SF Physical Optics

Q1 Introduction

(i)What is the intensity associated with a light wave (in vacuum) with $B=3\times10^{-6}$ T?

(ii) What is the mean energy density associated with a light wave of intensity $I=1075\ W/m^2$?

(iii)A 1D light source emits light as a cylindrical wavefront. The magnitude of the electrical field at a distance 1m from the source is 100 V/m. What is the magnitude of the field 5 cm from the source?

Q2 Interaction of light and matter

The imaginary part of the refractive index is given by $\varepsilon_2(\omega) = \frac{Ne^2}{\varepsilon_0 m}\left[\frac{\gamma\omega}{\left(\omega_0^2-\omega^2\right)^2+\left(\gamma\omega\right)^2}\right]$

(i) What do all the quantities in this expression mean?

(ii) We can get the refractive indices from the permittivity using

$$\begin{aligned}\varepsilon_1 &= n_1^2 - n_2^2 \\ \varepsilon_2 &= 2n_1 n_2\end{aligned}.$$

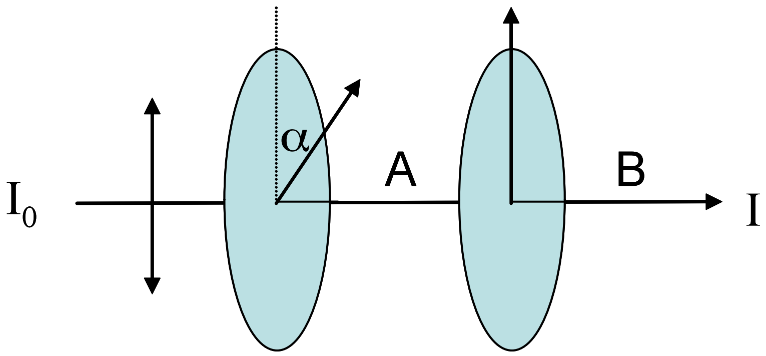
Use this to find the maximum value of n_2 for a gas of sodium atoms with an atom density of $10^{17}\ m^{-3}$.

(n_2 is maximised where light is absorbed, the main sodium absorption for sodium is at $\lambda=590$ nm ($\omega=3.2\times10^{15}$ rad/s) and has $\gamma\approx6\times10^{8}$ rad/s).

(Hinty: What value do you expect n_1 to have in a gas)

Q3 Polarisation and scattering

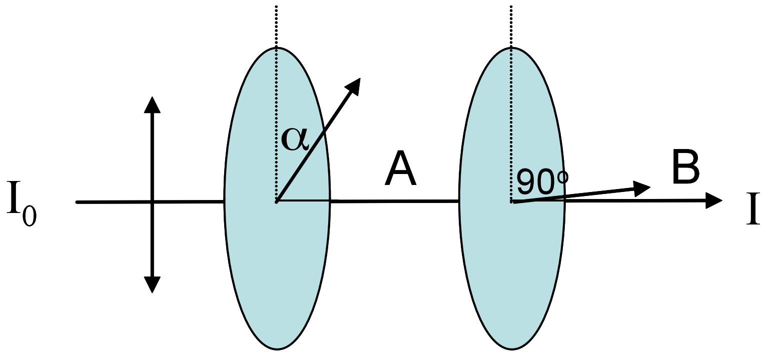
(i) Linearly (vertically) polarised light passes through a set of 2 polarisers as shown below. In each case the transmission axis is as shown by the arrow.



What value of α is required such that $I/I_0=0.1$?

This arrangement effectively reduces intensity without changing polarisation direction.

However if, for example, you want to rotate the polarisation by 90° using 2 polarisers, you need an arrangement like:



(ii) For an arrangement like this, the intensity gets reduced during the rotation process. What angle α minimises this reduction process. For this angle, what is I/I_0?

Q4 Interference

(i) Imagine a pair of Young's slits separated by 4 mm. A screen is a certain distance, L, away. A light shines through the slits casting an interference pattern on the screen. Using a ruler, you can measure the separation between adjacent bright fringes, Δy. If L is increased by 4m, measurements show that Δy increases by 0.5 mm. What is the wavelength of the light used?

(ii) In a normal Young's slits setup, the zeroth order fringe of the pattern is at the centre of the screen: y=0.

Imagine a thin slice of transparent material with refractive index n and thickness l is placed in front of one of the slits. Now what is the order of the fringe nearest the centre of the screen?

Assume, $l=5\mu m$, n=1.5, $\lambda=500nm$

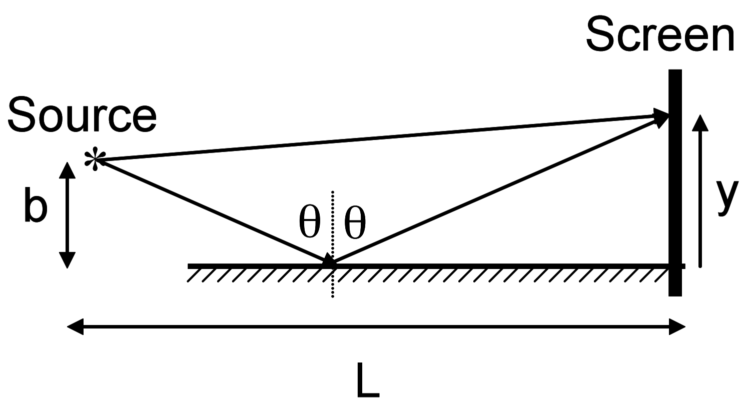
(Hint: work out the phase difference at the screen, δ, between rays coming from each slit. Make the approximation that the distance travelled by the light through the slice is always l. Note that the maxima occur for $\delta = 2m\pi$)

Q5 Interference

Imagine a Lloyds mirror arrangement consisting of a source, a mirror and a screen. A coherent, monochromatic light source, emitting spherical wavefronts (*) is positioned a distance b above the mirror and L from the screen.

Such an arrangement results in an interference pattern on the screen.

The intensity in the pattern is given by $I = 4I_0 Cos^2 \frac{\delta}{2}$, where I is the measured intensity on the screen, I_0 is the emitted intensity and δ is the phase difference between direct and reflected rays.



What is the ratio of measured intensity, I, to emitted intensity, I_0, at a point y=1mm above the mirror?
Take b/L=0.001 and λ=500nm.

Q6 Diffraction

Consider light of wavelength λ passing through a narrow slit (width b) and falling on a screen a distance L away. A diffraction pattern is formed such that the intensity at a position y (measured from the centre of the screen) is given by

$$I(\theta) = I_0 Sinc^2\left(\frac{\pi b y}{\lambda L}\right)$$

(i) What is the distance from the 3rd dark fringe on the left to the 4th dark fringe on the right of the pattern?
Take L/b=1000 and λ=500nm

(ii) A laser is shone through a narrow slit onto a screen forming a diffraction pattern. However the screen is dirty so only some of the pattern is clearly visible to the eye. Diffraction minima are observed at positions y= 1.266, 2.532, 5.064 and 6.963 mm. What is the wavelength of the laser?
Take L/b=1000.