Answers to examination-style questions

Answers	Marks	Examiner's tips
1 (a) • Diagram/description of electric wave and magnetic wave in phase. • Diagram/description/statement that electric wave is at 90º to the magnetic wave. • Diagram/description/statement that direction of propagation/travel is perpendicular to both waves.	3	It is a good idea to use a diagram, but very important that it is fully labelled. A 3D diagram is tricky to draw, but the perpendicular nature of the electric and magnetic parts can be indicated or described.
(b) (i) • (Conduction) electron (in the metal) absorbs a photon and gains energy hf. • Work function of a metal is the minimum energy needed by an electron to escape from the metal (surface). • An electron can only escape if $hf \geq$ work function.	max 2	One electron absorbs one photon; it is essential to stress the work function is a **minimum** energy.
(ii) • The photon is the quantum of e-m radiation/light. • Classical wave theory could not explain threshold frequency. • Classical wave theory was replaced by the photon theory. • [*or* photons can behave as waves or particles][*or* photons have a dual wave/particle nature].	max 2	The overall significance of Einstein's explanation is the the photon model became accepted. It needs to explained in detail how this arises from the failure of the wave model.
2 (a) (i) • Emission of (conduction) electrons from a heated metal (surface) or filament/cathode. • Work done on electron = eV	2	
(ii) Gain of kinetic energy (or $\frac{1}{2}mv^2$) = eV; rearrange to give required equation.	1	It is often useful to start this kind of explanation from a "word equation" rather than just jump into symbols to make it clear.

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(b) (i) • Work done = force × distance moved in direction of force • Force (due to magnetic field) is at right angles to the direction of motion/velocity [or no movement in the direction of the magnetic force ∴ no work done] • Electrons do not collide with atoms **Alternative for first and second marks:** • (magnetic) force has no component along direction of motion • No acceleration along direction of motion or acceleration perpendicular to velocity]	max 2	
(ii) $r = \frac{mv}{Be}$ or $\left(Bev = \frac{mv^2}{r}\right)$ $v^2 = \frac{2eV}{m}$ $\therefore r^2 \left(= \frac{m^2v^2}{B^2e^2}\right) = \frac{m^2}{B^2e^2} \times \frac{2eV}{m}$ giving $\frac{2mV}{B^2e}$	3	Starting from a known equation, show as many steps as possible.
(iii) (Re-arranging gives) $\frac{e}{m} = \frac{2V}{B^2r^2}$ $\frac{e}{m} = \frac{2 \times 530}{(3.1 \times 10^{-3})^2 \times (25 \times 10^{-3})^2}$ $= 1.7(6) \times 10^{11}$ C kg^{-1}	2	Be careful to change the numbers to base units. [You could work out e/m from the data sheet to see if it gives the same value.]

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3 (i) $t = \left(\dfrac{\text{distance}}{\text{speed}} = \dfrac{34}{0.95 \times 3.0 \times 10^8}\right)$

$= 1.1(9) \times 10^{-7}$ (s)

Marks: 1

Examiner's tips: The measurements are in the rest frame of the detectors, so the time calculated is the dilated time, *t*.

(ii)

- Use of $t = \dfrac{t_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}$
- where t_0=18 ns, and *t* is the half-life in the detectors' frame of reference.
- $\therefore\ t = \dfrac{18 \times 10^{-9}}{\sqrt{1 - 0.95^2}}$

  $= 57.(6) \times 10^{-9}$ s
- Time taken for π meson to pass from one detector to the other = 2 half-lives (approx) (in the detectors' frame of reference).
- 2 half-lives correspond to a reduction to 25%, so 75% of the π mesons passing the first detector do not reach the second detector.

Alternatives for first three marks:

1. Use of $t = \dfrac{t_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ where $t_0 = 18$ ns

$\therefore\ t = \dfrac{18 \times 10^{-9}}{\sqrt{1 - 0.95^2}}$

$= 57.(6) \times 10^{-9}$ s

Journey time in detector frame
$(= 2t) = 2 \times 57.6$ ns ($\approx$ 2 half-lives)

2. Use of $t = \dfrac{t_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ where t =119 ns

$\therefore\ t_0 = 119\sqrt{(1 - 0.95^2)} = 37$ ns
journey time in rest frame = 2 × 18 ns
(which is 2 half-lives)

Marks: 4

Examiner's tips: The simplest method is to calculate the half-life in the frame of the mesons, then show how many half-lives this. Each half-life is a further 50% reduction, so two half-lives is 50% of 50%, i.e. 25% remaining.

4 (a)

- The beam deflects towards Y
- because each electron is acted on by an electric force towards Y (or is attracted to Y or repelled by X).

Marks: 2

(b) (i)

- Each electron is acted on by a magnetic force in the opposite direction to the electric force.
- When $B = B_0$ the magnetic force is equal (and opposite) to the electric force.

Marks: 2

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(ii) • Magnetic force = Bev, electric force $\frac{eV}{d}$ • $B_0ev = \frac{eV}{d}$ (at $B = B_0$) • $\left(\therefore v = \frac{V}{B_0d}\right)$	2	
(c) • Work done on electron (or change of potential energy of electron) = eV_A (where V_A = 3800 V). • ∴(kinetic energy of electron), $\frac{1}{2}mv^2 = eV_A$ • (rearranging this equation gives) $\frac{e}{m}\left(= \frac{v^2}{2V_A}\right) = \frac{(3.7 \times 10^7)^2}{2 \times 3800}$ $= 1.8 \times 10^{11}$ C kg^{-1}	3	
5 (a) • Radio wave is an electromagnetic wave/ includes a magnetic (or electric) wave. • Magnetic flux (or field or wave) through the loop changes as the waves pass the loop. • Induced emf is due to changing magnetic flux through the loop. • Induced emf is alternating because flux (or field or wave) alternates. *Alternatively:* • Electric wave passes the loop. • Electrons in loop forced to oscillate by electric wave. • Movement of electrons causes an induced emf.	max 3	
(b) • Radio waves from T are polarised. • Magnetic flux through loop decreases as it is rotated (or component of magnetic flux density perpendicular to loop decreases). • At 90º, no magnetic flux passes through loop, so induced emf is zero.	3	

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6 (a) (i) To see if they could detect the ether (or absolute motion of the Earth through space or absolute rest).	max 3 for (a)(i) and (a)(ii)	
(ii) • Light reaches the observer from the light source via each mirror. • There is a phase difference between the two light beams. • Bright fringes are seen where the two light beams are in phase (or dark fringes are seen where the two light beams are out of phase by 180º).		
(b) (i) • Earth's motion through space was thought to affect the speed of light (along each arm of the apparatus). • The distance travelled by each beam of light did not change. • The difference in the time taken by light to travel along each arm would change. • The phase difference between the two lights beams would change.	max 3 for (b)(i) and (b)(ii)	
(ii) • Earth's motion through space does not affect the speed of light (or ether does not exist, or absolute motion does not exist, or all motion is relative, or absolute rest).		
7 (a) (i) • Drag (or viscous) force acts upwards on droplet. • Drag (or viscous) force increases with speed. • At this speed, drag (or viscous) force (+ upthrust) = weight of droplet (or force of gravity on it). • No resultant force so acceleration is zero (and therefore velocity (or speed) is constant).	max 3	Use your AS mechanics here. The key is that forces produce acceleration, so zero resultant force is no acceleration.
(ii) • Viscous force = $6\pi\eta rv$ weight (or mg) = $\frac{4}{3}\pi r^3 g\rho$ $\therefore \frac{4}{3}\pi r^3 g\rho = 6\pi\eta rv$ • $r^2 \left(= \frac{9\eta v}{2\rho g}\right)$ $= \frac{9 \times 1.8 \times 10^{-5} \times 7.8 \times 10^{-5}}{2 \times 960 \times 9.81}$ $(= 6.7 \times 10^{-13}\ \text{m}^2)$ (which gives $r = 8.2 \times 10^{-7}$ m)	2	This is a very important derivation to learn. Balance up the weight with the viscous force from Stokes' law.

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(iii) Mass, $m \left(= \frac{4}{3}\pi r^3 \rho\right)$ $= \frac{4}{3}\pi \times (8.2 \times 10^{-7})^3 \times 960$ $(= 2.2 \times 10^{-15}$ kg) *Alternatively:* $m \left(= \frac{6\pi\eta r v}{g}\right)$ $= \frac{6\pi \times 1.8 \times 10^{-5} \times 8.2 \times 10^{-7} \times 7.8 \times 10^{-5}}{9.81}$ $(= 2.2 \times 10^{-15}$ kg)	1	Even if you couldn't do the previous part, you can use the radius that has been given to work out the mass of the spherical drop.
(b) (i) • Electric force acts upwards and slows droplet. • Electric force depends on/varies with speed. • Pd adjusted until electric force = weight so droplet becomes stationary (or droplet becomes stationary when electric force = weight)	max 2	
(ii) (electric force = weight) $\frac{QV}{d} = mg$ $Q = \frac{mgd}{V}$ $= \frac{2.2 \times 10^{-15} \times 9.81 \times 6.0 \times 10^{-3}}{410}$ $(= 3.2 \times 10^{-19}$ C)	2	You need to know about electric fields to complete this part of the question.
(iii) • Droplet charge is always a whole number $\times 1.6 \times 10^{-19}$ C *or* • 1.6×10^{-19} C is the basic quantum of charge (or the charge of the electron).	1	

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8 (a) $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$ gives $9.5 \times 10^{-28} = \frac{1.9 \times 10^{-28}}{\sqrt{1-\frac{v^2}{c^2}}}$ $\therefore \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{9.5}{1.9} = 5.0$ $\frac{v}{c} = 0.98 \times 3.0 \times 10^8 = 2.94 \times 10^8$ m s^{-1} $v = 2.94 \times 10^8$ m s^{-1} **Alternative for (a)** $m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$ gives $\frac{v}{c} = \sqrt{1-\frac{{m_0}^2}{m^2}}$ Correct substitution of m, m_0 and c gives $v = 2.94 \times 10^8$ m s^{-1}	4	Always work in terms of $\frac{v}{c}$ until the final part of the question. Putting in a value of c too early makes it much more difficult. Remember you are expecting a value close to the speed of light.
(b) E_K $(= (m - m_0)c^2)$ $= (9.5 \times 10^{-28} - 1.9 \times 10^{-28}) \times (3 \times 10^8)^2$ $= 6.8(4) \times 10^{-11}$ J	2	Don't use $E_k = \frac{1}{2}mv^2$!

Nelson Thornes is responsible for the solution(s) given and they may not constitute the only possible solution(s).