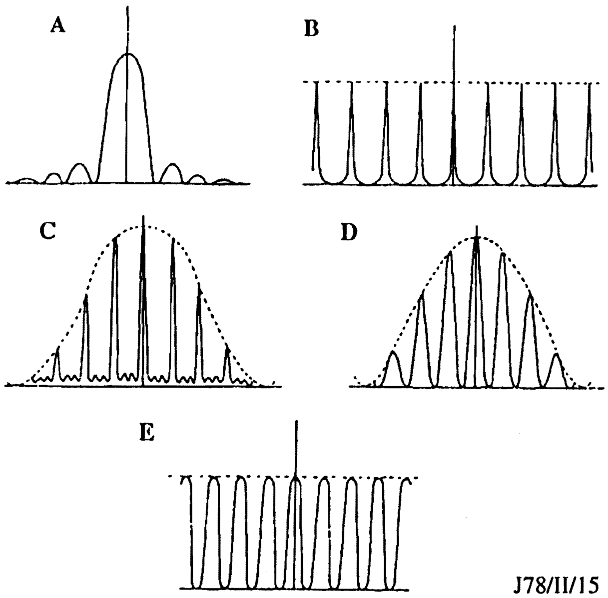
TOPIC 16 Diffraction

Single-Slit

1 A single slit is illuminated by parallel light and a diffraction pattern is formed on a screen some distance away. Which one of the following diagrams represents the intensity distribution across the screen?



J78/II/15

2 A slit of width d is illuminated normally by parallel monochromatic light of wavelength λ. A converging lens L of focal length f projects the diffraction pattern on to a screen S in its focal plane (Fig. 1).

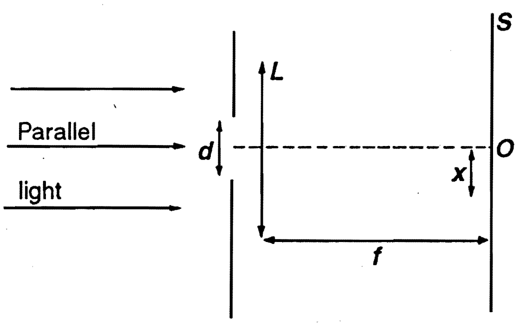


Fig. 1

The intensity of illumination on the screen is greatest at O and first becomes zero at a distance x from O. The quantities d, λ, f and x are related by the equation

A $x = d\lambda/f$
B $x = \lambda f/d$
C $x = df/\lambda$
D $\lambda x = d/f$
E $\lambda x = 1/df$

J79/II/16

3 An opaque object 10 cm wide casts a shadow when placed in a beam of light but has little effect on a beam of sound emitted by a small source of frequency 500 Hz. This is because

A sound is a pressure wave whereas light is an electromagnetic wave.
B sound travels much more slowly than light.
C sound waves are longitudinal whereas light waves are transverse.
D sound waves have a much longer wavelength then light waves.
E the power per unit area in a beam of sound is much lower than that in a beam of light.

N81/II/8

4 Light of wavelength λ incident on an adjustable single slit produces on a screen the diffraction pattern shown in Fig. 2 below when the slit width is a.

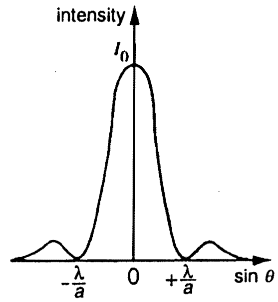
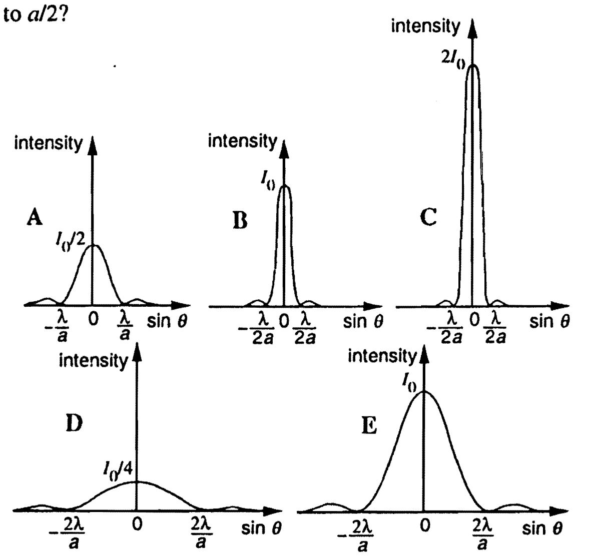


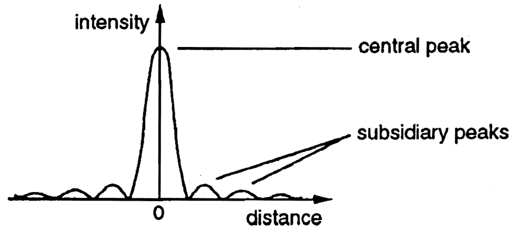
Fig. 2

Which one of the following diagrams best represents the diffraction pattern when the width of the slit is reduced to $a/2$?



J82/II/12

5 Monochromatic light incident on an adjustable single slit produces on a screen a distribution of intensity represented by the figure below.



What happen when the width of the slit is reduced?

A All peaks decrease in intensity and the width of the pattern increases.

B All peaks increase in intensity and the width of the pattern decreases.

C The central peak increases in intensity and the subsidiary peaks decrease in intensity.

D All peaks decrease in intensity and the width of the pattern remains unchanged.

E The intensity of all peaks remains the same and the width of the pattern increases.

J89/I/12; N85/I/11; N82/II/12

6 Monochromatic light of wavelength λ is incident normally on a single slit *RS* of width *a*. The diffraction pattern is formed on a screen *PP'*. The first minimum of this pattern makes an angle θ with the direction of the incident light, as shown in Fig. 3.

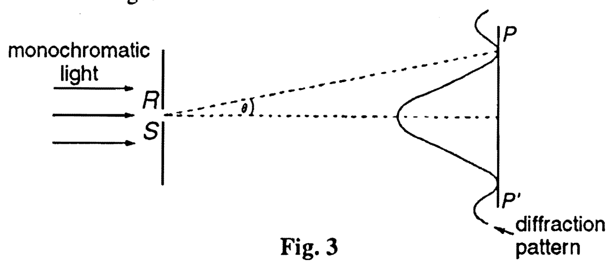


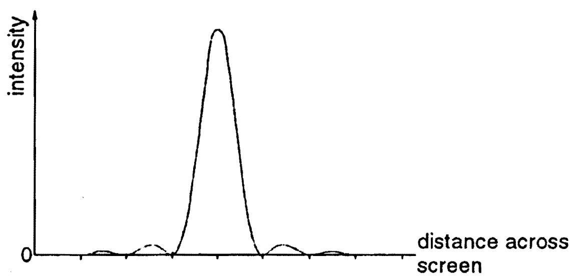
Fig. 3

Which one of the following gives the correct expressions both for the path difference (*SP–RP*) and for sin θ?

	(*SP–RP*)	sin θ
A	$\lambda/2$	$\lambda/2a$
B	$\lambda/2$	λ/a
C	$\lambda/2$	$2\lambda/a$
D	λ	$\lambda/2a$
E	λ	λ/a

N83/II/14

7 The diagram below represents the intensity distribution produced on a screen by the diffraction of light.



This can be achieved by using

A one single wavelength and a single slit.

B one single wavelength and a double slit.

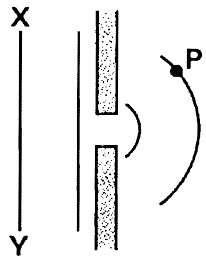
C two separate wavelengths and a single slit.

D two separate wavelengths and a double slit.

E two separate wavelengths and a diffraction grating.

J87/I/14

8 A monochromatic plane wave of speed *c* and wavelength λ is diffracted at a small aperture. The diagram illustrates successive wavefronts.

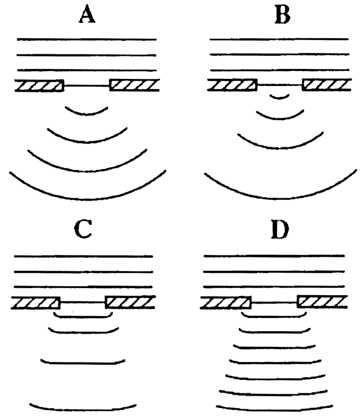


After what time will some portion of the wavefront **XY** reach **P**?

A $\frac{3\lambda}{2c}$ B $\frac{2\lambda}{c}$ C $\frac{3\lambda}{c}$ D $\frac{4\lambda}{c}$ E $\frac{6\lambda}{c}$

N93/I/8

9 Which diagram of a ripple-tank experiment shows the appearance of plane water waves passing through a wide gap?



N94/I/11

10 *(a)* The upper and lower limit of the frequencies of the notes of a piano are about 3.4 kHz and 34 Hz respectively. Find the limits of the corresponding range of wavelengths in air.

(b) When a recording is played through a loudspeaker, it is desirable that the speaker should act as a point source, rather than being directional. Estimate the maximum diameter of speaker that would ensure adequate spreading of sound waves from a recording of a piano. Explain your reasoning.
[Speed of sound in air = 340 m s^{-1}.] N78/I/5

11 The phenomenon of Fraunhofer diffraction may be demonstrated by illuminating a wide slit by a parallel beam of monochromatic light and focusing the light that passes through the slit on to a white screen. A diffraction pattern may then be observed on the screen.

(a) Sketch the intensity variation in the diffraction pattern as a function of distance across it.

(b) What would happen to the intensity variation if the width of the slit were halved?

J79/I/4

12

Fig. 4

Monochromatic light, incident normally on a narrow slit S (Fig. 4), is diffracted. A screen PQ is set up some distance from the slit in order to observe the diffraction pattern.

(a) Sketch a graph of intensity I against distance x from the central point O along the line PQ on the screen.

(b) Describe qualitatively what happens to the diffraction pattern as the width of the slit is gradually reduced. (Assume that it is practicable to reduce the slit-width until it is equal to the wavelength of the incident light.)

J84/I/5

13 Monochromatic light of wavelength λ is incident normally on a narrow slit of width D and is focused on a screen by a lens of focal length f, situated just beyond the slit. Sketch a graph to illustrate in detail the intensity distribution of the resulting diffraction pattern. State the width of the central fringe. N86/III/2

14 *(a)* (i) State what is meant by the *diffraction* of a wave. [2]

(ii) The diagrams of Fig. 5 and Fig. 6 represent plane wavefronts approaching a wide gap and a narrow gap respectively.

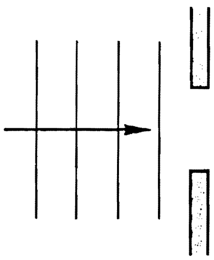


Fig. 5

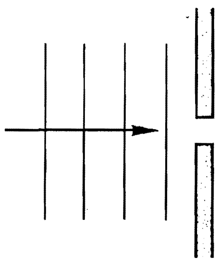


Fig. 6

Draw on each diagram lines, illustrating diffraction, to represent the wavefronts after passing through the gaps. [3]

N92/II/2 (part)

15 *(b)* Sketch on Figs. 7 and 8 the diffraction of waves through gaps which are

(i) large compared with the wavelength,

(ii) small compared with the wavelength. [3]

Fig. 7

Fig. 8

J2000/II/4 (part)

Long Questions

16 *(a)* (i) Sketch a graph to show the variation of intensity in the diffraction pattern formed when mono chromatic light passes through a single narrow slit. [4]

(ii) Draw a labelled diagram to illustrate the apparatus you would use to demonstrate single-slit diffraction. Suggest suitable dimensions for the apparatus. [4]

N89/III/8 (part)

17 *(b)* (i) Explain the meaning of the term *diffraction*. [2]

(ii) How does the width of the aperture through which a wave is passing affect the diffraction of the wave? [2]

J93/III/2 (part)

18 *(c)* An experiment is set up to demonstrate the behaviour of water waves in a ripple tank.

(i) Draw diagrams, one in each case, to show the diffraction of water waves through

1. a narrow gap,
2. a wide gap.

(ii) Suggest why two-source interference of water waves, using a double-slit arrangement, may not be observed when the slits are wide but, when the slits are narrow with the same separation as previously, interference *is* observed. [8]

J96/III/3 (part)

Grating

19 A parallel beam of white light (range of wavelengths 4.5×10^{-7} m to 7.5×10^{-7} m) is incident normally on a diffraction grating. The most deviated wavelength in the second order spectrum is diffracted through an angle of 60° from the direction of the incident beam. How many lines per metre are there on the grating?

A 5.8×10^5
B 9.6×10^5
C 11.6×10^5
D 19.2×10^5
E 2.3×10^6

J77/II/14

20 Monochromatic light of wavelength 600 nm is used in a spectrometer to illuminate a diffraction grating set normally to the collimator. The grating has 3×10^5 lines per metre. The telescope is used to scan the field to one side of the straight-through position. Not counting the 'straight-through' image, the maximum number of diffracted images of the slit visible to the observer will be

A 2 B 5 C 8 D 10 E 11

J79/II/15

21 Monochromatic light of wavelength λ is incident normally on a diffraction grating consisting of alternate opaque strips of width a and transparent strips of width b. The angle between the emerging zero-order and first-order spectra depends on

A a, b and λ.
B a and λ only.
C b and λ only.
D a and b only.
E λ only.

J85/I/11

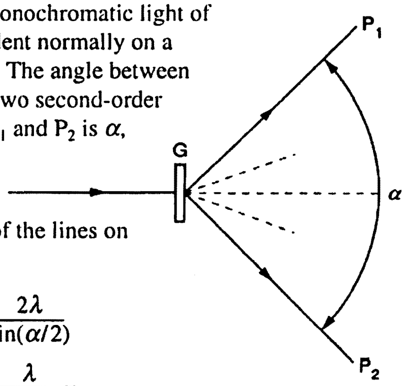
22 Which one of the following characteristics of electromagnetic waves is needed to explain the spectrum produced when white light falls on a diffraction grating?

Electromagnetic waves can

A interfere.
B be linearly polarised.
C change speed in passing from one material into another.
D be reflected with little, if any, loss in intensity.
E be shown to exchange energy with matter in quantised amounts.

N85/I/9

23 A parallel beam of monochromatic light of wavelength λ is incident normally on a diffraction grating G. The angle between the directions of the two second-order diffracted beams at P_1 and P_2 is α, as shown.



What is the spacing of the lines on the grating?

A $\dfrac{2\lambda}{\sin\alpha}$
B $\dfrac{\lambda}{\sin\alpha}$
C $\dfrac{2\lambda}{\sin(\alpha/2)}$
D $\dfrac{\lambda}{\sin(\alpha/2)}$

J86/I/II; N99/I/11

24 A beam of monochromatic light of wavelength λ falls normally on a diffraction grating of line spacing d. The angle between the second order diffracted beam and the direction of the incident light is θ.

What is the value of $\sin\theta$?

A $\dfrac{\lambda}{d}$
B $\dfrac{2\lambda}{d}$
C $\dfrac{2d}{\lambda}$
D $\dfrac{d}{2\lambda}$

N87/I/11; N98/I/11

25 In a spectrometer experiment, monochromatic light is incident normally on a diffraction grating having 4.5×10^5 lines per metre. The second order line is seen at an angle of 30° to the normal. What is the wavelength of the light?

A 200 nm
B 430 nm
C 500 nm
D 556 nm
E 589 nm

J88/I/12

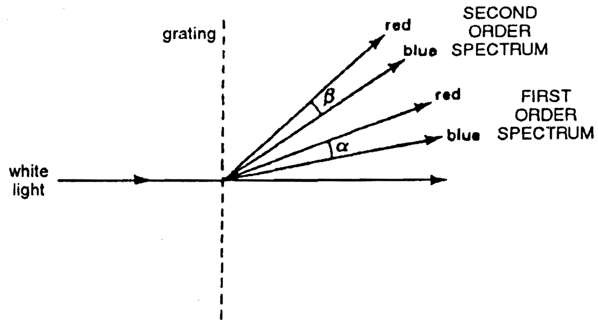
26 Light of wavelength λ is incident normally on a diffraction grating for which the slit spacing is equal to 3λ.

What is the sine of the angle between the second order maximum and the normal?

A $1/6$
B $1/3$
C $2/3$
D 1
E $3/2$

N88/I/9

27 White light covers the range of wavelengths from 400 nm to 700 nm. A diffraction grating with 6×10^5 lines per metre is placed at right angles to a ray of white light and produces the first and second order spectra shown in the diagram, which is not drawn to scale.



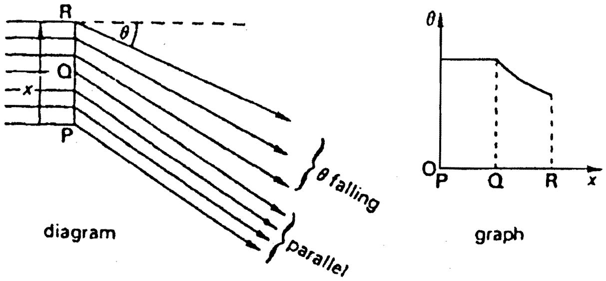
The angle between the red and blue ends of the spectrum is α for the first order spectrum and β for the second order spectrum. How do α and β compare?

A $\alpha < \tfrac{1}{2}\beta$
B $\alpha = \tfrac{1}{2}\beta$
C $\alpha = \beta$
D $\alpha = 2\beta$
E $\alpha > 2\beta$

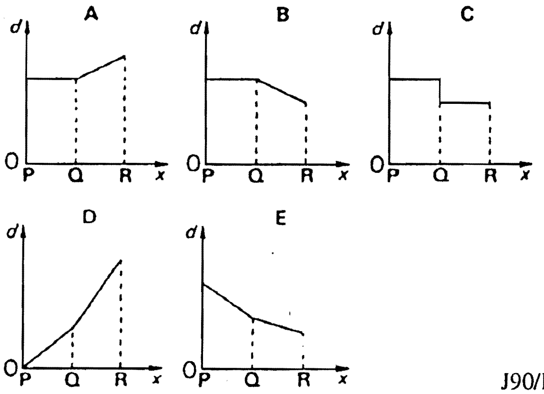
N89/I/6

28 The grating spacing d of a diffraction grating is the distance between successive slits and should be uniform across the grating.

The diagram shows the formation of the first order spectrum when parallel rays of monochromatic light fall perpendicularly on a substandard diffraction grating **PQR**. For the part of the grating between **P** and **Q**, the angle of deviation θ is constant and the diffracted rays emerge parallel. However, from **Q** to **R**, θ falls progressively as shown in the graph.



Which graph best shows how the grating interval d varies with x, the distance from **P**?



J90/I/14

29 In a diffraction grating experiment, the first order image of the 435.8 nm blue light from a commercial mercury vapour discharge lamp occurred at an angle of 15.8°. A first order red line was also observed at 23.7°, thought to be produced by an impurity in the mercury.

The wavelengths of red lines of various elements are listed below. Which element is the impurity in the mercury lamp?

	element	*wavelength /nm*
A	zinc	636.0
B	cadmium	643.3
C	hydrogen	656.3
D	neon	670.8
E	caesium	697.8

J91/I/11

30 A parallel beam of white light is incident normally on a diffraction grating. It is noted that the second-order and third-order spectra partially overlap.

Which wavelength in the third-order spectrum appears at the same angle as the wavelength of 600 nm in the second-order spectrum?

A 300 nm **C** 600 nm
B 400 nm **D** 900 nm

N91/I/12; N97/I/11

31 A diffraction grating is ruled with 600 lines per millimetre. When monochromatic light falls normally on the grating, the first-order diffracted beams are observed on the far side of the grating each making an angle of 15° with the normal to the grating.

What is the frequency of the light?

A 1.2×10^{13} Hz
B 4.7×10^{13} Hz
C 1.9×10^{14} Hz
D 3.6×10^{14} Hz
E 7.0×10^{14} Hz

J92/I/11

32 When monochromatic light of wavelength 5.0×10^{-7}m is incident normally on a plane diffraction grating, the second-order diffraction lines are formed at angles of 30° to the normal to the grating.

What is the number of lines per millimetre of the grating?

A 250 **D** 2000
B 500 **E** 4000
C 1000

N93/I/9

33 A narrow beam of monochromatic light falls at normal incidence on a diffraction grating. Third-order diffracted beams are formed at angles of 45° to the original direction.

What is the highest order of diffracted beam produced by this grating?

A 3rd **C** 5th
B 4th **D** 6th

J94/I/11

34 Two monochromatic radiations X and Y are incident normally on a diffraction grating. The second order intensity maximum for X coincides with the third order intensity maximum for Y.

What is the ratio $\dfrac{\text{wavelength of X}}{\text{wavelength of Y}}$?

A $\frac{1}{2}$ **B** $\frac{2}{3}$ **C** $\frac{3}{2}$ **D** $\frac{2}{1}$

J99/I/13

35 A diffraction grating has a spacing of 1.6×10^{-6} m. A beam of light is incident normally on the grating. The first order maximum makes an angle of 20° with the undeviated beam.

What is the wavelength of the incident light?

A 210 nm **C** 420 nm
B 270 nm **D** 550 nm

J2000/I/11

36 Light from a white source passes through a filter that transmits only the band of wavelengths from 400 nm to 600 nm. When this filtered light is incident normally on a certain diffraction grating, the 400 nm light in one order of the spectrum is diffracted at the same angle, 30°, as the 600 nm light in the adjacent order. Find the spacing between the lines in the grating.

N77/I/5

37 Light from a mercury lamp is incident normally on a plane diffraction grating ruled with 6000 lines per cm. The spectrum contains two strong yellow lines of wavelengths 577 nm and 579 nm. What is the angular separation of the second-order diffracted beams corresponding to these two wavelengths?
J80/I/4

38 In the spectrum of white light obtained by using a certain diffraction grating, the second and third orders partially overlap. What wavelength in the third-order spectrum will appear at the angle corresponding to a wavelength of 650 nm in the second-order spectrum? J82/I/4

39 Red light is incident normally on a plane diffraction grating having 5×10^5 lines per metre. Estimate the angular deviation of the first order spectrum [3]
N87/III/3

40 *(b)* Parallel monochromatic light is incident normally on a diffraction grating having 3.0×10^5 lines per metre. A metre rule is positioned 2.00 m from the grating and parallel to its plane as shown in Fig. 9.

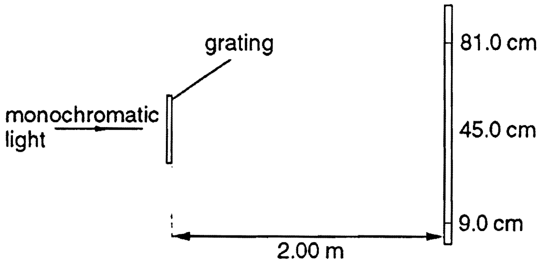


Fig. 9 (not to scale)

The axis of the rule is normal to the lines of the grating. Bright lines are observed on the rule at the 9.0 cm, 45.0 cm and 81.0 cm marks. Calculate the wavelength of the light. [4]
N92/II/2 (part)

41 Light from a distant source of monochromatic light of wavelength 590 nm passes through a fine nylon mesh. The light is then incident on a screen, as illustrated in Fig. 10.

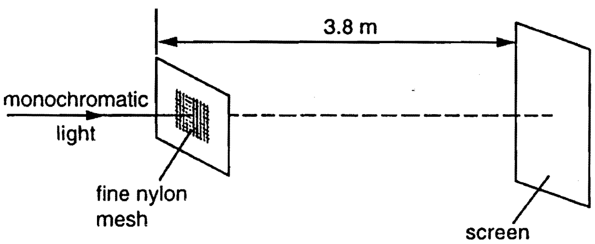


Fig. 10

The threads of the nylon mesh act as a diffraction grating with lines in the horizontal and in the vertical direction. Part of the pattern of spots of light on the screen is shown in Fig. 11.

(a) Explain what is meant by the *diffraction* of light. [2]

(b) State which line of spots of light, AB or CD, is produced by the *horizontal* nylon threads. [1]

(c) Calculate the angle, in radians, between the orders of the diffracted light. [2]

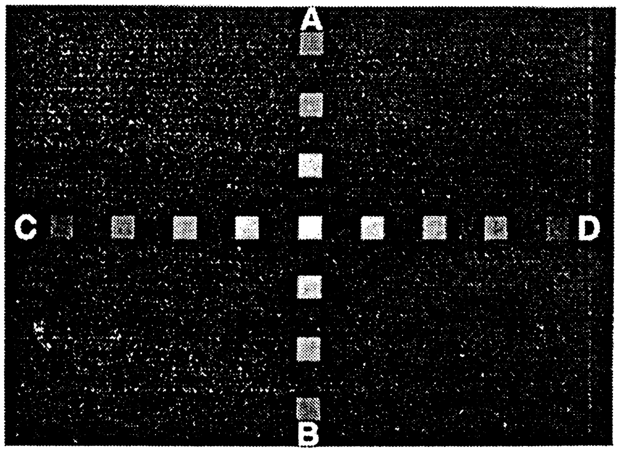


Fig. 11 (full size)

(d) Using your answer to *(c)*, determine the number of nylon threads per millimetre of the mesh.

number per millimetre = ... [4]

N2000/II/4

Long Questions

42 Discuss how interference and diffraction contribute to the action of a diffraction grating.

Draw a wave diagram to show how a grating produces a second order beam from plane monochromatic light.

Parallel light is incident normally on a grating having m lines per unit length. The spectrum consists of two close lines of wavelength λ and $\lambda + d\lambda$. If θ is the mean angle of deviation, show that $\delta\theta$, the angular separation between the two emergent beams, is given by

$$\delta\theta = \frac{\delta\lambda \,.\, \tan\theta}{\lambda}$$

Calculate $\delta\theta$ from the data below.

Wavelength: $\lambda = 589.0 \times 10^{-9}$ m,
$\lambda + \delta\lambda = 589.6 \times 10^{-9}$ m;

Lines per unit length, $m = 4.0 \times 10^5\ \text{m}^{-1}$;
Order of spectrum employed, $n = 2$ (second order).

If the light originally came through a collimating lens of focal length 0.5 m and a slit of width 0.5 mm, discuss whether the spectral lines could ever be distinguished in practice.
J78/III/2 (part)

43 Parallel light from a sodium vapour lamp is incident normally on a grating having p lines per unit length. Derive the grating equation

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

and explain the meanings of the symbols used.

The first order spectrum has two closely-spaced yellow lines which are observed at angles θ and $\theta + \delta\theta$. Show that

$$\delta\theta = (\delta\lambda / \lambda) \tan \theta.$$

Calculate θ and $\delta\theta$ given that

$$\lambda = 589 \times 10^{-9} \text{ m}$$
$$\delta\lambda = 0{\cdot}6 \times 10^{-9} \text{ m}$$
$$p = 5{\cdot}0 \times 10^{5} \text{ m}^{-1}.$$

Discuss whether the lines could be distinguished if the only factor limiting resolution were the 2 cm diameter objective lens of the telescope. N85/III/9 (part)

44 Give a quantitative account of the action of a simple diffraction grating which is illuminated normally by monochromatic light.

A grating 2.5 cm wide has 2.10×10^4 lines and is mounted on the table of a grating spectrometer. It is illuminated normally by a beam of light in which the wavelengths range continuously from 400 nm to 700 nm. Describe, with the aid of a labelled diagram and appropriate calculations, the appearance of the zero, first and second order spectra as seen through the telescope of the spectrometer.

What is likely to be the appearance of the first order spectrum if the collimator slit is illuminated by light from

(a) a tungsten filament lamp.

(b) a low pressure sodium vapour lamp?

Briefly describe what happen to your observations in *(b)* if every other aperture on the grating were to be blocked.

J87/III/9

45 *(a)* Distinguish clearly between *refraction* and *diffraction* of light. Draw diagrams, one in each case, to illustrate these phenomena. [5]

(b) A plane diffraction grating having p lines per unit length is illuminated normally by a source of monochromatic light of wavelength λ. Derive the grating equation

$$\sin \theta = np\lambda$$

and explain the significance of n and θ. [4]

(c) A diffraction grating is set up at the centre of a rotating table which completes one revolution every 3.0 s. The grating is illuminated normally by parallel monochromatic light from a source which is also mounted on the table (see Fig. 12).

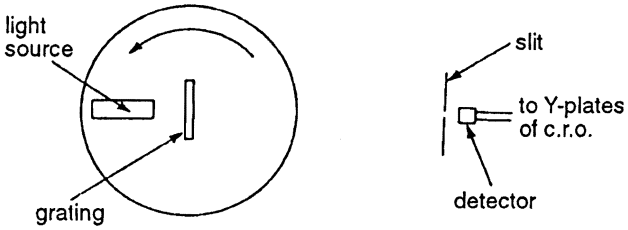


Fig. 12

The emergent beams of light from the grating are monitored by means of a stationary detector situated behind a single slit. The output from the detector is displayed on a cathode-ray oscilloscope (c.r.o.). With the timebase set at 0.10 s cm^{-1}, the trace shown in Fig. 13 is obtained, the relative positions of the peaks being as indicated.

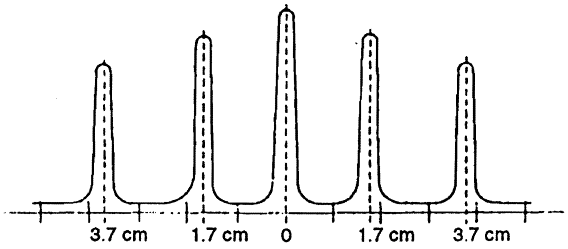


Fig. 13

(i) Give an explanation for the appearance of the trace and calculate a value for the wavelength of the light if $p = 5.5 \times 10^5 \text{ m}^{-1}$. [9]

(ii) Briefly discuss the effect on the trace of reducing the width of the single slit situated in front of the detector. [4] N88/III/8

46 *(c)* A beam of red light from a laser is shone normally on to a diffraction grating. Bright light is seen emerging at certain angles as shown in **Fig. 14**. Use the principle of superposition to suggest a qualitative explanation of this effect. [2]

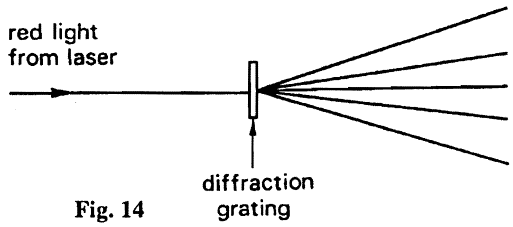


Fig. 14

(d) A diffraction grating with a grating spacing of 2.20×10^{-6} m is used to examine the light from a glowing gas. It is found that the first order violet light emerges at an angle of 11.8° and the first order red light at an angle of 15.8° as shown in **Fig. 15**.

(i) Calculate the wavelengths of these two colours. [3]

(ii) Describe and explain what will be observed at an angle of 54.8°. [3]

(iii) Without making any further calculations, draw a sketch similar to **Fig. 15** showing the whole pattern observed. [3]

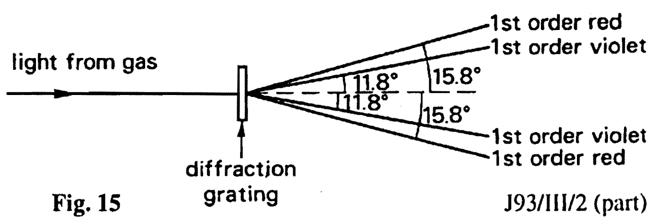


Fig. 15

J93/III/2 (part)

47 *(b)* Explain the meaning of the term *diffraction*. [2]

(c) Both diffraction and superposition of waves occur when a diffraction grating is used to produce a spectrum. The same principles are involved when a compact disc (CD) is viewed in white light and is seen to produce multicoloured streaks of light.

Explain how a diffraction grating produces a spectrum and suggest what this implies about the nature of the surface of the CD. [5]

(d) When a distant street light, which is behaving as a point source of light of wavelength 5.90×10^{-7} m, is viewed through a nylon net curtain, the pattern of light seen is as shown in Fig. 16.

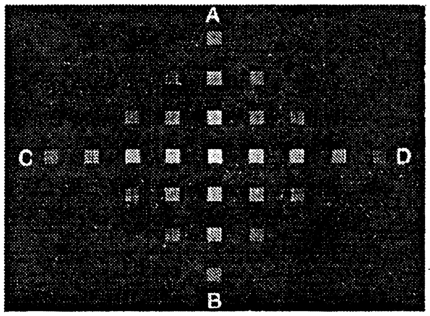


Fig. 16

The main feature of this pattern is the two lines (AB and CD) of bright images.

(i) Why do these bright images appear?

(ii) What is the spacing of the strands of nylon in the net curtain if the angle as viewed between the central image and the first adjacent image is 0.60°?

(iii) Why is the spacing of the images constant? [7]

(e) Patterns such as this can be used to determine the spacing of atoms in crystals. Suggest one problem that occurs in carrying out such an experiment with the wavelength used in *(d)*. Indicate how a different wavelength of radiation can overcome the problem. [2]

N94/III/2 (part)

48 *(c)* You are asked to find the wavelength of monochromatic red light emitted by a laser. The apparatus is illustrated in Fig. 17.

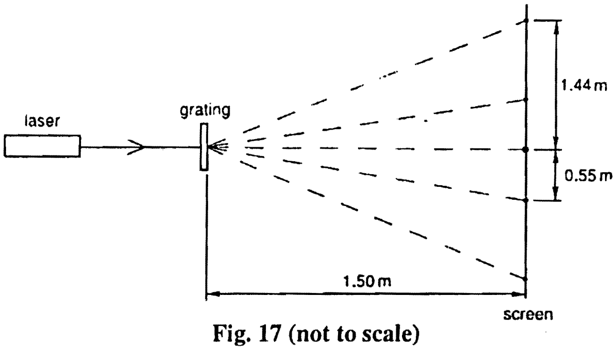


Fig. 17 (not to scale)

The diffraction grating has 5.5×10^5 lines per metre and is set so that its plane is normal to the incident light and is situated 1.50 m from a large screen. Bright spots are observed at 0.55 m and 1.44 m from the central bright spot.

(i) Calculate the wavelength of the laser light from observations of the first-order diffracted light.

(ii) Suggest one advantage and one disadvantage of obtaining the wavelength by using observations of the second-order diffracted light rather than the first-order diffracted light. [6]

N95/III/3 (part)

49 *(a)* Explain, using clearly labelled sketches where appropriate, the meaning of the following terms when applied to wave motion.

(i) displacement,

(ii) amplitude,

(iii) wavelength,

(iv) phase difference between two waves,

(v) coherence of two waves,

(vi) diffraction. [9]

(b) A diffraction grating with 250 lines per millimetre is placed in front of a monochromatic source of red light. A screen placed 200 cm beyond the grating has red light images measured at certain positions on a scale on the screen, as shown in Fig. 18.

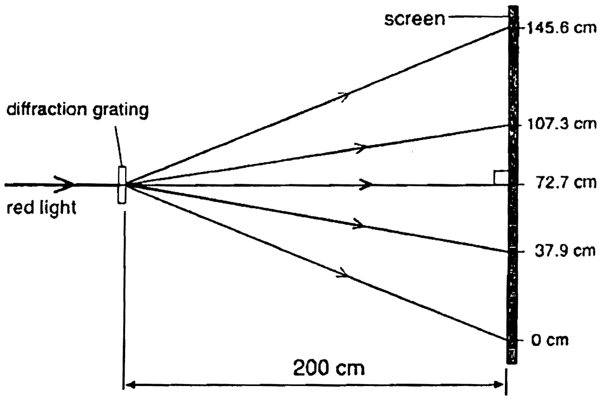


Fig. 18

(i) Use the first order spectrum to deduce a value for the wavelength of the red light.

(ii) Make a check, using the second order spectrum, to show that your calculation is correct. [6]

(c) How would the pattern obtained be different if blue light were used in place of red light? You are not expected to make any calculations when answering this part of the question. [3]

(d) What main problem would arise if the experiment were repeated with infra-red radiation?

Suggest how this problem could be overcome. [2]

J97/III/3

50 *(e)* Light from a low pressure sodium lamp consists mostly of two wavelengths, 588.99 nm and 589.59 nm. This light is allowed to fall normally on a diffraction grating with 500.00 lines per millimetre.

(i) Describe quantitatively the pattern which would be observed.

(ii) Calculate the maximum angular separation between the light of the two wavelengths.

(iii) What problem would be likely to arise in observing the spectral lines in the order in (ii)? [8]

N2000/III/3 (part)