Mark scheme – Electromagnetic Waves

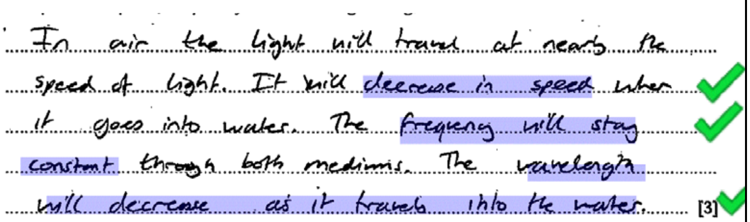
Question			Answer/Indicative content	Marks	Guidance
1			Both travel at the same speed / speed of light/ 3.0×10^8 <u>m s^{-1}</u>	B1	**Ignore** travels at 'c'
			Total	**1**	
2			C	1	
			Total	**1**	
3			(They have different) wavelength / frequency	**B1**	**Allow**: (They have different) <u>photon</u> energy / ionisation (effects) **Not** wrong physics, e.g. *X–rays have longer wavelength* **Ignore** uses of these wave(s)
			Total	**1**	
4			B	1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions. The correct key was **B**. Many candidates showed poor knowledge of this topic. The refractive index of glass is 1.5. The angle of refraction r is given by the expression $1.0 \times \sin r = 1.5 \sin 10°$. This gives 15° for the value of *r*. The most common distractor was **A**, which used the incorrect expression $1.0 \times \sin 10° = 1.5 \sin r$.
			Total	**1**	
5			**B**	**1**	
			Total	**1**	
6			**C**	1	
			Total	**1**	
7			C	1	
			Total	**1**	
8			**A**	1	
			Total	**1**	
9			**C**	**1**	
			Total	**1**	

10			B	1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions.
			Total	**1**	
11			C	1	**Examiner's Comments** All of the questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A do require careful reading and scrutiny. Candidates are advised to reflect carefully before recording their response in the box. Candidates must endeavour to use a variety of quick techniques when answering multiple choice questions. The candidates to demonstrate their knowledge and understanding of physics.
			Total	**1**	
12			**C**	**1**	
			Total	**1**	
13			**C**	**1**	**Examiner's Comments** All questions showed a positive discrimination, and the less able candidates could access the easier questions. The questions in Section A require careful inspection. Candidates can underline or circle key information to make the questions accessible. Whilst highlighter pens may be used to identify useful information in the printed question, they must not be used to record any part of the answer as they are not visible when scanned. No detailed calculations are expected on the pages, so any shortcuts, or intuitiveness, can be employed to get to the correct answers. Questions **1, 4, 5, 7, 10** and **12** proved to be particularly straightforward, allowing most of the candidates to demonstrate their knowledge and understanding of physics. Question **10** tested the learning outcome 4.5.1(e)(i) on LEDs; a good number of candidates successfully rearranged the expression $eV = hc/\lambda$ to get the correct answer **D.** At the other end of the scale, Questions **2, 8, 9** and **14,** proved to be more challenging. • Question **2** was about the refraction of light through a triangular glass prism. The most popular distractors were **D** and **B,** where the incident and emergent rays were parallel. Perhaps the candidates were thinking about a rectangular block, where such rays are parallel. Only a quarter of the candidates got the correct answer **C.** • Question **8** was about two resistors in a parallel combination and percentage uncertainty. The correct answer was **A.** The popular distractor was **B** where the candidates simply

					added the percentage uncertainties for each resistor. The best way of tackling this tough question was to use the equation $1/R = 1/R_1 + 1/R_2$ to calculate either the maximum or the minimum value of the total resistance R and then the percentage uncertainty. This question was accessible to only a quarter of the candidates. • Question **9** was about a potential-divider circuit with an LDR. The resistance of the LDR increases when the intensity of the light is reduced. The smaller current in the circuit would lead to a smaller p.d. across the fixed resistor. The answer had to be **A.** On the back of some erroneous analysis, the most frequent answer was **B.** • Question **14** was about the de Broglie wavelength of an electron when the accelerating p.d. is doubled. Less than a third of the candidates got the correct answer **B.** All the other distractors were equally popular. The logical way to tackle this would have been as follows: ○ $KE = e \times V$; doubling the p.d. V will double the kinetic energy of the electron. ○ $KE = ½mv^2$; the speed v of the electron will increase by a factor of $\sqrt{2}$. ○ $\lambda p = h$; the wavelength λ will decrease by a factor of $\sqrt{2}$.
			Total	**1**	
14			B	1	
			Total	**1**	
15			B	1	
			Total	**1**	
16			B	1	
			Total	**1**	
17			D	1	
			Total	**1**	
18			A	1	
			Total	**1**	
19			**A**	1	
			Total	**1**	

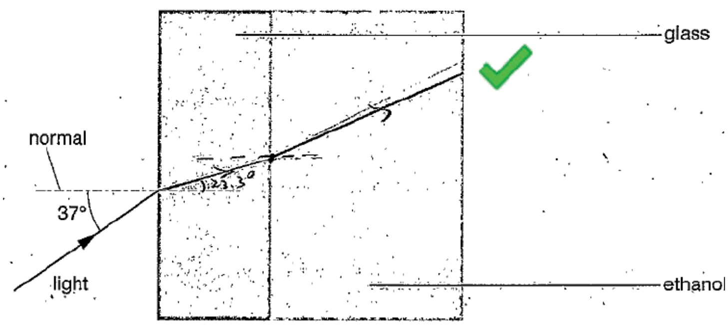
20			A	1	**Examiner's Comments** This question was about the critical angle and refractive index equation sinC = 1/*n* which appears in the Data, Formulae and Relationship Booklet. The majority of the candidates realised that the largest value of the refractive index would give the smallest critical angle. The answer had to be A. It was good to see the equation above scribbled on many of the scripts.
			Total	**1**	
21			distance = 6.0/cos 33.7 **or** 7.2 (cm) **OR** $v = 3.00 \times 10^8 / 1.50$ **or** 2.00×10^8 (m s^{-1}) $t = 7.2 \times 10^{-2} / 2.00 \times 10^8$ $t = 3.6 \times 10^{-10}$ (s)	C1 A1	**Allow** 34° **Allow** 2×10^8
			Total	**2**	
22			Microwaves from **T** are transverse/polarised wtte At 0° or 180° the grille blocks (all) the (polarised) waves <u>and</u> at 90° the grille allows all the microwaves to pass.	**B1** **B1**	**Allow** E field perpendicular to direction of motion **Allow** explanation in terms of $I = I_0 \cos^2 \theta$ **Examiner's Comments** Candidates found this question difficult. Candidates often did not state that the microwaves were polarised or mistakenly thought that the grille caused the microwaves to become polarised. Candidates also did not appear to read the question carefully often thinking that the detected signal varied from a maximum initially. Some candidates quoted $I = I_0 \cos^2 \theta$ to help explain their answer.
			Total	**2**	
23			Straight line to centre of block and reflects along original ray P Straight line to centre of block and refracts with angle *q* less than 49.9° but greater than 30°	B1 B1	
			Total	**2**	
24			No sideways momentum before hits ground	B1	AW

			Movement in opposite sideways directions needed to conserve momentum	B1	
			Total	**2**	
25			Use a polaroid / polarising filter Rotation will change intensity	B1B1	**Allow** brightness / light **Examiner's Comments** Most candidates scored well deserved 2 marks here for opting to use a polarising filter and rotating it to see variation in the intensity of the transmitted light. A small number of candidates chose the wrong equipment – the most common of these were diffraction grating, a single slit and microwave receiver.
			Total	**2**	
26			c = *f*λ **or** *f* = 3.0 × 10^8 / 0.60 *f* = 5.0 × 10^8 (Hz)	C1 A1	**Allow** *v* = *f*λ **Allow** 5 × 10^8
			Total	**2**	
27		i	(*f* = *v*/*λ*) = 3.00 × 10^8 ÷ 4.69 × 10^{-7} (= 6.40 × 10^{14} Hz)	B1	6.397 × 10^{14} Hz
		ii	1.96 × 10^8 (ms^{-1}) 3.07 × 10^{-7} (m)	B1 B1	**Allow** 3.06 × 10^{-7} (m) (uses **(i)**) **Not** ECF for incorrect speed
			Total	**3**	
28			Diagram showing angle within the block measured relative to the normal Increase the (incident) angle until the ray of light runs along the boundary / suffers total internal reflection (ORA) **or** angle measured using a protractor *n* determined using *n* = 1/sin*C*	B1 B1 B1	Allow *i* / *θ* / *C* as the angle to be measured. Must be clear which angle is being measured. Expect the normal as a line perpendicular to straight edge of block, and emergent ray.No labels expected for the rays or the normal. Formula in this arrangement **Examiner's Comments** This question required a knowledge of how to practically determine the refractive index using the given apparatus. It was clear that candidates were not sure how to carry out this experiment correctly and responses often were confusing with a misconception of what the critical angle is. It was often not clear what angle was being measured as many different angles were usually drawn on the diagram. Many candidates showed the ray of light entering the straight face of the block which would make it impossible to determine the critical angle.
			Total	**3**	

29			(k.e. =) $E = 5.0 \times 10^6 \times 1.6 \times 10^{-19}$ $v = \sqrt{(2E/m)}$ **or** $= \sqrt{(2 \times 8.0 \times 10^{-13} / 6.6 \times 10^{-27})} = 1.6 \times 10^7$ (ms^{-1}) p (= mv) = $6.6 \times 10^{-27} \times 1.6 \times 10^7$ giving $p = 1.1 \times 10^{-19}$ (kg m s^{-1})	C1 C1 A1	$E = 8(.0) \times 10^{-13}$ J **or** ($E = p^2/2m$ so) $p = \sqrt{(2mE)}$ **Note:** A value of $v = 1.6 \times 10^7$ (ms^{-1}) automatically scores both C1 marks even if the calculation for E is not shown **or** p (= $\sqrt{(2mE)}$ = $\sqrt{(2 \times 6.6 \times 10^{-27} \times 8.0 \times 10^{-13})}$ giving $p = 1.0 \times 10^{-19}$ (kg m s^{-1}) Full substitution of values must be shown and answer (if calculated) must be correct **Examiner's Comments** This question provided an excellent opportunity for candidates to produce immaculate responses: identify the physics involved, select and write down the correct formula, do the necessary conversion (MeV to J), rearrange the formula, substitute correctly and then write the final response in standard form to a correct number of significant figures. Some of the common errors were: • forgetting to convert 5.0 MeV into J • not showing a full substitution of values (which is necessary for a 'show that' question) • not calculating the response to more than 1 s.f. (which is necessary for a 'show that' question).
			Total	**3**	
30	a		Speed of light is less in water (ORA) Frequency is the same (in both) Wavelength is smaller in water (ORA)	**B1** **B1** **B1**	**Allow** calculated values for air **and** water **Allow** speed decreases (from air to water) **Not** v or c **Allow** f is the same **Allow** wavelength / λ decreases (from air to water) **Examiner's Comments** Most candidates gained two or more marks. Many candidates were aware that the speed of light was less in water than in air. A significant number of candidates also knew that the frequency of light remains constant and successfully argued the fate of the wavelength using the wave equation $v = f\lambda$. **Exemplar 12**  In air the light will travel at nearly the speed of light. It will decrease in speed when it goes into water. The frequency will stay constant through both mediums. The wavelength will decrease as it travels into the water. [3] This exemplar illustrates a flawless answer from a top–end candidate. It had all the main ingredients for scoring 3 marks. The

					answers matched well with the marking points – the examiner had no issues with following the text.
	b		Laser / ray box **or** protractor mentioned Ray diagram showing (incident) ray **within** the block, (refracted) ray along the straight edge of block **and** critical angle marked between the incident ray and the normal (Refractive index determined using) $n = 1/\sin C$	**B1** **B1** **B1**	**Not** 'ray of light' for laser / ray box **Allow** *C*, critical angle, θ or *i* for the angle marked between the incident ray and normal **Note**: No labelling of rays or normal is required **Ignore** direction of rays **Ignore** any internally reflected ray **Note** this mark is for the **ray diagram. Ignore** description, unless there are <u>multiple</u> refracted rays shown **Allow** any subject and terms do not need to be defined **Not** bald '$n_1\sin\theta_1 = n_2\sin\theta_2$' **<u>Examiner's Comments</u>** The range of marks was poor in this practical question on refraction and critical angle. Most candidates did score a mark for selecting the correct expression for critical angle and refractive index from the Data, Formulae and Relationships booklet. The ray diagram lacked clarity and often showed incorrect critical angle in the air, rather than within the block. There were many missed opportunities here. No credit could be given for generic PAG–type description involving a rectangular block and plotting sini against sinr graph.
			Total	**6**	
3 1			Clear indication that angles of incidence and refraction are being measured relative to the normals refractive index = sin*i*/sin*r* Any <u>one</u> from: • Measure angle(s) using a protractor • Plot sini against sinr graph or average sin*i* /sin*r* value<u>s</u> • Use narrow beam of light (for ray box) / draw thin pencil lines • Conduct experiment in a dark room	B1 B1 B1	Note this can be scored from a clear diagram. The angles must have sensible labels, e.g. *i, r, θ1,* ***θ****2*, etc Ignore angle of refraction > angle of incidence **Allow** *n* for refractive index **Allow** $n_1\sin\theta_1 = n_2\sin\theta_2$, as long as all labels have been correctly identified <u>and</u> the refractive index for air/vacuum is taken as 1 **Not** $n = c/v$ **<u>Examiner's Comments</u>** This question produced a wide spectrum of marks, with only the upper quartile of the candidates generally securing 2 or 3 marks. Candidates are reminded that if a diagram is drawn to support an answer, it must be adequately annotated. On many scripts, the normal was missed out and the angles of incidence and refraction were marked incorrectly (often between the light beam and the straight edge of the rectangular block). A significant number of candidates decided to change the block to a semi-circular one, and focused erroneously on determining the refractive index n using the critical angle equation sin*C* = 1/*n*.
			Total	**3**	

32			The ray is refracted away from the normal, therefore the refractive index of water is less than the refractive index of glass or speed of light in water is greater than the speed of light in glass.	B1	
			The frequency remains constant.	B1	
			$v = f\lambda$ and therefore the wavelength of light increases as it travels from glass to water.	B1	
			Total	**3**	
33			1.00 × sin56.3 = 1.50 × sin*r* (Any subject) *r* = 33.7° Correct working / reasoning leading to 90.0° (e.g. *θ* = 180 − (56.3 + 33.7), therefore *θ* = 90.0°)	M1A1 A1	**Allow** with or without the 1.00 **Allow** 34° **<u>Examiner's Comments</u>** Generally, candidates answered this question well with most making a good start with the equation *n*sinθ = constant. Most candidates correctly calculated the angle of refraction to be 33.7°; only a small proportion lost marks because of rounding errors. The final mark was reserved for steps clearly showing that the angle *θ* marked on the figure was equal to 90.0°. A pleasing number of candidates annotated the figure with angles and labels in order to ensure this last mark was picked up. A very small number of candidates attempted to either use sin*C* = 1/*n* or omitted *n*sinθ = constant altogether.
			Total	**3**	
34	a	i	1.36 1.97×10^8	**B1** **B1**	**Not** 1.3 or 1.4 **Not** 1.9 or 2.0 **<u>Examiner's Comments</u>** This question was generally well answered. Some lower ability candidates were careless in the calculation of the speed of light in glass and gave their answers as either 1.9 or 2.0 as opposed to 1.97. There were also some candidates who gave an answer of 4.56×10^8 m s^{-1} – this is where candidates should check the pattern in the table.
		ii	$\left(\frac{5.2\times10^{-7}}{1.52} =\right)$ $3.4(2) \times 10^{-7}$ (m)	**B1**	**Allow** 3.41×10^{-7} (m) **Not** ECF from (a)(i)

					Examiner's Comments Surprisingly, this question did not score highly – many candidates did not realise that the wavelength of light in the glass would be the wavelength of light in air divided by the refractive index of glass.
	b	i	$\sin\theta = \frac{\sin 37}{1.52} (= 0.39593)$ θ = 23(.3)°	C1 A1	**Examiner's Comments** Many candidates correctly applied Snell's law. Common mistakes were either using the wrong refractive index or inverting the answer.
		ii	Ray in glass bends towards normal and ray in ethanol bends away from normal but at a smaller angle than 37° Rays are straight by eye	B1	**Note** Ray should not be parallel to incoming ray. **Not** angle of refraction is zero in glass **Examiner's Comments** This question required candidates to apply the previous answers to this question to draw an appropriate ray diagram. Candidates do need to use a ruler. A common error was for the emergent ray in the ethanol to be parallel to the incident ray in the air. This question required candidates to think through their diagram stage by stage using information from the previous part and the table given earlier in the question. **Exemplar 8**  This candidate has used a ruler and drawn straight rays. The candidate has marked on the normal and indicated the angle of refraction in the glass. It is clear that the ray in the ethanol is not parallel to the original ray.
			Total	**6**	
35		i	3 downward arrows correctly labelled.	B1	longest being 4.33 × 10^{-7} (m)
		ii	ΔE = hc/λ	C1	
		ii	λ = 6.63 × 10^{-34} × 3 × 10^{8}/ 4.8 × 10^{-20} = 4.1(4) × 10^{-6} (m)	A1	
		ii	region: infra red	B1	**allow** ecf if wavelength calculation incorrect.

			Total	**4**	
3 6		i	Microwave: 2 cm X-ray 200 pm	B1 B1	
		ii	Any two from: May be reflected / refracted / diffracted / interference May be polarised Travel in a vacuum (at a constant speed / 3 x 108 m s-1) Oscillation of electric and magnetic fields.	B1 × 2	**Allow** speed of light
			Total	**4**	
3 7		i	It is longitudinal	B1	
		ii	Loudspeaker, microphone / ear and slit Sound spreads from the slit AW Size of slit comparable to the wavelength (of sound)	B1 B1 B1	**Allow** doorway for a slit / gap - receiver for microphone **Not** diffraction (since it is in the stem of the question)
			Total	**4**	
3 8		i	sin *C* = 1/*n* = 1/1.69 (= 0.592) *C* = 36°	C1 A1	
		ii	Total internal reflection occurs because the angle of incidence (at the surface) is greater than the critical angle/ 36°	B1 B1	**allow** because i > *C* **Examiner's Comments** Almost all of the candidates managed to calculate the critical angle correctly. The explanation in part (ii) was not so successful. The majority gained the mark for total internal reflection but most omitted the crucial words of *incidence* to qualify which angle must be greater than the critical angle. The example here (exemplar 10) shows the perfect succinct answer. **Exemplar 10**

					the crystal has a higher refractive ind than air and the angle of incidence i greater than the critical angle, so the light undergoes total internal reflecti
			Total	**4**	
3 9	a		Photon(s) mentioned One-to-one interaction between photons and electrons Energy of photon is independent of intensity / intensity is to do with rate (of photons / photoelectric emission) / photon energy depends on frequency / energy of photon depends on wavelength / photon energy ∝ frequency / photon energy ∝ $1/\lambda$ energy of uv photon(s) > work function (of zinc) / frequency of uv > threshold frequency	B1 B1 B1 B1	**Allow** 'photon absorbed by an electron' **Allow:** collide etc. for interaction **Allow** $E = hf$ or $E = hc/\lambda$ **Allow** energy of light photon(s) < work function (of zinc) / frequency of light > threshold frequency **Allow** ≥ instead of > here **Not** $f > f_0$ **Examiner's Comment** Many candidates wrote enthusiastically about photoelectric effect and understood the significance of work function energy (or threshold frequency) and the one-to-one interaction between photon and an electron. Some candidates did not mention 'photons' and this limited the marks they could acquire. The role of intensity was less understood. Many candidates thought it was linked to 'the *number of photons'* or *'the amount of electrons emitted.* The important term **rate** of the missing ingredient. Top-end candidates gave eloquent answers, typified by the response: *'intensity of visible light only affects the rate of photons incident on the plate but not the energy of each photon'*. Two common misconceptions were: • Photons were emitted from the negative plate. • Confusing threshold frequency and work function energy.
	b		$\phi = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.9\times10^{-7}}$ or 6.86 × 1 E = 5.1 × 1.60 × 10^{-19} or 8.16 × 10^{-19} (J) max kinetic energy = (8.16 − 6.86) × 10^{-19} max kinetic energy = 1.3 × 10^{-19} (J)	C1 C1 A 1	**Note:** Using 5.1 and not 8.16 × 10^{-19} cannot score this mark or the next mark **Allow** 2 marks for 0.81 eV **Examiner's Comment** This was a notable success for most of the candidates. Examiners were pleased to see a range of techniques being used to get the correct answer of 1.3 × 10^{-19} J. Many answers showed excellent structure, effortless conversion of energy from electronvolt to joule and excellent use of the calculator when dealing with powers of ten. Most candidates scored three marks. A small number of candidates

					left the final answer as 0.81 eV; the only thing missing was the conversion to J.
	c		Any <u>three</u> from: The electrons are repelled by **C** / electrons travel against the electric field (AW) The electrons are emitted with a ‘range’ of speed / velocity / kinetic energy (AW) As *V* increases the slow(er) electrons do not reach **C and** hence *I* decreases maximum KE in the range 2.1 <u>eV</u> to 2.2 <u>eV</u> or 3.36 × 10^{-19} <u>J</u> to 3.52 × 10^{-19} <u>J</u>	B1×3	**Note** ‘range’ can be implied by ‘highest’ or ‘lowest’ **Allow** ‘find p.d. when current is (just) zero, and then KE = $e \times V$ **Examiner’s Comment** The electrons emitted from the metal plate have a **range** of kinetic energy. The emitted electrons are repelled by the negative electrode **C.** Fewer electrons reach **C** as the p.d. is increased. When the p.d. is about 2.2 V, and the current zero, the most energetic electron are stopped from reaching **C.** This makes the maximum kinetic energy of the electrons equal to 2.2 eV or 3.4 × 10^{-19} J. The question baffled most candidates. Some top-end candidates commented on *‘the electrons repelled by C’* and the maximum kinetic energy of the emitted electrons being 2.2 eV. Such answers were rare. Too many candidates made guesses with answers such as *‘the current drops because resistance increases’* and *‘temperature increases and hence the current decreases’*.
			Total	**10**	
40	a		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	**Allow** astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut) **<u>Examiner’s Comments</u>** **Misconception** Experiencing weightlessness is not the same as being in freefall There was a lack of understanding of the nature of feeling weightless. The sensation of ‘weightlessness’ is a lack of the physiological sensation of ‘weight’. The skeletal and muscular systems are no longer in a state of stress. This sensation is caused by a lack of contact forces as a result of the ISS and the astronaut experiencing the same acceleration. Common incorrect responses included: • the astronaut is weightless because he is falling • there is no resultant force on the astronaut • gravity is too weak to have any effect on the astronaut • the ISS orbits in a vacuum where there is no gravity.
	b	i	M = 5.97 x 10^{24}(kg) **or** ISS orbital radius R = 6.78 x 10^{6}(m) **or** $g \propto 1/r^2$	C1 C1	

			(gr^2 = constant so) g x (6.78 x 10^6)^2 = 9.81 x (6.37 x 10^6)^2 g = 8.66 (N kg^{-1})	A1	**or** g (= GM/R^2) = 6.67 x 10^{-11} x 5.97 x 10^{24} / (6.78 x 10^6)^2 **Allow** rounding of final answer to 2 SF i.e. 8.7 (N kg^{-1}) **Examiner's Comments** The simplest method here was to use the fact that g is inversely proportional to r^2, so gr^2 = constant. If this was not used, a value for the mass of the Sun had to be calculated, which introduced a further step. Candidates who omitted this calculation and used a memorised value of the Sun's mass instead were unable to gain full marks, because they invariably knew it to 1 s.f. only, whereas 3 were required. Errors occurred when candidates used the incorrect distance in the formula for g. Common errors included: • forgetting to square the radius • using the Earth's radius rather than the orbital radius of the satellite • calculating (6.37 × 10^6 + 4.1 × 10^5) incorrectly.
		ii	$2\pi r/T = v$ **or** T = 2 × 3.14 × 6.78 × 10^6 / 7.7 × 10^3 T = 5.5 × 10^3 s (= 92 min)	M1 A1	**ECF** incorrect value of R from **b(i)**
	c		$\frac{1}{2}Mc^2$ ($\frac{1}{2}N_Amc^2$) = $\frac{3}{2}RT$ c^2 = 3 × 8.31 × 293 / 2.9 × 10^{-2} = 2.52 × 10^5 $\sqrt{c^2}$ = 500 (m s^{-1}) (= 7.7 × 10^3 / 15)	C1 C1 A1 A0	**or** $\frac{1}{2}mc^2 = \frac{3}{2}kT$ **or** $c^2 = 3kT/m$ **or** c^2 = 3 ×1.38 x 10^{-23} × 6.02 x 10^{23} x 293/2.9 × 10^{-2} = 2.52 × 10^5 **not** (7.7 × 10^3 / 15) = 510 (m s^{-1}) **Examiner's Comments** The success in this question depended on understanding the meaning of the term m in the formula $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ given in the Data, Formulae and Relationship booklet. A significant number of candidates took m to be the mass of one mole (the molar mass, M) whereas m is actually the mass of one molecule. Candidates who used the formula $\frac{1}{2}M\overline{c^2} = \frac{3}{2}RT$ were usually more successful because the molar mass had been given in the question stem.
	d		power reaching cells (= IA) = 1.4 × 10^3 × 2500 = 3.5 × 10^6 W power absorbed = 0.07 × 3.5 × 10^6 = 2.45 × 10^5 W cells in Sun for (92 – 35 =) 57 minutes average power = 57/92 × 2.45 × 10^5 = 1.5 × 10^5 (W)	C1 C1 C1 A1	mark given for multiplication by 0.07 at any stage of calculation (90 – 35 =) 55 minutes using T = 90 minutes **ECF** value of T from **b(ii)** 55/90 × 2.45 × 10^5 = 1.5 × 10^5 (W) using T = 90 minutes **Examiner's Comments** Although this question looked daunting, it was actually quite linear and many candidates who attempted it were able to gain two or

					three marks even if they did not eventually get to the correct response. Candidates who set out their reasoning and working clearly were more liable to gain these compensatory marks.
			Total	**13**	
41		i	$I = I_0/r^2$ or $I = kr^{-2}$	B1	**allow** inverse square law statement
		i	(k = 20) so I = 20/(0.25)^2 = 20 × 16 = 320	B1	
		ii	640	B1	
		iii	640 = 20/r^2	C1	**ecf(ii)1**
		iii	so r = √(20/640) = 0.18 (m)	A1	**accept** 0.177 (m)
			Total	**5**	
42	a		(When two or more waves meet at a point in space) the resultant (displacement) is equal to the (vector) sum of the individual <u>displacements</u> of waves (meeting at a point)	**B1**	**Allow** total / Σ / net for resultant **Not** amplitude for displacement **Examiner's Comment** Most candidates made a poor start to Section B by incorrectly stating the principle of superposition. Instead of *'the resultant displacement being the sum of the individual displacements of the waves',* candidates wrote about the addition of **amplitudes.** Some simply wrote about constructive (or destructive) interference and stationary waves.
	b	i	Clear evidence of at least two fringe separations used to determine *x* **and** *x* in the range 7.0 to 9.0 mm $\lambda = \frac{0.25\times10^{-3}\times8\times10^{-3}}{4.25}$ (Allow any subject) *A* = 4.7 × 10^{-7} (m)	**B1** **C1** **A1**	**Expect** 8 (mm) **Allow** ecf for incorrect value of *x* **Examiner's Comment** One mark for this question was reserved for accurately determining the separation *x* between adjacent fringes using at least two fringe separations. About a quarter of the candidates did this and secured maximum marks for calculating the wavelength of blue light. A wide range of 7 mm to 9 mm was allowed for *x.* Most candidates used the correct equation and had no problems with powers of ten. Almost all the answers were written in standard form.
		ii	Red light has longer wavelength / *λ* **and** separation between fringes increases (AW) Separation between fringes justified	**M1** **A1**	**Allow** other acceptable labels for *D* and *a* **Examiner's Comment**

			in terms of $x \propto \lambda$ or $x = \lambda D / a$, *D* <u>and</u> *a* are constants		This was generally well answered with most candidates giving correct explanation of why the fringe pattern was more spread out. Many candidates wrote concise answers such as '*the fringe separation increases because red light has longer wavelength and fringe separation x wavelength'*. The two most common errors were: • Red light has shorter wavelength than blue light. • The pattern had something to do with the refraction of light through the double-slit.
			Total	**6**	
4 3			**Level 3 (5 – 6 marks)** Response shows clear distinction between investigations; clear and correct reasoning is given for the situations which give maximum / minimum readings in <u>both</u> cases, including correct numerical values *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3 – 4 marks)** Response refers to both investigations; some reasoning is given for the situations which give maximum / minimum readings in <u>both</u> investigations, including some numerical values *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited reasons are given for the situations which give maximum / minimum readings in <u>either</u> investigation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1 x 6	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc.** **Indicative scientific points may include:** **explanation 1** • receiver aerial vertical – electrons are driven (maximum distance) up and down along the length of the aerial because the oscillations (of the electric field) are vertical, causing maximum (a.c.) current • receiver aerial horizontal – electrons are driven (minimum distance) across the aerial because the oscillations (of the electric field) are only in the vertical plane (no oscillation along the aerial to cause current), so zero / minimum current • rotation of receiver aerial by ± 90° (or 90° and 270°) from vertical leads to zero current **explanation 2** • reflected wave superposes with incident wave at receiver aerial • coherent waves as from same source • constructive interference / waves in phase gives max current • reflected wave has travelled nλ further, n = 0,1, etc • so max current when plate is at λ/2, 2λ/2, etc from receiver aerial, i.e. 30, 60 cm • destructive interference / waves 180° (π rad) out of phase gives zero current • reflected wave has travelled (2n +1)λ/2 further, n = 0,1, etc • so zero current when plate is at λ/4, 3λ/4, etc from receiver aerial, i.e. 15, 45 cm • reflected signal will be weaker the further it has to travel so no longer complete cancellation (ammeter reads close to zero) **Note:** Give full credit to candidates who take the 180° (π rad) phase change on reflection into account, which gives max current at 15, 45 cm etc and zero current at 30, 60 cm etc. **<u>Examiner's Comments</u>**

					This was the second of the two LoR questions in this paper. It required knowledge of polarisation, superposition and interference. There is no one perfect model response but generally, for Level 3, candidates were required to give clear reasoning for the situations which gave both maximum and minimum readings in both investigations. Such candidates included correct numerical values in their responses (although 'half a wavelength' was acceptable in place of 30cm). Level 2 responses were sometimes incomplete (e.g. giving the maximum position but not the minimum position) or confused (e.g. the maximum and minimum positions were given but were the wrong way around). Level 1 responses came from candidates who misunderstood the physics of one of the situations, or who confused phase difference and path difference, or whose descriptions were generally too vague to gain much credit. It may be helpful to point out that investigation **2** was not about the formation of a stationary wave; rather, it was about two overlapping coherent waves forming regions of constructive and destructive interference. A common misconception was that the maximum and minima signals were related to antinodes and nodes. ? **Misconception** A minimum or zero reading does not occur when two waves are merely out of phase. They must be *completely* out of phase. The best way to describe this is to say that they are **in antiphase**.
			Total	**6**	
4 4			**Level 3 (5–6 marks)** Clearly labelled diagram. Procedure is correct including appropriate measurements Analysis is correct and includes A5. (6 marks) Any point omitted or incorrect (5 marks). *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Good diagram. Most measurements made Some analysis. (4 marks) Any point omitted or incorrect (3 marks). *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.*	B1 x 6	**Diagram** 1. Labelled diagram of glass block & ray box 2. Incident and refracted rays shown 3. Normal shown and correct i and r **Procedure** 1. Block placed on paper 2. Incident and refracted rays marked 3. Angles measured using a protractor **Analysis** 1. sin i and sin r calculated 2. sin i against sin r graph plotted 3. Straight line of best fit drawn 4. gradient = refractive index (n) 5. Error bars drawn to find the gradient

			Level 1 (1–2 marks) Basic diagram with incomplete labels. Some measurements. Limited analysis. (Maximum 2 marks) *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.		
			Total	**6**	
4 5		i	(speed in material =) $\frac{3.0 \times 10^8}{1.20}$ **or** 2.5×10^8 (ms^{-1}) (t_V =) $\frac{1.5 \times 10^{-6}}{3.0 \times 10^8}$ **or** 5.0×10^{-15} (s) (t_M =) $\frac{1.5 \times 10^{-6} \times 1.20}{3.0 \times 10^8}$ **or** 6.0×10^{-15} (s) $t = [6.0 – 5.0] \times 10^{-15} = 1.0 \times 10^{-15}$ (s)	C1 C1 C1 A0	**Allow other correct methods** **Note** omitting or incorrect use of 1.2 is XP **Allow** 1 SF answer 5×10^{-15} **Allow** 1 SF answer 6×10^{-15} **Note** this also scores the first C1 mark **Note** omitting or incorrect use of 1.2 is XP **<u>Examiner's Comments</u>** Generally, candidates answered this question extremely well and most scoring full marks In **(c)(i)**, the solutions ranged from being well-structured to an assortment of equations and substitutions filling the entire answer space. Equations for refractive index and speed were easily used to show the answer to be 1.0×10^{-15} s. In **(c)(ii)**, candidates either calculated the frequency of 5.0×10^{14} Hz and then used $T = f^{-1}$ or calculated T directly using $T = \frac{6.0 \times 10^{-7}}{3.0 \times 10^8} = 2.0 \times 10^{-15}$ s. **(c)(iii)** provided some discrimination with middle and top candidates getting the correct answer of 180°. As always, error carried forward (ECF) rules apply in calculations. This helped those candidates who got an incorrect answer of 2.4×10^{-15} s in **(c)(ii)** to score a mark for 150°. **Misconception** There were some missed opportunities, with some candidates making the following mistakes.

					• In **(c)(i)** calculating the difference in the time for the two rays by halving the period of 2.0×10^{-15} s. • In **(c)(ii)** using the wavelength in vacuum of 6.0×10^{-7} m but the incorrect speed of 2.5×10^{8} ms^{-1} to calculate the period. This gave an answer of 2.4×10^{-15} s; examiners allowed 1 mark for this method. • In **(c)(iii)**, a small number of candidates, mainly at the low-end, confused the symbol φ for phase difference to be work function. This produced some bizarre answers.
		ii	$(f =) \frac{3.0\times10^{8}}{6.0\times10^{-7}}$ **or** 5.0×10^{14} (Hz) **or** $(T =) \frac{6.0 \times 10^{-7}}{3.0 \times10^{8}}$ $T = 2.0 \times 10^{-15}$ (s)	C1 A1	**Allow** 1 SF of 2×10^{-15} **Allow** 1 mark for 2.4×10^{-15} (s); 2.5×10^{8} ms^{-1} used
		iii	$\varphi = 180°$	B1	Possible ECF from **(i)** and **(ii)** **Note** answer must be φ = **(c)(i)** × 360°/**(c)(ii)** **Not** an answer in rad, e.g. π rad
			Total	**6**	
46		i	(refraction index) = speed of light in vacuum ÷ speed of light in material	B1	**Note** light must be mentioned at least once **Allow** n = c / v if all terms defined **Allow** ration of speed of light in vacuum to speed of light in material **NOT** speed of light in air for c
		ii	1 Frequency (of light) is the same (in **A** and **B**) (Light travels) slower in **B or** $v_B = 0.77\ v_A$ ORA $v = f\lambda$ and $\lambda_B < \lambda_A$ 2 *sin60° = 1.3 × sinθ* *θ= 42 (°)* *(No total internal reflection)* 3 *Internal reflection / critical angle can only occur for light travelling from **B** to **A** AW*	B1 B1 B1 C1 A1 B1	**Allow** *f* for frequency **Allow** *v* directly proportional to *k* ***Allow*** *TIR can only occur for light entering an optically less dense material / lower refractive index ORA* ***Not*** $\theta < \phi$
			Total	**7**	
47		i	**1.** $p = 30°$ **2.** sin q = 0.5 × 1.53 or 0.765 $q = 50°$	B1 C1 A1	**Allow** 49.9° **Note** 19 ° does not score
		ii	p always equals i or p increases with i / when i = 60°, p = 60° Any three from:	B1 B1 ×3	

			as i increases, q increases (until i equals the critical angle) when i = critical angle, q = 90° critical angle = 41° when i is greater than critical angle, total internal reflection occurs when i = 60°, there is no angle q or no refracted ray		**Not** q = 0
			Total	**7**	