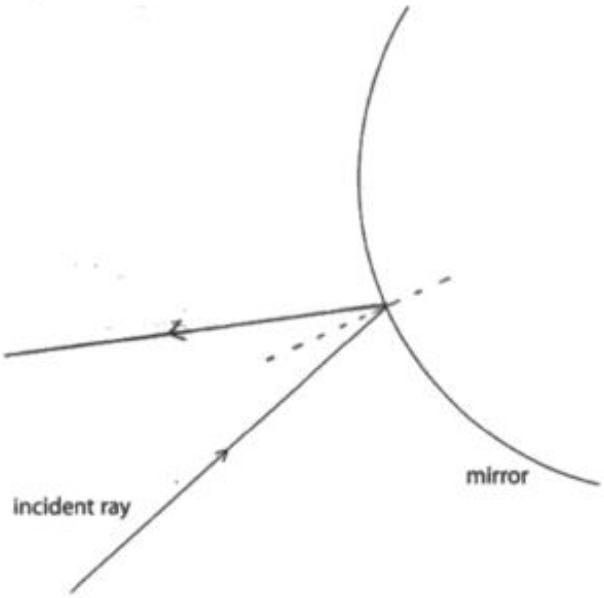
Refraction and Reflection Mark Scheme

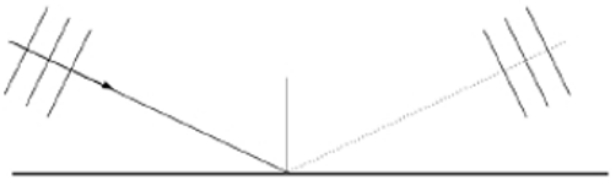
Reflection

Q1.

(c)	(i)	normal line drawn correctly at mirror surface;	ignore tangent lines does not need to be labelled but should be drawn at 90° by eye where the ray meets the mirror	1
	(ii)	ray drawn reflecting; angle of reflection correct; e.g.  	reject if ray passes into the mirror DOP judge by eye allow ecf from (c)(i)	2

Total for Question = 3 marks

Q2.

Question number	Answer	Notes	Marks
(a) (i)	line drawn at 90 degrees to side of boat at point where direction of travel touches boat;	ignore normal inside boat	1
(ii)	66 (degrees);	accept in range 64-68 degrees	1
(iii)	three wavefronts parallel and constant wavelength;	by eye; condone different wavelength to incident wavefronts	3
	to the right of the normal and above boat surface; correct angle of reflection; 	by eye; allow 'reflected ray' if no other mark awarded	

Q3.

Question number	Answer	Notes	Marks
(a)	C; A cannot be correct as the angle of reflection is not equal to the angle of reflection. B and D cannot be correct as the ray penetrates into the mirror rather than reflects.		1
(b)	protractor;		1

Q4.

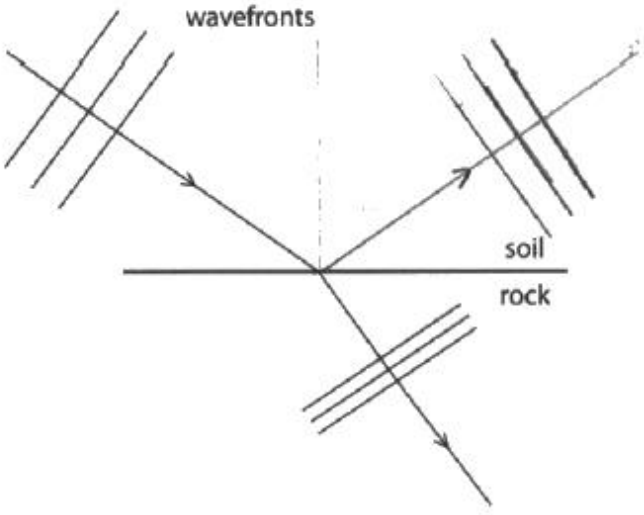
Question number	Answer	Notes	Marks
(a)	protractor;		1
(b) (i)	any indication that the angle is between the normal and the incident ray;		1
(ii)	79 (degrees);	allow 78-80 (degrees) ecf from indicated angle of incidence in (i) e.g. 10-12 (degrees) if angle marked between ray and boundary	1
(iii)	any straight ray to the right of the normal that comes from the point of incidence; correct angle of reflection;	judge by eye judge by eye	2

Q5.

Question number	Answer	Notes	Marks
(a) (i)	line drawn in top-right quadrant; correct angle by eye;	accept if drawn on diagram 1 instead of diagram 2 DOP	2
(ii)	32 (degrees);	allow in range 31-33 (degrees)	1
(iii)	refractive index = sin(angle of incidence) / sin(angle of refraction);	allow standard symbols and rearrangements e.g. 'i' for angle of incidence 'r' for angle of refraction 'n' for refractive index	1
(iv)	substitution; evaluation to at least 3s.f.; e.g. n = sin(64) / sin (32) n = 1.70	allow ecf from (ii) allow 1.696...	2
(v)	sin(c) = 1 / n;	allow standard symbols and rearrangements	1
(vi)	substitution OR rearrangement; evaluation; e.g. sin(c) = 1/1.7 OR c = $\sin^{-1}(1/n)$ (c =) 36 (degrees)	allow ecf from (iv) allow 36.03...(degrees)	2
(b)	light undergoes total internal reflection; angle of incidence is above the critical angle; light (would be) going from more (optically) dense to less (optically) dense;	allow TIR for 'total internal reflection' allow idea that light would speed up if it travelled through the boundary / light travels faster in air than in material	3
		Total for Question = 12 marks	

Q6.

Question number	Answer	Notes	Marks
(a) (i)	speed = frequency × wavelength;	allow rearrangements and standard symbols e.g. $\lambda = v/f$ allow s for speed	1
(ii)	substitution; rearrangement; evaluation; e.g. $3.0 \times 10^8 = 170 (\times 10^6) \times \lambda$ $\lambda = v/f$ OR $\lambda = 3.0 \times 10^8 / 170 (\times 10^6)$ (wavelength =) 1.8 (m)	ignore units -1 for POT error from not converting units or an incorrect attempt at converting units allow 1.76(4...) (m)	3

(b) (i)	reflected ray/wavefronts drawn to right of 'normal' and above rock; wavefronts perpendicular to reflected ray; wavefronts parallel to each other and spacing consistent with incident wavefronts; e.g.  	normal does not need to be drawn reflection angle does not need to be correct ignore if wavefronts extended in to the rock can only be scored if first mark awarded judge by eye can only be scored if first mark awarded judge by eye	3

]

(ii)	any three from: MP1. wavefronts closer together; MP2. idea that rock is (optically) denser than soil; MP3. idea of reduction in speed; MP4. idea of constant frequency; MP5. correct reference to wave speed equation / speed = frequency × wavelength;	 ignore wavelength is smaller allow wave refracts towards normal allow idea that rock has a larger refractive index can only be scored if MP3 or MP4 awarded	3
		Total for Question = 10 marks	

Q7.

Question number	Answer	Notes	Marks
(a) (i)	correctly reflected ray of light drawn at A;	judge angle of reflection = angle of incidence by eye allow dotted lines, lines without arrowheads ignore lines inside the block	1
(ii)	i = 60 (°); r = 31 (°);	allow 59-61 inclusive allow 30-32 inclusive	2
(iii)	n = sin(i) / sin(r);	allow in words and rearrangements	1
(iv)	substitution; evaluation; e.g. (n =) sin(60) / sin(31) (n =) 1.68	allow ECF from (ii) allow 1.61-1.75	2
(v)	any three from: MP1. take repeat readings **at a specific angle**; MP2. vary angle of incidence; MP3. find mean values for one angle i / mean refractive index; MP4. plot graph of sin(i) against sin(r); MP5. find refractive index from gradient of graph;	ignore bald "repeat and average" ignore "repeat investigation"	3
(b)	ray drawn with smaller angle of refraction than red light when it enters block; ray bends away from the normal when it leaves the glass block; ray drawn parallel to red light as it leaves block;		3

Q8.

Question number	Answer	Notes	Marks
(a) (i)	protractor;		1
(ii)	angle of incidence between 42 and 46 degrees; angle of refraction between 26 and 30 degrees;		2
(iii)	refractive index = sin(angle of incidence) ÷ sin(angle of refraction)	allow standard symbols i.e. n or eta for ref. index i , r etc	1
(iv)	substitution; correct evaluation; correct answer: 1.5 e.g. n = sin(i) ÷ sin(r) n = sin() ÷ sin() = 1.479...	Allow ecf from (ii) allow full credit for correct answer with no working reject division of i and r giving approx 1.5-1.6 range of values with 'in tolerance' values for i and r is 1.34-1.64	2

Q9.

Question number	Answer	Notes	Marks
(a) (i)	C - 51°; Angle should be measured and cannot be either A, B or D.		1
(ii)	refractive index = sin (i)/sin (r);	allow n, η for refractive index	1
(iii)	substitution; rearrangement; correct evaluation; correct answer: 31 degrees e.g refractive index = sin (i)/sin (r) $1.52 = \sin(51)/\sin(r)$ $\sin(r) = \sin(51)/1.52$ $\sin(r) = 0.511...$ $r = \sin^{-1}(0.511...) = 30.7...$ degrees	allow ECF from (i) answers of 26.66..., 28.76..., 32.06... all score 3 marks ECF	3
(b) (i)	use of formula $\sin c = 1/n$; substitution; correct evaluation; correct answer: 41 (degrees) e.g. $\sin c = 1/n$ $\sin c = 1/1.52$ $c = \sin^{-1}(1/1.52) = 41.1$ (degrees)		3
(ii)	total internal reflection (TIR) / angle of incidence is above the critical angle and so reflects;		1
		Total for Question = 9 marks	

Q10.

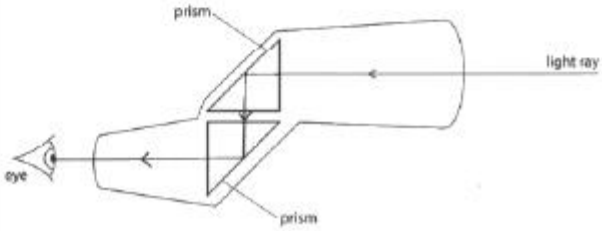
Question number	Answer	Notes	Marks
(a) (i)	36 (degrees);		1
(ii)	refractive index = sin(i) / sin(r);	allow standard symbols and rearrangements e.g. n = sin(i) / sin(r)	1
(iii)	substitution; evaluation; answer quoted to 2 s.f.; e.g. refractive index = sin(61) / sin(36) (refractive index =) 1.48799... (refractive index =) 1.5	allow ecf from (i) mark independently	3
(b)	red refracts less than violet; correct link made between colour and refractive index; correct link made between wavelength and refractive index;	allow RA allow red bends less than violet e.g. red has a lower refractive index than violet e.g. refractive index decreases with increasing wavelength	3

Q11.

Question number	Answer	Notes	Marks
(a)	waves change {speed / wavelength / direction} when they change medium;	allow waves bending allow any reasonable alternative to 'change medium' i.e. changing (optical) density, pass from one material to another etc.	1
(b) (i)	straight ray bent towards normal at the air-water boundary; correct angle of refraction by eye;	judge straightness of ray by eye	2
(ii)	refractive index = sin*i* / sin*r*;	allow rearrangements and standard symbols e.g. n = sin*i* / sin*r*	1
(iii)	substitution; evaluation to at least 3s.f.; e.g. (n =) sin45 / sin33 (n =) 1.30	reject 45/33 reject 1.36 reverse argument scores 1 mark only e.g. calculating *i* or *r* using n allow 1.298... condone 1.29	2

Question number		Answer	Notes	Marks
(c)	(i)	the angle of incidence (in the slower medium); above which gives total internal reflection OR gives an angle of refraction of 90°; 	allow ideas if clear from diagram allow TIR for total internal reflection	2
	(ii)	$\sin c = 1 / n$;	allow rearrangements and mixture of symbols and words	1
	(iii)	substitution; rearrangement; evaluation; e.g. $\sin c = 1/1.3$ $c = \sin^{-1}(1/1.3)$ (c =) 50 (°)	 allow 50.3, 50.28...	3
	(iv)	single straight ray reflected downwards from water surface; angle correct by eye;	any ray above water surface scores zero	2

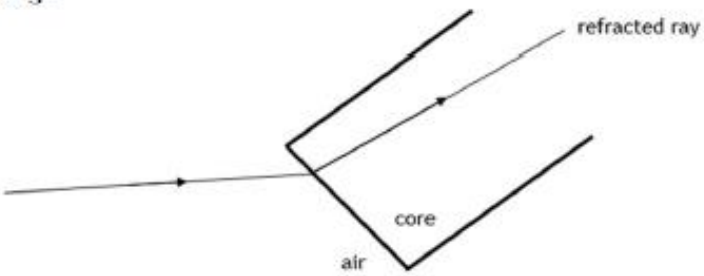
Q12.

Question number	Answer	Notes	Marks
(a)	the angle of incidence (in the slower medium); above which gives total internal reflection OR gives an angle of refraction of 90°;	ALLOW ideas if clear from diagram ALLOW TIR for total internal reflection where light is refracted along the media boundary	2
(b)	TIR in both prisms; no refraction as ray enters and leaves prisms; emergent ray parallel to incident ray;  		3

Q13.

Question number	Answer	Notes	Marks
(a)	17 (degrees);	Allow in range 15-19 degrees	1
(b)	refractive index = sin(i) / sin (r);	accept n or η for refractive index accept any valid rearrangement	1
(c)	substitution; evaluation of either sine correctly; evaluation; e.g. refractive index = sin(29)/sin(17) refractive index = 0.484.../0.292... refractive index = 1.7	allow ecf from (a) 0.48480962/0.292371705 1.6581961	3
		(Total for Question = 5 marks)	

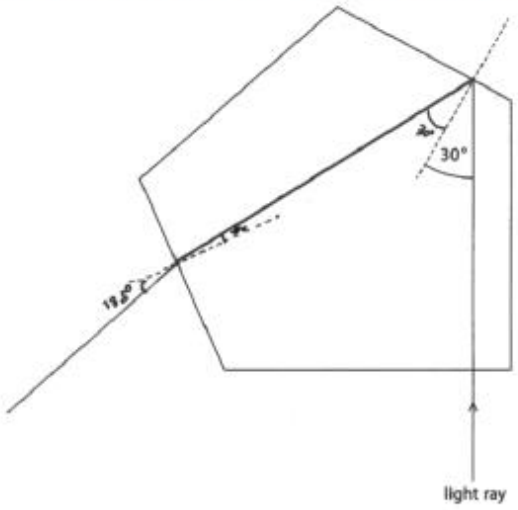
Q14.

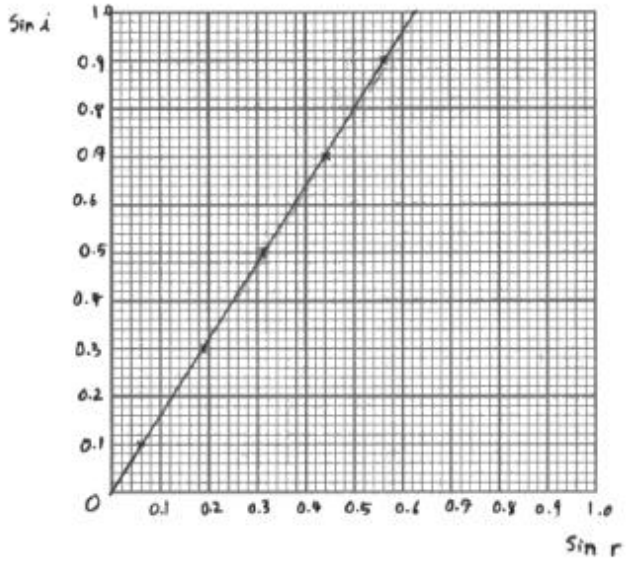
Question number	Answer	Notes	Marks
(a)	D (waves transfer energy and information without transferring matter); A is incorrect because waves do not transfer matter B is incorrect because waves do transfer energy and information C is incorrect because waves do transfer information		1
(b) (i)	ray drawn such that it shows correct change of direction into the core i.e. bending towards normal; e.g.  	arrow on ray is not required	1
(ii)	refraction;	allow recognisable spelling reject if spelling implies reflection	1
(c)	(total internal) reflection; (because) core has higher refractive index than air; (because) angle (of incidence) is greater than critical angle;	allow core is more (optically) dense than air / light travels from a dense to a less dense medium	3
		Total for Question = 6 marks	

Q15.

Question number	Answer	Notes	Marks
	any six from:		6
	MP1. ray A is refracted and changes direction;	may be shown on diagram by ray passing through boundary ignore reflected rays allow 1 mark max. from MP1 and MP2 if either ray is refracted in the wrong direction	
	MP2. ray B is refracted and changes direction;		
	MP3. correctly measured angle of incidence for either ray;	allow 34° -38° for ray A, 58° -62° for ray B	
	MP4. correctly calculated angle of refraction for either ray A or ray B;	may be shown on diagram allow ecf from angles of incidence expect 24° -28° for A and 39° -42° for B	
	MP5. water and air have different (optical) densities;	condone air having a higher (optical) density than water	
	MP6. light travels slower in water than air;	allow RA	
	MP7. TIR does not happen because water is more (optically) dense than air;	ignore calculated values of the critical angle as not relevant	

Q16.

Question number	Answer	Notes	Marks
(a) (i)	n =1/sin(c);	accept any rearrangement or word equation	1
(ii)	substitution; evaluation; e.g. n = 1/sin(26) n = 2.3	 allow 2.28...	2
(iii)	correct TIR at first boundary; refraction at boundary at 7 o'clock; refraction away from the normal at exit point;  	 allow ECF for incorrect TIR and correct subsequent boundaries.	3

(b)	(i)	any FOUR from: MP1 any method of recording an incident ray; MP2 any method of recording a refracted ray; MP3 range of angle of incidences; MP4 normal lines drawn; MP5 angles measured using a protractor;	accept marks on a clear, labelled diagram	4
	(ii)	axes labelled; appropriate scale with data enclosed by 3 x 3 grid or larger; points plotted correctly within ½ a square;		3
	(iii)	best fit straight line drawn with ruler;	judge by eye	1
	(iv)	evidence of gradient triangle used; evaluation of 1.6;  	accept markings on graph or evidence of a gradient calculation. accept answer in range 1.55 - 1.65 consistent with candidate's LoBF allow ecf from candidate's LoBF	2
			Total for Question = 16 marks	

Q17.

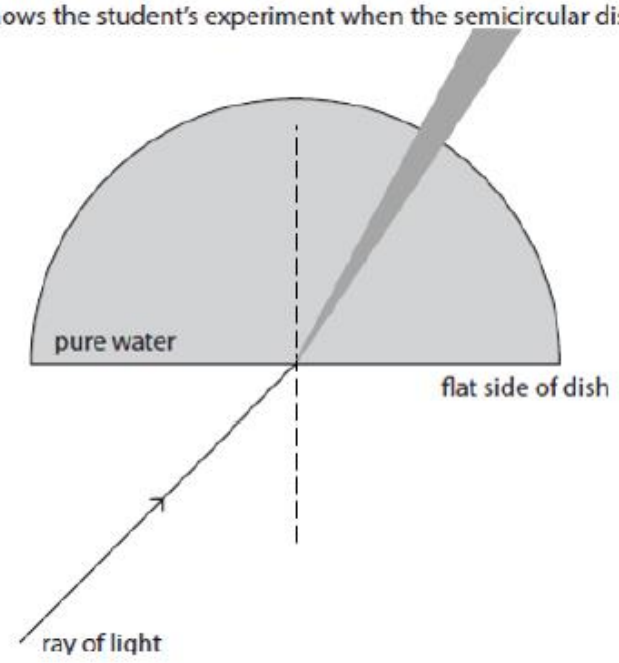
Question number	Answer	Notes	Marks
(a) (i)	light {refracts, bends, changes direction, changes speed, changes wavelength} = 1 mark; light {refracts/bends towards normal, slows down, wavelength decreases} = 2 marks;;		2
(ii)	normal;		1
(iii)	sin(c) = 1/n;	allow in words and rearrangements	1
(iv)	substitution; rearrangement; evaluation; e.g. sin(c) = 1/1.6 (c =) $\sin^{-1}(0.625)$ (c =) 39 (°)	 allow 38.68...	3
(v)	TIR at the glass/air boundary; angle of incidence = angle of reflection;	allow ecf from (iv) that would suggest refraction e.g. if answer to (iv) is greater than 50° judge by eye	2
(b)	light ray is refracted out into the air; refracting away from the normal;	ray does not need to show deviation reject if ray emerges to the left of the normal	2

Q18.

<table>
<tr><th>Question number</th><th>Answer</th><th>Notes</th><th>Marks</th></tr>
<tr><td>(a)</td><td>all 5 rows correct = 4 marks

4 rows correct = 3 marks
2-3 rows correct = 2 marks
any 1 row correct = 1 mark

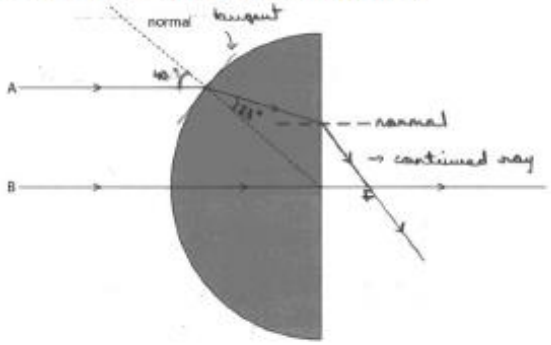
<table>
<tr><th>Variable</th><th>Independent</th><th>Dependent</th><th>Control</th></tr>
<tr><td>amount of water</td><td></td><td></td><td>✓</td></tr>
<tr><td>angle of incidence</td><td></td><td></td><td>✓</td></tr>
<tr><td>angle of refraction</td><td></td><td>✓</td><td></td></tr>
<tr><td>mass of sugar</td><td>✓</td><td></td><td></td></tr>
<tr><td>wavelength of light</td><td></td><td></td><td>✓</td></tr>
</table>
</td><td>reject row if more than one tick given</td><td>4</td></tr>
<tr><td>(b) (i)</td><td>normal drawn perpendicular to boundary where incident ray hits it;</td><td>normal only needs to be drawn on the water side of the normal</td><td>1</td></tr>
<tr><td>(ii)</td><td>ray drawn refracting in the correct direction;
angle of refraction is equal to 32 degrees;

e.g.
The diagram shows the student's experiment when the semicircular dish contains pure water.

</td><td>judge by eye - ray should intersect "mic" in "semicircular" if extended (dark grey region in diagram below)
ignore reflected rays</td><td>2</td></tr>
</table>

(c)	(i)	all points plotted correctly; **Mass of sugar in g** / **Angle of refraction in °** 0 / 32.0 25 / 31.2 50 / 30.4 75 / 29.7 100 / 28.9 125 / 28.3 150 / 26.5 175 / 27.0	allow to nearest ½ square	1
	(ii)	point at (150,26.5) circled;	allow if circled in table	1
	(iii)	smooth curve of best fit drawn that ignores anomaly;	reject straight line(s) curve should pass through every point curve does not need to extend beyond 175g	1
	(iv)	simple pattern statement e.g. as mass of sugar increases, angle of refraction decreases; relationship is non-linear;	ignore inversely proportional	2

(Total for question = 12 marks)

Q19.

Question number	Answer	Notes	Marks
(a) (i)	angle of incidence = 40 (°); angle of refraction = 23 (°);	allow 38-42 allow 21-25	2
(ii)	n = sin(i)/sin(r);	allow rearrangements reject n = i/r	1
(iii)	substitution of candidate's values into formula; evidence of sines of angles; evaluation; e.g. n = sin(40)/sin(23) n = 1.6(5)	allow ecf from (i) i.e 0.642... for sin(40), 0.390... for sin(23) reject 1.73913 or any value clearly angle of incidence divided by angle of refraction NB - using extreme values from (i), n rounds the range 1.46 to 1.87	3
(b) (i)	single ray emerges and extended to horizontal ray; ray bends away from normal by eye;  		2

(ii)	idea that F moves away from the prism; idea that red ray bends less than green at either interface; idea that red ray bends less than green at both interfaces;	i.e. the crossing point is further away or moves out allow angle of refraction is smaller at second interface allow angle of refraction is larger at first interface allow angle of refraction is closer to angle of incidence/eq condone 'less refraction'	3

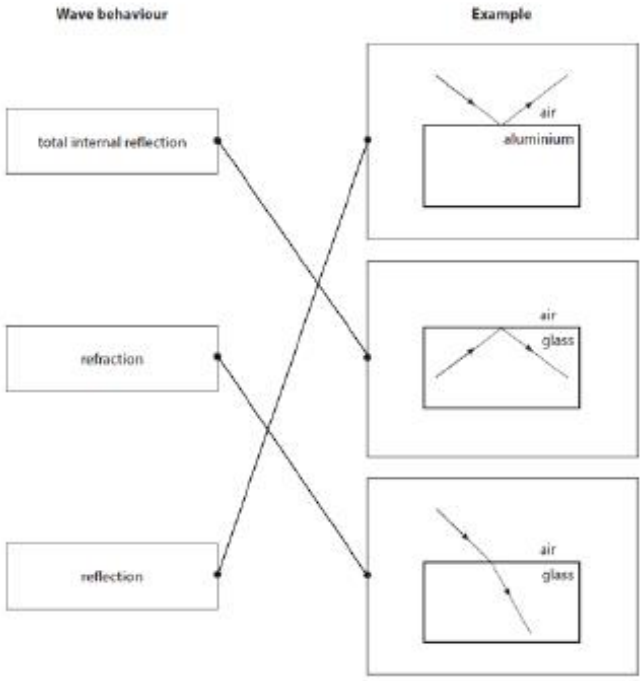
Q20.

Question number	Answer	Notes	Marks
(a) (i)	47 (°);		1
(ii)	sin(c) = 1 / n;		1
(iii)	substitution OR rearrangement; evaluation; e.g. sin(47) = 1/n OR n = 1/sin(c) (n =) 1.4	allow ecf from (i) answer is 1.37 to 3sf if (i) is given as 43° then expected answer is 1.5 to 2sf /1.47 to 3 sf	2
(b)	ray is refracting / angle of incidence is less than critical angle; critical angle for water is greater than for acetone; refractive index of water is less than for acetone;	award full marks for a correct calculation of the refractive index of water with correct conclusion e.g. $n_{water} = 1.33 < n_{acetone}$ Allow correct conclusion with $n_{water} = 0.75...$ for 1 mark MAX reject response with otherwise incorrect calculation of n_{water}	3

Q21.

Question number		Answer	Notes	Marks
(a)	(i)	angle of incidence;	ignore incident ray	1
	(ii)	recognising 67 (degrees) as anomalous; evaluation of a mean; e.g. mean angle = (22 + 23) / 2 = 23 (degrees)	allow 1 mark if anomalous result included e.g. 37, 37.3... (degrees) allow 22, 22.5 (degrees)	2
	(iii)	n calculated for multiple angles; mean value obtained for n; OR idea of graph plotted of sin(i) against sin(r); n found from gradient of (sin(i)-sin(r)) graph;		2
(b)	(i)	substitution into n = sin(i) ÷ sin(r) ; evaluation; e.g. refractive index = sin(82) ÷ sin(47) (refractive index =) 1.4	 1.3 scores 1 mark only allow 1.35...	2
	(ii)	sin(c) = 1/n;	allow any correct rearrangement	1
	(iii)	substitution and rearrangement; evaluation; e.g. $c = \sin^{-1}(1/1.7) = \sin^{-1}(0.588...)$ (critical angle =) 36 (degrees)	 allow 36.03... (degrees)	2
(c)		light undergoes TIR; (because) angle (of incidence) is greater than critical angle;		2
			Total for Question = 12 marks	

Q22.

Question number	Answer	Notes	Marks
(a)	one mark for each correct line drawn;;;  	allow line for reflection drawn to first or second example diagram allow two lines drawn from reflection to first and second diagrams only reject mark if two lines drawn from either TIR or refraction	3
(b)	any two from: (all waves) reflect; (all waves) refract; idea that (all waves) transfer energy (without transferring matter); (all waves) have amplitude/wavelength/frequency;	allow higher level common properties e.g. diffraction, interference etc. allow 'information' for energy	2
		Total for Question = 5 marks	

Q23.

Question number	Answer	Notes	Marks
(a) (i)	light ray refracting and bending in the correct direction;	ignore any response in the air e.g. reflected wavefronts or direction of travel of reflected ray	3
	wavefronts in water drawn closer together by eye;	allow wherever seen in diagram	
	wavefronts drawn in water join up with wavefronts in air;		
(ii)	wavelength decreases; (because) wave speed decreases **and** frequency remains constant;		2
(b) (i)	normal drawn at right angles where light ray meets boundary;	judge by eye	1
(ii)	55°;	allow range 54-56°	1
(iii)	substitution into sin c = 1/n; rearrangement; evaluation; e.g. sin c = 1/1.6 (c =) $\sin^{-1}$ (1/1.6) (c =) 39°	 condone intermediate rounding allow 38.682...	3
(iv)	(path shows) total internal reflection;	allow TIR	3
	(because) ray is travelling from high to low refractive index;	however expressed e.g. reduction of (optical) density / increase in speed from glass to air	
	(and) angle of incidence is greater than the critical angle;		
		Total for Question = 13 marks	

Q24.

Question number	Answer	Notes	Marks
(a) (i)	sin(c) = 1/n;	allow rearrangements and/or words for symbols	1
(ii)	substitution; rearrangement; correct evaluation to 5 s.f.; e.g. sin(88.500) = 1/n n = 1/sin(88.500) n = 1.0003	 answer of 1.00034... scores 2 marks	3
(b) (i)	straight line drawn passing into atmosphere above normal line; line bends towards normal;	 DOP accept any bend towards normal however small	2
(ii)	angle of incidence is zero; angle of refraction must be zero also;	allow idea that ray 'hits' atmosphere at 90°, ray is travelling along the normal allow angle of refraction is equal to angle of incidence	2
(iii)	any two from: • reference to speed = frequency × wavelength; • frequency is constant; • speed decreases (so wavelength must decrease);		2
(iv)	any one from: • idea that rays of light from different parts of the Sun refract by different amounts; • amount of refraction very large (when Sun is close to the horizon);		1
		Total for Question = 11 marks	