QUESTION ONE: LIGHT FANTASTIC (8 marks)

Planck's constant = 6.63×10^{-34} J s
Speed of light = 3.00×10^{8} m s^{-1}

(a) When viewing white light from a glowing source through a spectroscope, a spectrum is seen. If a gas is now placed between the source and the spectroscope the spectrum shows dark absorption lines. Explain fully how these lines are formed.

(b) Discuss how diffraction and the photoelectric effect demonstrate the wave/particle nature of light.

QUESTION TWO: SPECTROSCOPE (8 marks)

The speed of light = 3.00×10^8 m s^{-1}

A spectroscope fitted with a diffraction grating is used to observe the spectrum of excited helium gas in a laboratory discharge tube. One first order bright line of wavelength 587.563 nm is observed at a deviation of 20.6426°.

(a) Calculate the number of lines per cm on the diffraction grating.

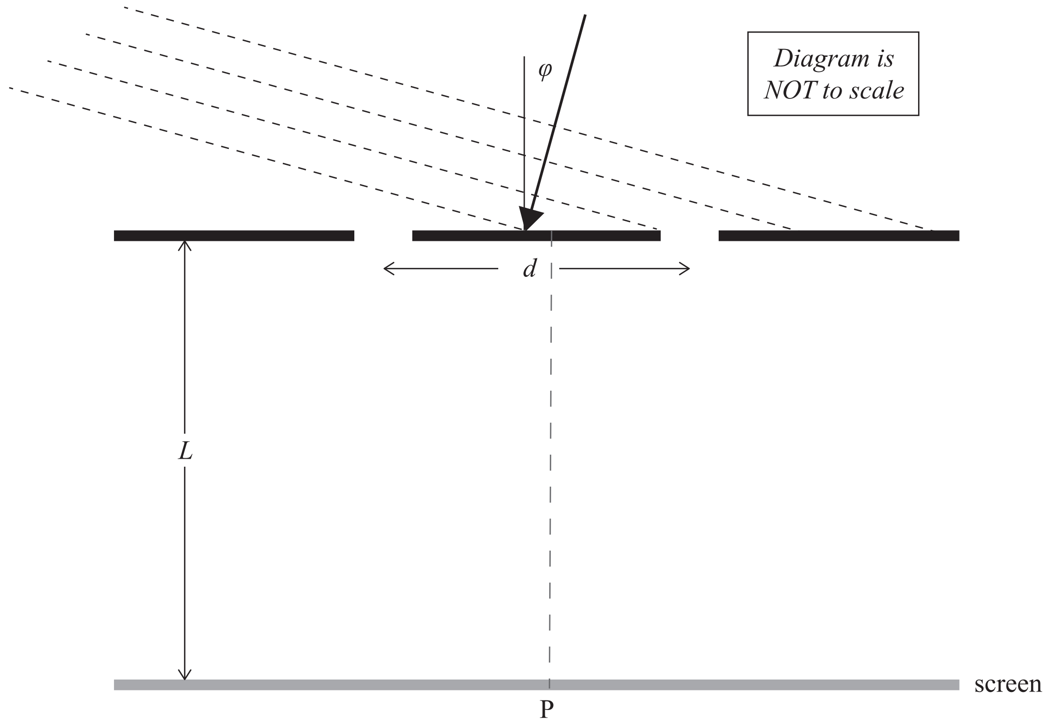
The spectroscope and grating are used to obtain the spectrum of a distant star, which shows a bright line blurred between 587.60 nm and 587.67 nm. This line is thought to be due to the same electron transition that produced the 587.563 nm line in the laboratory.

(b) Explain the difference between the laboratory and the stellar wavelengths.

QUESTION THREE: INTERFERENCE

(a) State the conditions for stationary interference fringes to be produced by two sources of light a distance *d* apart.

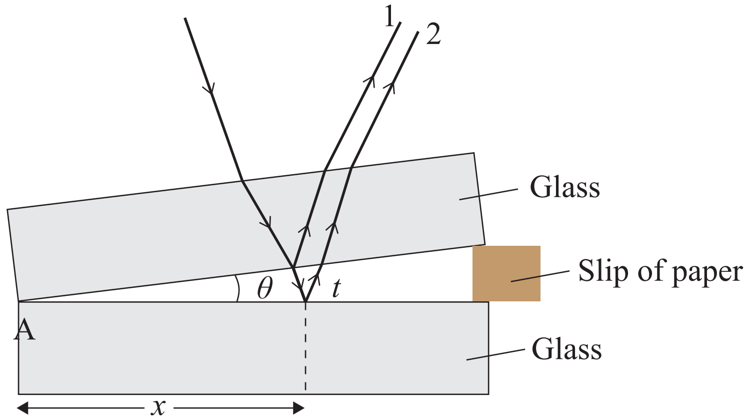
(b) Two narrow slits separated by a distance, *d*, are illuminated by light at an incident angle φ, as shown below. Light from the two slits produces an interference pattern on a screen a distance, *L*, away. Assume that *L* is much greater than *d*.



If $d = 1.00 \times 10^{-4}$ m, and the wavelength is 633 nm, calculate the smallest angle φ that will give an intensity of zero at the point P on the screen as shown in the diagram.

Another way to produce an interference pattern is to illuminate a small wedge-shaped air gap as shown in the diagram below. When viewed from above, alternate bright and dark fringes are observed. The horizontal distance to the *n*th dark fringe is x, and at this point the thickness of the air gap is equal to t.

Note that when light travelling in air reflects off glass, it undergoes a 180 degree phase change.



(c) From directly above the position marked A on the diagram, a dark fringe is observed.

Explain why this occurs.

(d) Light of wavelength 550 nm is incident normally on an air gap of angle 3.5×10^{-4} rad.

Calculate the number of dark fringes observed per metre.

(e) If the angle of the wedge-shaped air gap, θ, becomes too large, no fringes are observed.

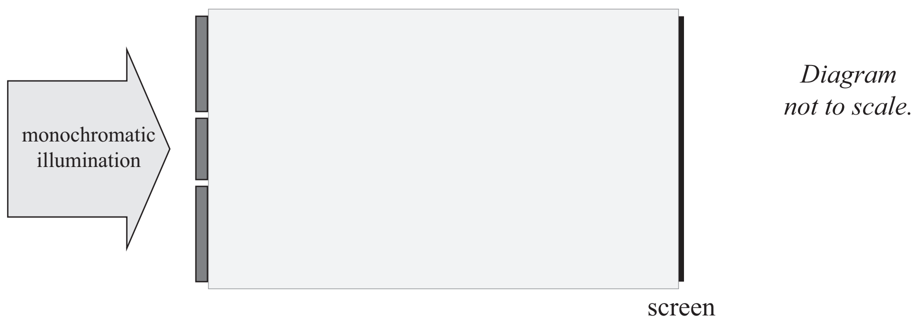
Explain.

(8)

QUESTION FOUR: INTERFERENCE

A pair of narrow parallel slits is illuminated by monochromatic light of wavelength 500 nm to produce Young's fringes on a screen.

(a) Explain the differences and similarities between the interference patterns produced by monochromatic illumination on a double slit and on a diffraction grating of the same slit separation.



The space between the slits and the screen is then completely filled with a block of transparent material for which the refractive index, n, is 1.6. Assume the refractive index is constant for all wavelengths.

$$\text{refractive index, } n = \frac{\text{velocity of light in vacuum}}{\text{velocity of light in the material}} = \frac{c}{v_{\text{material}}}$$

(b) Describe and explain the changes that will take place in the pattern of the Young's fringes.

The block of material is removed and a very thin slice of the transparent material from the block is used to cover the top slit, as shown in the diagram below. When this is done, the central maximum bright fringe (zeroth order) is observed to move up the screen.

(c) Explain why the pattern shifts up the screen.

(d) The slice of material has thickness, t, and the central maximum shifts up the screen to take the position originally held by the fifth order bright fringe produced when no material was between the slits and the screen.

Show that the thickness of the slice is less than or equal to 4.17×10^{-6} m.

(e) The monochromatic illumination is replaced by sunlight.

Explain how this will assist the experimenter to determine the position of the new central maximum bright fringe.

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(8)

QUESTION FIVE: DIFFRACTION (8 marks)

(a) When light is incident on a pair of slits (Young's slits), the light can undergo diffraction. The diffracted waves might then interfere with each other.

Explain what conditions are needed for diffraction and interference to take place.

(b) The formulae $n\lambda = \frac{dx}{L}$ and $n\lambda = d\sin\theta$ can both be used in interference calculations.

What are the limitations on the use of these formulae?

(c) Light of wavelength of 632 nm is incident on a double slit diffraction grating. The distance between the slits is 2.00×10^{-5} m. The diffraction pattern is observed on a screen at a distance of 1.20 m from the diffraction grating.

Calculate how far the second order dark fringe is from the central maximum.

(d) When a particular line spectrum is examined using a diffraction grating of 300 lines per mm with the light coming in along the normal, it is found that a line at 24.46º contains both red (640 to 750 nm) and blue / violet (360 to 490 nm) components.

Are there any other angles at which both red and blue / violet components are observed?

(8)

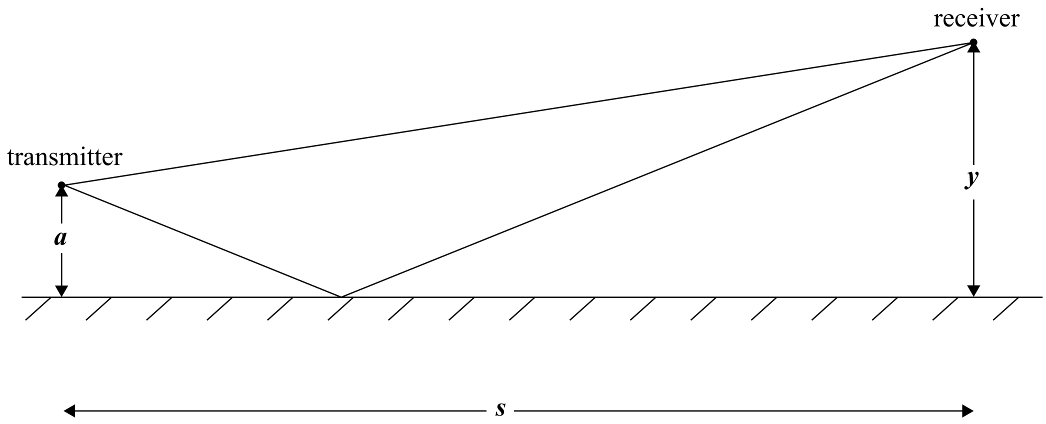
QUESTION SIX: INTERFERENCE (8 marks)

Kate and Tim are using a small ultrasound transmitter to investigate reflection from various surfaces. When the ultrasound beam is at a grazing incidence to the bench, they measure points of lower and higher intensity as the detector is moved vertically upwards. The transmitter is 5.00 cm above the bench. The transmitted ultrasound has a wavelength of 8.50 mm and the horizontal distance between the transmitter and detector is 1.00 m.

In analysing their experiment Kate and Tim assume the following:

- That two beams can be drawn – one directly from the transmitter and one originating from the transmitter but reflected from the bench top.
- That the beam reflected from the bench top experiences no change in phase as it is reflected from the bench top.

A diagram showing the setup Kate and Tim used is shown below.



(a) Explain why fluctuations in sound intensity occur as the detector is moved upwards from the bench surface.

(b) Explain why you would expect a local maximum to be observed at the surface of the bench top.

(c) Derive a relationship between the variables ***y***, ***s*** and ***a***, for points of constructive interference. (Hint: Construct a model similar to that of Young's two-slit experiment.)

(d) If the ultrasound transmitter is replaced by a suitable light source, the interference pattern changes with a minimum being observed when a detector is very close to the table surface.

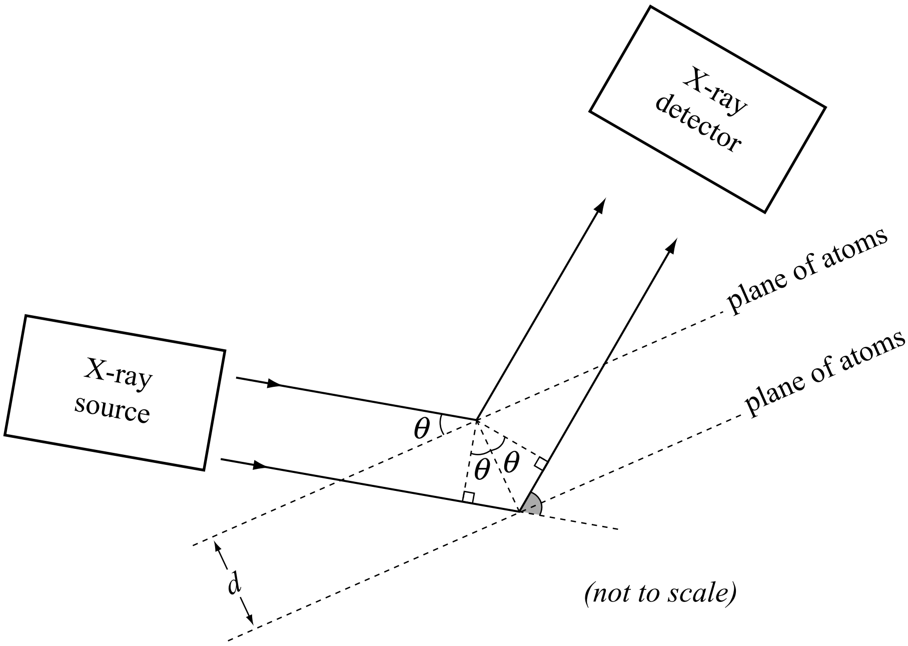
Suggest a reason for this.

(8)

QUESTION SEVEN: BRAGG'S LAW

(i) State the necessary conditions for interference fringes to be produced by two sources of light at a distance *d* apart.

The regularly spaced atoms in a crystalline solid can be used to produce interference effects. The diagram shows how incident X-rays are reflected such that there is a path difference between the reflections from adjacent planes of atoms. The distance between each plane is *d*.



(ii) Using your knowledge of the necessary conditions for constructive interference of the rays, derive Bragg's Law:

$$m\lambda = 2d\sin\theta \qquad m = 1, 2, 3, \ldots$$

(iii) In one particular crystalline solid, a third order X-ray diffraction maximum is observed when the shaded angle equals 29.2°. The wavelength of the X-rays is 1.27×10^{-10} m.

Calculate the interplanar distance d.

interplanar distance = ____________

(iv) Given the value of d calculated above, comment on why X-rays rather than visible light are used for diffraction experiments with crystals.