A Level AQA Physics

28 Wave particle duality and special relativity – answers

OXFORD Revise

Question	Answers	Extra information	Mark	AO	Spec reference
01.1	The speed of light is 3.0×10^{8} m s^{-1} Estimate of distance: 3000 m–10 000 m Time for light to travel that distance = $\frac{d}{v}$ For 3000 m: $t = \frac{3000}{3.0\times10^{8}} = 10^{-5}$ s For 10 000 m: $t = \frac{10\,000}{3.0\times10^{8}} = 3.3\times10^{-5}$ s The time is far too short to be measured with the instruments of the time	Estimation of distance Calculation of time and comment	1 1	2	3.12.1.3
01.2	A toothed wheel that was rotated at high speed Pulses of light were transmitted through the gaps in the wheel At low speeds of rotation, light from the source passed through a gap and then passed through the same gap on its return so the observer could see the light As the speed of rotation increased, there came a time when the returning beam was blocked by the adjacent tooth The difference between these two speeds could be used to calculate the time it took for light to travel		1 1 1 1 1	1	3.12.2.3
01.3	Total distance travelled by the light = 2 × 8630 m = 17 260 m Time to travel this distance = $\frac{d}{v} = \frac{17\,620}{3.0\times10^{8}} = 5.87\times10^{-5}$ s A tooth replaces a gap after $\frac{1}{2n}$ of a revolution, where n = number of teeth, so $\frac{1}{1440}$ There is one revolution in $\frac{1}{f}$ seconds, then the tooth replaces the gap in $\frac{1}{1440}f = 5.87\times10^{-5}$ s $f = \frac{1}{1440\times5.87\times10^{-5}\text{ s}} = 11.8$, or 12 rotations s^{-1}	Calculation of time Relationship between time and frequency Answer	1 1 1	2	3.12.2.3

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01.4	Similarity: A beam of light from a light source is split by the mirror Difference: The Michelson-Morley experiment involved two measurements at 90° angles; the Fizeau equipment did not move		1 1	3	3.12.2.3 3.12.3.1
02.1	An alternating potential difference To make the electrons in the dipole oscillate Oscillating electrons produce oscillating electric and magnetic fields		1 1 1	1	3.12.2.3
02.2	The oscillating fields produce a force on the electrons in the receiver A changing potential difference/current is produced in the dipole that is detected as the signal		1 1	1	3.12.2.3
02.3	Electromagnetic waves emitted by the dipole are polarised/plane polarised so the receiving dipole needs to be in the same plane as the transmitter to detect any waves		1 1	2	3.3.1.2
02.4	Distance from node to node = $\frac{\lambda}{2}$ Wavelength = 30 cm, frequency = 1 GHz = 10^9 Hz $v = f\lambda = 0.3 \times 10^9$ Hz $= 3 \times 10^8$ m s^{-1}	Correct wavelength Substitution/answer	1 1 1	2	3.12.2.3
02.5	The expression for the speed according to Maxwell is independent of frequency The speed of electromagnetic waves depends on two constants: ε_0, μ_0		1 1	3	3.12.2.3
03.1	A black body emits all wavelengths of radiation that are possible for that temperature		1	1	3.12.2.4

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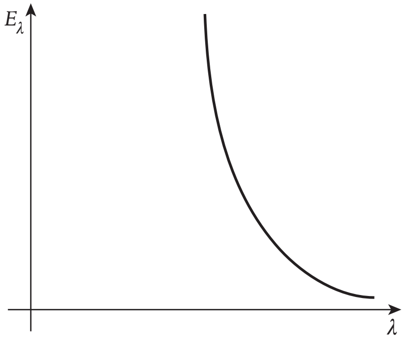
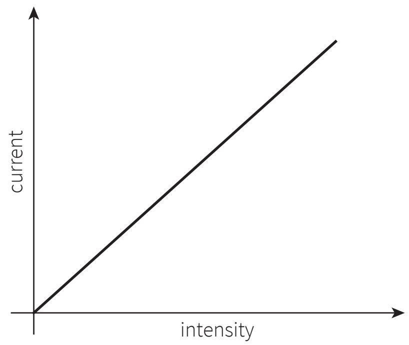
03.2	 Most of the energy is emitted at short (ultraviolet) wavelengths/would become infinite at very short wavelengths	Negative gradient Correct shape Correct comment	1 1 1	1	3.12.2.4
03.3	An energy quantum is hf High frequency/low wavelength radiation is emitted in larger 'chunks' of energy		1 1	2	3.12.2.4
03.4	Photons are quanta that have an energy related to frequency Particles with momentum show wave behaviour, so photons have momentum A change in momentum produces a force		1 1 1	3	3.12.2.4
04.1		Positive relationship (straight or curved) Correctly labelled axes	1 1	3	3.12.2.4
04.2	Yes, more intense radiation transfers more energy per second, releasing more electrons per second, producing more current		1 1	3	3.12.2.4

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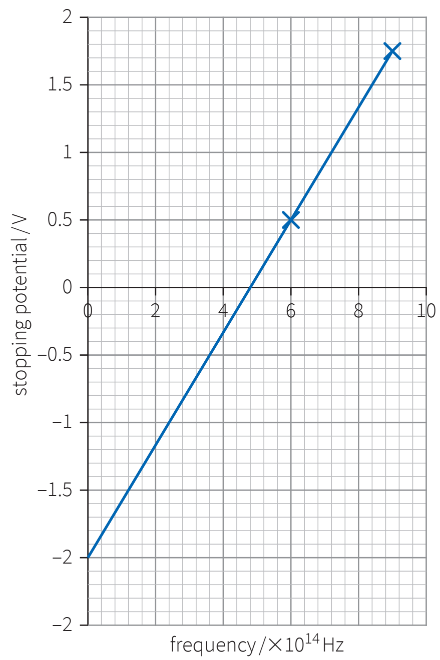
04.3	The power supply can be turned around So that the potential can be applied so as to stop the electrons = stopping potential		1 1	2	3.12.2.4
04.4	$eV_{\text{stopping}} = \frac{1}{2}mv^2 = hf - \phi$ $\phi = hf - eV_{\text{stopping}}$ $= 6.63\times10^{-34} \times 6.00\times10^{14} - 1.60\times10^{-19} \times 0.5$ $= 3.97\times10^{-19} - 0.8\times10^{-19}$ $= 3.07\times10^{-19}$ J	Use of equation Substitution of one pair of numbers. Answer	1 1 1	2	3.12.2.4
04.5	Either: Plot a graph of stopping potential against frequency. There will be a threshold below which no electrons are emitted, so the stopping potential is zero, which is not explained by wave theory 		 1 1	3	3.12.2.4

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	Or: Equation of line is $V_{stopping} = \frac{hf - \phi}{e}$ so $V_{stopping} = 0$ when $hf = \phi$				
05.1	1 nm/10^{-9} m		1	1	3.12.2.6
05.2	The electrons behave like (matter) waves with a wavelength $\lambda = \frac{h}{mv}$, which can be the order of magnitude of 1×10^{-10} m For sufficiently small gaps or barrier, the amplitude of the matter wave decreases, but does not fall to zero, so there is a probability of finding an electron the other side of the barrier or gap		1 1	1	3.12.2.6
05.3	Similarities: The electrons tunnel across the gap to produce a current The probe is at a small constant potential Differences: In constant height mode, the change of current is used to generate an image of the image In constant current mode, the change of current is used to move the probe vertically upwards or downwards and the change in height is used to generate the image		2 2	1	3.12.2.6
05.4	As the speed of the electron approaches the speed of light its mass increases $\lambda = \frac{h}{mv}$, and $v = \sqrt{\frac{2ev}{m}}$, $\lambda = \frac{h}{\sqrt{2mev}}$, so if m increases V needs to decrease to produce the same wavelength		1 1	3	3.12.3.5

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06.1	$eV = \frac{1}{2}mv^2$ Assuming non-relativistic speeds, $v << c$ $mv = \sqrt{2meV}$ $\lambda = \frac{h}{mv}$ $= \frac{h}{\sqrt{2meV}}$ $= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 1.60 \times 10^{-19} \times 3000}}$ $= 2.24 \times 10^{-11}$ m	Equating energy to find mv Assumption Expression for λ, explicit or implied Answer	1 1 1 1	2	3.12.2.5
06.2	Assuming the diffraction obeys the equation for diffraction Or: Assume that for appreciable diffraction the size of the grating spacing/ aperture is of the same order of magnitude as the wavelength of the light Grating spacing for electrons is approximately 10^{-10} m $n\lambda = d\sin\theta$ If the angles are the same, assuming $n = 1$ $\left(\frac{\lambda}{d}\right)_{\text{visible}} = \left(\frac{\lambda}{d}\right)_{\text{electrons}}$ $d_{\text{visible}} = \lambda_{\text{visible}}\left(\frac{d}{\lambda}\right)_{\text{electrons}}$ $\frac{540 \times 10^{-9} \times 10^{-10}}{2}$ $= 2.4 \times 10^{-6}$ m	Clear assumption Grating spacing for electrons Relationship between wavelength and spacing Answer	1 1 1 1	3	3.3.2.2

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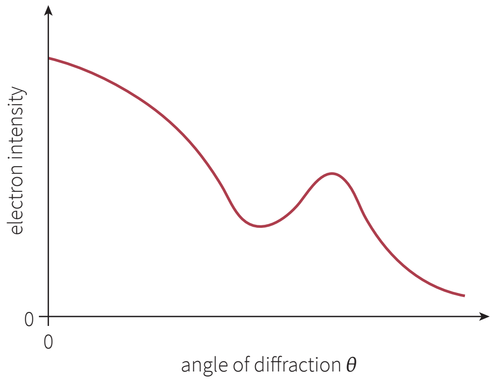
06.3	The wavelength is larger So the angle at which maxima are observed will be larger, so the pattern will spread out		1 1	3	3.3.2.2
06.4	The wavelength of the electrons is inversely proportional to the square root of potential difference used to accelerate the electrons / as $\lambda\uparrow$, pd$\downarrow$ To increase the wavelength for the electrons, the potential difference will need to be reduced		1 1	3	3.12.2.5
06.5		electron intensity decreasing with angle of diffraction to a non-zero first minimum	1 1	1	3.8.1.6
06.6	$R = R_0 A^{\frac{1}{3}}$ $A = \left(\frac{R}{R_0}\right)^3$ $= \left(\frac{6.6\times10^{-15}}{1.1\times10^{-15}}\right)^3$ $= 216$	 Substitution Answer	1 1 1	2	3.8.1.5

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07.1	Newton was the pre-eminent scientist of the time (in the UK) and his opinion held more weight than that of Huygens There were no experimental observations that could not be explained with the particle theory		1 1	1	3.12.2.1
07.2	The result was predicted by the wave theory of refraction/contradicted particle theory, so confirmed the wave theory as correct		1 1	1	3.12.2.1
07.3	Pair production is the production of a subatomic particle and its antiparticle from a neutral boson/photon Wave–particle duality had been established		1 1	2	3.2.1.3
07.4	Peer review where the work is examined/replicated by other scientists		1	1	3.2.2.4
08.1	Energy = 5 MeV = $5.0\times10^{6} \times 1.6\times10^{-19}$ $= 8.0\times10^{-13}$ J Electrical potential energy = $\frac{Q_1Q_2}{4\pi\varepsilon_0 r} = 8.0\times10^{-19}$ $r = \frac{79 \times 2 \times (1.6\times10^{-19})^2}{4\pi\varepsilon_0 \times 8.0\times10^{-13}}$ $= 4.5\times10^{-14}$ m	Calculation of energy Substitution Answer	1 1 1	2	3.8.1.5
08.2	Alpha particles ionise atoms/knock electrons out of atoms		1	2	3.2.2.2
08.3	$E = mc^2 = \frac{m_0c^2}{\sqrt{1-\frac{v^2}{c^2}}}$ $= \frac{9.11\times10^{-31} \times (3.0\times10^{8})^2}{\sqrt{1-0.58^2}}$ $= 1.00\times10^{-13}$ J	Substitution Answer	1 1	2	3.12.3.5

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08.4	The energy is greater, so the energy difference is smaller Light with wavelengths in the violet/blue end of the spectrum will be absorbed Light from green/orange/yellow/red will be reflected giving it a ‘gold’ appearance		1 1 1	3	3.2.2.3
08.5	Speed = $1.7 \times 0.58\,c = 0.986\,c$ Time to travel between the observatories in the frame of an observer at rest = $\frac{1500\text{ m}}{0.986 \times 3\times10^{8}}$ $= 5.07\times10^{-6}$ s Half-life for moving muons $\frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$ $\frac{2.2\times10^{-6}}{\sqrt{1-0.986^2}} = 1.32 \times 10^{-5}$ s Number of half-lives elapsed for moving muon = $\frac{5.07\times10^{-6}}{1.32\times10^{-5}}$ = 0.38 Intensity = $\left(\frac{1}{2}\right)^{0.38}$ = 0.75, or 75%	Correct time Correct half-life for moving muons Correct intensity	1 1 1	3	3.12.3.3

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Skills box answers

Question	Answer
1	First calculate t using time dilation equation: $t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{3.0 \times 10^{-6}}{\sqrt{1 - \frac{(0.999\,c)^2}{c^2}}}$ $= 6.71 \times 10^{-5}$ s Then use $v = \frac{s}{t}$ to calculate distance: $s = (0.999 \times 3.0 \times 10^8) \times 6.71 \times 10^{-5} = 2.0 \times 10^5$ m
2	$t_0 = 26$ ns $= 26 \times 10^{-9}$ s Using the time dilation equation $t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{2.6 \times 10^{-9}}{\sqrt{1 - \frac{(0.995\,c)^2}{c^2}}}$ $t = 2.6 \times 10^{-8}$ s
3	Using the length contraction equation: $l_0 = 1.0 \times 10^3$ m $l = l_0\sqrt{1 - \frac{v^2}{c^2}} = 1.0 \times 10^3 \sqrt{1 - \frac{(0.7c)^2}{c^2}} = 1.0 \times 10^3 \times 0.714 = 710$ m