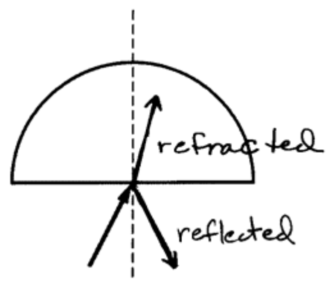
Question 4

15 points total **Distribution of points**

(a)



(i) 2 points

For drawing a reflected ray at approximately the same angle to the normal as the incident ray — 1 point
For clearly indicating that this is the reflected ray — 1 point

(ii) 4 points

Snell's law is used to find the angle of refraction
$n_1 \sin\theta_1 = n_2 \sin\theta_2$
For correctly substituting values into Snell's law — 1 point
$1.0\sin 27° = 1.51\sin\theta_2$
$\sin\theta_2 = \sin 27°/1.51 = 0.30$
For the correct value of the angle — 1 point
$\theta_2 = 17.5°$
For drawing a ray at approximately the correct angle — 1 point
For clearly indicating that this is the refracted ray — 1 point

(iii) 1 point

The speed in the block can be determined using the definition of index of refraction.
$\upsilon = c/n = \left(3.00 \times 10^8 \text{ m/s}\right)/1.51$
For the correct answer — 1 point
$\upsilon = 1.99 \times 10^8 \text{ m/s}$

Question 4 (continued)

Distribution of points

(a) (continued)

(iv) 2 points

For a statement that the frequency is the same in the two materials, or an equation that is an application of that fact — 1 point

$$f = \frac{v_{air}}{\lambda_{air}} = \frac{v_{plastic}}{\lambda_{plastic}}$$
$$\lambda_{plastic} = \frac{v_{plastic}\lambda_{air}}{v_{air}} \quad \text{OR} \quad \lambda_{plastic} = \frac{\lambda_{air}}{n}$$

$$\lambda_{plastic} = \frac{1.99 \times 10^8 \text{ m/s}}{3 \times 10^8 \text{ m/s}}(650 \text{ nm}) \quad \text{OR} \quad \lambda_{plastic} = \frac{650 \text{ nm}}{1.51}$$

For the correct answer with units — 1 point

$\lambda_{plastic} = 431$ nm OR 430 nm

(b) 2 points

The following points were only awarded if rays were shown or described in part (a)

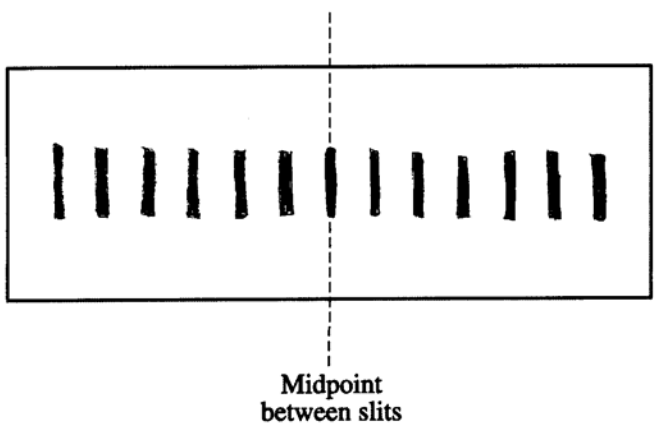
For indicating that the angle of reflection does not change — 1 point

For indicating that the angle of refraction becomes smaller — 1 point

(c)

(i) 2 points

Example in which the dark lines in the drawn pattern represent the bright bands of blue light



For indicating a central peak in the pattern — 1 point

For having approximately even spacing between maxima — 1 point

A sketch of the intensity graph was also acceptable

Question 4 (continued)

Distribution of points

(c) (continued)

(ii) 2 points

For using an appropriate formula (or combination of formulas) and correctly substituting — 1 point

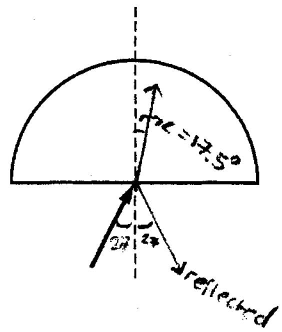
For example

$$x_m \approx \frac{m\lambda L}{d}$$

$$x_m \approx \frac{(1)\left(450 \times 10^{-9}\ \text{m}\right)(1.4\ \text{m})}{0.15 \times 10^{-3}\ \text{m}}$$

For the correct answer — 1 point

$x = 4.2\ \text{mm}$



4. (15 points)

A ray of red light in air ($\lambda = 650$ nm) is incident on a semicircular block of clear plastic ($n = 1.51$ for this light), as shown above. The ray strikes the block at its center of curvature at an angle of incidence of 27°.

(a) Part of the incident ray is reflected and part is refracted at the first interface.

i. Determine the angle of reflection at the first interface. Draw and label the reflected ray on the diagram above.

$\angle$ incidence $=$ $\angle$ reflection $= 27°$

ii. Determine the angle of refraction at the first interface. Draw and label the refracted ray on the diagram above.

$$n = \frac{\sin \angle_{air}}{\sin \angle_{med}} \Rightarrow \sin \angle_{med} = \frac{\sin 27}{n} = \frac{\sin 27}{1.51}$$

$$\Rightarrow \sin \angle_{med} = 0.3 \Rightarrow \angle_{med} = \underline{17.5}°$$

iii. Determine the speed of the light in the plastic block.

$$n = \frac{C_{air}}{C_{med}} \Rightarrow C_{med} = \frac{3.0\times10^8}{1.51} = \underline{1.99\times10^8}\ m/s$$

iv. Determine the wavelength of the light in the plastic block.

$$v = \lambda f \Rightarrow f = \frac{3.0\times10^8}{650\times10^{-9}} = 4.62\times10^{14}\ Hz$$

$$\lambda = \frac{v}{f} = \frac{1.99\times10^8}{4.62\times10^{14}} = \underline{431\ nm}$$

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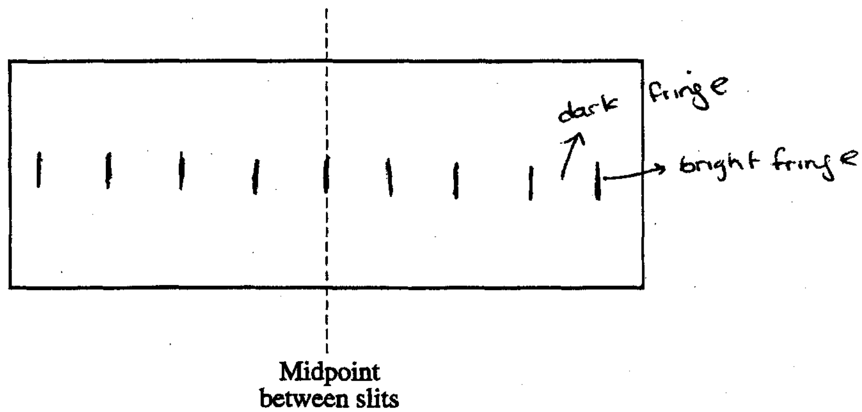
(b) The source of red light is replaced with one that produces blue light (λ = 450 nm), for which the plastic has a greater index of refraction than for the red light. Qualitatively describe what happens to the reflected and refracted rays.

The reflected ray will be identical to the present one (27°)
The ∠ between the refracted ray and the normal will be less than that for red light $\Rightarrow \angle_{refracted} < 17.5°$

(c) The semicircular block is removed and the blue light is directed perpendicularly through a double slit and onto a screen. The distance between the slits is 0.15 mm. The slits are 1.4 m from the screen.

i. On the diagram of the screen below, sketch the pattern of light that you should expect to see.



ii. Calculate the distance between two adjacent bright fringes.

$$x_m = \frac{m\lambda D}{s} \quad (m = 1)$$

$$x_m = \frac{(450\times10^{-9})(1.4)}{0.15\times10^{-3}} = 4.2\times10^{-3}\ \text{m}$$

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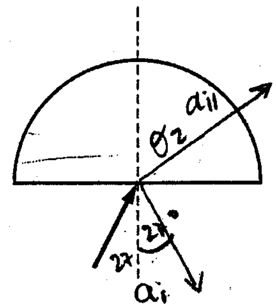

4. (15 points)

A ray of red light in air ($\lambda = 650$ nm) is incident on a semicircular block of clear plastic ($n = 1.51$ for this light), as shown above. The ray strikes the block at its center of curvature at an angle of incidence of 27°.

(a) Part of the incident ray is reflected and part is refracted at the first interface.

i. Determine the angle of reflection at the first interface. Draw and label the reflected ray on the diagram above.

θ of reflection = 27°

ii. Determine the angle of refraction at the first interface. Draw and label the refracted ray on the diagram above.

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$1 \sin 27 = 1.51 \sin\theta_2$

$\theta_2 = 43.306°$

iii. Determine the speed of the light in the plastic block.

$n = \frac{c}{v}$

$1.51 = \frac{3.0 \times 10^8}{v}$

$v = 1.9 \times 10^8$ m/s

iv. Determine the wavelength of the light in the plastic block.

$v = \lambda f$

$3.0 \times 10^8 = 650 f$

$f = 4.6 \times 10^{11}$ Hz

$1.9 \times 10^8 = \lambda \, 4.6 \times 10^{11}$

$\lambda = 4.1 \times 10^{-4}$ m

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(b) The source of red light is replaced with one that produces blue light ($\lambda = 450$ nm), for which the plastic has a greater index of refraction than for the red light. Qualitatively describe what happens to the reflected and refracted rays.

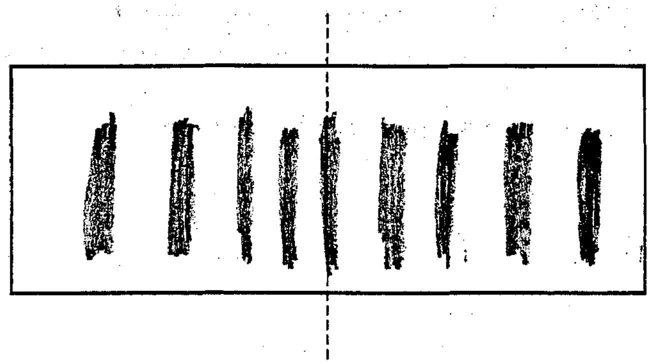
With higher index of refraction → the refracted ray would be at smaller angle

→ the reflected ray would be the same.

(c) The semicircular block is removed and the blue light is directed perpendicularly through a double slit and onto a screen. The distance between the slits is 0.15 mm. The slits are 1.4 m from the screen.

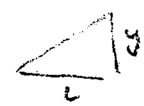
i. On the diagram of the screen below, sketch the pattern of light that you should expect to see.

$d \sin\theta = m\lambda$



Midpoint between slits

ii. Calculate the distance between two adjacent bright fringes.



$d \sin\theta = m\lambda$

$1.5\times10^{-4} \sin\theta = 450 \times 1$

$\sin\theta = 0.3$

$\theta = 17.46°$

$\tan\theta = \frac{y}{L}$

$\tan 17.46° = \frac{y}{1.4}$

$y = 4.4$ m.

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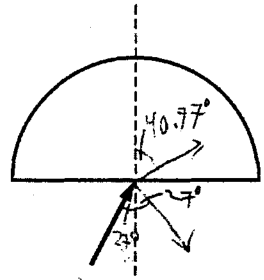

4. (15 points)

A ray of red light in air (λ = 650 nm) is incident on a semicircular block of clear plastic (n = 1.51 for this light), as shown above. The ray strikes the block at its center of curvature at an angle of incidence of 27°.

(a) Part of the incident ray is reflected and part is refracted at the first interface.

i. Determine the angle of reflection at the first interface. Draw and label the reflected ray on the diagram above.

$27°_{(\text{incident})} = 27°_{(\text{out})}$

ii. Determine the angle of refraction at the first interface. Draw and label the refracted ray on the diagram above.

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$1 \cdot \sin 27 = 0.454$

$1.51 \cdot \sin^{-1} 0.454 = 40.77°$

iii. Determine the speed of the light in the plastic block.

$n = \frac{c}{V}$

$V = \frac{c}{n}$

$V = \frac{3 \cdot 10^8}{1.51} = 1.99 \cdot 10^8$

iv. Determine the wavelength of the light in the plastic block.

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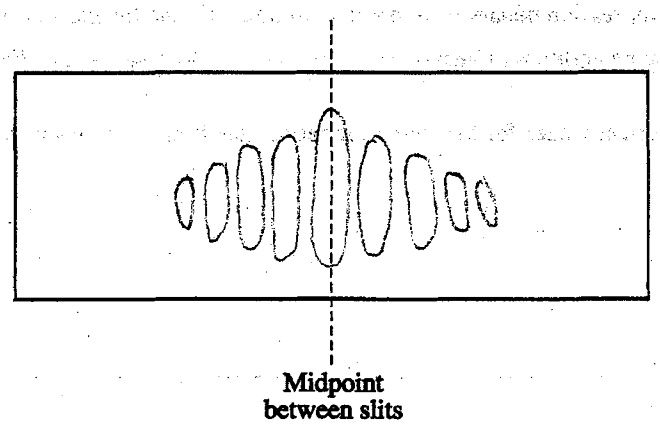
B4C2

(b) The source of red light is replaced with one that produces blue light (λ = 450 nm), for which the plastic has a greater index of refraction than for the red light. Qualitatively describe what happens to the reflected and refracted rays.

The reflected rays bounce off the plastic, and the refracted rays slow down and bend at an angle.

(c) The semicircular block is removed and the blue light is directed perpendicularly through a double slit and onto a screen. The distance between the slits is 0.15 mm. The slits are 1.4 m from the screen.

i. On the diagram of the screen below, sketch the pattern of light that you should expect to see.



ii. Calculate the distance between two adjacent bright fringes.

$$x_n = \frac{m\lambda L}{d}$$

$$\frac{1\cdot 450\cdot 1.4}{1.5\cdot 10^{-4}} =$$

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Question 4

Sample: B4A
Score: 15

This neat, well-organized response earned full credit. Even though the student does not use the word “refracted” in the diagram, labeling the 17.5 degree angle is sufficient identification when combined with the correct calculation.

Sample: B4B
Score: 9

This response earned full credit for the reflected ray in part (a) but only 1 point for substituting correctly into Snell’s law in the refraction part. The correct speed inside the block earned 1 point, and the wavelength calculation has a substitution error and earned only 1 point for using the same frequency in both materials. Part (b) earned full credit as well as part (c)(i) since the fringes are reasonably equally spaced. Although a correct combination of equations is used in part (c)(ii), no credit was earned since an error is made in substituting the wavelength.

Sample: B4C
Score: 5

In part (a), 2 points were earned for the reflected ray; work for the refracted ray earned nothing since the substitutions into Snell’s law are not correct; and the correct speed of the block earned 1 point. Part (b) earned nothing. Part (c)(i) earned full credit even though the height of the fringes decreases, and part (c)(ii) earned nothing since a substitution error is made.