NAWAB SHAH ALAM KHAN COLLEGE OF ENGINEERING & TECHNOLOGY

UNIT-1 b

DIFFRACTION

Diffraction:A) Distinction between Fresnel and Fraunhofer diffraction, B) diffraction due to single slit, N-slits,C) Diffraction grating experiment.

A) Distinction between Fresnel and Fraunhofer diffraction,

1. What is meant by diffraction of light?

The phenomenon of bending of light into the geometrical shadow region is called diffraction. This is shown by all kinds of waves, irrespective of their nature.

2. What are the types of diffraction and give the differences between them? (June 2005, June 2011)

3. Explain Fresnel and fraunhofer diffraction (May 2017)

Diffraction phenomenon can be divided into following two general classes:

(1) Fresnel's diffraction: In this class of diffraction, source and screen are placed at finite distances from the aperture of obstacle having sharp edges. In this case no lenses are used for making the rays parallel or convergent. The incident wave front are either spherical or cylindrical.

(2) Fraunhofer's diffraction: In this class of diffraction source and the screen or telescope (through which the image is viewed) are placed at infinity or effectively at infinity. In this case the wave front which is incident on the aperture or obstacle is plane. OR

	Fresnel diffraction	**Fraunhofer diffraction**
1	In this class of diffraction, source and screen are placed at finite distances from the aperture of obstacle having sharp edges.	In this class of diffraction source and the screen or telescope (through which the image is viewed) are placed at infinity or effectively at infinity.
2	The incident wavefront are either spherical or cylindrical.	In this case the wave front which is incident on the aperture or obstacle is plane.
3	Source used is small in size	Big or extended source is used
4	Lenses are not used	Lenses are used

4. What is the difference between interference and diffraction? (June 2005)

5. Differentiate between interference and diffraction. (May 2007, June 2011)

6. Explain what is meant by diffraction of light. How diffraction is different from interference? (June 2011)

Following are the differences between interference and diffraction phenomena:

INTERFERENCE	DIFFRACTION
Interference is due to the interaction between two separate wave fronts originating from two coherent sources	Diffraction is due to the interaction between the secondary wavelets originating from different points of same wave front.
In an interference pattern all the maxima are of same intensity	In a diffraction pattern the intensity decreases on either side of the central maximum
In interference all fringes have equal widths.	In diffraction the central maximum is very wide. The width decreases on either side
In the interference pattern the regions of minimum intensity are usually almost perfectly dark	In the in diffraction pattern the regions of minimum intensity are not perfectly dark.

B) diffraction due to single slit, N-slits

7. a) Give the theory of Fraunhofer diffraction due to single slit and hence b) obtain the condition for primary and secondary maxima. Using this c) obtain intensity distribution curve (June 2006)

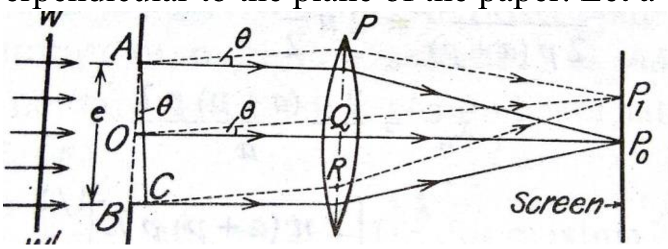
8. Obtain the condition for primary maxima in Fraunhofer diffraction due to a single slit and d) derive an expression for width of central maximum (2005, 2011)

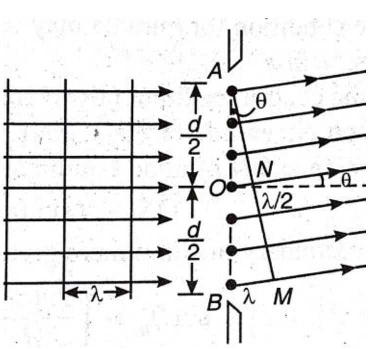
9. Briefly explain Fraunhofer diffraction at single slit (May 2017)

10. Sketch a neat diagram of Fraunhofer diffraction at a single slit (May 2017)

a) FRAUNHOFER DIFFRACTION AT SINGLE SLIT

Suppose AB is a narrow slit width ‘a’ and perpendicular to the plane of the paper. Let a plane wave front WW′ of monochromatic light of wave length λ propagating normally to the slit be incident on it. Let the diffracted light be focussed by means of a convex lens on a screen placed in the focal plane of the lens. The secondary wavelets travelling normally to the slit, i.e., along the direction OP_o are brought to focus at Po by the lens. Thus Po is a bright central image. This is called zero order maximum. The secondary wavelets travelling at an angle θ with the normal are focussed at a point P_1 on the screen. In order to find out intensity at P_1, draw a perpendicular AM to the diffracted rays.





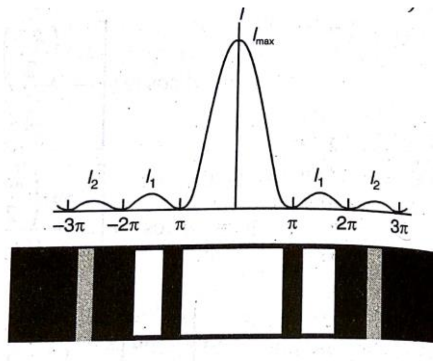
b) Suppose the slit is divided into two halves AO and OB. Suppose the waves starting from the top of the two halves have a path difference λ/2. These two waves interfere destructively producing minimum. For every point in the first half there is a corresponding point in the second half producing waves having a path difference λ/2.

$\frac{a}{2}\sin\theta = \frac{\lambda}{2}$ or a $\sin\theta = \lambda$ ………………(1)

The path difference between secondary wavelets from A and B direction θ.
The rays travelling in this direction interfere destructively producing minimum called first order minimum. The higher order minima can be obtained in the direction

a $\sin\theta = m\lambda$

where m = 2,3,4,..



In addition to the central maximum there are secondary maxima which lie in between the secondary minima on either side. Hence for secondary maxima

a $\sin\theta = (2m + 1)\lambda/2$

It should be noted that secondary maxima do not fall exactly mid-way between two minima, but they are displaced towards the centre of the pattern, of course, the displacement decreases as the order of maximum increases.

Thus the diffraction pattern due to single slit consists of a central bright maximum flanked by secondary maxima and minima on both the sides.

c) Intensity distribution in diffraction pattern

Suppose the width of the slit is divided into n equal parts and the amplitude of the wave from each part is 'a' (because width of each part is same). Suppose the phase difference between any two consecutive waves from these parts would be 'δ'

$$\frac{1}{n}\left(\frac{2\pi}{\lambda}a\sin\theta\right) = \delta = \frac{1}{n}2\alpha \text{ (say)}$$

Using the method of vector addition of amplitudes, the resultant amplitude A_θ is given by $A = a\frac{\sin\frac{n\delta}{2}}{\sin\frac{\delta}{2}}$

$$A_\theta = a\left[\frac{\sin\alpha}{\sin\frac{\alpha}{n}}\right]$$ for large value of n , α/n is very small.

Hence $A_\theta = na\left[\frac{\sin\alpha}{\alpha}\right]$

$$A_\theta = A_o\left[\frac{\sin\alpha}{\alpha}\right]$$

The intensity in any direction is given by $I_\theta = I_o\left[\frac{\sin\alpha}{\alpha}\right]^2$

where Io is the intensity of the principal maximum at θ = 0.

Figure represents the intensity distribution. It is a graph of $I_o\left[\frac{\sin\alpha}{\alpha}\right]^2$ (along Y-axis) as a function of α or sin θ (along X-axis).

It can be seen that most of the light is confined to the central maximum. The intensity of the secondary maxima falls off rapidly Io/22, Io/61 ..

d) Linear width of the principal maximum

Linear width of the principal maximum is distance between the first order secondary minima on either side of the central maximum. If x is the distance of the first secondary minimum from the center then the width of the central maximum

W = 2x.

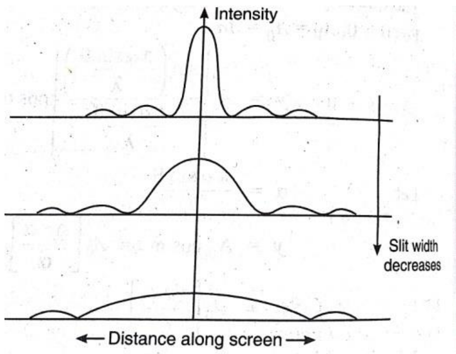
If 'f ' is the focal length of the lens used to focus the diffraction pattern we have $\sin\theta = x/f$

But $\sin\theta = \lambda/a$.

Therefore $\frac{x}{f} = \frac{\lambda}{a}$ or $x = \frac{f\lambda}{a}$

Hence, the width of the central maximum is given by

$W = 2x = \frac{2f\lambda}{a}$



From the above it is clear that as the slit narrows the width of the central maximum increases as shown.

11. How do you measure the slit width.

Measurement of slit width

The slit is illuminated with a laser beam and the diffraction pattern is obtained on a screen placed at a distance one meter. The distance between the first minima on either side 2x is measured. The slit width a can be measured using $a = \frac{f\lambda}{x}$

where f is the focal length of the lens or distance of the screen from the slit.

Problem 1: A slit is illuminated with light of wave length λ. find the angular width of the central maximum if the width of the slit is 1) 4λ 2) 3λ 3) 2λ 4) λ.

Hint: $a \sin\theta = \lambda$

In the above if the screen is at a distance 2 m find the width of the central maximum.

Problem 2: A slit of width 1.5 mm is illuminated by a light of wavelength 500 nm and diffraction pattern is observed on a screen 2 m away. Calculate the width of the central maximum. [**1.33 mm**]

Hint: $2x = \frac{2D\lambda}{a}$

Problem 3: A screen is placed 2 m away from a narrow slit. If the first minima lie at 5 mm on either side of the central maximum when light of wavelength 500 nm is used. Find the width of the slit.[**0.2 mm**] Hint: $a = \lambda D/x$.(**May 2017**)

Problem 4: A lens whose focal length is 40 cm forms a Fraunhofer diffraction pattern of a slit 0.3 mm wide. Calculate the distances of the first dark band and of the next bright band from the axis (wavelength of light used is 5890 Å [**0.785 mm, 1.178 mm**]

Hint: $x_1 = \frac{f\lambda}{a}$ and $x_2 = \frac{3f\lambda}{2a}$

Problem 5: find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width 12×10^{-5} cm when the slit is illuminated by light of wave length 6000Å.[30°]

Hint: $a \sin\theta = n\lambda$

Problem 6: Find the angular width of the central maximum in the Fraunhofer diffraction using a slit of width 1 μm when the slit is illuminated by light of wavelength 600 nm.(June 2006) [θ = 36.87°][2θ = 73.74°]

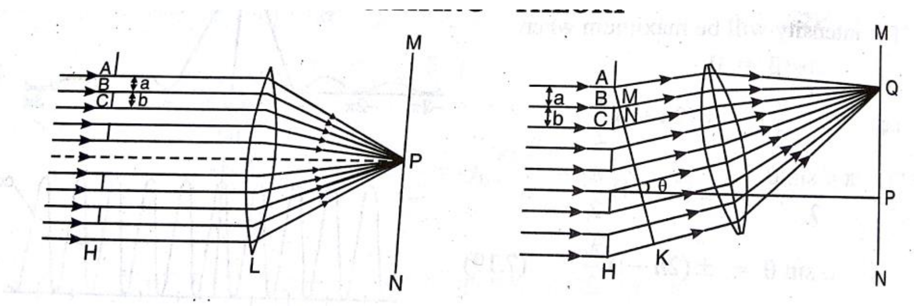
Hint: a $\sin\theta = \lambda$

Problem 7: Calculate the angular separation between the first order minima on either side of central maximum when the slit is 6 x10^{-4} cm width and light illuminating it has a wavelength 6000 Å

12. Explain with theory the Fraunhofer diffraction due to 'N' slits. (May 2003, June 2004, June 2011)

Fraunhofer Diffraction due to N slits (Diffraction grating)

Diffraction grating consists of very large number of narrow slits side by side and separated by opaque spaces. The incident light is transmitted through the slits and blocked by opaque spaces. Such a grating is called transmission grating. When light passes through the grating, each one of the slit diffracts the waves. All the diffracted waves reinforce one another producing sharper and intense maxima on the screen. In practice a plane transmission grating is a plane sheet of transparent material on which opaque rulings are made with a diamond point. The spaces between the rulings are equal and transparent and constitute the parallel slits. The rulings are opaque and are of equal width. The combined width of a ruling and a slit is called grating element.

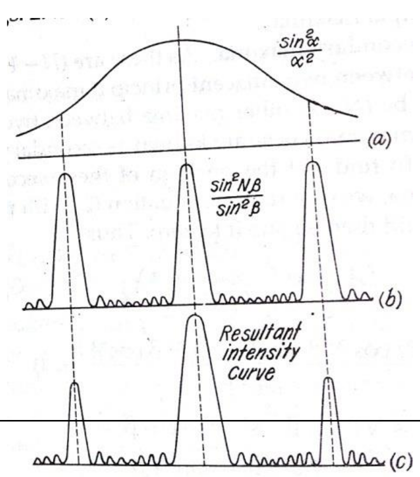


Theory of plane transmission grating

Let ABC….H represent the section of grating normal to the plane of the paper. Let the width of each slit be 'a' and that of opaque ruling be 'b'. Now (a + b) which is the combined width of a ruling and a slit is called grating element. It is also the distance between two successive slits. Any two points on successive slits separated by a distance (a + b) are called corresponding points. Let a plane wave front be incident normally on the grating. The points in the slits act as secondary sources of light giving rise to secondary waves. These waves spread in all directions on the other side of the grating. These waves are brought to focus on a screen with the help of a lens. The secondary waves travelling in the same direction as that of the incident wave are focused at Po. Since all these secondary waves have travelled equal distance to reach Po, they reinforce constructively and hence the point Po is the position of central bright maximum.

Now let us consider secondary waves travelling at an angle θ with the direction of incidence and reaching P_1. The intensity at P_1 depends on the path difference between the secondary waves originating from the corresponding points of two adjacent slits. Since the distance between corresponding points is (a + b) the path difference is (a + b) $\sin\theta$.

The intensity at P_1 will be maximum if $(a + b)\sin\theta = n\lambda$



Intensity distribution

Suppose the waves from the grating reach a point on the screen.

Suppose the phase difference between two waves form the edges of a slit is given by $\left(\frac{2\pi}{\lambda} a \sin\theta\right)$ = 2α (say)

and suppose the phase difference between two waves form the adjacent slits is given by $\left(\frac{2\pi}{\lambda}(a+b)\sin\theta\right)$ = 2β (say)

The intensity at any point is due to diffraction as well as interference. It is given as

$$I = \left(\frac{A\sin\alpha}{\alpha}\right)^2 \left(\frac{\sin N\beta}{\sin\beta}\right)^2$$

The factor $\left(\frac{A\sin\alpha}{\alpha}\right)^2$ gives the distribution of intensity due to diffraction at single slit.

while the factor $\left(\frac{\sin N\beta}{\sin\beta}\right)^2$ gives the distribution of intensity as a combined effect of all slits.

Principal maxima: the most intense maxima are called principal maxima. They are obtained for (a + b) sinθ = ± nλ where n = 0,1,2,3…..

The intensity of principal maxima is $I = \left(\frac{A\sin\alpha}{\alpha}\right)^2 N^2$

Minima: in between any two principle maxima there will be (N - 1) minima.

Secondary maxima: as there are (N - 1) minima there will be (N - 2)

Problem 8: If a grating has 2540 line/inch find the grating element [10^{-3} cm]

Problem 9: a grating produces first order spectrum for a certain wavelength at 10^o. At what angle we second order spectrum.

Problem 10: A grating has 6000 lines/cm. find the angular separation for sodium D_1 and D_2 lines in the second order.(May 2007)[0.0058^o]

problem 11: A grating diffracts light of wavelength 5000Å at 30^o in the second order. Find the grating element and the number of lines per inch.

13. Calculate the maximum number of orders possible for a plane diffraction grating. (June 2011)

The principal maxima in a grating satisfy the relation (a + b) sinθ = nλ or $n = \frac{(a+b)\sin\theta}{\lambda}$

The maximum angle of diffraction can be 90^o.

Hence the maximum possible order is given by $(n)_{max} = \frac{(a+b)\sin 90^o}{\lambda} = \frac{(a+b)}{\lambda}$

Problem 12: A grating has 25400 lines per inch. Find the highest order that can be observed.

Problem 13: Find the highest order that can be seen with a grating having 15000 lines/inch. The wavelength of light used is 600 nm (2003)[2]

Hint: $n \le \frac{1}{N\lambda}$

Problem 14: How many orders will be visible in the wavelength of incident light is 500 nm and the number of lines on the grating is 2620 in 1 inch?(May 2017)

14. Find the missing order in a grating spectrum

In a grating spectrum the total intensity is controlled by diffraction at a single slit and interference due to two adjacent slits.

If the intensity due to any one cause is zero the total intensity at that point will be zero.

Suppose at a point we n^{th} principal maximum satisfying the relation

$(a + b) \sin \theta = n \lambda$ …….(1)

Suppose at the same point we get m^{th} diffraction minimum satisfying the relation

$a \sin \theta = m \lambda$ …….(2)

If both the conditions (1) and (2) are satisfied simultaneously then n^{th} diffraction order will be missing. Dividing equation (1) by (2) we get

$\frac{(a+b)\sin\theta}{a \sin\theta} = \frac{n}{m}$ or $\frac{(a+b)}{a} = \frac{n}{m}$ …….(3)

15. What do you understand by grating element (May 2017)

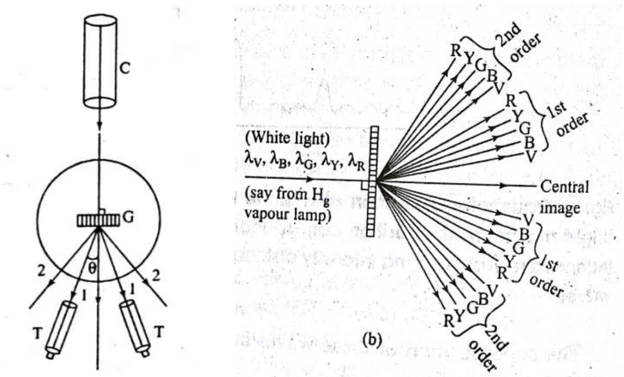
It is defined as the distance between the centers of adjacent slits. Or it is also defined as the sum of the widths of an transparency ‘a’ and opacity ‘b’

<u>C) Diffraction grating experiment.</u>

16. Explain with theory how wavelength of spectral line is determined using Plane diffraction grating (M 2003, J 2004)

The wavelength of monochromatic light or wave length of spectral lines of a composite light can be determined using a diffraction grating and spectrometer.

The collimator C of the spectrometer is adjusted to produce parallel rays and the telescope T is adjusted to receive the parallel rays, by focussing a distant object.



The grating G is then placed on the grating table such that it is normal to the axis of collimator C. The collimator slit is now illuminated by the monochromatic source whose wavelength is to be determined. The telescope is brought in line with the collimator to view the un diffracted bright image. The telescope is slowly turned to one side viewing through it until first order diffracted image coincides with the vertical cross wire of the eye piece. The reading of the telescope in this position is noted. Now the telescope is turned to the other side and the vertical cross wire is made to coincide with the first order diffracted 1mage. The reading of the telescope in this position is also noted. The difference between the two readings gives us 2θ, where θ is the angle of diffraction. Substituting this value in the equation given below, the wavelength of the given monochromatic source of light can be determined. $(a + b) \sin \theta = n\lambda$ or where $(a + b)$ is graying element and n is the order of the spectrum.

The above can also be written as $\frac{\sin\theta}{nN} = \lambda$ where N is the number of lines per cm.

the experiment may be repeated in higher orders.

In order to determine the wavelength of different spectral lines of a composite light source, the slit of the collimator is illuminated by the source. In the first order diffraction itself the angle of diffraction for different colours are measured . Substituting those values in the formula, wavelength of different spectral lines of the composite light.

Thus grating is very useful in determination of wavelength of any spectral line.

Problem 15: A grating has 6000 lines / cm Find the angular separation between two wavelengths 500 nm and 510 nm in the 3rd order.(May 2003/June 2004). [2.48^o]

Hint: $\sin\theta = nN\lambda$

17. What is resolving power? What is its formula?(May 2017)

The resolving power of a grating is defined as the capacity to form separate diffraction maxima of two wavelengths λ1 and λ2 which are very close to each other. It is given by λ/dλ where λ is the average wavelength and dλ is the difference in wavelengths. For a grating it is given as $\frac{\lambda}{d\lambda} = nN$ where N is the total number of lines on the grating.

The resolving power of a grating depends on the total number of lines on the grating and the order of the spectrum.

Problem 16: Examine if two spectral lines of wavelengths 5890Å and 5896Å can be clearly resolved in the 1) first order 2) second order by a diffraction grating 2 cm wide and having 425 lines/cm (May 2017)

Hint: $\frac{\lambda}{d\lambda} = nN$ [the lines will be clearly resolved in second order]

DIFFRACTION OBJECTIVE

FILL IN BLANKS

1. The bending of light round the corner of obstacles is called ………(**diffraction**)
2. The bending of light in to the geometrical shadow region………(**diffraction**)
3. Diffraction phenomenon indicates the **(wave nature)** of light.
4. Diffraction is shown by ….(**all**) kinds of waves.
5. Diffraction effect is clearly observed when the obstacle or opening are of the order of …..(**wavelength**)
6. Diffraction of sound is ……….(**more**) than that of light.
7. Diffraction of sound is more than that of light because sound waves have …(**longer**) wave lengths.
8. When the source and screen are at finite distances from the opening or obstacle it is called ….(**Fresnel diffraction**)
9. In Fresnel diffraction the wave fronts involved are …..(**spherical or cylindrical**)
10. In Fresnel diffraction the rays involved are …..(**diverging or converging**)
11. In Fresnel diffraction the sources involved are …..(**point or line or small size**)
12. In Fresnel diffraction lenses are …(**not used**)
13. Diffraction is due to superposition of wavelets from the (**same wave front**)
14. When the source and screen are at infinite distances from the opening or obstacle it is called ….(**Fraunhofer diffraction**)
15. In Fraunhofer diffraction the wave fronts involved are …..(**plane**)
16. In Fraunhofer diffraction the rays involved are …..(**parallel**)
17. In Fraunhofer diffraction the sources involved are …..(**highly extended or big**)

18. In Fraunhofer diffraction lenses are …(**used**)

FRAUNHOFER DIFFRACTION AT SINGLE SLIT

19. The diffraction condition for m th order minimum is a sinθ = mλ
20. The diffraction condition for first minimum is a sinθ = λ
21. In a single slit diffraction the first minimum is obtained at 30^o, the second minimum will be obtained at…..(90^o)
22. In a single slit diffraction the first minimum is obtained at 30^o. if the wavelength of light used is 500 nm, the slit width (1000 nm)
23. The diffraction condition for first maximum is a sinθ = 1.5 λ
24. The diffraction condition for second maximum is a sinθ = 2.5 λ
25. If a = λ, the first minimum is obtained at an angle ….(90^o)
26. If a = (**λ**), the diffraction pattern cannot be observed on the screen.
27. If a = 2λ, the first minimum is obtained at an angle ….(30^o)
28. If a = 4λ, the second order minimum is obtained at an angle ….(30^o)
29. The angular width of the central maximum in Fraunhofer diffraction is [$\mathbf{2\theta = 2\sin^{-1}(\lambda/a)}$]
30. The width of the central maximum. [$2x = \frac{2D\lambda}{a}$]
31. The distances of the first dark band and of the next bright band from the axis are $x_1 = \frac{f\lambda}{a}$ and $x_2 = \frac{3f\lambda}{2a}$
32. In the above the distance between first dark and the next bright is ($\Delta x = \frac{f\lambda}{2a}$)
33. With decrease in slit width the width of the diffraction central maximum (**increases**.)
34. In diffraction pattern the bands have (**different**) width
35. Due to diffraction most of the light energy is concentrated in (**central maximum**)
36. With the increase in order the intensity of secondary maxima (**decrease**)
37. The intensities of diffraction maxima are in the ratio…1: 1/22: 1/61
38. In a single slit diffraction the resultant amplitude in any direction is given by $$A = a\frac{\sin\frac{n\delta}{2}}{\sin\frac{\delta}{2}}$$
39. In a single slit diffraction the resultant amplitude in any direction is given by $$A_\theta = A_o\left[\frac{\sin\alpha}{\alpha}\right]$$
40. In a single slit diffraction the resultant The intensity in any direction is given by $$I_\theta = I_o\left[\frac{\sin\alpha}{\alpha}\right]^2$$
41. If a slit of width a slightly greater than λ is used we get (**diffraction**)
42. If a slit of width a = λ is used diffraction pattern is (**not observed**).
43. If two slits each of width a = λ are used we get (**interference only**)
44. If two slits each of width a > λ are used we get (**interference and diffraction**)
45. In a grating the distance between the centres of two successive slits is called (**grating element**)
46. The total thickness of slit 'a' and an opacity 'b' is called (**grating element**)

47. Two points occupying similar positions in two successive slits are called (**corresponding points**)

48. In a grating the number of lines per cm N = $\left(\frac{1}{a+b}\right)$

49. The condition of diffraction maximum in a grating is (a + b) sinθ = nλ

50. In a grating spectrum the (**violet**) color is deviated least.

51. In a prism spectrum the (**red**) colour is deviated least.

52. In a grating spectrum the intensity of principal maxima is $I=\left(\frac{A\sin\alpha}{\alpha}\right)^2 N^2$

53. In a grating spectrum the maximum possible order is given by

$(n)_{max} = \frac{(a+b)\sin 90^o}{\lambda} = \frac{(a+b)}{\lambda}$

54. In a grating spectrum n^{th} diffraction order will be missing if $\frac{(a+b)\sin\theta}{a\ \sin\theta}=\frac{n}{m}$ or

$\frac{(a+b)}{a}=\frac{n}{m}$

55. The resolving power of a grating is given by $\frac{\lambda}{d\lambda} = nN$

MULTIPLE CHOICE QUESTIONS:

56. The Penetration of waves into the regions of the geometrical shadow Is
    a) interference **b) diffraction** c) polarization (1) dispersion

57. light waves show
    a) interference b) diffraction c) polarization **d) all**

58. If a wave shows diffraction it can be
    a) longitudinal only b) transverse only **c) either a or b** d) none

59. Sound waves cannot show
    a) interference b) diffraction **c) polarization** d) all

60. In a Single slit diffraction, the first diffraction minima is observed at an an angle of 30^o, when the light of wavelength 500 nm is used. The Width of the slit is
    a) $5x10^{-5}$cm b) $2.5x10^{-5}$ cm **c) 10 x 10^{-5}cm** d) $1.5x10^{-5}$ cm

61. In Fraunhofer diffraction the wave front undergoing diffraction has to be
    a) spherical b) cylindrical c) elliptical **d) plane**

62. In a single slit experiment if the slit width is reduced
    a) the fringes becomes brighter
    b) the fringes become narrower
    c) the fringes become wider
    d) the colour of the fringes change

63. Instead of red colour source, if blue colour source is used in single slit experiment
    a) the diffraction pattern does not change
    b) the diffraction bands become wider
    c) the diffraction pattern becomes narrower and crowded together
    d) the diffraction pattern disappears .

64. The diffraction pattern of a single slit consists of
    a) wider dark band at the center with alternate bright and dark bands on either side.
    b) narrow bright band at the center with alternate dark and bright bands of equal

intensity on either side .

c) wider bright band at the center with alternate dark and bright bands of equal intensity on either side .

d) wider and brighter band at the center with alternate dark and bright bands of decreasing intensity on either side.

65. A beam of light of wavelength 600 nm falls on a single slit 0.1 mm wide and the resulting diffraction pattern is obtained on a screen 2 m away. The distance between the first dark fringes on either side of the central bright band

a) 2.4 mm b) 1.2 cm c) 1.2 mm d) 2.4 cm

66. A single slit is illuminated with a parallel beam if wavelength 500 nm. The emergent beam diverges at 30°. The size of the aperture is

a) 1 μm b) 10 μm c) 2.5 d) 25 μm

67. A parallel beam of monochormatic light falls normally on a plane diffraction grating having 5000 lines/ cm. A second order Spectral line is diffracted through an angle of 30°. The wavelength of light is

a) 5×10^{-7} cm b) 5×10^{-6} cm **c) 5×10^{-5} cm** d) 5×10^{-4} cm

68. When white light is incident on a diffraction grating, the light diffracted more

a) blue b) yellow c) violet (1) red

69. Monochromatic light falling normally on a grating gives rise to diffracted second order beam at angle 30°. If the grating has 5000 lines / cm, the wavelength of light is

a) 600 nm b) 400 nm **c) 500 nm** d) 650 nm

70. Maximum number of orders possible with a grating is

a) independent of grating element

b) directly proportional to grating element.

c) inversely proportional to grating element.

d) directly proportional to wavelength.