

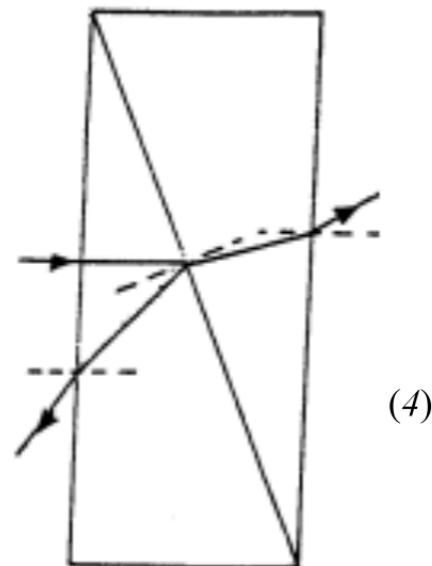
# Mark Scheme Refraction Past Paper Questions Jan 2002 to Jan 2009

**NOTE : Jan 2009 onwards are new spec'**

Question 6		
(a)	(i) (refractive index of water = $1/\sin 49.0$ ) = <b>1.33</b> (not 1.3 or 1.325) ✓ (ii) ray P shown in the air to right of vertical ✓ refracted away from the normal in the correct direction ✓ correct partial reflection shown ✓	<b>4</b>
(b)	<div style="text-align: right; font-weight: bold; font-size: 1.2em;">Q6 Jan 2009</div> (i) <b>critical angle</b> for water-air boundary = $49.0^\circ$ or angle of (incidence of) Q is $\theta_c$ ✓ the angle of incidence (of R) exceeds the critical angle ✓ (ii) figure 6 shows that R undergoes TIR at water surface and strikes the glass side ✓ angle of incidence at glass side = $30^\circ$ ✓ R enters the glass and refracts towards the normal ✓ because $n_g > n_w$ ✓ (or water is optically less dense than glass) (calculates angle = $26.2^\circ$ gets last two marks)	<b>6</b>
<b>Total</b>		<b>10</b>

4(a) Ray diagram to show:

- (i) refraction towards normal at boundary ✓  
emerging ray refracted away from normal ✓
- (ii) reflection at boundary with  $i \approx r$  ✓  
emerging ray refracted away from normal ✓



(b)(i)  $20^\circ$  ✓

(ii)  ${}_1n_2 = \frac{n_2}{n_1} = \frac{\sin \theta_1}{\sin \theta_2}$  ✓

$\frac{1.60}{1.40} = \frac{\sin 20^\circ}{\sin \theta_2}$  ✓

$\theta_2 = 17(.4)^\circ$  ✓

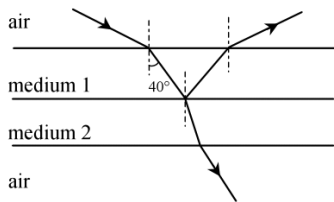
**Q4 Jan 2002**

(c) ( $\sin \theta_c = 1/n$  gives)  $\sin \theta_c = 1/1.60$  ✓  
 $\theta_c = 38.7^\circ$  ✓

(2)  
(10)

**Q3 Jun 2002**

3(a)



- (i) incident angle  $> 40^\circ$  ✓  
 angle of refraction into medium 2  $< 40^\circ$  ✓  
 emergent ray with correct refraction ✓

- (ii) reflection at boundary between media with  $i \approx r$  ✓  
 (hence) emergent ray at approximately same angle as incident ray  
 and showing correct refraction ✓

max(4)

(b)(i) (use of  ${}_1n_2 = \frac{\sin \theta_1}{\sin \theta_2}$  gives)  $1.35 = \frac{\sin \theta_1}{\sin 40}$  ✓  
 $\theta_1 = 60(2)^\circ$  ✓

(ii) (use of  ${}_1n_2 = \frac{n_2}{n_1} = \frac{\sin \theta_1}{\sin \theta_2}$  gives )  $\frac{1.65}{1.35} = \frac{\sin 40}{\sin \theta_2}$  ✓ ✓  
 $\theta = 31.7^\circ$  ✓

(5)

- (c) (total internal reflection) only occurs when light goes  
 from a higher to a lower refractive index  
 [or goes from a more dense to a less dense medium/material] ✓

(1)  
(10)

7

**Q7 Jan 2003**

- (a)(i)  $\theta_c$  marked ✓

(a)(ii)  $\sin \theta_c = \frac{1}{n}$  ✓  $\left( = \frac{1}{1.55} \right)$   
 $\theta_c = 40.2^\circ$  ✓

(3)

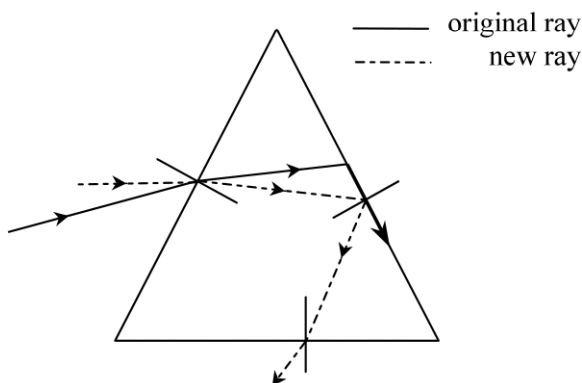
(b)  $n = \frac{\sin \theta_1}{\sin \theta_2}$  ✓

$(\theta_2 = 90 - 75.2 = 14.8^\circ)$

$\theta_1 (= \sin^{-1}\{1.55 \sin 14.8\}) = 23.3^\circ$  ✓

(2)

(c)



- correct refraction at first surface ✓
- total internal refraction at second surface ✓
- correct refraction at third surface ✓

(3)  
(8)

5

(a)(i) (use of  $n = \frac{c_1}{c_2}$  gives)  $c_{\text{glass}} \left( = \frac{3.00 \times 10^8}{1.45} \right) = 2.07 \times 10^8 \text{ m s}^{-1} \checkmark$

**Q5 Jun 2003**

(a)(ii) use of  $\frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2} \checkmark$

$$c_{\text{liquid}} = \frac{2.07 \times 10^8 \times \sin 29.2^\circ}{\sin 26.6^\circ} = 2.26 \times 10^8 \text{ m s}^{-1} \checkmark \quad (3)$$

(allow C.E. for values of  $c_{\text{glass}}$  from (i))

(b) use of  ${}_1n_2 = \frac{c_1}{c_2}$  and  ${}_1n_2 = \frac{n_2}{n_1} \checkmark$

to give  $n_{\text{liquid}} = \frac{1.45 \times 2.07 \times 10^8}{2.26 \times 10^8} = 1.33 \checkmark$

$$\left[ \text{or } n_l = \frac{c_1}{c_{\text{liquid}}} = \frac{3 \times 10^8}{2.26 \times 10^8} = 1.33 \right] \quad (\text{allow C.E. for value of } c_{\text{liquid}})$$

[or use  ${}_1n_2 = \frac{\sin \theta_1}{\sin \theta_2}$  and  ${}_1n_2 = \frac{n_2}{n_1}$  to give correct answer] (2)

- (c) diagram to show :  
 total internal reflection on the vertical surface  $\checkmark$   
 refraction at bottom surface with angle in air greater  
 than that in the liquid ( $29.2^\circ$ )  $\checkmark$  (2)

(7)

3

- (a)(i) diagram to show: refraction towards normal on entry  $\checkmark$   
 total internal reflection shown along fibre  $\checkmark$   
 refraction away from normal on leaving glass  $\checkmark$

- (ii) speed of light decreases on entry into glass and increases on leaving  $\checkmark$  (4)

(b)(i) (use of  $\sin \theta_c = \frac{1}{n}$  gives)  $\sin \theta_c = \frac{1}{1.57} \checkmark$   
 $\theta_c = 39.6^\circ \checkmark$

**Q3 Jan 2004**

(ii)  ${}_1n_2 \left( = \frac{n_2}{n_1} \right) = \frac{1.57}{1.47} \checkmark \quad (= 1.07)$

$$\sin \theta_c = \frac{1}{1.07} \quad \checkmark$$

$$\theta_c = 69.4^\circ \quad \checkmark$$

- (iii) to protect the core surface  
[or to prevent cross-over]  $\checkmark$

(6)  
(10)

4

### Q4 Jun 2004

- (a)(i) (angle) F  $\checkmark$

- (ii) angle D is greater than angle B  
[or at the glass-water boundary, ray R<sub>1</sub> refracts away from the normal]  $\checkmark$  (2)

- (b)(i) (use of  $\sin \theta_c = \frac{1}{n}$  gives)  $\sin 48.8 = \frac{1}{n} \quad \checkmark$   
 $n = 1.3 \quad \checkmark$  (1.33)

- (ii) use of  $\frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2} \quad \checkmark$

$$\frac{\sin 48.8}{\sin 42.9} = \frac{c_{\text{water}}}{c_{\text{glass}}} \quad \checkmark$$

$$\frac{c_{\text{water}}}{c_{\text{glass}}} = 1.1 \quad \checkmark \quad (1.11) \quad (5)$$

### Question 6

### Q6 Jan 2005

- (a)  $c_g (= \frac{c_a}{n}) = \frac{3 \times 10^8}{1.5} \quad \checkmark$   
 $= 2.0 \times 10^8 \text{ m s}^{-1} \quad \checkmark$  (2)

- (b)(i)  $\sin \theta_1 (= n \sin \theta_2) = 1.5 \times \sin 15 \quad \checkmark$   
 $\theta_1 = 23^\circ \quad \checkmark$  (22.8°)

- (ii) use of  $\frac{n_2}{n_1} = \frac{\sin \theta_1}{\sin \theta_2} \quad \checkmark$  (or equivalent)

$$n_2 = \frac{1.5 \times \sin 60}{(\sin 90)} \quad \checkmark$$

$$= 1.3 \quad \checkmark \quad (5)$$

- (c) total internal reflection at A  $\checkmark$   
correct refraction out of glass at r.h. surface  $\checkmark$  (same angles as l.h. side) (2)  
(9)

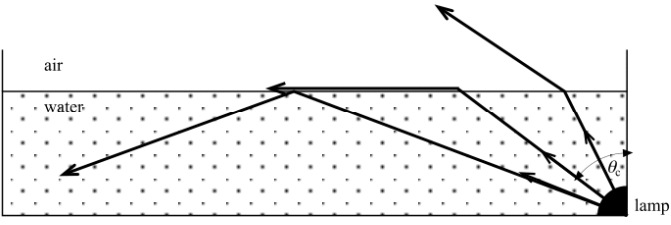
Quality of Written Communication marks: Q3 (a) (i) and Q5 (b) (iii)  $\checkmark \checkmark$  (2)

(2)

Question 4	<b>Q4 Jun 2005</b>	
(a)	diagram to show: total internal reflection on side face ✓ ray emerging at base bent away from normal ✓ with $\approx$ correct angles ✓	<b>3</b>
(b)	$n = \frac{1}{\sin \theta_c} \quad \checkmark$ $= \frac{1}{\sin 45} \quad \text{with calculation } \checkmark (= 1.41)$	<b>2</b>
(c)	$\sin \theta_i = n \sin \theta_r \quad \checkmark$ $\sin \theta_i = 1.41 \times \sin 40 \quad \checkmark$ $\theta_i = 65^\circ \quad \checkmark$	<b>3</b>

Question 5	<b>Q5 Jan 2006</b>	
(a) (i)	$\left(\text{use of } n = \frac{\sin \theta_1}{\sin \theta_2} \text{ gives}\right) 1.45 = \frac{\sin \theta_1}{\sin 15.5^\circ} \quad \checkmark$ $\theta_1 = 22.8^\circ \quad \checkmark$	<b>7</b>
(ii)	$n = \frac{1}{\sin \theta_c} \quad \checkmark$ $n = \left(\frac{1}{\sin 38.7^\circ}\right) = 1.6(0) \quad \checkmark$	
(iii)	$\text{use of } {}_1n_2 = \frac{\sin \theta_1}{\sin \theta_2} \text{ and } {}_1n_2 = \frac{n_2}{n_1} \quad \checkmark$ <p>[or <math>n_1 \sin \theta_i = n_2 \sin \theta_t</math>]</p> $1.45 \sin \theta_3 = 1.60 \sin 51.3 \quad \checkmark$ $\theta_3 = 59.4^\circ \quad \checkmark$ (allow C.E. for value of $n$ from (ii))	
(b)	block 1 ✓(requires some explanation) reference to $\frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2} \quad \checkmark$ [or statement such as light refracts/bends towards normal as it enters a denser/higher refractive index material, or block 1 has lower refractive index]	<b>2</b>
(c)	reflection at boundary with $i = r \quad \checkmark$ refraction (at bottom surface) bending away from normal ✓	<b>2</b>
	<b>Total</b>	<b>11</b>

Question 3		
(a)	$n = \left( \frac{\sin \theta_1}{\sin \theta_2} \right) = \frac{\sin 15.0^\circ}{\sin 10.0^\circ} \checkmark (= 1.49)$	1
(b)	TIR on hypotenuse <b>and</b> refraction at top surface $\checkmark$ 55°, 10° and 15° all marked correctly $\checkmark$	2
(c)	<p>(i) use of <math>{}_1n_2 = \frac{\sin \theta_1}{\sin \theta_2}</math> and <math>{}_1n_2 = \frac{n_2}{n_1}</math> <b>Q3 Jun 2006</b>                      [or <math>n_1 \sin \theta_1 = n_2 \sin \theta_2</math>] <math>\checkmark</math>  <math>1.49 \sin 55^\circ = 1.37 \sin \theta_2 \checkmark</math>  <math>\theta_2 = 63^\circ \checkmark</math></p> <p>(ii) (use of <math>n = \frac{c_1}{c_2}</math>) gives <math>1.37 = \frac{3.0 \times 10^8}{c_2} \checkmark</math>  <math>c_2 = 2.2 \times 10^8 \text{ m s}^{-1} \checkmark</math> (<math>2.19 \times 10^8 \text{ ms}^{-1}</math>)</p> <p>(iii) refraction at boundary between prisms, refracted away from normal <math>\checkmark</math>                      emerging ray (r.h. vertical face) refracting away from normal <math>\checkmark</math></p>	7
<b>Total</b>		<b>10</b>

Question 6		
(a)	<p>(i) use of <math>n_w = \text{speed of light in air} / \text{speed of light in water} \checkmark</math>  <math>c_w (= 3.00 \times 10^8 / 1.33) = 2.26 \times 10^8 \text{ ms}^{-1} \checkmark</math></p> <p>(ii) use of <math>n = 1 / \sin \theta_c</math>  <math>\theta_c (= \sin^{-1}(1 / 1.33)) = 48.8^\circ \checkmark</math> <b>Q6 Jan 2007</b></p>	3
(b)	 <p style="text-align: right;">mark for each ray <math>\checkmark\checkmark\checkmark</math></p>	3
(c)	<p>the critical angle (for water-oil boundary) is larger <math>\checkmark</math>                      there is a smaller difference between the refractive index of the oil and water than there is between the air and water <math>\checkmark</math></p>	2
<b>Total</b>		<b>8</b>

<b>Question 4</b>		
(a)	(i) the angle of incidence at the more dense - less dense boundary ✓ producing an angle of refraction of 90° ✓ (or definitions in terms of minimum or maximum angles of incidence for TIR or refraction)	<b>4</b>
	(ii) use of $\sin \theta_c = 1/n$ ✓ $\theta (= \sin^{-1} 1/1.54) = 40.5^\circ$ ✓	
(b)	ray P showing TIR ✓ ray Q showing refraction at 90° ✓ ray R showing correct refraction ✓	<b>3</b>

**Q4 Jan 2008**

(c)	(i) ray would leave the core bending away from the normal increase in critical angle reference to light speed increase	<b>6</b>
	(ii) to protect the core or to prevent leakage of light or to prevent cross-talk ✓	
	(iii) ${}_1n_2 = \sin \theta_1 / \sin \theta_2 = n_2 / n_1$ ✓ $\theta_c = \sin^{-1} (1.46/1.54)$ ✓ $\theta_c = 71.5^\circ$ ✓	
<b>Total</b>		<b>13</b>

**any two points ✓✓**

<b>Question 5</b>		
(a)	(i) $n_{\text{glass}} (= \sin \theta_{\text{air}} / \sin \theta_{\text{glass}}) = \sin 45^\circ / \sin 29^\circ$ ✓ $n_{\text{glass}} = 1.46$ ✓	<b>5</b>
	(ii) use of ${}_{\text{glass}}n_{\text{gel}} = n_{\text{gel}} / n_{\text{glass}} = \sin \theta_{\text{glass}} / \sin \theta_{\text{gel}}$ or $\sin \theta_c = \frac{n_2}{n_1}$ or $\frac{n_{\text{gel}}}{n_{\text{glass}}}$ ✓ $n_{\text{gel}} = 1.46 \times \sin 74^\circ / \sin 90^\circ$ ✓ $n_{\text{gel}} = 1.40$ ✓	
(b)	TIR from the bottom surface ✓ with 74° marked ✓ refracting away from the normal from the side of the prism ✓ emergent ray (horizontal) with angles marked ✓	<b>4</b>
(c)	$v (= cn) = 3.00 \times 10^8 / 1.59 (= 1.89 \times 10^8 \text{ m/s})$ ✓ $t (= s/v) = 5.00 / 1.89 \times 10^8 = 2.65 \times 10^{-8} \text{ s}$ ✓ [2 → 4 sig fig]	<b>2</b>
<b>Total</b>		<b>11</b>

**Q5 Jun 2008**