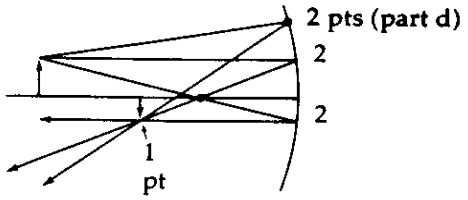
MIRRORS

1978 Q5

Solution | *Distribution of Points*

a) 7 points



real 1
left 1

b) 3 points

$H_o = 6$ cm

$D_o = 30$ cm

$f = 10$ cm

$\frac{1}{D_i} + \frac{1}{D_o} = \frac{1}{f}$ 2

$\frac{1}{D_i} = \frac{1}{f} - \frac{1}{D_o} = \frac{1}{10} - \frac{1}{30} = \frac{2}{30}$

$D_i = 15$ cm 1

Alternate:

$H_o = 6$ cm

$S_o = 20$ cm

$f = 10$ cm

$S_i S_o = f^2$ 2

$S_i = \frac{f^2}{S_o} = \frac{100}{20} = 5$ cm 1

c) 3 points

$\frac{H_i}{H_o} = \frac{D_i}{D_o}$ 2

$H_i = \frac{15}{30}(6) = 3$ cm 1

Alternate

$\frac{H_i}{H_o} = \frac{f}{S_o} = \frac{S_i}{f}$ 2

$H_i = \frac{5}{10}(6)$ or $H_i = \frac{10}{20}(6)$

$H_i = 3$ cm 1

d) 2 points

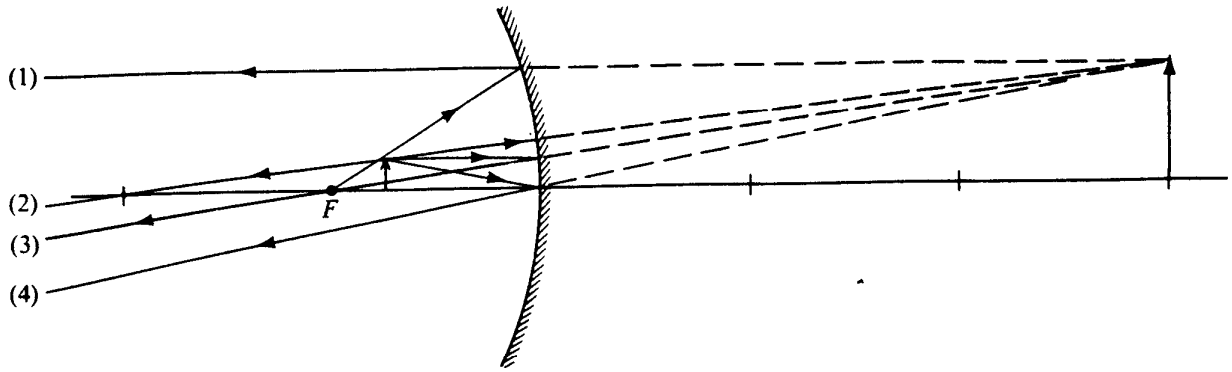
See diagram above.

Reflected ray passing through tip of image	2
Showing $\angle i = \angle r$ at surface of mirror at point Q but not reflected through tip of arrow.	1

1983 Q5

Distribution of points

5. (a) 6 points



There are four principle rays that can be drawn:
(1) Through focal point, reflected parallel to axis.
(2) Through center of curvature, reflected on itself.
(3) Parallel to axis, reflected through focal point.
(4) Reflected where axis intersects mirror.

For any one of these rays — 2 points
For a second ray — 2 points
For extrapolating the rays so they intersect — 1 point
For drawing an arrow at the image position — 1 point

(b) 2 points

The image is virtual, because it is behind the mirror and defined only by extrapolation of rays — 2 points

(c) 4 points

The object distance D_0 and the image distance D_I are related by

$$\frac{1}{D_0}+\frac{1}{D_I}=\frac{1}{f}$$ — 1 point

Substitution of $D_0 = 15$ cm, $f = 20$ cm gives

$$\frac{1}{D_I}=\frac{1}{20}-\frac{1}{15}=-\frac{1}{60}$$ — 1 point

So $D_I = -60$ cm. The image is 60 cm behind the mirror. — 2 points

(d) 3 points

The formula for magnification is

$$M=\left|\frac{H_I}{H_0}\right|=\left|\frac{D_I}{D_0}\right|$$ — 1 point

So $M=\frac{60}{15}=4$ — 1 point

and the image height is
$H_I = 4H_0 = 4 \cdot 3 = 12$ cm — 1 point

1983 Q5 (continued)

Distribution of points

Alternate solution to (c) and (d) using Newton's form of the mirror equation: *(Alternate points)*

(c) $S_0 S_I = f^2$ (1 point)

(Where S_0 and S_I are measured from the focal point)

$S_I = \frac{f^2}{S_0} = \frac{20^2}{-5} = -80$ (1 point)

So the image is 80 cm to the right of the focal point, 60 cm from the lens. (2 points)

(d) $M = \frac{f}{S_0} = \frac{20}{5} = 4$ (2 points)

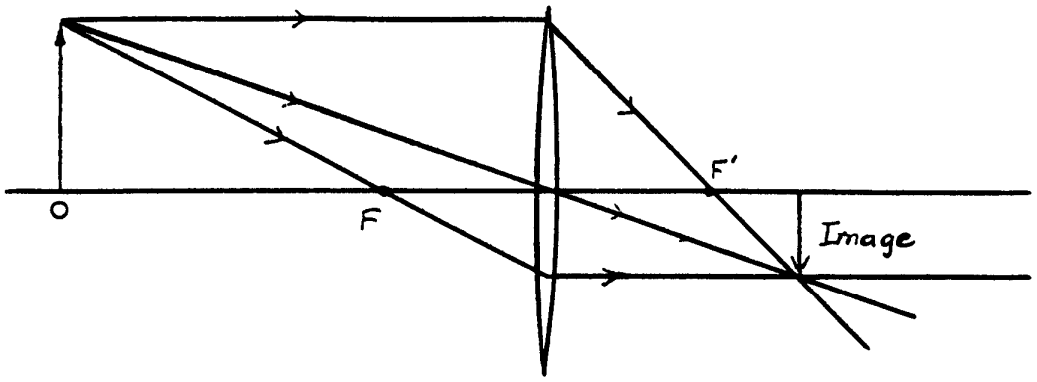
and so $H_I = 4 \cdot 3 = 12$ cm (1 point)

LENSES

1981 Q5

5. a) 4 points

The image can be located by drawing any two of the three principal rays shown on the diagram below.



Principal ray parallel to axis refracted through F′ or principal ray through F refracted parallel to axis	2 points
Either or both of the other two principal rays	1 point
Drawing arrow for image at intersection of rays	1 point

b) 3 points

The image is real	1 point
Correct explanation, such as The rays actually meet at the image, The image is on the opposite side of the lens from the incident light, or The real object is more than one focal length from a converging lens	2 points

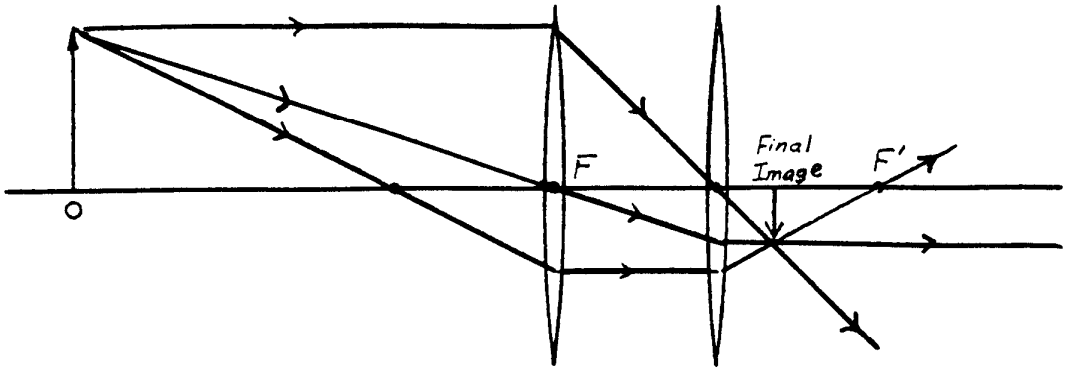
c) 4 points

Thin lens equation: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$	1 point
$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{6} - \frac{1}{18} = \frac{1}{9}$	2 points
Distance of image from lens is $q = 9$ cm	1 point
	Alternate Points
Alternate method:	
Newton's equation $s_o s_i = f^2$	(1 point)
s_o = distance from object to F = 18 − 6 = 12 cm	(1 point)
$s_i = \frac{6^2}{12} = 3$ cm	(1 point)
Distance from lens to image is $f + s_i = 6 + 3 = 9$ cm	(1 point)

1981 Q5 (continued)

d) 4 points

In this case, the principal rays for the first lens are also principal rays for the second lens and can be traced through both lenses to locate the final image.



Principal ray through F of second lens (center of first lens) refracted parallel to axis or principal ray emerging from first lens parallel to axis refracted through F'	2 points
Either or both of the other two principal rays	1 point
Drawing arrow for image at intersection of rays	1 point
Total	15 points

1982 Q6

6. a) 6 points

The position of the image can be calculated by using the thin lens equation

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$ 2 points

Since the object distance $p = \frac{3f}{2}$,

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{3f/2} = \frac{1}{f} - \frac{2}{3f} = \frac{1}{3f}$$ 2 points

Hence $q = 3f$ 1 point

which means that the image is located a distance 3f to the right of the lens. 1 point

Alternate method: *Alternative Points*

One can use Newton's form of the thin lens equation, $s\,s' = f^2$. (2 points)

Here s is the distance of the object to the left of the first focal point, i.e., $s = \frac{1}{2}f$ (1 point)

and so $s' = \frac{f^2}{\frac{1}{2}f} = 2f$ (1 point)

This means that the image is 2f to the right of the second focal point, i.e., 3f to the right of the lens. (2 points)

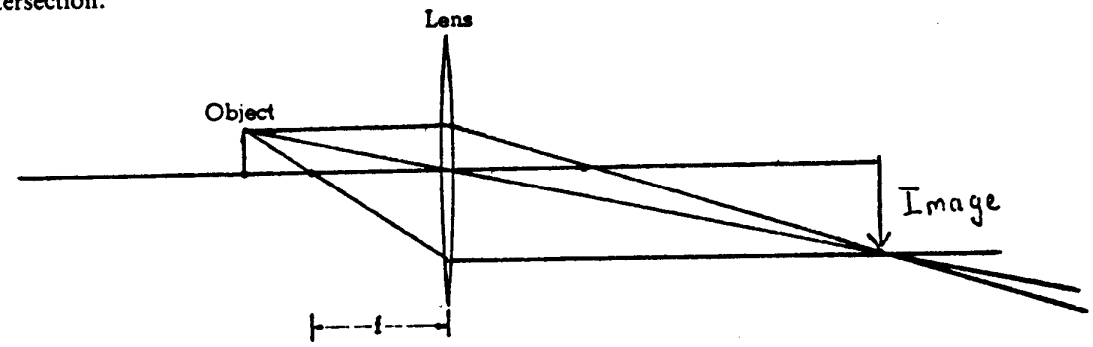
b) 5 points

There are three principal rays that might be traced, as shown on the diagram.

For any one of these three: 2 points

For a second one: 1 point

For extending the rays until they meet and indicating that the image is at their point of intersection: 2 points



c) 4 points

The focal length of the second lens, f_2, must be greater. 1 point

Algebraic justification using thin lens equation: Image height h′ and image distance q are related by

$$\frac{h'}{q} = \frac{\text{object height}}{p}$$

If the new image height is greater, the new image distance q_2 must be greater than the old image distance q. 2 points

1982 Q6 (continued)

The new focal length f_2 satisfies

$$\frac{1}{f_2} = \frac{1}{p} + \frac{1}{q_2}, \quad \text{while } \frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Since $q_2 > q$, $\frac{1}{q_2} < \frac{1}{q}$ and $\frac{1}{f_2} < \frac{1}{f}$ — 1 point

Therefore $f_2 > f$

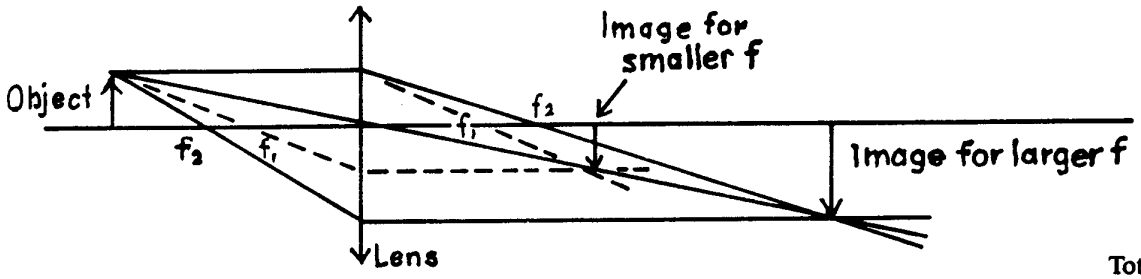
Alternate methods: — *Alternative Points*

Algebraic justification using Newton's equation:
Object height h and image height h′

satisfy $\frac{h'}{h} = \frac{f}{s}$ — (2 points)

By increasing f, which decreases s, one can increase h′ — (1 point)

Geometric justification:
By drawing a ray diagram with two different focal points f_1 and f_2, both less than p, one sees that image height increases as f increases. — (3 points)

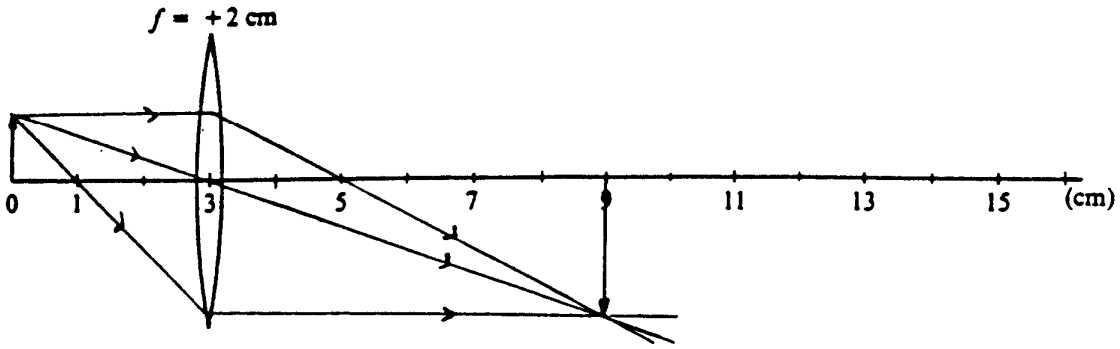


Total 15 points

1986 Q6

6.

(a) 3 points



For two correct principal rays — 2 points

For locating image at intersection of rays — 1 point

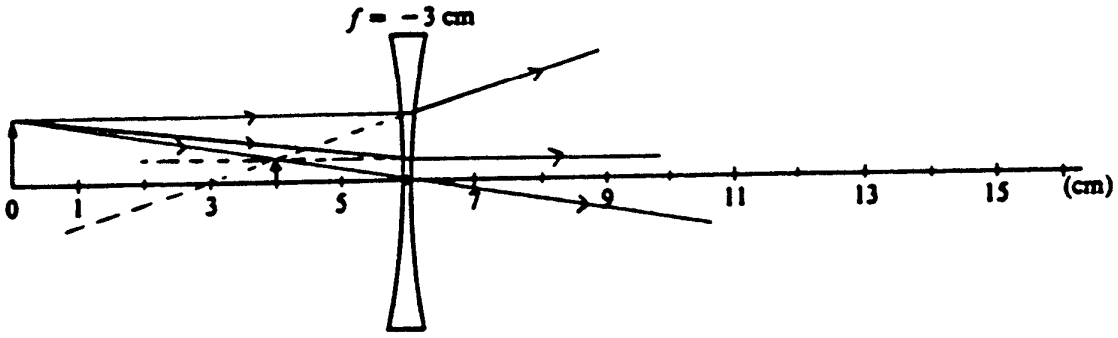
(b) 2 points

$\frac{y_i}{y_o} = \left|\frac{s_i}{s_o}\right|$ — 1 point

$\frac{y_i}{y_o} = \frac{6\ cm}{3\ cm} = 2$ — 1 point

Student could also indicate relative sizes of 2:1 on a good, carefully drawn sketch in part (a).

(c) 3 points



For two correct principal rays, extended back as necessary — 2 points

For locating image at intersection of rays — 1 point

6. (cont)

(d) 3 points

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$ 1 point

$$\frac{1}{6} + \frac{1}{s_i} = \frac{1}{-3}$$ 1 point

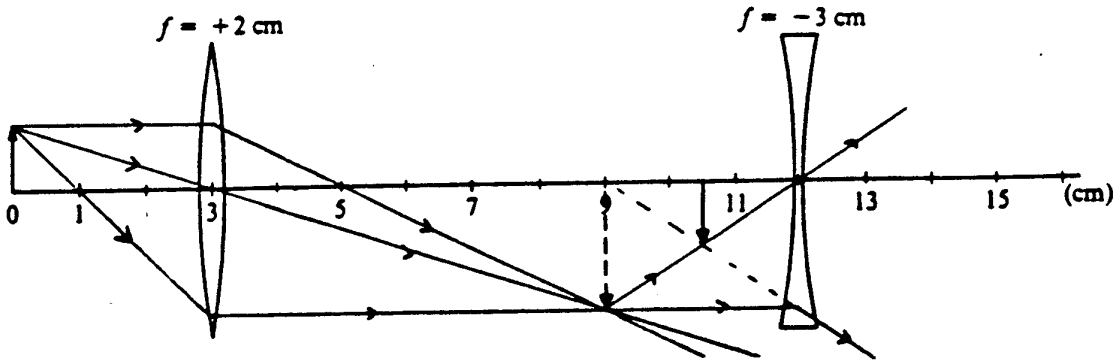
$$\frac{1}{s_i} = \frac{1}{3} - \frac{1}{6} = -\frac{3}{6} = -\frac{1}{2}$$

$$|s_i| = 2 \text{ cm}$$ 1 point

(e) 1 point

Virtual 1 point

(f) 3 points



For forming the image of the first lens as in part (a) 1 point

For using rays from this image to the second lens 1 point

For obtaining the correct final image 1 point

1989 Q5

5.

(a) 2 points

The image is real — 2 points

(b) 3 points

For lens equation: $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ — 1 point

For correct substitution: $\frac{1}{60\ \text{cm}} + \frac{1}{d_i} = \frac{1}{20\ \text{cm}}$ — 1 point

$$\frac{1}{d_i} = \frac{1}{20\ \text{cm}} - \frac{1}{60\ \text{cm}} = \frac{3-1}{60\ \text{cm}} = \frac{2}{60\ \text{cm}} = \frac{1}{30\ \text{cm}}$$

$d_i = 30$ cm — 1 point

(c) 3 points

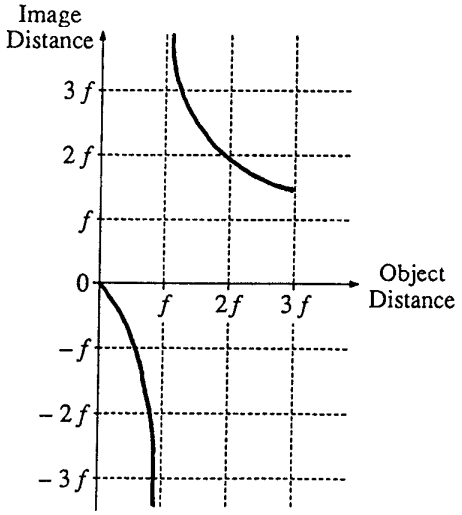
$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$ — 1 point

For correct substitution: $M = -\frac{30\ \text{cm}}{60\ \text{cm}}$ — 1 point

$M = -\frac{1}{2}$ — 1 point

If the answer was inverted ($M = -2$), 1 point was awarded if no work was shown, and 2 points were awarded if work was shown.

(d) 4 points



For $d_i \longrightarrow \infty$ as $d_o \longrightarrow f$ from the right — 1 point

For $d_i = 1.5\ f$ when $d_o = 3f$ — 1 point

For "concave up" curve between the above points — 1 point

For an increasingly negative curve for $d_o < f$, asymptotic at $d_o = f$ — 1 point

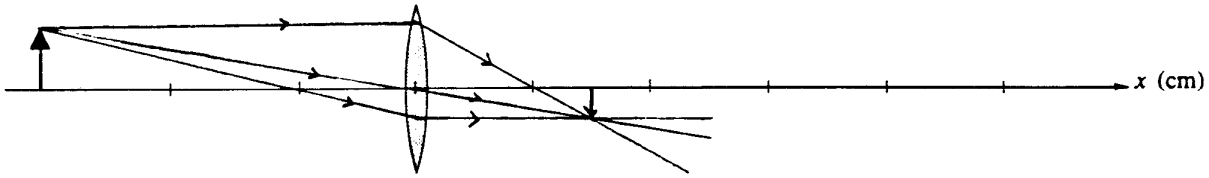
5. (continued)

(e) 3 points

Focal length decreases	2 points
For any valid explanation (which may include ray diagrams) For example: Snell's Law indicates that an increase in index of refraction causes increased angle of refraction. If rays "bend" more, the focal length is decreased.	1 point

1992 Q6

(a) 4 points



One point each for up to two correct principal rays	2 points
For correctly locating image at the point where rays cross, with one end on axis (whether or not rays are correct)	1 point
For correct inverted orientation of image (or consistent with rays drawn)	1 point

(Last point was awarded for merely an indication that image is to the right of lens and inverted, without drawing rays)

(b)

i. 3 points

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$ 2 points

$$d_i = \frac{d_0 f}{d_0 - f}$$

$$= \frac{(45\ \text{cm})(15\ \text{cm})}{45\ \text{cm} - 15\ \text{cm}}$$

$d_i = 22.5$ cm 1 point

(b) (continued)

(Alternate solution) (Alternate points)

$x_0 x_i = f^2$ (1 point)

$x_i = f^2/x_0$

$= (15\text{ cm})^2/(30\text{ cm})$

$x_i = 7.5$ cm (1 point)

$d_i = 22.5$ cm (1 point)

ii. 2 points

$\text{Magnification} = \frac{h_i}{h_o} = \frac{d_i}{d_o}$ 1 point

$h_i = \frac{d_i}{d_o} h_o$

$= \frac{(22.5\text{ cm})}{(45\text{ cm})} 8\text{ cm}$

$h_i = 4$ cm 1 point

(Alternate Solution) (Alternate points)

$\text{Magnification} = \frac{h_i}{h_0} = \frac{f}{x_0} = \frac{x_i}{f}$ (1 point)

$h_i = \frac{fh_0}{x_0}$

$= \frac{(15\text{ cm})(8\text{ cm})}{(30\text{ cm})}$

$h_i = 4$ cm (1 point)

(c) 3 points

Only effect would be a dimming of the image.

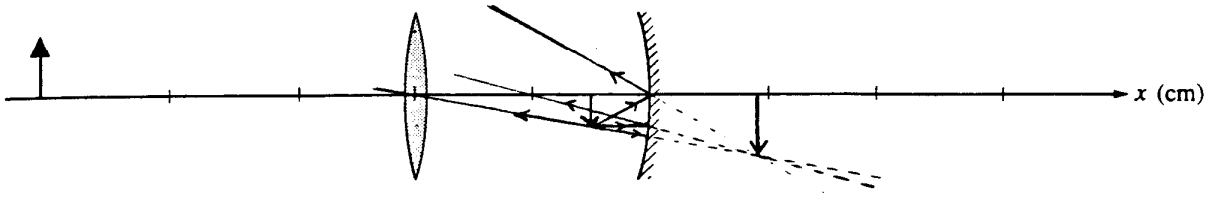
For any indication that there is no change in location 1 point

For any indication that there is no change in size 1 point

For any indication of a reduction in intensity 1 point

6. (continued)

(d) 3 points



One point each for up to two correct principal rays	2 points
For correct location and orientation of image (consistent with rays drawn)	1 point

1997 Q5

Question 5 (15 points)

(a) 2 points

For indicating that the lens is converging — 1 point
For a correct explanation — 1 point
Examples:
The image from a diverging lens is always on the same side of the lens as the object, so this lens must be converging.
The image from a diverging lens is always closer to the lens than the object, and the image here is farther.
The magnification is greater than 1.

(b) 3 points

Using the lens equation

$$\frac{1}{f} = \frac{1}{s_i} + \frac{1}{s_o}$$

For correct substitution — 1 point

$$\frac{1}{f} = \frac{1}{90\text{ mm}} + \frac{1}{30\text{ mm}}$$

$$\frac{1}{f} = \frac{4}{90\text{ mm}}$$

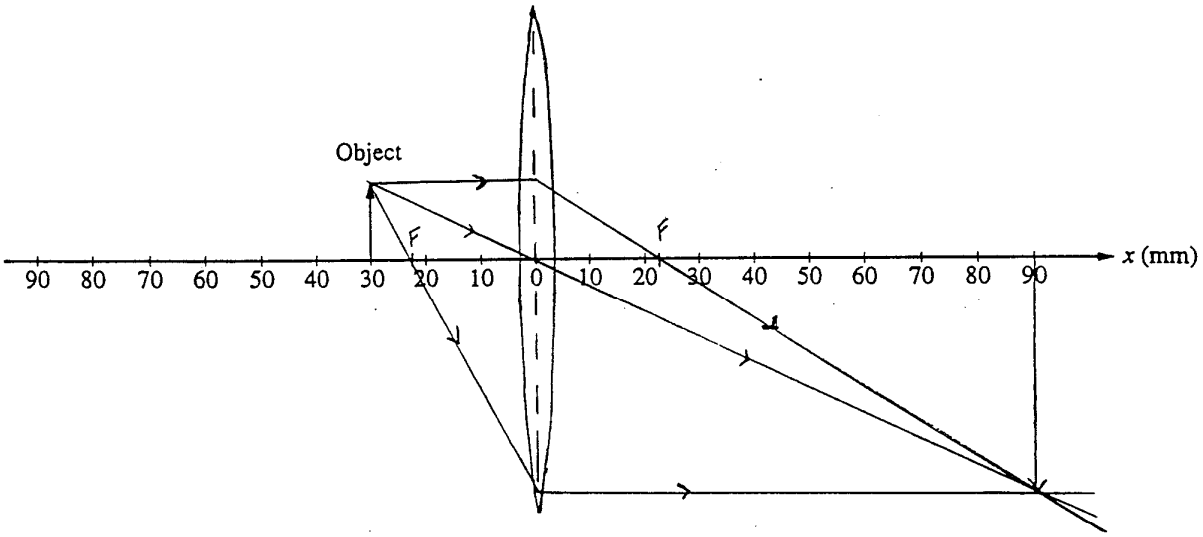
$$f = \frac{90\text{ mm}}{4}$$

For the correct numerical answer — 1 point
For correct units — 1 point
$f = 22.5$ mm

Full credit can be earned for an answer taken from the student's diagram in part (c) if the student explicitly stated that this was the method used.

Question 5 (continued)

(c) 3 points



For correctly showing a lens at $x = 0$ — 1 point
If just a straight line or only the front surface was drawn, a ray going through the lens had to be present to make it clear that student was treating this as a lens and not a mirror.

For correctly drawing up to two of the principal rays shown (1 point each) — 2 points
If the ray through the center of the lens is used, and the image is drawn at 90 mm and three times larger than the object, credit was also awarded for a second ray that was any other correct non-principal ray.

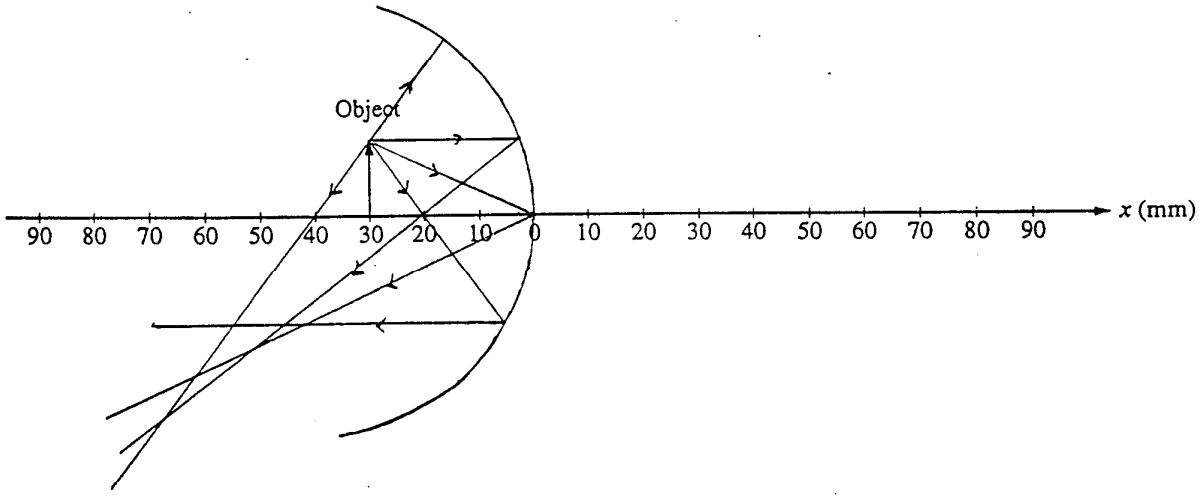
(d) 3 points

The image is real. — 1 point
The image is larger than the object. — 1 point
The image is inverted compared to the object. — 1 point
To receive credit, the answers must be consistent with the image that the student drew in part (c), and the image must be drawn or its position indicated by crossed rays.

Question 5 (continued)

(e) 4 points

Note: Given the size of the object with respect to the curvature of the mirror, the principal rays used to locate the position of the image are not all paraxial. The result is that these rays do not all meet at one point, and the location of the image depends on the choice of rays. Therefore, a range of image positions was allowed.



For correctly drawing a concave mirror at $x = 0$	1 point
For correctly drawing up to two of the principal rays shown (1 point each)	2 points
For having two rays intersecting to indicate an image that is inverted, below the axis, and between 40 and 70 mm	1 point

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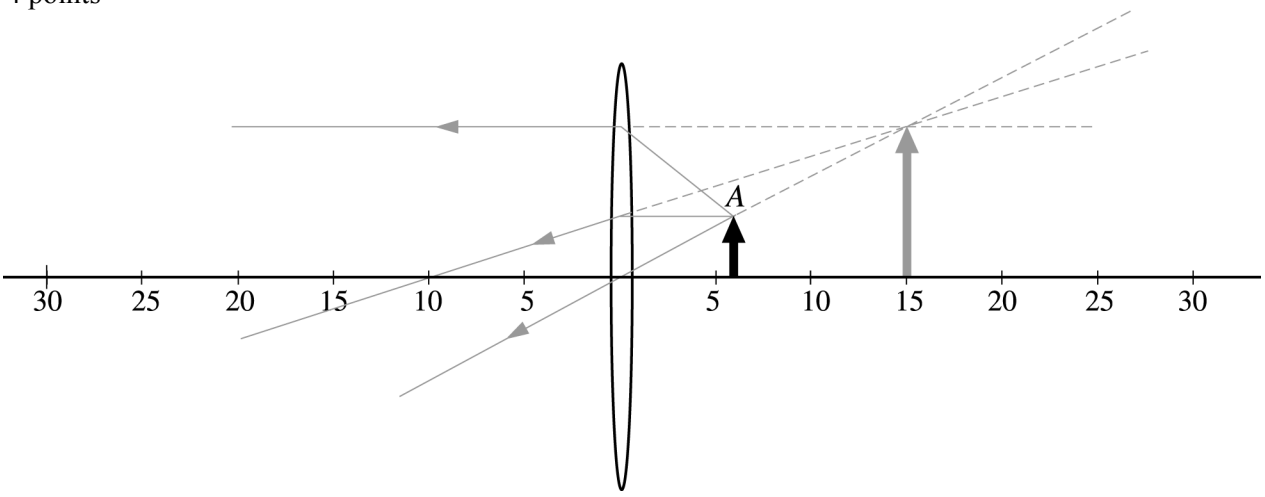
2002 SCORING GUIDELINES

Question 4

15 points total **Distribution of points**

(a) 4 points



For any two correct rays through the lens 2 points
Two of the three principal rays shown on the diagram above were expected.
One point was subtracted for additional incorrect rays. No credit was awarded for reflected rays.
For correct extension of the rays backward 1 point
For showing the image with correct size, position, and orientation 1 point

(b) 2 points

For stating that the image is virtual, or for stating a choice consistent with the ray diagram in part (a) 1 point
If there were no supporting diagrams or calculations, virtual was the only accepted answer.
For a correct explanation consistent with the choice given, such as: 1 point
The light rays diverge on the left side of the lens, but appear to come from a point behind the object. OR The image is on the same side of the lens as the object. OR The object is placed between the converging lens and the focal point.
This point was not awarded if additional wrong statements were part of the response.

(c) 3 points

For the lens equation OR for the lens equation with substituted quantities 1 point

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f} \quad \text{OR} \quad \frac{1}{s_i} = \frac{1}{10\ \text{cm}} - \frac{1}{6\ \text{cm}}$$

For the correct solution 2 points
$s_i = -15$ cm (Minus sign was not necessary to receive full credit.)
Only 1 of the 2 answer points was awarded for the correct number without units.

Question 4 (cont'd.)

Distribution of points

(c) continued

Alternate points

Alternate Solution

Let x_o = distance from object to focal point and x_i = distance from image to focal point.

For the correct formula — *1 point*

$$\frac{x_i}{f} = \frac{f}{x_o}$$

For correct substitutions — *1 point*

$$\frac{x_i}{10\ \text{cm}} = \frac{10\ \text{cm}}{10\ \text{cm} - 6\ \text{cm}}$$

$$x_i = \frac{(10\ \text{cm})^2}{4\ \text{cm}} = 25\ \text{cm}$$

$$s_i = 25\ \text{cm} - 10\ \text{cm}$$

For the correct answer — *1 point*

$s_i = 15$ cm

(d) 2 points

For the correct image size to object size ratio with no units, or with units that cancel — 2 points

$$\frac{h_i}{h_o} = \frac{s_i}{s_o} = \frac{15\ \text{cm}}{6\ \text{cm}} = \frac{5}{2}$$

Notes:

Students could use either a calculation or a ray diagram to arrive at the final answer.

1 point only was awarded if the correct ratio was imbedded in extra calculations or if units were provided for the answer (for example, 2.5 cm).

No points were given for giving the object size to image size ratio.

(e) 4 points

Since the question asked for a description, a verbal response was expected, although the image position, size, and orientation could be determined from either a calculation or a ray diagram.

For the correct position:

- Image on the opposite side of the lens from the object — 1 point
- Distance from the image to the lens in the range 20 cm ± 3 cm — 1 point

For the correct size: image size same as object size, or for size consistent with value for position — 1 point

For the correct orientation: image is inverted — 1 point

INDEX OF REFRACTION

1979 Q6

(a) 5 points
From Snell's law, one has

$\frac{\sin i}{\sin r} = \frac{v_i}{v_r}$ — 2 points

$\angle i = 53°, \angle r = 37°$ — 1 point

$v_i = c$ — 1 point

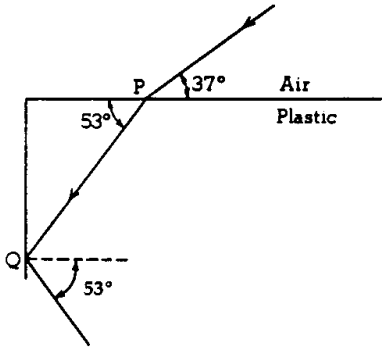
$v_r = (\sin 37°/\sin 53°)c$
$= (3/4)c$ — 1 point

or alternate solution involving index of refraction.

(b) 5 points
Again applying Snell's law one has

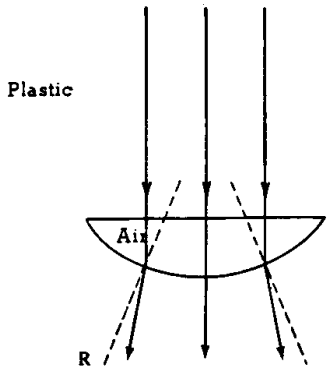
$\sin r = \left[\frac{c}{(3/4)c}\right] \sin 53° = 16/15$ — 1 point

Since $\sin r > 1$, there is no refracted ray. — 2 points



Correct drawing — 2 points

(c) 5 points



Correct drawing — 3 points

The rays diverge because medium II is more dense than medium I (or some equivalent statement). — 2 points

Total 15 points

1987 Q5

(a) 2 points

Angle of incidence = angle of refraction (or $\theta_1 = \theta_3$) — 1 point

$\theta_3 = 30°$ — 1 point

(b) 3 points

$n_1 \sin \theta_1 = n_2 \sin \theta_2$ — 1 point

$(1.6)(\sin 30°) = (1)(\sin \theta_2)$ — 1 point

$\theta_2 = \sin^{-1}(0.8)$ or $\theta_2 = 53.1°$ — 1 point

(c) 3 points

$v = \frac{c}{n}$ or $\frac{v_1}{v_2} = \frac{n_2}{n_1}$ — 1 point

$v_g = \frac{3.00 \times 10^8}{1.6}$ — 1 point

$v_g = 1.875 \times 10^8$ m/s — 1 point

(d) 4 points

$v = f\lambda$ or $\lambda = v/f$ — 1 point

$\lambda_g = \frac{v_g}{f} = \frac{1.875 \times 10^8}{6 \times 10^{14}}$ — 1 point

$\lambda_g = 3.125 \times 10^{-7}$ m or $\lambda_g = 3125$ Å — 2 points

(One point for numerical value, one point for units)

Alternate Method — (Alternate Points)

$\lambda_a = \frac{c}{f}$ (for both equations)

$\lambda_g = \frac{\lambda_a}{n}$ — (1 point)

$\lambda_g = \frac{c}{fn}$ (for correct substitution) — (1 point)

$\lambda_g = \frac{3.00 \times 10^8}{(6 \times 10^{14})(1.6)}$

$\lambda_g = 3.125 \times 10^{-7}$ m or $\lambda_g = 3125$ Å — (2 points)

(One point for numerical value, one point for units)

(e) 3 points

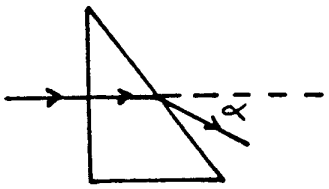
For an indication of the occurrence of either a critical angle or total internal reflection, or the equation $n_1 \sin \theta_1 = \sin 90°$ — 1 point

$1.6 \sin \theta_1 = \sin 90° = 1$ — 1 point

$\theta_1 = \sin^{-1}(0.625)$ or $\theta_1 = 38.7°$ — 1 point

1988 Q5

(a) 2 points



Horizontal ray in the prism — 1 point

Ray emerging below horizontal (or consistent with Snell's law and ray in prism, if ray in prism is incorrect) — 1 point

(b) 5 points

Snell's Law $n_1 \sin \theta_1 = n_2 \sin \theta_2$ — 1 point

$$\sin \theta_2 = \frac{1.5 \sin 37^\circ}{1.0}$$ — 2 points

(1 point for sin 37°, 1 point for correct indices of refraction)

$\theta_2 = 65^\circ$ — 1 point

$\alpha = 65^\circ - 37^\circ = 28^\circ$ — 1 point

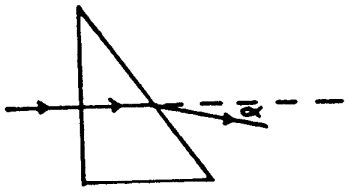
(c) 3 points

$$n' = 1.0 \frac{\sin 90^\circ}{\sin 37^\circ}$$ — 2 points

(1 point for sin 90°, 1 point for correct indices of refraction)

$n' = 1.67$ — 1 point

(d) 2 points



horizontal ray in prism — 1 point

emerging ray below horizontal (or consistent with Snell's law and ray in prism if ray in prism incorrect) — 1 point

5. (continued)

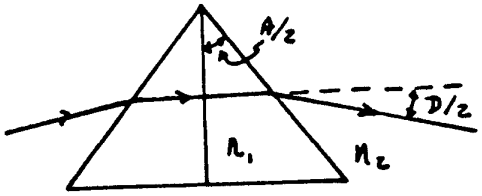
(e) 3 points

$$\sin \theta_2' = \frac{1.67 \sin 37^\circ}{1.33}$$ 1 point

$\theta_2' = 49^\circ$ 1 point

$\alpha = 49^\circ - 37^\circ = 12^\circ$ 1 point

Alternate solutions for parts (b) and (e) (Alternate Points)



For recognition of symmetry and connection with minimum deviation for double prism as shown above (2 points)

For Snell's law and minimum deviation formula

$$\frac{n_1}{n_2} = \frac{\sin (A/2 + D/2)}{\sin A/2}$$ (2 points)

Application to (b) to obtain $D/2 = 28^\circ$ (2 points)

Application to (e) to obtain $D/2 = 12^\circ$ (2 points)

1990 Q6

(a) 3 points

For some statement that the angle of reflection equals the angle of incidence, or an indication of equal angles on the diagram — 2 points

$\theta_{refl} = \tan^{-1}\left(\frac{2}{3}\right)$ or $\sin^{-1}\left(\frac{2}{\sqrt{13}}\right)$ or $\cos^{-1}\left(\frac{3}{\sqrt{13}}\right) = 34°$ — 1 point

(b) 3 points

$n_a \sin \theta_a = n_w \sin \theta_w$ — 1 point

$\sin \theta_a = \frac{(1.33)}{(1)} \sin 34°$ — 1 point

$\theta_a = 48°$ — 1 point

(c) 4 points

$\sin \theta_{crit} = \frac{n_a}{n_w}$

or some other indication that the critical angle must be calculated — 1 point

$\theta_{crit} = 49°$ — 1 point

$\tan \theta_{crit} = \frac{2}{d}$ (where d is the depth) — 1 point

$d = 1.8$ m — 1 point

(d) 1 point

For the correct answer, air-oil, and no incorrect answers — 1 point

(e) 4 points

$2t = \left(M + \frac{1}{2}\right)\lambda_{oil}$ (where t is the thickness of the oil and M is an integer)

or some indication that interference is involved — 1 point

$\lambda_{air} = n_{oil}\lambda_{oil} = \frac{2(1 \times 10^{-7}\ \text{m})(1.5)}{(M + 1/2)}$ or $\lambda_{oil} = \frac{2(1 \times 10^{-7}\ \text{m})}{(M + 1/2)}$ — 1 point

$\lambda_{air} = 600$ nm, 200 nm... or $\lambda_{oil} = 400$ nm, 133 nm.... — 1 point

For selecting the proper λ_{air} that lies in the visible range:

$\lambda_{air} = 600$ nm or red

or indicating that the visible range is 400 nm to 700 nm — 1 point

1993 Q4

(a) 2 points

The definition of the index of refraction relates the speed of light in vacuum and in glass.

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

Solving for v:

$v = \frac{c}{n}$ 1 point

Substituting:

$v = (3 \times 10^8 \text{ m/s})/ 1.60$

$v = 1.9 \times 10^8 \text{ m/s}$ (or $0.625\ c$) 1 point

(b) 2 points

For the relation for the wavelength in glass and in vacuum:

$\lambda_g = \frac{\lambda_v}{n}$ 1 point

$\lambda_g = (700 \times 10^{-9} \text{ m})/ 1.50$

$\lambda_g = 4.7 \times 10^{-9} \text{ m}$ 1 point

(c) 3 points

For recognizing that the frequency of the light does not change when the light enters a different medium. 1 point

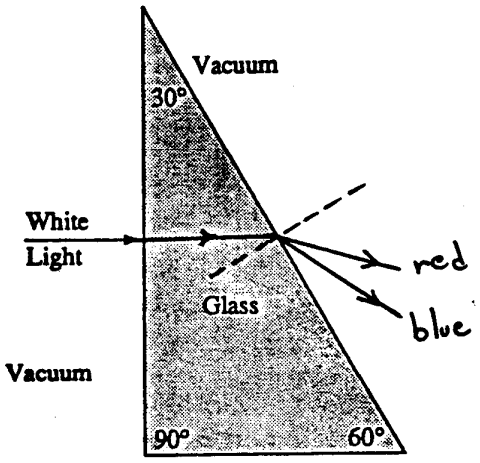
$f = \frac{c}{\lambda}$ 1 point

Substituting:

$f = (3 \times 10^8 \text{ m/s})/(700 \times 10^{-9} \text{ m})$

$f = 4.3 \times 10^{14} \text{ Hz}$ 1 point

4. (continued)
(d) 4 points

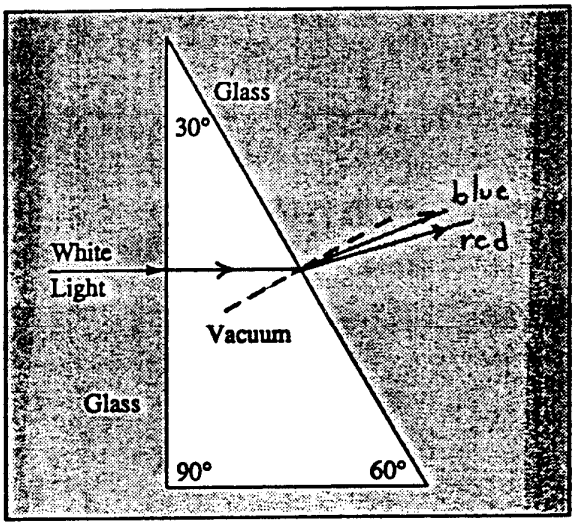


For indicating no refraction at the first surface	1 point
For indicating the red ray bending away from the normal at second surface (i.e. below horizontal)	1 point
For indicating the blue ray bending away from the normal at second surface	1 point
For indicating that the blue ray bends more than the red ray.	1 point

(If refraction is shown at the first surface, the last three points may still be awarded for correctly refracting the incorrect rays at the second surface)

(If no points were earned for ray diagram, 1 point could be awarded for writing Snell's Law in either part (d) or part (e).)

4. (continued)
(e) 4 points



For indicating no refraction at the first surface — 1 point

For indicating the red ray bending toward the normal at the second surface. — 1 point

For indicating the blue ray bending toward the normal at the second surface. — 1 point

For indicating that the blue ray bends more than the red ray — 1 point

(If refraction is shown at the first surface, the last three points may still be awarded for correctly refracting the incorrect rays at the second surface)

1994 Q5

5.

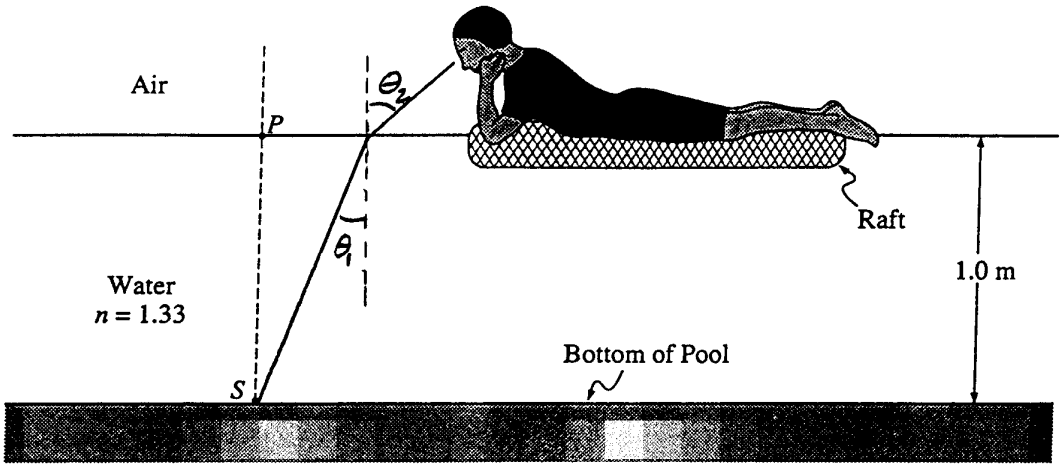
(a) 3 points

$v = \frac{c}{n}$ 1 point

$= \frac{3 \times 10^8 \text{ m/s}}{1.33}$ 1 point

$v = 2.26 \times 10^8 \text{ m/s}$ 1 point

(b) 3 points



For straight line in the water from S, with θ_1 to the right 1 point

[This point also awarded for straight wave propagation, i.e. ∿∿∿∿→]

For straight line in air from the point of intersection of ray with surface to the eye with $\theta_2 > \theta_1$ to the right 1 point

For no incorrect rays 1 point

(c) 3 points

Using Snell's Law:

$n_w \sin \theta_w = n_a \sin \theta_a$ 1 point

At the critical angle, $\theta_w = \theta_c$ and $\sin \theta_a = 1$

$\sin \theta_c = \frac{n_a}{n_w} = \frac{1}{1.33}$ 1 point

$\theta_c = 48.8°$ 1 point

5. (cont.)

(d) 4 points

Using the lens equation:

$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$ 1 point

$\frac{1}{20\text{ cm}} + \frac{1}{d_i} = \frac{1}{30\text{ cm}}$ 1 point

$d_i = -60\text{ cm}$ 1 point

The image is 60 cm below the lens but the lens is 20 cm above the bottom of the pool, so the image is 60 cm − 20 cm = 40 cm below the bottom of the pool. 1 point

(Alternate solution) (Alternate points)

$d_i d_o = f^2$ (1 point)

$d_i(-10\text{ cm}) = (30\text{ cm})^2$ (1 point)

$d_i = -90\text{ cm}$ (distance from focal point) (1 point)

Distance from bottom of pool is 90 cm - 30 cm - 20 cm = 40 cm (1 point)

[Full credit also awarded for a correct solution given from the perspective of being in the air above the water.]

(e) 2 points

i. There is no refraction at either surface of the lens, so no image is formed other than at the source itself. (Point given for any correct statement describing that the lens has no effect on the light from *S*.) 1 point

ii. The index of refraction of the material is closer to that of the lens, so the refraction is less than that with water.

The image is smaller and closer to *S* than in part (d). (Point given for any correct statement and no incorrect statement.) 1 point

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Question 4

15 points total **Distribution of points**

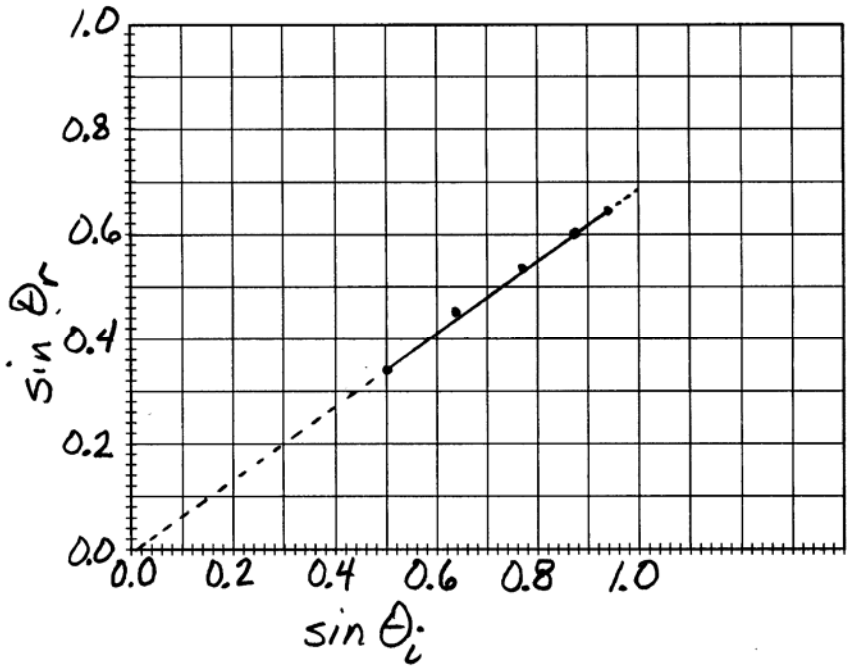
(a) 2 points

Trial	θ_i	θ_r	$\sin\theta_i$	$\sin\theta_r$
1	30°	20°	0.50	0.34
2	40°	27°	0.64	0.45
3	50°	32°	0.77	0.53
4	60°	37°	0.87	0.60
5	70°	40°	0.94	0.64

For identifying that both quantities to be graphed are the sines of the angles 1 point
For correctly calculating the sines using degrees 1 point

(b) 4 points

Example:



For correctly labeling both axes with the sines of the angles 1 point
For correctly labeling both axes with appropriate numerical scales 1 point
For plotting the five points 1 point
For correctly drawing a best fit line that includes the entire range of data points and may extend beyond them 1 point

Question 4 (continued)

Distribution of points

(c) 4 points

For a statement or implicit use of Snell's Law — 1 point
$n_1 \sin\theta_i = n_2 \sin\theta_r$ (or $\sin\theta_i = n_2 \sin\theta_r$ since $n_1 = n_{air} = 1$)

For indicating that the index of refraction n can be obtained from the slope or inverse of the slope depending on choice of variable plotted on each axis — 1 point
Example using graph above
$$n = \frac{\sin\theta_i}{\sin\theta_r} = \frac{1}{\text{slope}}$$

For using two sets of points directly from the line to find the slope — 1 point
$$\text{slope} = \frac{0.53 - 0.41}{0.78 - 0.60} = 0.67$$

For a correct calculation of the index of refraction consistent with the slope of the graph — 1 point
$n = 1/0.67 = 1.5$

(d) 1 point

For checking "The air-oil interface only" — 1 point

(e) 4 points

For indicating that the optical path difference between the waves reflecting off the air-oil interface and the oil-water interface is one-half wavelength — 1 point
$\Delta\ell = \lambda/2$

For indicating that the wave reflecting off the oil-water interface travels a distance equal to twice the thickness of the oil — 1 point
$\Delta\ell = 2t$

For indicating that the wavelength of the light in the oil film is different from the wavelength of the light in air — 1 point
$\lambda_{film} = \lambda_{air}/n_{film}$

The three equations above are combined to relate the film thickness to the wavelength.
$2t = \lambda_{film}/2 = \lambda_{air}/2n_{film}$
$t = \lambda_{air}/4n_{film}$
$t = 6.0 \times 10^{-7}\,\text{m}/4(1.43)$

For the correct answer with appropriate units — 1 point
$t = 1.05 \times 10^{-7}\,\text{m} = 105\ \text{nm}$

<u>Notes</u>:
A student who checked "The oil-water interface only" *in part (d) and then correctly calculated a wavelength of 105 nm for the thickness of the oil was awarded full credit.*
A student who checked "Both interfaces" *or* "Neither interface" *in part (d) and then correctly calculated a wavelength of 210 nm for the thickness of the oil was awarded full credit.*

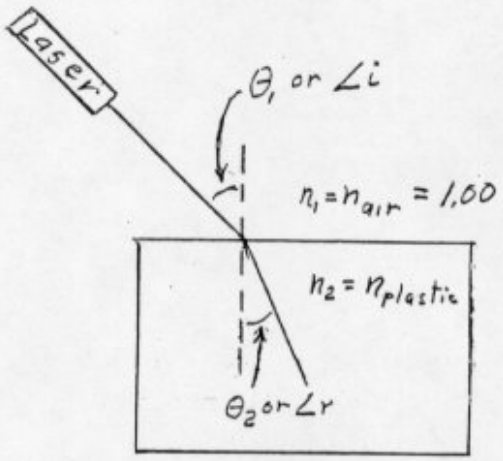
Question 6 (10 points)

(a) 6 points

For a verbal description of the procedure — 1 point

An example of a complete procedure would be: Place the laser on the table so that the beam will travel along the white screen placed on the tabletop. Locate the plastic block so that the light enters it at an angle to the normal to the surface of the plastic. Draw a line representing the surface of the block and the incident ray. Mark where the ray exits the block and remove the block. Draw a ray from the exit point back to the normal and incident ray. Measure the angle of incidence and the angle of refraction. Use Snell's law and the fact that the index of refraction in air is unity to calculate the index of refraction of the plastic.

(Shorter descriptions were also acceptable for this point.)



Points awarded for diagram

For all the correct rays drawn and meeting at the interface — 1 point

For both θ_1 and θ_2 measured from the normal — 1 point

For $\theta_2 < \theta_1$ — 1 point

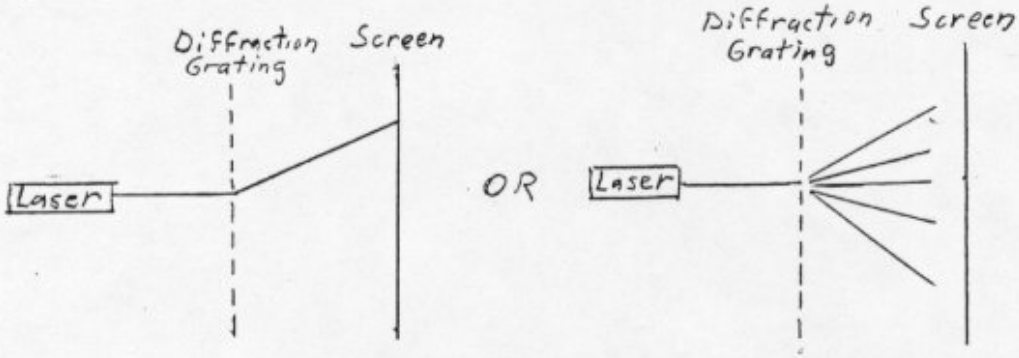
For all quantities being labeled on the diagram, including n_1 and n_2 (n_1 and n_2 could also be described in the text.) — 1 point

For the correct equation — 1 point

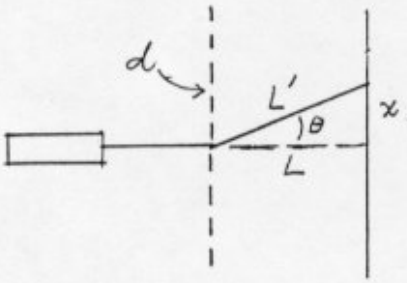
$n_1 \sin\theta_1 = n_2 \sin\theta_2$ OR $\dfrac{\sin\angle i}{\sin\angle r} = n$

Question 6 (continued)

(b) 4 points



For diagram that must include laser, diffraction grating, screen, and some indication of bending or spreading of light at the grating, as shown above — 1 point



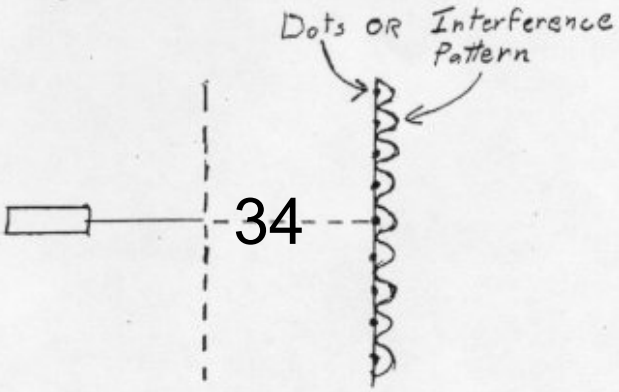
For the labels on the diagram as shown above that correspond to those in the equation used — 1 point
For the equation and any necessary assumptions made — 1 point
The equation could be any one of the following three.

$n\lambda = d\sin\theta$; d and θ must also be shown in the diagram

$n\lambda = xd/L'$; d and L' must be shown in the diagram

$n\lambda = xd/L$; only for small angles using the approximation $\sin\theta \approx \tan\theta$, and d and L must be shown in the diagram

For indicating in some fashion that n is equal to the number of a particular bright line. — 1 point
This could be with a verbal description or by showing successive dots or an interference pattern, as shown in the example below.

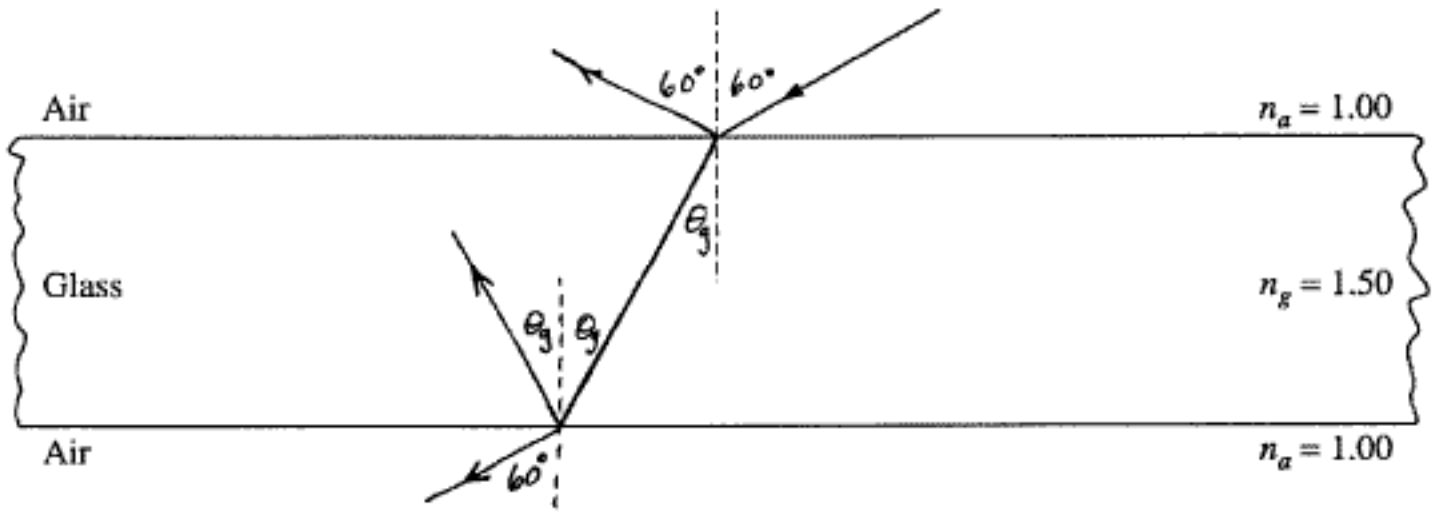


Note: Only one diagram was necessary if it included all the features described. For purposes of these standards several diagrams were used to clearly illustrate how the points were awarded.

2000 Physics B Solutions **Distribution of points**

Question 4 (15 points)

(a) 8 points



For correctly labeling the initial 60° angle of incidence — 1 point

For each correctly drawn ray with angle of reflection or refraction labeled one point was awarded — 4 points

For correctly labeling the angle of incidence at the lower interface — 1 point

Using Snell's law:

$n_a \sin \theta_a = n_g \sin \theta_g$

For correct substitution — 1 point

$1.0 \sin 60° = 1.5 \sin \theta_g$

For the correct value of θ_g — 1 point

$\theta_g = 35.3°$ OR 0.61 rad

At each interface, only one point was awarded for a correct sketch of rays with incorrect or missing angle labels.

At each interface, one point was deducted for an incorrect sketch with correct angle labels.

(b)

i. 2 points

Using the relationship between frequency and wavelength:

$c = f\lambda$

For substituting the correct values in air — 1 point

$$f_a = \frac{c}{\lambda_a} = \frac{3 \times 10^8 \text{ m/s}}{5.25 \times 10^{-7} \text{ m}}$$

For the correct answer — 1 point

$f_a = 5.71 \times 10^{14}$ Hz

Distribution of points

Question 4 (continued)

ii. 1 point

For a correct answer — 1 point
$f_f = 5.71 \times 10^{14}$ Hz OR indicating it's the same value as part i

iii. 2 points

For correctly applying one or more equations, including substitution — 1 point

$\lambda_f = \frac{\lambda_a}{n_f}$ OR $v_f = \frac{c}{n_f}$ and $\lambda_f = \frac{v_f}{f_f}$

$\lambda_f = \frac{5.25 \times 10^{-7} \text{ m}}{1.38}$ OR $\lambda_f = \frac{(3 \times 10^8 \text{ m/s})/1.38}{5.71 \times 10^{14} \text{ Hz}}$

For the correct answer, with proper units — 1 point
$\lambda_f = 3.8 \times 10^{-7}$ m OR 380 nm

iv. 2 points

For indicating the correct condition for constructive interference — 1 point
$2L = \lambda_f$

$2L = 3.8 \times 10^{-7}$ m

For the correct answer, with proper units — 1 point
$L = 1.9 \times 10^{-7}$ m OR 190 nm

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Question 4

15 points total

4. (a) **3 points**

Distribution of Points

For using Snell's law OR indicating that the index of refraction is the slope of the graph **1 point**

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

For substituting or otherwise indicating use of data from the given graph **1 point**

$(1)(0.5) = n_2(0.8)$ OR $\text{slope} = \dfrac{0.8}{0.5}$

For the correct answer **1 point**

$n_2 = 1.60$

Alternate Solution

Alternate points

For using the expression for the critical angle *1 point*

$\sin\theta_c = \dfrac{n_2}{n_1}$

For using data from the graph *1 point*

The critical angle occurs when $\sin\theta_2 = 1$. From the graph, $\sin\theta_2 = \sin\theta_c = 0.625$

$0.625 = \dfrac{1}{n_1}$

For the correct answer *1 point*

$n_2 = 1.60$

Two points were awarded for inverting the values from the graph to obtain $n_2 = 0.625$

4. (b) i. **2 points**

For using the correct equation with the correct substitutions **1 point**

$f = v/\lambda$

$f = \left(3\times10^8 \text{ m/s}\right)/\left(675\times10^{-9} \text{ m}\right)$

For the correct answer **1 point**

$f = 4.44\times10^{14} \text{ Hz}$

Question 4 (cont.)

4. (b) ii. **2 points**

Distribution of Points

For using the correct equation with the correct substitutions **1 point**

$v = c/n$

$v = (3\times10^8 \text{ m/s})/1.60$

For the correct answer **1 point**

$v = 1.88\times10^8 \text{ m/s}$

If an incorrect answer was carried through to obtain a speed greater than 3×10^8 m/s, only **one point** was awarded for the solution. The **second point** could be earned if there was some indication that the student realized that the value must be incorrect, because it could not be greater than the speed of light.

4. (b) iii. **2 points**

For using the correct equation with correct substitutions (consistent with previous answers) **1 point**

$\lambda = v/f$

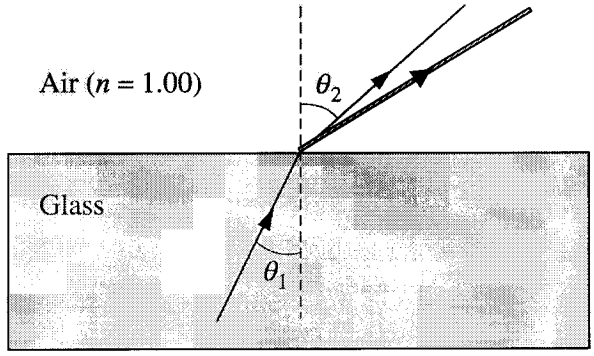
$\lambda = (1.88\times10^8 \text{ m/s})/(4.44\times10^{14} \text{ Hz})$

For the correct answer **1 point**

$\lambda = 423\times10^{-9} \text{ m} = 423 \text{ nm}$

Units point: For correct units on two of the three answers in part (b) **1 point**

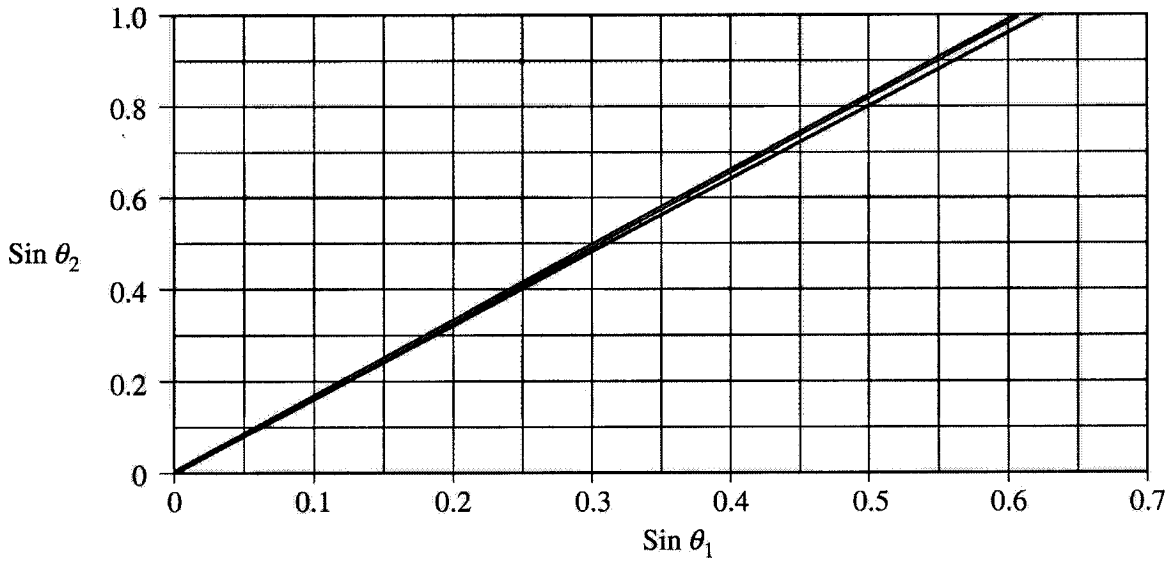
4. (c) i. **1 point**



For correctly indicating on the figure that θ_2 increases **1 point**

Question 4 (cont.)

4. (c) ii. **2 points**



	Distribution of Points
For a straight line that goes through the origin	**1 point**
For a steeper slope than the given line	**1 point**

Full credit was awarded for a line with less steep slope if it was consistent with the answer to part (a)

4. (d) **2 points**

For the correct equation for the critical angle **1 point**

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\sin\theta_c = \frac{1}{1.66} = 0.602$$

For the correct answer **1 point**

$\theta_c = 37°$ or 0.624 radians

DOUBLE SLIT

1991 Q6

6.

(a) 5 points

For the double-slit interference equation:
$m\lambda = d \sin\theta$ 1 point

For small angle approximation (or equivalent geometry)
$\sin\theta \approx \tan\theta = y/L$ 1 point

For using $m = 1$ 1 point

$$d = \frac{\lambda L}{y}$$

For correct substitution:
$d = (5.5 \times 10^{-7}\ \text{m})(0.85\ \text{m})/(1.2 \times 10^{-2}\ \text{m})$ 1 point

$d = 3.9 \times 10^{-5}\ \text{m}$ 1 point

(b) 2 points

For a correct relation to allow calculation of y_a:

$$y_a = \frac{\lambda_a L}{d} \quad \text{or} \quad \frac{y_a}{\lambda_a} = \frac{y_b}{\lambda_b}$$ 1 point

$$y_a = \frac{(4.4 \times 10^{-7}\ \text{m})(0.85\ \text{m})}{(3.9 \times 10^{-5}\ \text{m})}$$

$$\underline{\text{or}}\ y_a = \frac{(1.2 \times 10^{-2}\ \text{m})(4.4 \times 10^{-7}\ \text{m})}{(5.5 \times 10^{-7}\ \text{m})}$$

$y_a = 9.6 \times 10^{-3}\ \text{m}$ 1 point

(c) 3 points

For a correct definition of the work function:
$W_0 = hf_0$ 1 point

For a correct relationship between f and λ:
$f = c/\lambda$ 1 point

$$W_0 = \frac{hc}{\lambda_0} = \frac{(6.63 \times 10^{-34}\ \text{J}\cdot\text{s})(3 \times 10^{8}\ \text{m/s})}{(6 \times 10^{-7}\ \text{m})}$$

$W_0 = 3.3 \times 10^{-19}\ \text{J}$ (or 2.1 eV) 1 point

6. (continued)

(d) 4 points

For attempting to relate the kinetic energy to the work function and photon energy — 1 point

For a correct relationship:
K.E. = $hf - W_0$ — 1 point

For substitution of correct λ — 1 point

$$\text{K.E.} = \frac{(6.63 \times 10^{-34}\ \text{J}\cdot\text{s})(3 \times 10^{8}\ \text{m/s})}{(4.4 \times 10^{-7}\ \text{m})} - 3.3 \times 10^{-19}\text{J}$$

K.E. = 1.2×10^{-19} J (or 0.75 eV) — 1 point

For at least one answer with correct units, and no incorrect units — 1 point

1996 Q3
Question 3 (15 points)

Distribution of points

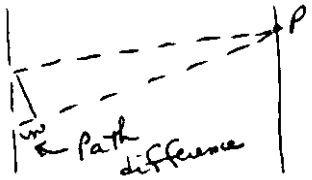
(a) 2 points — 2 points
For indicating that interference demonstrates the wave property of light or diffraction, or constructive and destructive interference

(b) 3 points — 3 points
For realizing that the distance of point P from the center of the in terference pattern is 3/2 the spacing of the pattern, and indicating that the path difference is 3/2 λ

Note: An answer of simple 3/2 was awarded 2 points.

(*Alternate solution 1)* — *(Alternate points)*

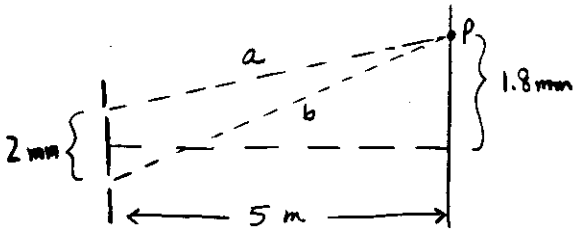
For a diagram showing the path difference — *1 point*



Path difference $= m\lambda = d\sin\theta$
For using $\sin\theta \approx \tan\theta \approx x / L$
Path difference $= dx / L = (2 \text{ x } 10^{-3} m)(1.8 \text{ x } 10^{-3} m) / (5m)$ — *1 point*
For the correct answer — *1 point*
Path difference $= 7.2 \text{ x } 10^{-7} m$

(Alternate solution 2) — *(Alternate points)*

For using the Pythagorean theorem — *1 point*



Using the geometry shown above
$a = \sqrt{(0.8\text{mm})^2 + (5000\text{mm})^2} = 25{,}000{,}000.64\text{mm}$

$b = \sqrt{(2.8\text{mm})^2 + (5000\text{mm})^2} = 25{,}000{,}007.84\text{mm}$

For subtracting the two lengths
Path difference $= b - a$ *1 point*
For the correct answer
Path difference $= 7.2 \times 10^{-7}$ m *1 point*

(c) 4 points

There are two methods for this solution corresponding to giving an answer of 3/2 λ in part (c).

Method 1	Method 2	
Path difference $= m\lambda = d\sin\theta$	$x \approx \frac{m\lambda L}{d}$	1 point
For correct substitution Using $\sin\theta$ or $\tan\theta \approx x / L$	For correctly substituting L, d, a value of x that corresponds to a maximum or minimum in the interference pattern, and whole of half integer number for m	**1 point**
Substituting the correct value of m corresponding to the value of x	Substituting the correct value of m corresponding to the value of x	**1 point**
$\lambda = \frac{d\,x}{m\,L}$	$\lambda = \frac{d\,x}{m\,L}$	
Choosing to make the substitutions for point P	Choosing to make the substitutions for point P	
$\lambda = \frac{(2 \times 10^{-3}\text{ m})(1.8 \times 10^{-3}\text{ m})}{(3/2)(5\text{m})}$	$\lambda = \frac{(2 \times 10^{-3}\text{ m})(1.8 \times 10^{-3}\text{ m})}{(3/2)(5\text{m})}$	
For a correct answer, in which the units match the magnitude $\lambda = 4.8 \times 10^{-7}$ m	For a correct answer in which the units match the magnitude $\lambda = 4.8 \times 10^{-7}$ m	1 point

(Alternate solution) *(Alternate points)*

For setting a numerical answer to part (b) (or a newly calculated value) equal to 2/3 λ *3 points*
For a correct answer, in which the units match the magnitude *1 point*

(d)
i. 2 points
For indicating that the interference pattern will be compressed toward the central maximum 1 point

ii. 2 points

For indicating that there will be a spreading of the pattern, or a larger central maximum in the pattern	1 point
For indicating that the new pattern is a one-slit diffraction pattern.	1point

iii. 2 points

For indicating that the interference pattern will be compressed toward the central maximum	1 point
For referring to the equation $x \approx \frac{m\lambda L}{d}$, and indicating that as d increases the pattern in compressed	1 point

Note: Allowance was made in all calculations for the small discrepancies in the reading values from the graph