

2023 ASSESSMENT REPORT

PHY415115 PHYSICS

General Comments

Overall, the examination included a broad range of questions that required students to demonstrate knowledge of most of the course content. Candidates were given ample opportunity to accumulate marks across all four sections of the paper, and it was observed that few students scored very low numbers of marks.

The threshold marks for each grade across the four examined criteria were decided by the Assessment Panel and are presented in the table below:

Section	A Newtonian Physics (Criterion 5)	B Electromagnetism (Criterion 6)	C Waves (Criterion 7)	D Twentieth Century (Criterion 8)
Threshold mark for:	Out of 45 marks	Out of 45 marks	Out of 45 marks	Out of 45 marks
A	36	33	36	34
B	26	22	26	23
C	14	10	14	11

Section A – Newtonian Physics (Criterion 5)

Question 1a

Answer

Vertical component of the arrow's velocity = $v \sin \theta = 70 \sin 10^\circ = \underline{12.2 \text{ m s}^{-1}}$ up

Horizontal Component = $v \cos \theta = 70 \cos 10^\circ = \underline{68.9 \text{ m s}^{-1}}$

Marking notes

- 1 mark for each component.

Marker's comments

This question was generally well done by all candidates.

Question 1b

Answer

$$\begin{aligned}\text{Time to travel 50 m} &= \text{horizontal distance / horizontal component of velocity} \\ &= 50 / 68.9 \text{ s} \\ &= 0.725 \text{ s}\end{aligned}$$

$$\begin{aligned}\text{Vertical Height at this time} &= v \sin \theta t + \frac{1}{2} at^2 \\ &= 12.2 \times 0.725 - 4.90 \times 0.725^2 \\ &= \underline{6.27 \text{ m}}\end{aligned}$$

The arrow goes over the centre of the target by 6.27m

Marking notes

- 1.5 marks for finding the correct time of flight.
- 1.5 marks for finding the vertical displacement.

Marker's comments

Generally done well, but there was evidence of some confusion between horizontal and vertical variables.

Question 2a

Answer

Energy stored is the area under the graph up to 0.70 m

$$\text{Energy} = \frac{1}{2} \times \text{base} \times \text{height} = 0.5 \times 0.7 \times 188 = \underline{65.8 \text{ J}}$$

Marking notes

- 1 mark awarded for $W = F s = 188 \times 0.7 = 132\text{J}$.
- 0.5 marks deducted for not converting s to metres.
- 0.5 marks deducted for using $F = 190$ (not regular intervals of 10).

Marker's comments

Many candidates didn't read the exact value of 188N off the graph. Students must pay attention to the scale. Many calculated $F \times s$ rather than finding the area under the graph.

Question 2b

Answer

$$\begin{aligned}\text{Energy given to arrow} &= 0.6 \times 65.8 \\ &= 39.48 \text{ J}\end{aligned}$$

$$\frac{1}{2} mv^2 = 39.48, \text{ so } v^2 = 2 \times 39.48 / 0.02 = 3944$$

$$v = \underline{62.8 \text{ m s}^{-1}}$$

Marking notes

- 1 mark for finding kinetic energy gained by arrow.
- 1 mark for finding velocity from energy.

Marker's comments

Many candidates showed full working except the final answer. They missed out on full marks due to error carried forward. If the answer doesn't match the "show that" value, candidates should still note it down.

Question 3a

Answer

At the equator the gas has a high speed as it circulates compared to the poles. It will tend to go in a straight line, by Newton's First Law of Forces, only to be pulled in by gravity. The tendency to go in a straight line will cause it to move away from the Earth's centre so making the Earth bulge at the equator relative to the poles.

Marking notes

- 1 mark for the explanation of the bulge.
- 1 mark for linking back to the question.
- No marks were awarded if students used $g = \frac{GM}{r^2}$ to justify their explanation as this is covered in question 3b.
- Part marks were awarded for partial explanations detailing the spin of the earth as the reason. E.g.; 'because the earth is spinning' was awarded 0.5 marks.

Marker's comments

Most candidates attempted an answer to this question, with a majority achieving part marks.

Question 3b

Answer

For a mass, $g = GM/r^2$ where g = gravitational field strength at radial distance r from the centre. With a larger radius at the equator, compared to the radial distance to the poles, the field strength will be weaker.

Marking notes

- 1 mark for stating that the radius is larger at the equator.
- 1 mark for linking a larger radius with a smaller gravitational field strength via $g = GM/r^2$

Marker's comments

Generally done well by most candidates.

Question 3c

Answer

Speed v for an object on the equator:

$$\begin{aligned}v &= 2\pi r / T \\ &= 2\pi \times 6.378 \times 10^6 / 24 \times 3600 \text{ m s}^{-1} \\ &= 464 \text{ m s}^{-1}\end{aligned}$$

$$\begin{aligned}a &= v^2 / r \\ &= 464^2 / 6.378 \times 10^6 \\ &= \underline{0.0337 \text{ m s}^{-2}}\end{aligned}$$

Marking notes

- 1.5 marks for calculating v correctly.
- 1.5 marks for calculating a correctly.

Marker's comments

Generally done well by most candidates, although there were some calculation errors. Candidates should be careful with calculator input.

Question 3d

Answer

- Force of gravity a person on the equator = mg . As g is smaller at the equator, the person's weight is less.
Hence the upward force on the person by the surface of the ground is less.
- The person is spinning around on the equator with a speed of 464 m s^{-1} . This implies an inwards, centripetal, net force.
As the net force is inwards and mg is unchanged, the upward force by the surface of the ground is less.

Marking notes

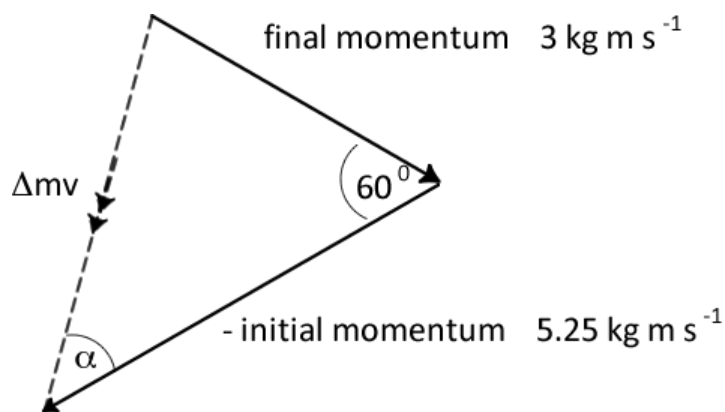
- For both parts, 1 mark for each statement.

Marker's comments

In part i), most candidates failed to make the connection between the weight and normal forces. In part ii), most students could articulate that there was a centripetal force at the equator but failed to link it to the "force of the ground on a person" as stated in the question.

Question 4a

Answer



Marking notes

- 1 mark for the diagram.
- 1 mark for the values on the diagram.

Marker's comments

Many candidates placed the initial and final vectors head to tail and received 0 marks. Vector subtraction was required.

Question 4b

Answer

Using cos rule on the diagram above:

$$\begin{aligned} \Delta mv &= 0.015 (200^2 + 350^2 - 2 \times 200 \times 350 \cos 60^\circ)^{1/2} \\ &= \underline{4.56 \text{ kg m s}^{-1}} \end{aligned}$$

Marker's comments

Generally done well by a majority of candidates.

Question 4c

Answer

Using the sin rule on the diagram above:

$$3 / \sin a = 4.56 / \sin 60^\circ$$

$$\text{So, } \sin a = 0.570$$

$$\text{and therefore } a = 34.7^\circ$$

Marker's comments

Generally done well by a majority of candidates. Error was carried forward in many cases, from part a).

Question 4d

Answer

$$\begin{aligned}\text{Force on bullet by plate} \quad F &= \Delta mv / t \\ &= 4.56 / (2 \times 10^{-3}) \\ &= 2280 \text{ N}\end{aligned}$$

By Newton's Third Law, the force by bullet on plate = 2280 N at an angle of 64.7° to the surface of the plate.

Marking notes

- 1 mark for the magnitude.
- 1 mark for the angle.
- 1 mark for reference to Newton's Third Law.

Marker's comments

Most candidates were able to calculate the force, but failed to acknowledge Newton's Third Law and failed to include the angle.

Question 5a

Answer

Linear momentum is conserved.

Momentum of the bullet before striking = momentum of bullet and plasticine after striking

$$\begin{aligned}m_b v_b &= (m_b + m_p) v \\ 5 \times 10^{-3} \times 100 &= 105 \times 10^{-3} v \\ v &= \underline{4.76 \text{ m s}^{-1}}\end{aligned}$$

Marker's comments

Many candidates tried to use conservation of energy to calculate the velocity of the combined pellet and plasticine.

Question 5b

Answer

Before collision: $E_k \text{ bullet} = \frac{1}{2} \times 5 \times 10^{-3} \times 10^4 = 25 \text{ J}$

After collision: $E_k \text{ bullet} + \text{plasticine} = \frac{1}{2} \times 105 \times 10^{-3} \times 4.76^2 = 1.19 \text{ J}$

Loss of kinetic energy = 23.8 J

Marking notes

- 0.5 marks each for energy before and after collision.
- 1 mark for calculating the difference.

Marker's comments

This was well done by a majority of candidates.

Question 5c

Answer

Loss in E_k = Work Done on plasticine = Force x distance

Average Force = $23.8 / 0.02 = 1.19 \times 10^3$ N on the plasticine

Marking notes

- 0.5 marks deducted for incorrect direction.
- 1 mark deducted for no direction at all, or no reference to N3.

Marker's comments

Many candidates tried to use equations of motion (with incorrect values).

Question 5d

Answer

E_k lost by plasticine and bullet = gravitational potential energy gained in swinging

So $1.19 = mgh = 0.105 \times 9.81 \times h$

And therefore $h = 1.16$ m

Marker's comments

This was done well by a majority of candidates.

Question 6a

Answer

Using $T^2 = 4\pi^2 r^3 / GM$, $r^3 = T^2 GM / 4\pi^2$

$T = 1.62 \times 24 \times 3600$ s = 1.40×10^5 s

$r^3 = 6.92 \times 10^{28}$ gives $r = 4.11 \times 10^9$ m

Marker's comments

Generally well done, but with many calculation errors. Candidates need to be careful with these more complicated calculations.

Question 6b

Answer

This is very close to the star so it will be HOT. Life is extremely unlikely.

Marker's comments

Generally done well. Any valid reason and justification was accepted. Most candidates acknowledged that it was too close and hence too hot.

Question 6c

Answer

As the planets b and c are orbiting the same central mass, we may use the ratio version of Kepler's Third Law:

$$\begin{aligned}(T_c / T_b)^2 &= (r_c / r_b)^3 \\ T_c &= T_b (r_c / r_b)^{3/2} \\ &= 1.62 (1.21 \times 1.50 \times 10^{11} / 4.11 \times 10^9)^{3/2} \\ &= \underline{479 \text{ days}}\end{aligned}$$

Marker's comments

Generally done well, but lots of calculation errors. Many candidates used incorrect values e.g., r_{earth}

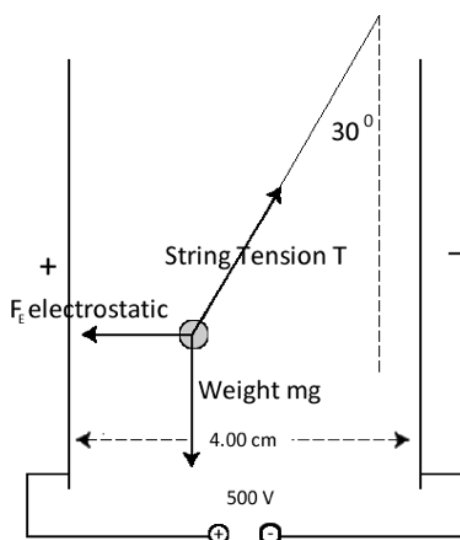
Section B – Electromagnetism (Criterion 6)

Question 7

It was pleasing to see the majority of candidates being able to solve most of this question.

Question 7a

Answer



Marking notes

- Full marks for a complete diagram.
- -0.5 marks for a missing force.
- -0.5 marks for a missing label (but not if the force was missing as well).

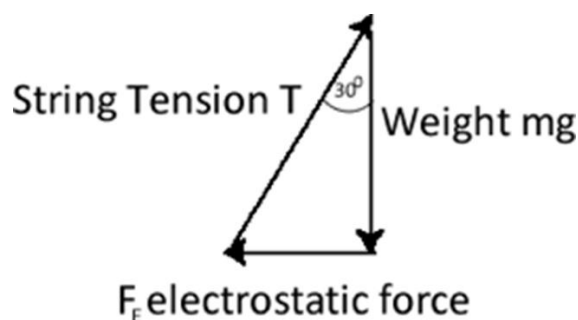
Marker's comments

A common mistake was in omitting the tension in the cotton thread, or including two separate electrostatic forces of attraction and repulsion on the ball. The overall E field will produce a force to the left being balanced by the weight and tension, so there is no net force on the ball (static equilibrium).

Question 7b

Answer

The forces add to zero, so, using a force triangle:



$$\tan \theta = F_E / mg \quad F_E = \tan \theta \times mg = \tan 30^\circ \times 3 \times 10^{-6} \times 9.81 = \underline{1.70 \times 10^{-5} \text{ N to the left}}$$

Marking notes

- 1 mark for the calculation.
- 1 mark for using tan as a ratio.
- 1 mark for stating the direction somewhere on the page (either in a diagram or as part of the final statement of the answer).

Marker's comments

Most candidates selected the correct trigonometric ratio.

Question 7c

Answer

$$\text{In a uniform field: } E = V/d = 500 / 0.04 = \underline{1.25 \times 10^4 \text{ N C}^{-1}}$$

Marking notes

- 1 mark for the original fraction being calculated.
- 1 mark for the answer.

Marker's comments

This question was exceedingly well answered.

Question 7d

Answer

$$F_E = qE \quad \text{so: } q = F_E / E = 1.70 \times 10^{-5} / 1.25 \times 10^4 = \underline{1.36 \times 10^{-9} \text{ C}}$$

Charge is negative, as the ball is attracted to positive plate.

Marking notes

- 0.5 marks for the magnitude.
- 0.5 marks for the correct (negative) sign.

Marker's comments

The magnitude of the charge on the ball was usually calculated correctly, but some candidates did not realise that the ball had to be negatively charged so that the force on it was to the left (or similar reasoning).

Question 8

This question proved a little more challenging than Question 7, but most candidates were able to work their way through most of the question. The most common losses of marks were due to not including directions in their answers.

Question 8a

Answer

Using $F = kQ_1 Q_2 / r^2 = 9 \times 10^9 \times 3 \times 6 \times 10^{-12} / (5 \times 10^{-2})^2 = \underline{64.8 \text{ N repulsion}}$

Marking notes

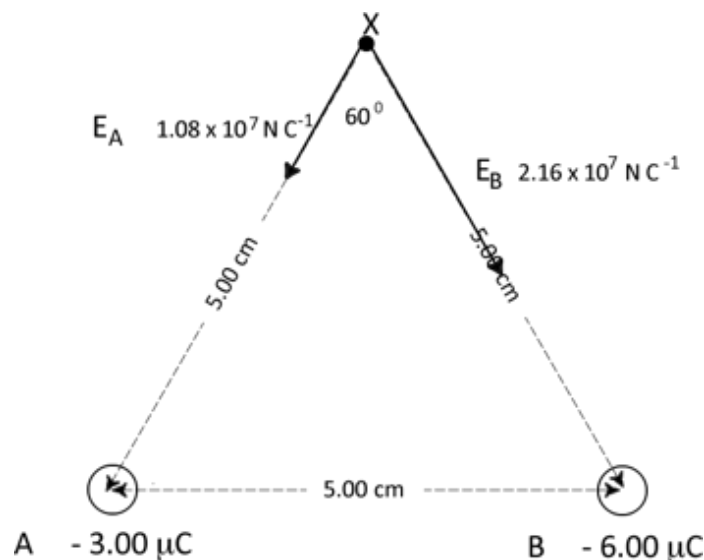
- 0.5 marks for the magnitude.
- 0.5 marks for the direction.

Marker's comments

This was done very well, although the direction was often omitted.

Question 8b

Answer



i) $E_A = kQ_A / r^2 = 9 \times 10^9 \times 3 \times 10^{-6} / (5 \times 10^{-2})^2 = \underline{1.08 \times 10^7 \text{ N C}^{-1} \text{ towards A}}$

ii) $E_B = kQ_B / r^2 = \underline{2.16 \times 10^7 \text{ N C}^{-1} \text{ towards B}}$

Marking notes

- 0.5 marks for each calculation.
- 0.5 marks for showing each vector on the diagram or correctly in a subsequent vector triangle calculation.

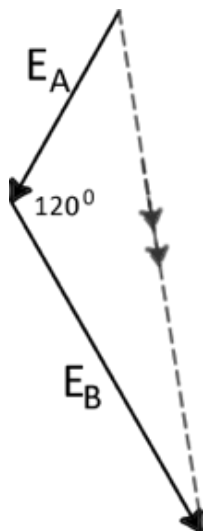
Marker's comments

The calculations were largely done well. Common errors were forgetting that the electric field strength formula has the square of distance on the denominator.

Question 8c

Answer

From the diagram, using the cosine rule:



$$E_T = 1.08 \times 10^7 (1^2 + 2^2 - 2 \times 1 \times 2 \times \cos 120) ^{1/2} = 2.86 \times 10^7 \text{ N C}^{-1}$$

Marking notes

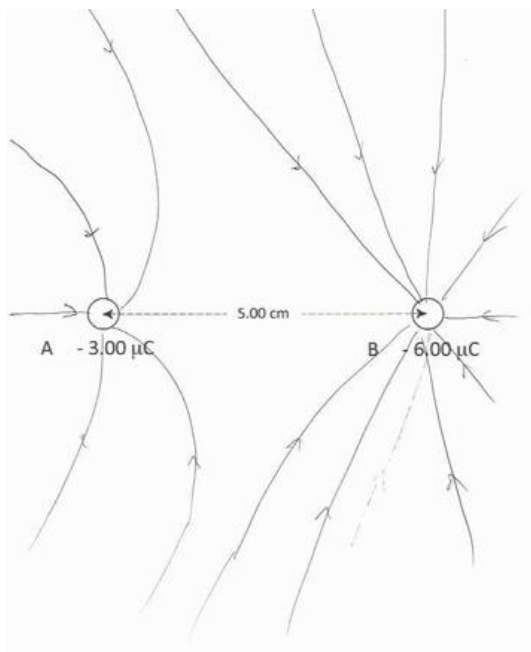
- 1 mark for triangle or components stated.
- 1 mark for the calculation.
- 1 mark for the answer (if using the cosine rule).
- If using the component method:
 - 0.5 marks for the split,
 - 0.5 marks for the correct addition and
 - 1 mark for the answer.
- A common mark obtained was 2 out of 3 because the candidate followed the cosine rule correctly but used 60 degrees instead of 120 degrees for the angle. No marks if vector triangle situation not used.

Marker's comments

Many candidates realised that this was a vector calculation, with the majority of those choosing the simpler cosine rule solution over the component method. The most common error was in choosing 60 degrees as the angle in the cosine rule formula instead of 120 degrees. Sometimes the vectors were stated in the opposite directions to where they should be, so candidates should remember that the direction of a field assumes that a positive 'test' charge is placed at that point.

Question 8d

Answer



Marking notes

- 1 mark for correct overall shape.
- 0.5 marks for asymmetry.
- 0.5 marks for non-obvious asymmetry.

Marker's comments

This was done quite well. However, asymmetry or a greater field line density near charge B was often not shown in the diagrams. Pleasingly, almost all candidates showing an electrostatic diagram had the field line directions drawn in correctly.

Question 9 – General Comments

This question was a little more challenging than Question 8, but many candidates showed resilience by attempting the majority of it.

Question 9a

Answer

$$F/l = k |q_1| |q_2| / r = 2 \times 10^{-7} \times 5 \times 10 / 0.05 = 2 \times 10^{-4} \text{ N m}^{-1}$$

Marking notes

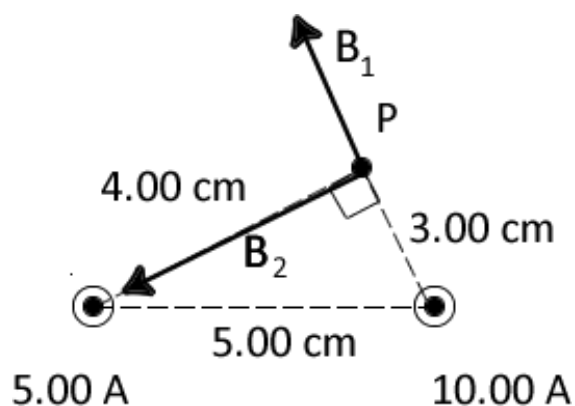
- 0.5 marks for magnitude.
- 0.5 marks for direction.

Marker's comments

This was done very well. However most candidates did not include a direction. The easiest way to describe the force between the wires in this situation is to write 'attraction' or 'attractive'.

Question 9b

Answer



- i) $B^1 = k I^1 / r = 2 \times 10^{-7} \times 5 / 0.04 = 2.5 \times 10^{-5} \text{ T}$
ii) $B^2 = k I^2 / r = 2 \times 10^{-7} \times 10 / 0.03 = 6.67 \times 10^{-5} \text{ T}$

Marking notes

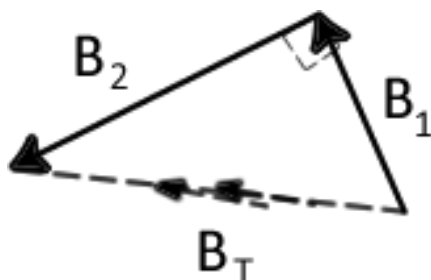
- 0.5 marks for each calculation.
- 0.5 marks for each answer.
- 1 mark for each direction.

Marker's comments

(i) and (ii) were done well in determining the magnitude, but many errors were made in terms of the directions on the field due to the wires. It was important for candidates to realise that the magnetic field at P was required, not the general field around the wires.

Question 9c

Answer



Angle between B^1 and B^2 is 90° . So magnitude of total $= 10^{-5} (6.67^2 + 2.5^2)^{1/2}$
 $= \underline{7.12 \times 10^{-5} \text{ T}}$

Marking notes

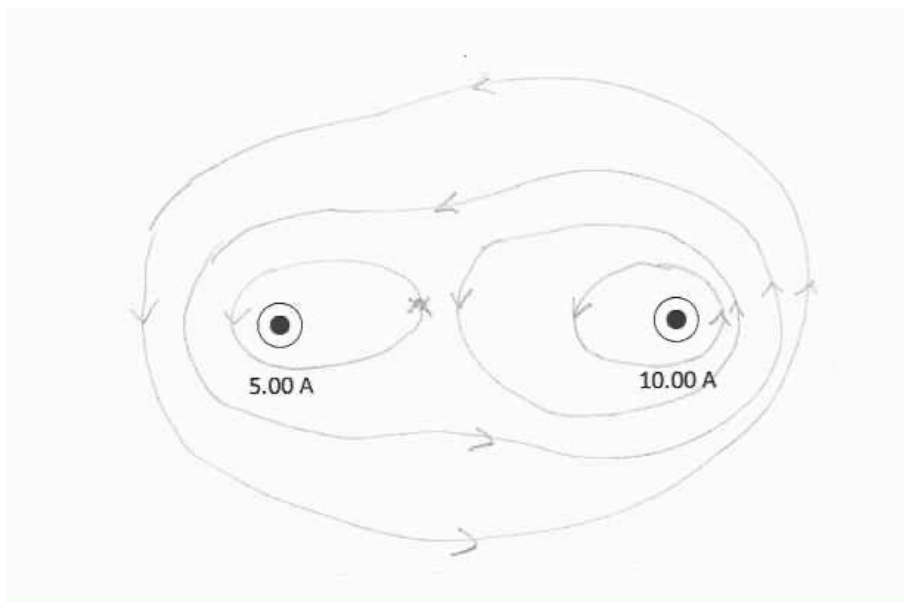
- 1 mark for calculation.
- 1 mark for answer.
- No marks if vector triangle situation not used.

Marker's comments

This was a simple Pythagorean vector calculation which the majority of candidates did well. The most common error was in assuming that the B fields from each wire were antiparallel rather than at 90 degrees to each other, resulting in a one-dimensional erroneous calculation instead of the right-angled triangle required.

Question 9d

Answer



Marking notes

- 0.5 marks for correct overall shape.
- 0.5 marks for arrows.
- 0.5 marks for asymmetry/density.
- 0.5 marks for showing overall flux line far away from the wire.

Marker's comments

This was also done quite well, but asymmetry was not always shown, nor the difference in magnetic flux line density around the 5.00A and 10.00A wires. It was really pleasing to see that flux lines far away from the wires were shown and directions were usually correct.

Question 10

Responses to this question varied substantially, with few students receiving middling marks. It appeared that candidates' ability to understand and correctly complete part b) were indicative of their overall success on this question.

Question 10a

Answer

$$F = I l B \sin \theta$$

Marker's comments

Essentially all candidates completed this correctly.

Question 10b

Answer

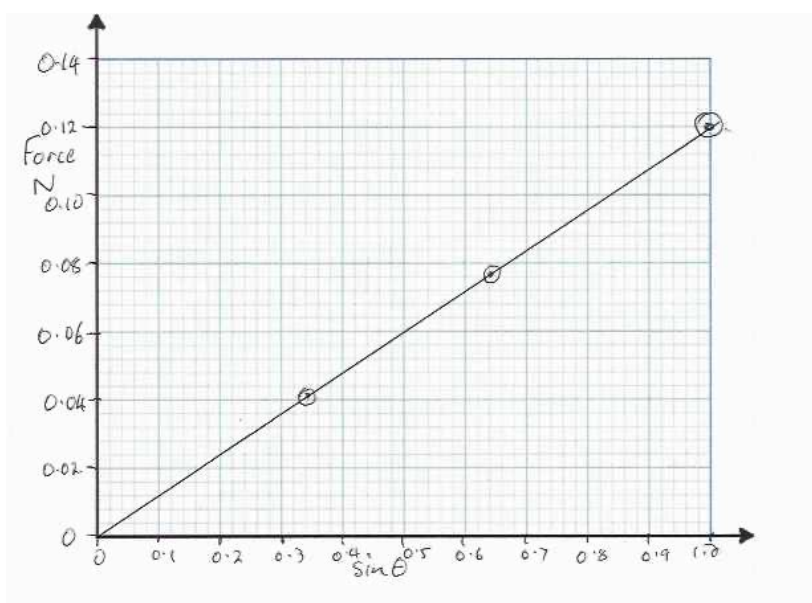
Angle degrees	0°	40°	90°	160°
$\sin\theta$	0	0.642	1	0.342
Balance reading grams	0	7.83	12.2	4.17
Force on the wire $N = mg$	0	0.077	0.12	0.041

Marker's comments

Many candidates were unable to connect their answer from part a) to complete the empty row with $\sin\theta$ values.

Question 10c

Answer



Marker's comments

Where part b) had been completed correctly, candidates were generally able to complete this part well.

Question 10d

Answer

$F = l B \sin\theta$ thus slope = $l B$.

From graph, slope = $0.12 / 1 = 0.12$

$$0.12 = l B$$

$$\text{so } B = 0.12 / 10 \times 0.01 = \underline{1.2 T}$$

Marker's comments

Where parts b) and c) had been completed correctly, students were generally able to complete this part well, with occasional order of magnitude errors relating to conversions.

Question 11

This question was completed with moderate success overall, and it was positive to see that candidates were willing to tackle later parts of the questions even if they had not been successful in earlier parts. A surprising number of candidates had difficulty algebraically, particularly on part c).

Question 11a

Answer

$$7 \text{ TeV } c^{-1} = 7 \times 10^{12} \times 1.6 \times 10^{-19} / 3 \times 10^8 = 3.73 \times 10^{-15} \text{ s N}$$

Marker's comments

Candidates were moderately successful, but generally understood what the question required. Even candidates who were not fully successful often showed an understanding that the values of electron charge q_e and speed of light c were relevant.

Question 11b

Answer

Momentum = mv ,

$$\begin{aligned} \text{so } v &= 3.73 \times 10^{-15} / 1.67 \times 10^{-27} \\ &= \underline{2.2 \times 10^{12} \text{ m s}^{-1}} \gg \gg \text{ speed of light} \end{aligned}$$

Marker's comments

Completed well, with a small minority of candidates either not using the converted measurement from part a) or interpreting this value as E_k rather than momentum.

Question 11c

Answer

$$\begin{aligned} r &= mv / qB \\ &= \text{momentum} / qB \\ &= 3.73 \times 10^{-15} / 1.6 \times 10^{-19} \text{ B} \\ &= 4.23 \times 10^3 \end{aligned}$$

$$B = 3.73 \times 10^{-15} / 1.6 \times 10^{-19} \times 4.23 \times 10^3 = \underline{5.5 \text{ T}}$$

Marker's comments

Whilst the majority of candidates identified the relevant formula ($r = \frac{mv \sin \theta}{qB}$), a large number of candidates failed to correctly make B the subject of the equation.

Question 11d

Answer

Consider two protons separated by 64 mm.

$$F_E = k (1.6 \times 10^{-19})^2 / (64 \times 10^{-6})^2$$
$$= 5.6 \times 10^{-20} \text{ N}$$

Acting on a mass of $1.67 \times 10^{-27} \text{ kg}$ gives an acceleration of $3 \times 10^8 \text{ m s}^{-2}$.

10^{11} protons will tend to move apart so mechanisms are needed to bring them back to a small group to maximise a chance of collision in the accelerator.

Marker's comments

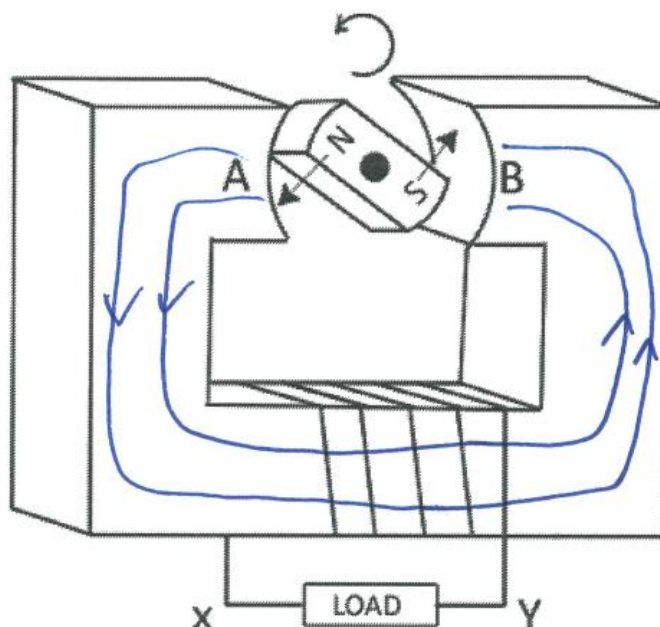
The responses to this question ranged in quality, with only a few candidates relating the size of the force (very small in absolute terms) to the size of the effect on a particle like a proton (a large acceleration for such a small mass), hence determining the overall difficulty.

Question 12

Many candidates struggled with this question but were often able to collect some marks along the way. The source of difficulty appeared to centre on whether students could isolate the various steps in the magnetic process and address each part.

Question 12a

Answer



Marker's comments

Surprisingly few candidates drew field lines in the iron, often opting for lines between AB or generally emanating out of the spinning magnet. Some candidates drew opposing field lines from the Lenz's Law process in the coil.

Question 12b

Answer

- i. INCREASING - the north pole and south poles are entering the gap AB
- ii. X to Y

Marker's comments

Completed with moderate success, somewhat independently of responses to a).

Question 12c

Answer

As the field increases from left to right due to the rotating magnet, by Lenz's Law, an induced field OPPOSES this change and will point from right to left. This corresponds to an induced current Up on the near side windings, so from X to Y in the load.

Marker's comments

This was rarely done successfully, although a partial understanding was often shown. Relatively few students identified that the iron became a temporary magnet, induced by the magnet coming into alignment, and that this temporary magnetic core would induce a current in the coil/load that satisfied Lenz's Law. These concepts were independently communicated (induction, Lenz's Law, Right-hand Rule for coils) but rarely coherently.

Section C – Waves (Criterion 7)

Question 13

This question was generally very well answered, with most candidates achieving a majority of the available marks.

Question 13a

Answer

$$\lambda = 2L = 2 \times 0.389m$$

$$v = f\lambda = 440 \times 2 \times 0.389 = 342.32 = 342ms^{-1}$$

Marking notes

- 1 mark for the correct wavelength.
- 1 mark for the wave velocity calculation.

Marker's comments

A surprising number of candidates used $\lambda = L$.

Question 13b

Answer

$$v = \sqrt{\frac{T}{\mu}} \text{ and so } \mu = \frac{T}{v^2} = \frac{667}{342^2} = 5.703 \times 10^{-3}kgm^{-1}$$

$$m = \mu \times L = 5.703 \times 10^{-3} \times 0.389 = 2.22 \times 10^{-3}kg$$

Marking notes

- 1.5 marks for calculation of linear mass density.
- 0.5 marks for subsequent mass calculation.

Marker's comments

Linear mass density calculations were mostly done correctly, despite a significant number of candidates carrying an error forward from part a). A surprising number of candidates calculated linear mass density but did not attempt the subsequent mass calculation.

Question 13c

Answer

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{658}{5.703 \times 10^{-3}}} = 339.7 \text{ms}^{-1}$$

$$f = \frac{v}{\lambda} = \frac{v}{2L} = \frac{339.7}{2 \times 0.389} = 436.6 \cong 437 \text{Hz}$$

Marking notes

- 1 mark for calculating the new wave velocity.
- 1 mark for the subsequent frequency calculation.

Marker's comments

Errors were commonly carried forward, but most candidates performed these calculations correctly. A very small number of candidates correctly used a ratio method:

$$f_{\text{new}} = 440 \times \sqrt{\frac{658}{667}}$$

Question 13d

Answer

Beat will be heard.

The beat frequency will be $|440 - 437| = 3 \text{Hz}$.

Marking notes

- 1 mark for naming each “beat”.
- 1 mark for specifying the beat frequency.
- In the absence of one or both of the above:
 - 0.5 marks for describing beats.
 - 0.5 marks for specifying the average tone frequency.

Marker's comments

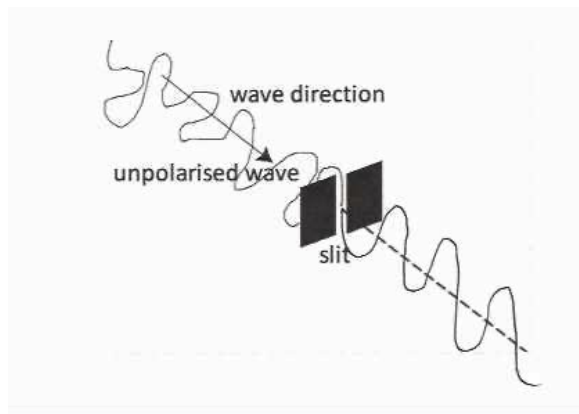
This question was generally very well done.

Question 14

This question was generally not well answered, with very few candidates achieving a majority of the available marks. A large number of students did not progress past part a). It seemed apparent that a majority of the candidates were not familiar with the idea of components of polarisation.

Question 14a

Answer



Marking notes

- Full marks for single, vertical direction of polarisation.
- 0.5 marks for a single, non-vertical direction of polarisation.

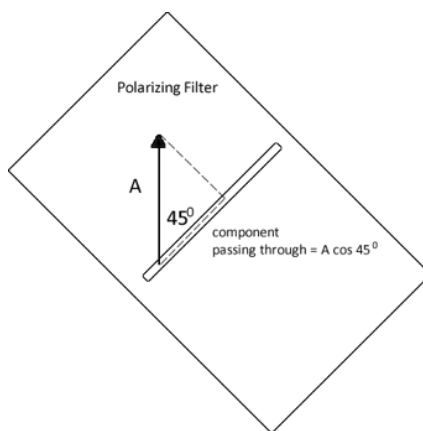
Marker's comments

Generally well done.

Question 14b

Answer

Component of vertical amplitude A across the slit = $A\cos(\theta) = A\cos(45^\circ) \approx 0.707A$



Marking notes

- Full marks for showing (using a diagram) that a polarised wave of amplitude A has its amplitude reduced by a factor of $\cos(45^\circ)$.
- 0.5 marks deducted if $\sin(45^\circ)$ used instead of $\cos(45^\circ)$.
- 0.5 marks deducted if the triangle was drawn as above, but with the angled component labelled as 'A'.
- 0.5 marks awarded, in the absence of a full answer, for sensible connections between reduced amplitude, 0.707, and $\cos(45^\circ)$ or $\sin(45^\circ)$.

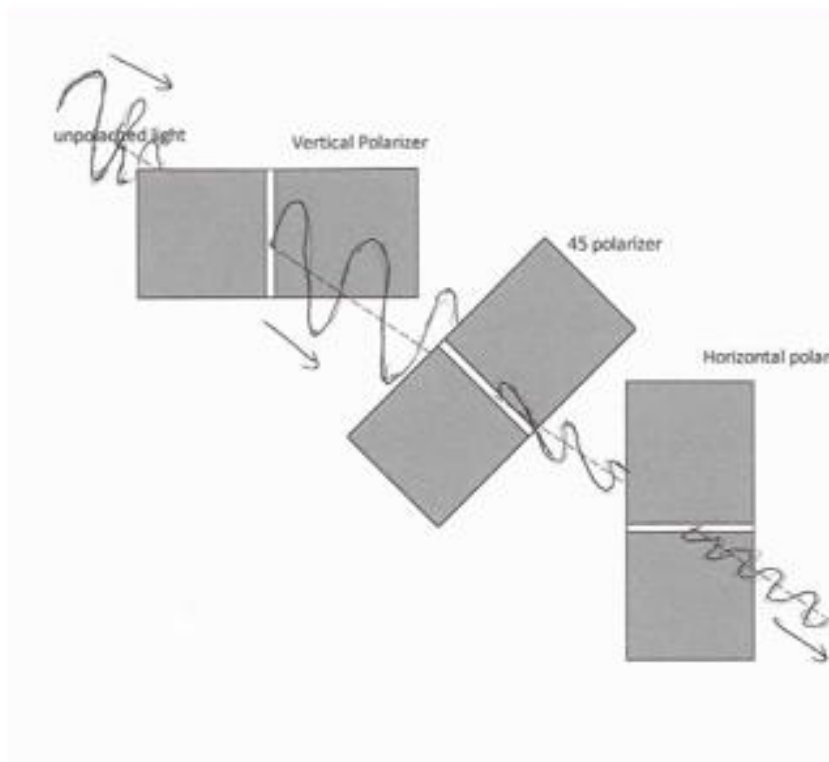
Marker's comments

Very few students received full marks for this question, but a majority were able to achieve part marks.

Question 14c

Answer

The filter at 45° between the crossed filters polarises light at 45° to the light emerging from the first at reduced intensity (amplitude 0.707) of the light leaving the first. This light now is at 45° to the last polariser so some light will pass through by the argument of part b. Some transmission overall then does occur with an amplitude of 0.707^2 of the light from the first filter.



Marking notes

- 1 mark for recognition of the link between parts b) and c) – that subsequent 45° filters will each reduce the amplitude by a factor of 0.707.
- 1 mark for a suitable diagram to illustrate the above.

Marker's comments

Very few candidates achieved full marks for this question. Those who attempted the question and made sensible statements about polarisation filters and light intensity were awarded part marks accordingly.

Question 15

This question was generally very well answered, with most candidates achieving a majority of the available marks.

Question 15a

Answer

- Period = time for one full wave = 2 milliseconds
- Frequency = $1 / \text{period} = 1 / (2 \times 10^{-3}) = \underline{500 \text{ Hz}}$
- Wavelength = speed of sound / frequency = $340 / 500 = \underline{0.680 \text{ m}}$

Marking notes

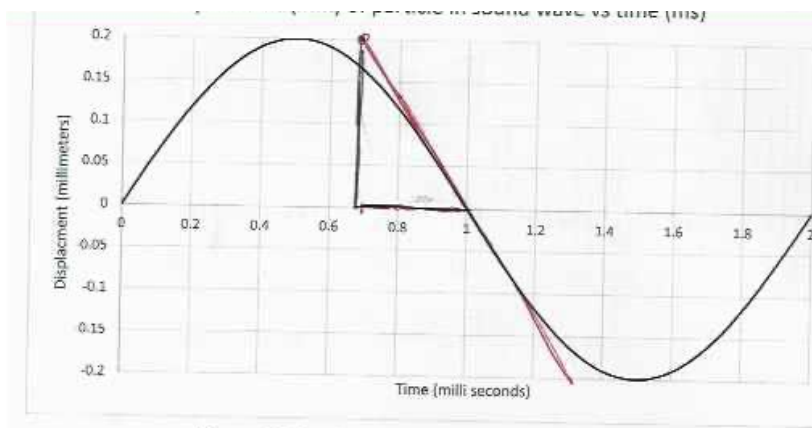
- 1 mark for part i).
- 1 mark for part ii).
- 2 marks for part iii).

Marker's comments

Most candidates achieved a majority of the available marks. There were a significant number of cases where small errors were carried through the subsequent calculations.

Question 15b

Answer



Speed of particle = slope of tangent to graph at 1 ms = $(0.2 \times 10^{-3}) / (0.3 \times 10^{-3})$ - about 0.670 m s⁻¹

Marking notes

- 1 mark for a suitable tangent.
- 1 mark for selecting suitable points for a gradient calculation.
- 1 mark for a correct gradient calculation.
- 1 mark for suitable explanation or justification of the working.
- 1 mark deduction for errors with the units/scale.

Marker's comments

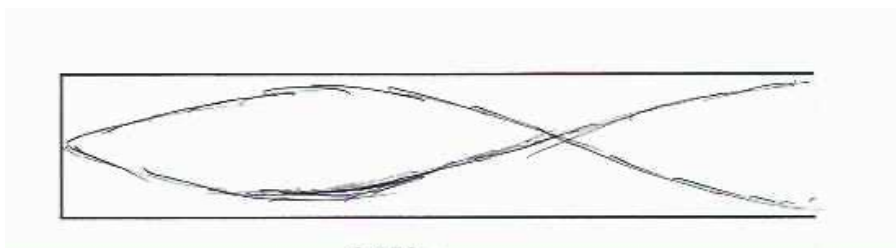
This question was generally well done.

Question 15c

Answer

i) ratio: tube length / wavelength = $0.510 / 0.680 = \underline{0.75}$

ii)



Marking notes

- For part i), suitable answers included: 0.51:0.68, 3:4, 0.75, along with fractional versions of these, or their reciprocals.
- For part ii), 1 mark was awarded for the overall shape and 1 mark for correct spacing of the nodes and antinodes.

Marker's comments

A surprising number of candidates did not realise that the wave in parts a), b) and c) is the same wave. A large proportion of responses indicated a ratio of 1:4 based on the fundamental wave pattern in a close-ended tube. Thus, many received 0 marks for part c) i), but then received marks for their error carried forward into c) ii).

Question 16

This question was generally not very well answered, with very few candidates achieving a majority of the available marks. It was clear that many candidates misinterpreted the context of the question, while others misinterpreted the provided diagram.

Question 16a

Answer

When a source is effectively a point source, its coherence is extremely high. So, interference effects become very noticeable and useful.

Marking notes

- 1 mark for mention of coherence, with marks also given for relevant discussion of phase relationships.
- 1 mark for linking coherence and/or consistent phase relationships with interference patterns and/or constructive interference.
- In the absence of the above, part marks were awarded for sensible references to the ability locate a point source, the treatment of rays from a distant point source as parallel, or the fact that spherical waves from a point source would be best 'gathered' by the dish.

Marker's comments

Very few candidates achieved full marks for this question – in most cases it was apparent that candidates had not connected this scenario with a phase difference/interference phenomenon.

Question 16b

Answer

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{3 \times 10^9} = 0.1 \text{ m}$$

Marking notes

- 1 mark for the correct calculation.
- 0.5 marks if $v = 344 \text{ m s}^{-1}$ was used.

Marker's comments

A surprising number of candidates used $v = 344 \text{ m s}^{-1}$, presumably believing that 'radio' waves are sound waves.

Question 16c

Answer

If the angle is zero, there are identical path lengths to the receiver. The received waves are therefore in phase, and so constructive interference takes place. A strong signal is received.

Marking notes

- 1 mark for stating that a strong signal is generated.
- 1 mark for linking the strong signal with constructive interference due to a superposition of in-phase signals.
- In the absence of the above, 1 mark was awarded in total if a candidate incorrectly stated that a weak signal was received but linked a weak signal with destructive interference due to a superposition of out-of-phase signals.

Marker's comments

Few candidates received full marks for this question. Many of the incorrect responses hinted at misinterpretation of the diagram.

Question 16d

Answer

The first weak signal would be when the path difference is $l / 2 = \underline{0.05 \text{ m}}$

Marking notes

- 1 mark for the correct answer.
- 0.5 marks if the answer was not calculated (i.e., if the candidate simply stated $l / 2$).
- Error was carried forward from part b) in many cases.

Marker's comments

For those candidates who understood this as an interference pattern scenario, this question was very well done. For others, it was often blank or guessed at.

Question 16e

Answer

$$\sin(\theta) = \frac{0.05}{296} \therefore \theta = \sin^{-1}\left(\frac{0.05}{296}\right) = 0.00968^\circ$$

Marking notes

- Full marks for the correct answer.
- 1 mark was awarded for the use of tan rather than sin.
- Errors were carried forward in many case from parts b) and d).

Marker's comments

This question was very well done by the majority of candidates who had done parts a) to d) correctly.

Question 17

This question was generally very well done, with most candidates achieving a majority of the available marks. Very few candidates achieved full marks for the whole question; however, this was usually due to minor attention-to-detail errors.

Question 17a

Answer

Snell's Law: $1.5 \times \sin \theta_r = 1.0 \times \sin 24^\circ$

$$\therefore \theta_r = \sin^{-1} \left(\frac{1.0 \times \sin 24^\circ}{1.5} \right) = 15.7^\circ$$

Marking notes

- 1 mark for the correct answer.

Marker's comments

This was well done by the majority of candidates.

Question 17b

Answer

Using the sum of angles in a triangle = 180°

$$180^\circ - 120^\circ - 15.7^\circ = 44.3^\circ$$

Marking notes

- 2 marks for the correct answer.
- 1 mark if the complementary angle (46.7°) was given.

Marker's comments

This was well done by the majority of candidates. A small number of candidates applied an inappropriate (not required) Snell's Law calculation here.

Question 17c

Answer

Snell's Law: $1.5 \times \sin \theta_c = 1.0 \times \sin 90^\circ$

$$\therefore \theta_c = \sin^{-1} \left(\frac{1.0}{1.5} \right) = 41.8^\circ$$

Marking notes

- 1 mark for application of Snell's Law.
- 1 mark for the correct answer.

Marker's comments

This was well done by the majority of candidates.

Question 17d

Answer

Total internal reflection occurs.

Marking notes

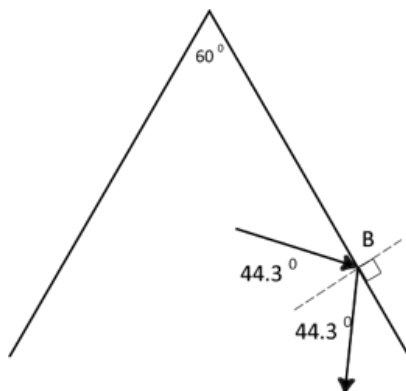
- 1 mark for the above answer.
- 0.5 marks for only stating that $\theta_i > \theta_c$.

Marker's comments

A surprising number of candidates lost 0.5 marks in this part, for not mentioning total internal reflection.

Question 17e

Answer



Marking notes

- 0.5 marks for showing reflection of the ray.
- 0.5 marks for labelling the rays correctly with an angle value.

Marker's comments

A surprising number of candidates lost 0.5 marks in this part, for not labelling the rays.

Question 18

Only a small proportion of candidates answered this question well. A large number received part marks for reasonable or partial attempts.

Question 18a

Answer

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{6 \times 10^6} = 50.0 \text{ m}$$

Marking notes

- 1 mark for the correct calculation.
- 0.5 marks if $v = 344 \text{ ms}^{-1}$ was used.

Marker's comments

A surprising number of candidates used $v = 344 \text{ ms}^{-1}$, presumably believing that 'radio' waves are sound waves.

Question 18b

Answer

Metal reflects electromagnetic radiation but wood is a poor reflector. The receiver would not detect radiation from the plane so the experiment would fail.

Marking notes

- Mention of strong reflection by metal and poor reflection by wood was required for full marks.

Marker's comments

Most candidates received part marks for this question, but full marks were relatively rare.

Question 18c

Answer

PD = TAR - TR

Marking notes

- 1 mark for the correct answer.
- 0.5 marks for sensible answers that demonstrated an understanding of the two paths involved.

Marker's comments

A significant number of candidates gave unnecessarily complicated answers involving right-angled geometry. It's possible that very few candidates have experience with expressing lines as a series of points in the way that the answer required.

Question 18d

Answer

The signal at the receiver is a combination of the transmitted and reflected waves. The path difference alters as the plane flies overhead so the path difference changes giving an interference signal that alters in strength from constructive interference to destructive interference.

Marking notes

- 1 mark for identifying constructive interference and destructive interference as the source of the oscillation.
- 1 mark for correctly linking interference with the changing path difference.

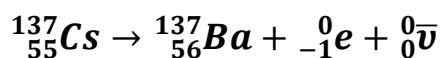
Marker's comments

Many candidates received part marks for this question, but full marks were relatively rare.

Section D – Twentieth Century (Criterion 8)

Question 19a

Answer



Marking notes

- 0.5 marks for each correct element of the decay equation.

Marker's comments

This question was generally well done by most candidates. Both types of beta emitter were accepted, as the question didn't indicate whether the beta emitter was positive or negative. Atomic number of Barium was not provided, which would have helped students determine they type of beta emission. The most common mistake was missing the antineutrino (-ve beta) or neutrino (+ve beta).

Question 19b

Answer

$$A = 0.693 N / T$$

$$\text{so } N = A T / 0.693$$

$$= 19 \times 109 \times 30.1 \times 365 \times 24 \times 3600 / 0.693$$

$$= \underline{2.60 \times 10^{19} \text{ atoms}}$$

Marking notes

- 1 mark for the decay constant.
- 1 mark for the number of atoms.

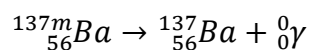
Marker's comments

This was generally well answered by most candidates. Common errors included:

- Not converting years to seconds when calculating decay constant.
- Attempting to use the molar mass formula to determine the number of atoms.

Question 19c

Answer



Marking notes

- 0.5 marks for each correct side of the decay equation.

Marker's comments

This was generally well answered by most candidates. Common mistakes included:

- Not marking the metastable element.
- Cs to Ba decay.
- Using an equal sign.
- Having the parts reversed.
- Not stating gamma in the decay.

Question 20a

Answer

$$\begin{aligned}\text{mass difference} &= \text{Mass of Cs-137} - \text{mass of nuclear decay products} \\ &= 136.907089 - (136.905827 + 0.000549) \\ &= \underline{7.11 \times 10^{-4} \text{ u}}\end{aligned}$$

Marking notes

- 1 mark for correctly setting up the expression for mass difference.
- 1 mark for the correct calculation.
- 1 mark deducted for leaving out the electron.

Marker's comments

Poorly done by most candidates. The most common mistakes included:

- Not including the mass of the electron when calculating mass difference.
- Trying to find the binding energy rather than mass difference.
- Changing to kg incorrectly (not even required).

Question 20b

Answer

$$\begin{aligned}\text{Maximum } E_k &= 7.11 \times 10^{-4} \times 931 \\ &= 0.662 \text{ MeV}\end{aligned}$$

Marking notes

- 1 mark for setting up the calculation of maximum E_k .
- 1 mark for a correct calculation.

Marker's comments

Generally done well by most candidates. The most common mistakes included:

- Multiplying by 940 instead of 931.
- Writing eV instead of MeV.
- Finding the MeV of the electron only.

Question 20c

Answer

Antineutrino is not ionising, so is not easily detectable.

Beta particle has too short a range in air.

Gamma has long range and is ionising so it is the radiation that would have been used to find the source.

Marking notes

- 0.5 marks each for ruling out the antineutrino and the beta particle.
- 1 mark for identifying the gamma emission and justifying the choice.

Marker's comments

Generally done well by some candidates. Most common mistakes included:

- Stating gamma but justifying beta.
- Not understanding the different types of radiation e.g., assume because was heavier must penetrate further.
- Not including antineutrino or talking about ionisation in answer.

Question 21a

Answer

$$\begin{aligned} \lambda_p &= 2.90 \times 10^{-3} / T \\ &= 0.00290 / 10000 \\ &= \underline{2.90 \times 10^{-7} \text{ m (blue colour)}} \end{aligned}$$

Marking notes

- 1 mark for setting up the correct calculation.
- 0.5 marks for the final wavelength calculation.
- 0.5 marks for nominating the colour.

Marker's comments

Generally done well by most candidates. Most common mistakes included:

- Not including the wave type (not writing a colour).

Question 21b

Answer

They are much smaller than A stars. so emit less energy overall.

Marking notes

- 1 mark for any well-constructed argument.

Marker's comments

Generally done well by most candidates. Most common mistakes included:

- Stating the smaller the size the brighter the star.

Question 21c

Answer

Using $E = mc^2$

Each second: $20 \times 3.84 \times 10^{26} = m (3 \times 10^8)^2$

gives mass loss = $8.53 \times 10^{10} \text{ kg s}^{-1}$

Marking notes

- 1 mark for calculating total energy.
- 1 mark for calculating mass.

Marker's comments

Generally done well by some candidates. Most common mistakes included:

- Not multiplying by 20.
- Using atomic mass units and getting confused.
- Forgetting per second in the units.

Question 21d

Answer

The high mass loss indicates a rapid use of nuclear fuels so the life expectancy of a very hot star would be shorter than that of the Sun.

Marking notes

- Full (2) marks for any valid, well-constructed argument.

Marker's comments

Generally done well by most candidates. Most common mistakes included:

- Not relating size to answer.

Question 22a

Answer

By using an equivalence of energy formulae:

$E = mc^2$ (for mass) = hc / λ (for a photon)

then the equivalent of momentum for a photon

$p = mc = hc / \lambda c$ giving momentum $p = h / \lambda$

Marking notes

- 1 mark for stating the two equations.
- 1 mark for combining and rearranging the equations as required.

Marker's comments

Generally done well by some/most candidates. Most common mistakes included:

- Trying to use kinetic energy instead of $E=mc^2$, and then ignoring the half.

Question 22b

Answer

$$\text{Either } 60 \text{ keV} = 9.60 \times 10^{-15} \text{ J}$$

$$= hc / \lambda$$

$$\text{so } h / \lambda = 9.60 / 3 \times 10^8$$

$$= 3.2 \times 10^{-7} \text{ kg m s}^{-1}$$

$$\text{Or } p = E / c$$

$$= 9.60 / 3 \times 10^8$$

$$= \underline{3.2 \times 10^{-7} \text{ kg m s}^{-1}}$$

Marking notes

- 1 mark for converting energy to Joules.
- 1 mark for the momentum calculation.

Marker's comments

Generally done well by some candidates. Most common mistakes included:

- Two step problem requiring an answer to put into another equation. If they couldn't get the answer, they couldn't answer the question.
- Using the wrong Planck's constant.

Question 22c

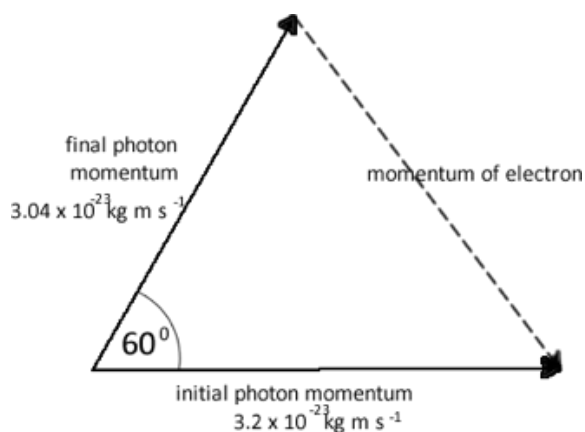
Answer

$$\text{i) } p = h / \lambda$$

$$= 6.63 \times 10^{-34} / 2.18 \times 10^{-11}$$

$$= \underline{3.04 \times 10^{-23} \text{ kg m s}^{-1}}$$

ii)



Marking notes

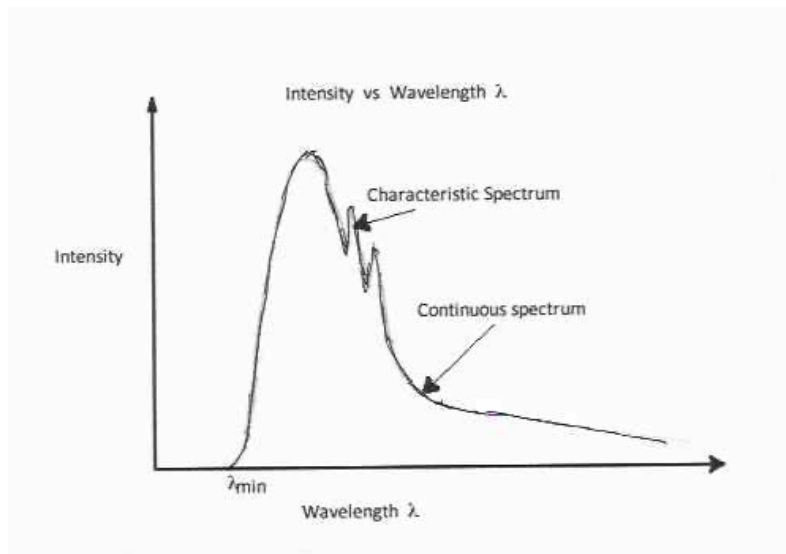
- Part i):
 - 2 marks for the correct calculation.
 - 0.5 marks deducted for using the wrong value of Planck's constant.
- Part ii):
 - 2 marks for a correct, labelled, vector diagram.
 - 0.5 marks deducted for missing labels.
 - 0.5 marks deducted if labels are not momentum.

Marker's comments

- Generally done well by most candidates. Most common mistakes included:
 - Using the wrong Planck's constant.
 - Incorrect units.
 - Using the angle to determine the momentum.
- Generally done well by some candidates. Most common mistakes included:
 - Drawing a free body diagram instead of a vector diagram.
 - Not labelling vectors.
 - Putting the given angle (60°) in the wrong spot on the diagram.

Question 23a

Answer



Marking notes

- 2 marks for the full diagram as shown.
- 0.5 marks deducted for each of the following (if absent):
 - Characteristic spectrum.
 - Continuous spectrum.
 - Hard stop at the minimum wavelength.
 - Wavelength on the horizontal axis.

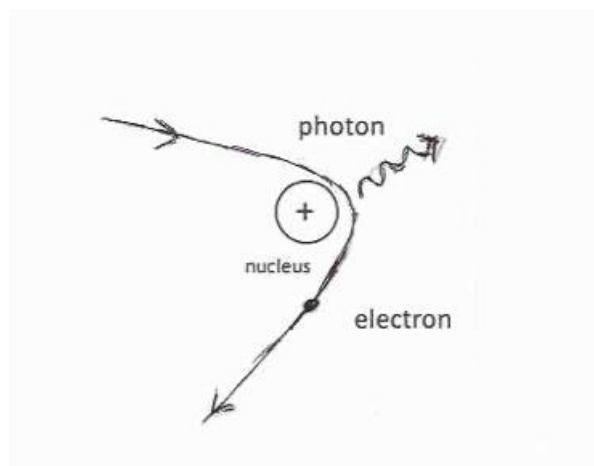
Marker's comments

Generally done well by some candidates. Most common mistakes included:

- Drawing frequency instead of wavelength.
- Not having a clear minimum wavelength.
- Not labelling spectral types.

Question 23bi

Answer



Continuous spectrum is produced by high energy electrons passing close to a positive nucleus and being strongly accelerated. The acceleration produces photons of energy up to that of the electron energy giving a clear cut off frequency or wavelength.

Marking notes

- 1 mark for discussing continuous range of angles.
- 1 mark for linking photon energies to deflection angles.

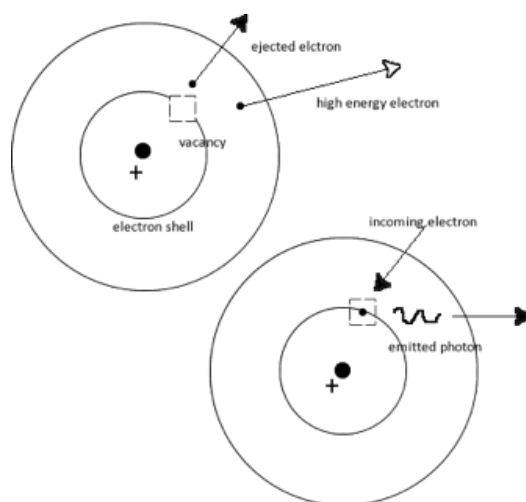
Marker's comments

Generally done well by some candidates. Most common mistakes included:

- Not using a diagram to support statements. This would have helped a lot of candidates in supporting what they wrote.
- Not describing how the range of continuous wavelengths is connected to a range of angles as the electron path is changed.
- Electron gaining energy instead of losing energy.

Question 23bii

Answer



The characteristic spectrum is a line spectrum caused by inner orbital electrons being pushed out of the atom. Electrons then fall into the vacant shell giving the line spectrum photon associated with that energy change.

Marking notes

- 1 mark for discussion of inner orbital electrons being ejected.
- 1 mark for linking ejections with subsequent spectral emission.

Marker's comments

Generally done well by most candidates. Most common mistakes included:

- Not using a diagram to support statements. This would have helped a lot of candidates in supporting what they wrote.
- Not linking the characteristic spikes to the element that the target consisted of.
- X-ray was causing the electron to move rather than a collision.

Question 23c

Answer

- i. The continuous spectrum does not increase in intensity, as there is no change to the electron current. The minimum wavelength will decrease corresponding to the increase electron energy.
- ii. The position of the lines will not change as these are signatures of the target element.

Marking notes

- Part i):
 - 1 mark for explanation of intensity.
 - 1 mark for explanation of energy.
- Part ii):
 - 1 mark for correctly answering.

Marker's comments

- i. Generally done well by some candidates. Most common mistakes included:
 - Talking about intensity changing instead of frequency (wavelength) changing.
- ii. Generally done well by most candidates. Most common mistake(s) included:
 - Talking about intensity changing instead of no change to characteristic peaks.

Question 23d

Answer

$$E_p \text{ lost} = qV$$

$$= \text{maximum photon energy}$$

$$= hc / \lambda$$

$$\text{Therefore } \lambda = hc / qV$$

$$= 6.63 \times 10^{-34} \times 3 \times 10^8 / 1.6 \times 10^{-19} \times 10^5$$

$$= \underline{1.24 \times 10^{-11} \text{ m}}$$

Marking notes

- 1 mark for transposing the required equation.
- 1 mark for a correct calculation.

Marker's comments

Generally done well by most candidates. Most common mistake(s) included:

- Using the wrong Planck's constant.
- Not effectively converting KV to Joules.

Question 24a

Answer

- i. $E = hf$, so blue photons have more energy thus more likely to expel negative electrons from the surface overcoming the natural attraction to the positive ions of the remaining structure.
- ii. Bright light simply means more photons of the same energy range so the maximum ejected electron kinetic energy will not change. More photons mean more ejected electrons so the current will increase.
- iii. The interaction between the photon and electron is like a bump and so it has a very short duration. This means the time between the light arriving on the surface and emission will be very short. Either the electron has gained enough energy to be emitted or it hasn't and will not be emitted.

Marking notes

- Part i):
 - 1 mark for linking frequency with energy.
 - 1 mark for linking energy with ejection (or lack thereof).
- Part ii):
 - 1 mark for linking higher intensity with more photons.
 - 1 mark for linking more photons with higher current.
- Part iii):
 - 1 mark for stating that the 1:1 photon:electron interaction is effectively instantaneous.
 - 1 mark for linking the 1:1 interaction with a lack of delay.

Marker's comments

- i. Generally done well by most candidates. Most common mistakes included:
 - Not mentioning the work function/electron being released from the metal.
 - Stating that lower wavelength had more energy but then stating no difference between blue and red light.
- ii. Generally done well by most candidates.
- iii. Generally done well by most candidates. Most common mistakes included:
 - Using the time given in the information to justify their answer.

Question 24b

Answer

- i. The energy in eV: $E = h c / \lambda$
 $= 4.14 \times 10^{-15} \times 3 \times 10^8 / 405 \times 10^{-9}$
 $= \underline{3.07 \text{ eV}}$
- ii. Photon energy = kinetic energy + work function to eject electron
 $= qV_s + W$ where V_s = stopping voltage
- So, $W = \text{photon energy} - qV_s$
 $= 3.07 - 0.20$
 $= \underline{2.87 \text{ eV}}$

Marking notes

- Part i):
 - 0.5 marks for setting up the calculation.
 - 0.5 marks for the correct calculation.
- Part ii):
 - 0.5 marks for setting up the calculation.
 - 0.5 marks for the correct calculation.

Marker's comments

- i. Generally poorly done by most candidates. Most common mistakes included:
- Using the stopping voltage to find the energy of the photon.
 - Candidates over complicating their working and as a result getting confused.
- ii. Generally done well by those candidates who got part (i) correct. Most common mistakes included:
- Finding qV but then not determining work function.