

1) (15 points)

Unpolarized light is moving left to right along the z axis with an intensity I. The light hits a polarizer with its axis pointed in the horizontal direction.

- After passing through the polarizer, in which directions to the E and B vectors of the light point?
- What is the intensity of the light after the polarizer?

The light then goes through a polarizer in the XY plane with its axis 45 degrees from the first one.

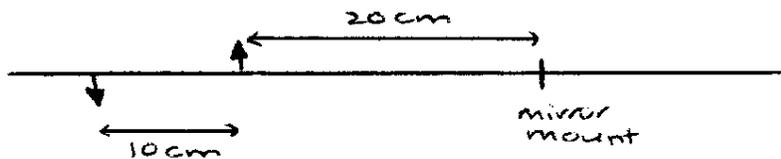
- What is the intensity of the light after passing through the 2<sup>nd</sup> polarizer?

- A horizontal polarizer has its polymers aligned horizontally. This results in the electric field components in the horizontal direction to be absorbed by the polarizer. The electric field vectors that are perpendicular to the polarizer's polymers are transmitted through the polarizer, i.e. the transmitted electric field vectors are in the vertical direction. The magnetic field must be perpendicular to the electric field in an electromagnetic wave as given by the Poynting vector,  $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$ . As only the electric field vectors in the vertical direction are transmitted, then only the magnetic field vectors in the horizontal direction are transmitted.
- The polarizer has absorbed all the horizontal components of the electric field from the originally unpolarized light, leaving only the vertical components of the electric field. The intensity is therefore half the intensity of the unpolarized light, i.e.  $I_{\text{trans}} = \frac{I}{2}$ .
- The angled polarizer has both horizontal and vertical components which transmit half of the vertically polarized electric field. The intensity is therefore half of the intensity of the polarized light, i.e.  $I_{\text{trans}} = \frac{I}{4}$ .

## 2) (15 points)

You have an object of height 2cm placed 20 cm to the left of a mirror mount. You want to create a real, inverted image 10cm to the left of the object. That image needs to be 3cm high.

- What shape (concave or convex) mirror can you place in the mount to do this? If neither shape will work, say why you think that.
- Find the focal length of the mirror in centimeters.
- Draw three principal rays on the diagram to demonstrate that the image is really where desired.



a) In order to create a real image from a real object, a concave mirror is used that will have a positive focal length. A convex mirror will not form a real image from a real object.

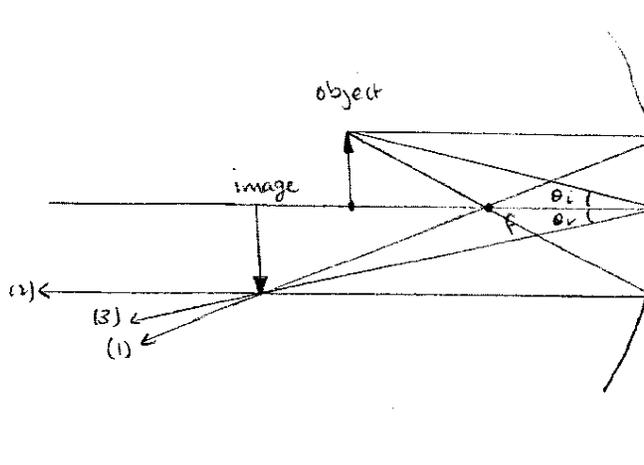
b) Object distance,  $d_o = 20 \text{ cm}$  ; positive as real object  
Image distance,  $d_i = 20 + 10 = 30 \text{ cm}$  ; positive as real image

The focal length can be found using

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{20} + \frac{1}{30} = \frac{5}{60} \Rightarrow \text{focal length, } f = 12 \text{ cm}$$

A positive focal length confirms we have a concave mirror.

c)



(1) travels parallel from object, reflects off the mirror, and passes through the focal point.

(2) passes through the focal point, reflects off mirror, and travels parallel.

(3) Angle of incidence,  $\theta_i$  equals angle of reflection,  $\theta_r$ .

3) (10 points)

Your eye has a near point of 40 cm. You put a magnifying glass (convex lens) with a focal length of 10 cm very close in front of your eye.

- a) How close can you bring an object and still keep it in focus when looking through the magnifying glass?
- b) How much larger does the object appear compared to if you'd kept it at your 40 cm near point? Explain.

a) The magnifying glass creates a virtual image at the near point, which has an image distance of  $d_i = -40$  cm (note: negative image distance as image is virtual). To produce an enlarged image at this distance, the object must be closer to the magnifying glass than its focal point. The object distance can be found using:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \Rightarrow \frac{1}{d_o} = \frac{1}{f} - \frac{1}{d_i} = \frac{1}{10} - \frac{1}{-40} = \frac{5}{40}$$

Therefore the object distance,  $d_o = 8$  cm; positive as real object

b) Two interpretations of this part was possible.

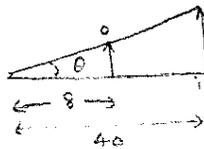
Interpretation 1)

Case 1: magnifying glass used with object at 8 cm.

Case 2: no magnifying glass with object at 40 cm.

Case 1:-

$d_o = 8$  cm



As image is not at infinity, use  $d_o$  instead of focal length.

$$M_1 = \frac{\theta'}{\theta} = \frac{NP}{d_o} = \frac{40}{8} = 5$$

Case 2:- no magnification, i.e.  $M_2 = 1$

Therefore total  $M = M_1 M_2 = 5 \times 1 = 5$

Object appears five times larger.

OR using lateral magnification,

$$m_1 = -\frac{d_i}{d_o} = -\frac{-40}{8} = 5; m_2 = 1 \text{ as no magnification}$$

Therefore total  $m = m_1 m_2 = 5 \times 1 = 5$

(Note: incomplete without answer explanation)

Interpretation 2)

Case 1: magnifying glass used with object at 8 cm.

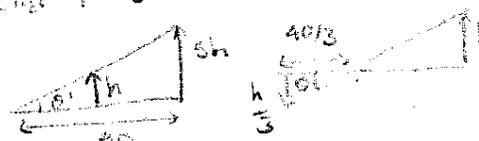
Case 2: magnifying glass used with object at 40 cm.

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{10} - \frac{1}{40} \Rightarrow d_i = 13.3 \text{ cm}$$

Compare the angles

Case 1:  $\theta'$

Case 2:  $\theta$



$$\text{Total } M = \frac{\theta'}{\theta} = \frac{5h \times 40}{\frac{h}{3} \times 40} = 5$$

Object appears five times larger

OR using lateral magnification,

$$m_1 = \frac{h'}{h} = \frac{5h}{h} = 5 \quad \text{total } m = \frac{5}{1/3} = 15$$

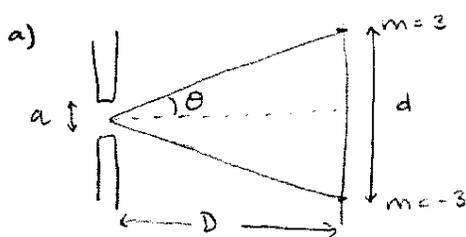
$$m_2 = \frac{h'}{h} = \frac{h/3}{h} = 1/3 \quad \Rightarrow \text{appears 15 times larger}$$

(Note: incomplete without answer explanation) **4**

## 4) (10 points)

Laser light of wavelength  $\lambda$  shines on a single slit that has been placed a distance  $D$  from a screen. The distance between the third intensity minima is  $d$ .

- a) What is the width of the slit? Express your answer in terms of  $\lambda$ ,  $D$ , and  $d$ . Explain how you obtained your answer. Note: the small angle approximation may be used.
- b) If the entire apparatus were submerged in water, would the width of the central peak change? Explain.



$$\tan \theta = \frac{d/2}{D} = \frac{d}{2D}$$

Small angle approximation can be used

$$\Rightarrow \tan \theta \approx \theta \approx \sin \theta$$

$$\Rightarrow \theta = \frac{d}{2D}$$

The width of the slit is related to the wavelength of the light, the order of minima, and the angle to the minima, and is given by:

$$\text{width, } a = \frac{m\lambda}{\sin \theta}$$

$$\text{as } \sin \theta \approx \theta, \Rightarrow a = \frac{m\lambda}{\theta}$$

$$m=3 \text{ and } \theta = \frac{d}{2D}, \Rightarrow a = \frac{3\lambda}{d/2D} = \frac{6\lambda D}{d}$$

- b) The wavelength of the original light will change

$$\lambda_{\text{water}} = \frac{\lambda_{\text{air}}}{n} = \frac{633 \times 10^{-9}}{1.33} = 476 \text{ nm}$$

As the wavelength of the light has decreased in the water, the width of the central peak will also decrease.