxima exist which are shown in the curve of tan Nβ = N tan β in fig.2 and the corresponding β values are also given in the table.



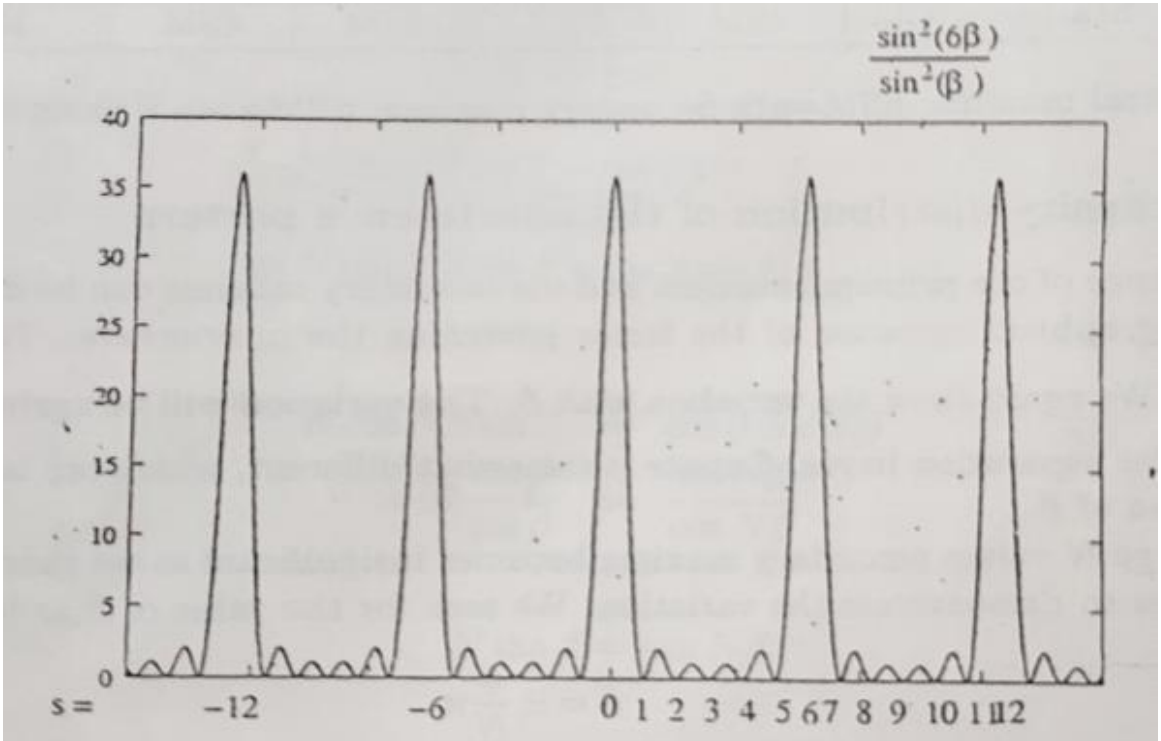


Figure 3 Intensity distribution of the interference pattern. Upper portion shows variation of $\sin^2 6\beta$ and $\sin^2 \beta$ separately. Lower one is the ultimate intensity pattern after dividing these two.

In the first part of the fig. 3 we get both the functions have the variation between 0 and 1. At the value of β = $\pm s\pi$ where s = pN denominator function (plotted with the thicker line) numerator function (plotted with lighter line) become zero simultaneously. In the limiting process the intensity shows high value. For other values of β (between two principal maxima) $\sin^2\beta$ increases gradually. For β= $\pm s\pi$ where s ≠ PN we get the minima. But in the other portions the intensity decreased due to gradually increment of $\sin^2 \beta$. Due to that reason secondary maxima have different intensities as is observed from the second part of the fig.3. The distribution is somewhat symmetrical. The secondary maxima besides two principal maxima have same intensity and nature of variation (slightly tilted towards principal maxima). The two secondary maxima at the middle are smaller, this is due to the maximum value of $\sin^2\beta$. However, if we increase N they are in comes smaller and smaller comparing the intensities of the principal maxima. All these variation of the height of secondary maxima will not be considered as a serious matter.

The diffraction envelope

The final intensity contains a term $A^2 \frac{\sin^2\alpha}{\alpha^2}$ coming from the single slit diffraction. This will govern the whole intensities. In the previous section we get the graphical representation of the interfering factor and existence of principal maxima. All of which have the same intensity. We often become very much pleased after getting these principal maxima and make an end of the discussion about the matter. But these principal maxima must not have the same intensity because they are inside the envelope of the diffraction pattern. Starting from the 0^{th} principal maxima as we go on either side intensities decrease due to the envelope or we may have to encounter missing of some principal maxima as we observed for double slits.

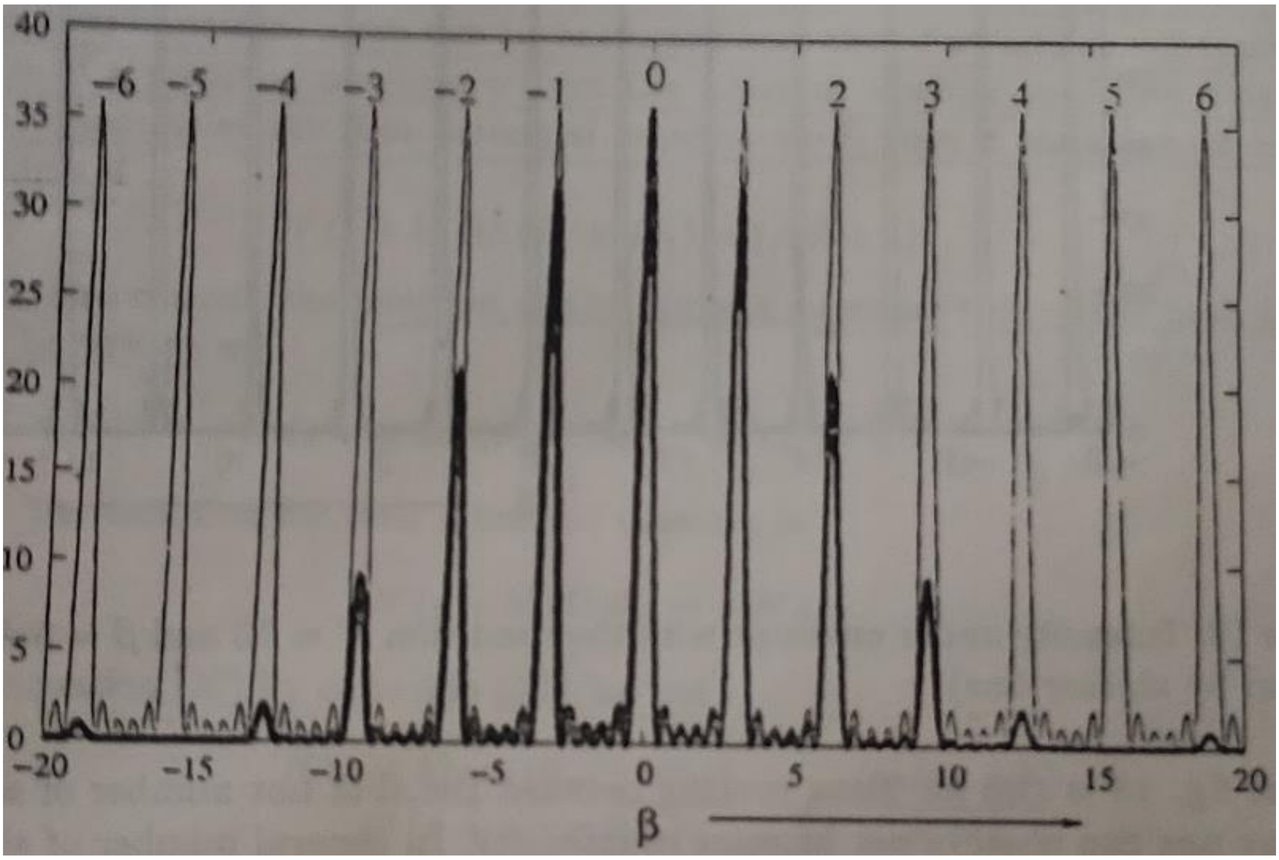


Figure 4: Intensity under envelope with the condition N = 6 and β = 5α (final intensity is given by thicker line).

For this discussion we consider the width of the opaque space in between two slits as four times greater. i.e., b/e = 4. Therefore $\beta = 5\alpha$ or $\alpha = \beta/5$. Since we gave all the plots in β space we have to represent the factor $\frac{\sin^2\alpha}{\alpha^2}$ in terms of β; i.e., we take the opportunity to plot the combined intensity as

$$\frac{\sin^2(\frac{\beta}{5})}{(\frac{\beta}{5})^2} \times \frac{\sin^2(6\beta)}{\sin^2\beta}$$

We choose the same N value (6) as have taken in the previous section for better comparison. The order of the principal maxima are indicated at the top (see fig. 4). The diminishing nature of intensity is clearly visible and on either side 5^{th} principal maxima are missing since they are under first diffraction minima.

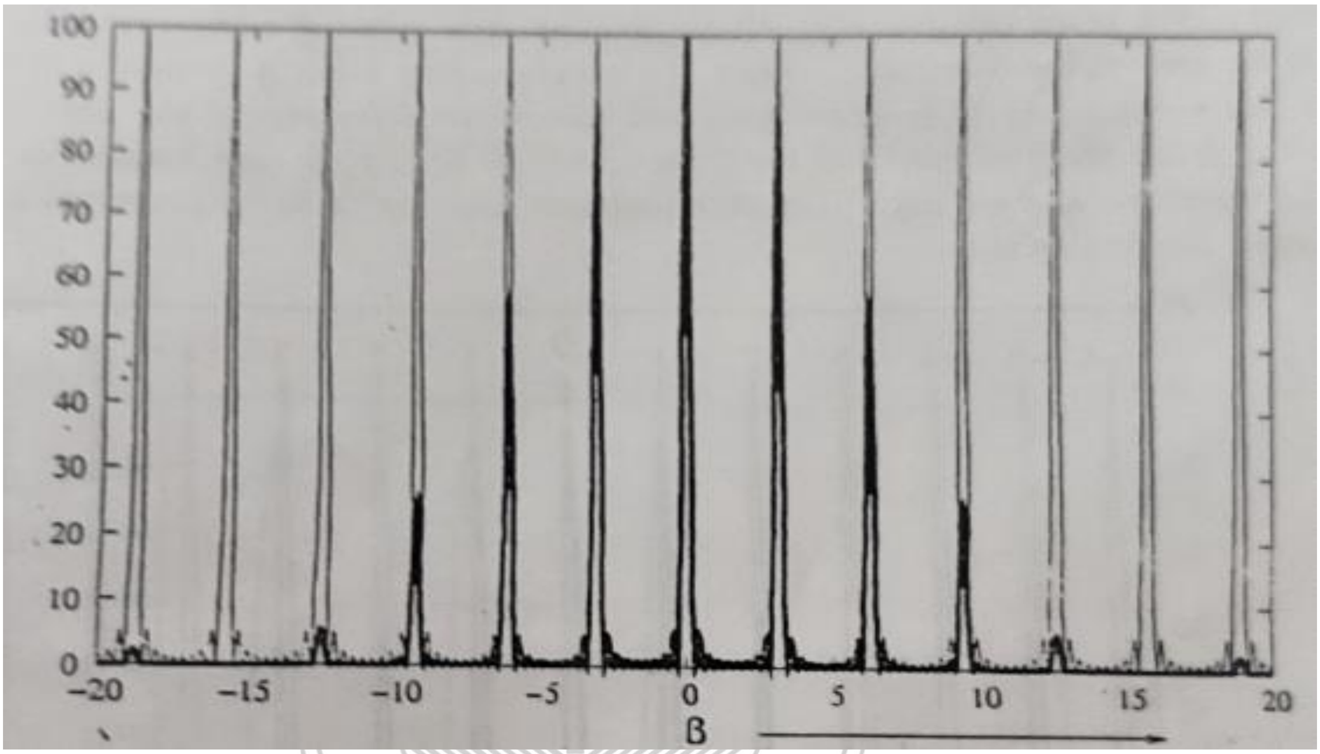


Figure 5: Intensity under envelope with the condition N = 10 and B = 5a (final intensity is given by thicker line)

The fig. 5 is also for same spacing between the slits but number of sources becomes 10. Anyone can observe net increase of intensity. In general number of slit associated in diffraction is so large that the variation of intensity is not very prominent and opaque space becomes much larger than slit width so that minima of diffraction envelope are formed at large angular separation. If there is no integral relationship between β and α which is often true for grating construction we will not have any missing order. However, for such case principal maxima under the secondary diffraction maxima appear to be feeble in intensity.

Angular width of the principal maxima

The condition of the principal maxima is given by the condition

$(e + b)\sin\theta = \pm m\lambda$

We multiply the equation by N, total number of slits involved both sides

$N(e + b)\sin\theta = \pm mN\lambda$

Using different values of we get the condition of the principal maxima of different order

$N(e+b)\sin\theta$ = 0, $N\lambda$,$2N\lambda$, $3N\lambda$,$4N\lambda$. . . . . .----------------------------(10)

(10) gives the condition of 0th, first, second, third, fourth order of principal maxima The condition of the sth minima is also given by the same type of relation

$(e+b)\sin\theta = \pm\frac{s\lambda}{N}$

Again multiplying this expression by N we get

$N(e+b)\sin\theta = \pm s\lambda$

Giving the value of s we get

$N(e+b)\sin\theta$ = 0, λ,2λ,3λ . . . . . .(N-1) λ,(N+1) λ,(N+2) λ ---------------------(11)

The condition for first, second, third minima. Comparing equation (10) one can realise the reason of absence the term Nλ in the equation (11), which is reserved for first principal maxima. Another important news can be extracted here that if we add or subtract λ from the condition of a principal maxima we get the adjacent minima on either side. If the angle of the formation of the first principal maxima be θ_1 then a variation of $\pm d\theta_1$ can produce minima if

$N(e+b)\sin(\theta_1 \pm d\theta_1) = (N\lambda \pm \lambda)$ -----------------------------(12)

Extending this concept the position of the minima on either side of the mth principal maxima can be written as

$N(e+b)\sin(\theta_m \pm d\theta_m) = (mN\lambda \pm \lambda)$ -----------------------------(13)

Where as the condition for mth principal maxima is

$N(e+b)\sin\theta_m = mN\lambda$ ---(14)

Dividing equation (13) by equation (14) we get

$$\frac{N(e+b)\sin(\theta_m \pm d\theta_m)}{N(e+b)\sin\theta_m} = \frac{(mN\lambda \pm \lambda)}{mN\lambda}$$

$$\frac{\sin(\theta_m \pm d\theta_m)}{\sin\theta_m} = 1 \pm \frac{1}{mN}$$

$$\frac{\sin\theta_m \cos d\theta_m \pm \cos\theta_m \sin d\theta_m)}{\sin\theta_m} = 1 \pm \frac{1}{mN}$$

Since the value of $d\theta_m$ is very small we can approximate sin $d\theta_m$ as $d\theta_m$ and cos $d\theta_m$, as 1. Therefore the above relation takes the form

$$\frac{\sin\theta_m \pm \cos\theta_m d\theta_m)}{\sin\theta_m} = 1 \pm \frac{1}{mN}$$

$$1 \pm \cot\theta_m d\theta_m = 1 \pm \frac{1}{mN}$$

$$\cot\theta_m \, d\theta_m = \frac{1}{\mathrm{mN}}$$

$$d\theta_m = \frac{1}{\mathrm{mN}\cot\theta_m} \qquad \text{---------------------(15)}$$

The value of m can be replaced from the equation (14) as m = $\frac{(e+b)\sin\theta_m}{\lambda}$

$$d\theta_m = \frac{1}{\frac{(e+b)\sin\theta_m}{\lambda}\mathrm{N}\cot\theta_m}$$

$$d\theta_m = \frac{\lambda}{(\mathrm{e+b})\mathrm{N}\cos\theta_m} \quad \text{--(16)}$$

These are the expressions for half angular width. Angular width therefore can be represented in two forms either

$$\Delta\theta_m = \frac{2}{mNcot\theta_m}$$

$$\Delta\theta_m = \frac{2\lambda}{(\mathrm{e+b})\mathrm{N}\cos\theta_m} = \frac{2\lambda}{\mathrm{A}\cos\theta_m}$$

The last expression shows that the angular width and hence the Sharpness of the principal maxima depends on the factor N (e + b). Here A = N (e+b) is the total surface area of the grating, because N is the total exposed number of slits and (e + b) is the separation between the two sources (slits).) Angular width is proportional to the λ, i.e. angular width increases for higher λ. Again, higher order spectrum is formed at greater angle. The value of the cosine of an angle decreases with increase of the angle. When we shift from one principal maxima to another principal maxima due to the decrement of the denominator (for the factor $\cos\theta_m$) angular width of the principal increases. But in practical sense this increment is hardly visible.

Formation of spectra by grating

Interference with white light always gave us frustration. We got only a white central fringe bounded by two distinct adjacent minima assisted by a few trails of red and green lines from their own interference pattern before fading out. In the case of single slit or double slit diffraction pattern we again got a single central or principal maxima. The condition of the central maxima was *zero path difference*. For single slit it is situated at the point opposite to the slit and in case of double slits it is in the midway between two slits. The condition of zero path difference is satisfied by the light of all the wavelengths. That means central maxima of all the wavelengths coincide at the same place. Only one difference exists among them that the spreading of the central maxima are different for different wavelengths) Width of central maxima increases with the wavelengths as was discussed in the single slit pattern. So the central maxima is always white for multi coloured source with some coloured boundary

The central maxima will also be white for grating spectra, where path difference is zero. But the main difference with the other two is that a series of sharply defined principal maxima are formed on either side of the central maxima. The positions of the principal maxima are governed by the wavelength associated with the light. If the grating is illuminated with white light (a light source where more than one wavelengths are associated) all the wavelengths form their own principal maxima for an order in different θ values. So in the field of view we observe images of slit but with different colour or in a nutshell we will get a spectra. Let us try to arrange the whole thing mathematically get some quantitative idea. The condition for mth maxima is given by

$(e+b)\sin\theta = \pm m\lambda$

For m = 1

$$\theta = \sin^{-1}(\pm\frac{\lambda}{e+b})$$

The value of sine of an angle increases with increment of the angle. Therefore from the above relation one can realise that the shift of the principal maxima of red light is higher than the shift of the principal maxima of violet light from the position of the central maxima. In a single word: *'more the wavelength more deviation'*. For a particular order number (m) we have a group of principal maxima for all wavelengths (present in the source) or spectra. In the case of grating therefore for each order we have a spectrum. To illustrate this we chose a particular arrangement of rulings where e = 0.044mm and b= 0.132mm. i.e.; (e+b) = 0.176mm. The grating is exposed under the radiation coming from helium source. The wavelengths associated in the helium spectra are given below.

Table 4: Specifications of the Helium spectrum

Colour	red	red	yellow	green	blue-gr	blue	violate
Wavelength (A^0)	7065	6678	5876	5016	4922	4713	4471
Identity	λ_{R1}	λ_{R2}	λ_Y	λ_G	λ_{B-G}	λ_B	λ_V

The angular position of the different colours in two order numbers are given; for m = 1 and m= 6. The lines are arranged in ascending order of wavelengths because higher order line produces its own principal maxima at higher angle for a particular order. For order number m the general expression is

$$\theta = \sin^{-1}(\pm\frac{m\lambda}{e+b})$$

So higher orders are shifted from central maxima (0 angle position). We also plot the angular separation between two adjacent lines. Definitely angular separation increases in the higher order spectrum.

Angular separation in the spectra of Helium formed by grating in 1st and 6th order

Order no.	wavelength	Θ(deg)	Δθ(deg)	Order no.	wavelength	Θ(deg)	Δθ(deg)
1	λV	0.1456	0.0079	6	λV	0.8733	0.0473
	λB	0.1534	0.0068		λB	0.9206	0.0408
	λB-G	0.1602	0.0031		λB-G	0.9614	0.0184
	λG	0.1633	0.0280		λG	0.9798	0.1680
	λY	0.1913	0.02610		λY	1.1478	0.1567
	λR2	0.2174	0.01260		λR2	1.3045	0.0756
	λR1	0.2300			λR1	1.3801	

We have plotted the above data i.e., the position of the principal maxima with the angle. Each line represents principal maxima. The lines λB-G and λG (shown with dashed line) are hardly separable in the first order but they are distinctly identified in the sixth order principal maxima.

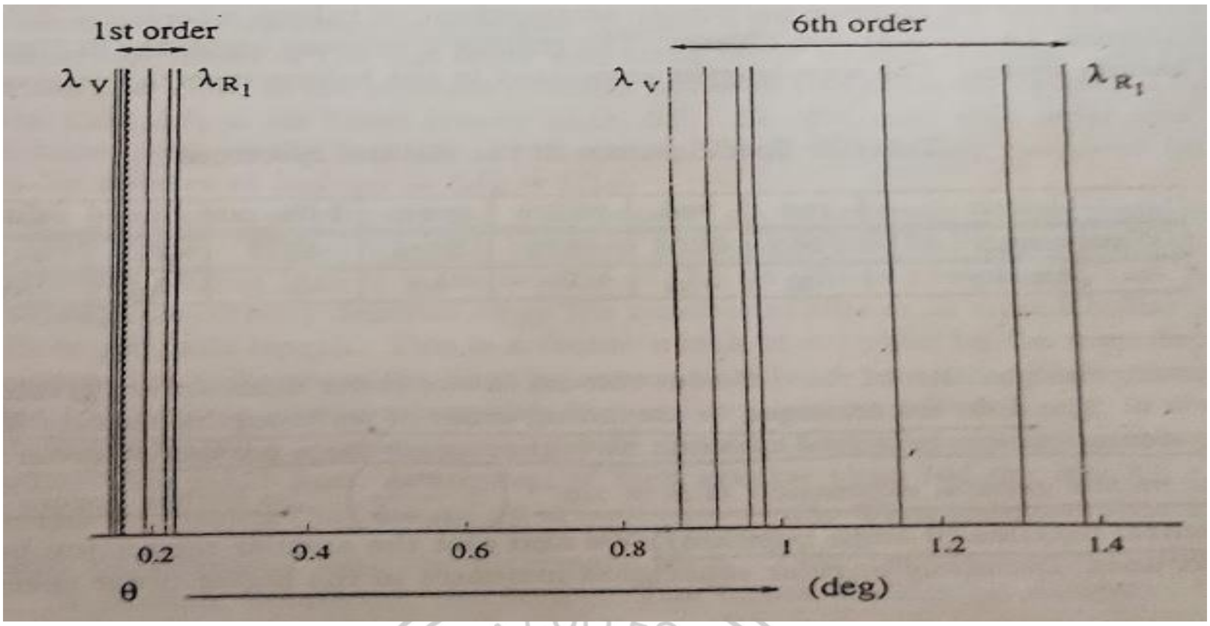


Figure 6: position of the 1st and 6th order principal maxima for Helium light (for data see the tables above)

Thus a *grating acts as a dispersive agent*. Generally we observed some medium with some geometric arrangement can act as a dispersive medium e.g., prism. The basic reason for the dispersion in prism is the variation of refractive index with wavelength which helped them to travel in different paths. Here only bending of light is responsible for dispersion and medium has nothing to do with this phenomenon. So we call the grating as an agent not the medium. There are different advantages and unique properties of the grating spectrum. We will discuss these later.