

2025 ASSESSMENT REPORT

PHY415115 PHYSICS

General Comments

This exam appeared well-balanced, with a variety of questions covering as much course content as possible within the constraints of the three-hour time limit. Candidates were given the opportunity to show their computational skills as well as their thinking in descriptive situations.

There was a good mix of difficulty levels between various parts of each question to give every candidate the opportunity to show what they had learnt during the year. It was pleasing to see in the candidate responses some excellent problem-solving skills being demonstrated. For the most part, candidates remembered to include units and directions.

However, there were some general skills which could have been improved upon by candidates. (These will be of interest to those of you reading this report as you practise this paper in your studies.) Fairly common calculation errors involving forgetting to square or take the square root of expressions, even though the formula (and in many cases, the subsequent expression) was correctly stated.

Candidates are always advised to always show intermediate calculations, as this provides more opportunities to be awarded partial marks, and to obtain credit for errors that are carried forward. In worded explanations, candidates should endeavour to use nouns, as writing the pronoun 'it' does not make it clear as to what noun the 'it' is referring.

Overall, Newtonian Physics (Section A/Criterion 5) and Electromagnetism (Section B/Criterion 6) proved the most challenging for a majority of candidates. Many candidates struggled with implementing the required computational skills in these sections.

Waves (Section C/Criterion 7) and Twentieth Century (Section D/Criterion 8) were less challenging, although still required candidates to demonstrate a suitable breadth of knowledge. In these sections, candidates tended to do either very well or poorly on a specific question, indicating that a lack of breadth of knowledge was a common problem.

Criterion 5: Section A (Newtonian Physics)

Question 1 a)

This was done well, with the most common mistake being not converting to ms^{-1} but then stating the units in ms^{-1} rather than kmh^{-1} .

Question 1 b)

This was done quite well. There were two approaches:

- work out how long it would take to travel 6m horizontally and then calculate the vertical distance, or
- instead calculate the time taken to drop the 2m and then see how much the rider has travelling horizontally.

Common errors were:

- incorrectly thinking that the starting velocity was 0 when the rider left the ramp (even though the starting velocity of 52 km/h was given in the question)
- calculating the distance travelled as hypotenuse of a 6m by 2m triangle without realising that the rider's trajectory is not a straight line, or
- forgetting to convert to ms^{-1} if the answer to the previous part was given in kmh^{-1} , and using inconsistent signs for the values of initial vertical velocity and acceleration.

Question 2 a)

This was done exceedingly well with only very few candidates not providing the simple calculation required.

Question 2 b)

It was pleasing to see many triangles, with most of them correct. However, sometimes the arrows were in the wrong direction on the triangle. The most common errors were:

- assuming that the triangle is right-angled (when it most definitely is not), or
- labelling the vectors with the wrong measurements (most commonly for the Δp vector which was left as a force value).

Vector triangles without all of the measurements were accepted, provided this was made clear by the candidate in part c).

Both velocity vector triangles and momentum vector triangles were accepted, since for this particular question since the mass was constant. More generally, however, a momentum approach would be safer.

Question 2 c)

This was done quite well, although surprisingly even though candidates wrote down the correct calculation using the cosine rule, they forgot the square root or appeared to mistype numbers on the calculator. The most common error stemmed from part b) where a right-angled triangle was assumed and very little "error carried forward" could be justified given the reduced complexity that this led to.

Question 2 d)

This question part was generally a great success for candidates provided parts b) and c) were correct. The most common error was incorrectly rearranging the sine rule formula with \sin^{-1} having the wrong expression inside it.

Question 3 a)

Most candidates achieved the correct value very efficiently here. The most common error was the wrong power of ten in the answer, either due to forgetting to convert from km into m, or instead writing the expression to be calculated with the incorrect number of zeros. A few students did not know that the circumference of a circle is given by $C = 2\pi r$.

Question 3 b)

Most candidates also obtained the correct answer for this part too, and if they got this part wrong, this was largely due to “error carried forward” from part a), which was taken into account in the marking. The most common unrelated error was using the circumference of the orbit rather than the radius for the r value in the centripetal acceleration calculation.

Question 3 c)

This question proved challenging for many candidates, with the marks gained reflecting either excellent understanding or conversely very limited understanding of how to approach the explanation.

Many different but equally valid explanations were accepted, for example:

- taking one of the ‘g’ values and applying an inverse square law to get the other ‘g’ value, **or**
- instead showing that ‘g’ multiplied by ‘r’ squared gives the same constant.

Some very limited partial marks were awarded if candidates made an attempt at least at explaining how they would approach this without any calculations or further justification being provided.

Question 3 d)

Whilst appearing less challenging than part c) for many candidates, there were still a significant number of candidates who made conceptual errors in this part. Examples of these include:

- using the 9.81 ms^{-2} ‘g’ value for the Earth with the radius of the Moon instead of the Earth
- using 420 km as the distance from the centre of the Earth, or
- incorrectly assuming that the ISS is a geostationary satellite and thus mistakenly using 24 hours as a period in their calculation (an approach not involving periods at all is more efficient anyway).

In this part, and also part c), it was not required to calculate the mass of the Earth, but many candidates obtained this, although such an approach and the subsequent calculations were more convoluted than necessary.

Question 4 a)

Common mistakes in parts i) and ii) included failure to square distances, or to give directions to fields.

The most common mistake in part iii) was to use 600 instead of 1200 in the cosine rule to calculate the total field strength.

Question 4 b)

This was not well done with many losing their way by not cancelling G or powers of 10, and then not taking a square root early. Those who did not take the square root ended with a messy quadratic equation solution.

Question 4 c)

The diagram was reasonably well done, although many failed to realise that the line through Y separating the two sets of fields is curved towards star B.

Question 5 a)

The fact that students were not given the formula for a cylinder created issues in part i) for some, but otherwise this was well done.

In part ii), most realised that the density had to be multiplied by the volume to give the mass.

Most correctly multiplied the mass by velocity in part iii), but there were a number of error carried forward issues.

Question 5 b)

This was poorly done by many candidates. Most failed to realise that the momentum change in one second constitutes a force and therefore that Newton's First Law now applies with balanced forces.

Question 5 c)

This was also poorly done in general. Many candidates tried to calculate the power by looking at the force from part a) iii) and multiplying it by the velocity of the air rather than the kinetic energy of the air in the cylinder of one second. Some credit was given to the incorrect technique.

Criterion 6: Section B (Electromagnetism)

Question 6 a)

Mostly well done.

Question 6 b)

Mostly well done, although some candidates used Figure 8 instead of Figure 7 (if done correctly, it was not penalised).

Question 6 c)

Few candidates received full marks for this question. Many candidates missed the question prompt of lightning forming from sharp points, and did not use ionisation field strength and the provided figure in their answer.

Question 6 d)

Many candidates stated the reason for hair standing on end due to build up of charges, but did not link it to why this would be an indication of danger to the person.

Question 6 e)

Mostly well done, although some candidates did not realise that the electric field strength was given, and some missed that the minimum potential difference was asked for.

Question 6 f)

Moderate success, as many candidates did not realise that charge transferred.

Question 6 g)

Generally well done, with many receiving error carried forward from previous calculations.

Question 7 a)

Many candidates had difficulty explaining the acceleration between A and B and why there was no acceleration between X and C. Many only stated that attraction and repulsion occur between plates and did not refer to the potential difference or to the electric field resulting in a net force (and hence acceleration). Some candidates successfully used an argument about conversion of electric potential energy to kinetic energy.

Question 7 b)

There were various answers to this question. The correct answers included showing understanding that there is no potential difference between X and C.

Question 7 c)

Generally well done.

Question 7 d)

Generally well done.

Question 7 e)

Generally well done, although some candidates lost marks due to errors with transposing the formula to calculate the mass.

Question 8 a)

Generally well done.

Question 8 b)

Most candidates determined the force correctly, but some either forgot to include direction or gave an unclear answer (left/right/up/down), without showing a force arrow to clarify intended direction or stating “towards the power source”.

Question 8 c)

Poorly done overall, with the most common mistake being confusing emf with the force on the rod in (b).

Question 8 d)

Poorly done overall.

Question 9 a)

Moderately well done by most. Many candidates selected Coulomb’s law, which is not the appropriate equation for calculating the force in this situation.

Question 9 b)

Part i) was generally poorly done. Candidates had trouble determining the direction of the positive ion using the right hand rule.

In part ii), some candidates missed the part of the question that indicated the acceleration due to the motion in part i) and hence determined the x-axis instead of the y-axis. Many candidates indicated motion in the z-axis direction, which is not possible – for magnetic force, the direction of travel and the field must be at right angles. This part was poorly done overall.

Question 9 c)

Poorly done, overall. A large number of candidates noticed that opposite charge would result in the ion being accelerated in the opposite direction due to the electric field. They then did not recognise that this would in turn cause the ion to be accelerated in the same direction as the positive ion due to the magnetic field along the y-axis. So, the direction of the magnetic force should be the same as in b) part ii) – hence no change.

Question 9 d)

This was also poorly done by most candidates – unsurprisingly, as it relied on success in the preceding parts. Most candidates were able to get partial marks by viewing the situation in the context of photons. The sunlight is moving away from the source; hence, both positive and negative ions will accelerate in the direction the photons are moving, which is away from source.

Question 10 a)

Poorly done overall – many candidates indicated that negative charge would build up at Q. The right-hand rule says that with magnetic field into the page and the plate's velocity to the right, positive charge will be forced upwards. Therefore, positive charge will build up at Q.

Question 10 b)

Most candidates recognised that the current would flow in a clockwise direction, but not every candidate realised that it should be overlapping the magnetic field. Half of the current should be inside the field, and half of the current should be outside the magnetic field.

Question 10 c)

Generally poorly done. Energy is being transformed from mechanical (kinetic) energy into electrical energy (current), and then into heat. There were many candidates who said that electrical potential energy is being transformed into kinetic energy, which indicates they missed the point of the question. Some candidates only gave one transfer instead of two.

Question 11 a)

Mostly done well. The key features required were:

- correct direction of the field lines (anticlockwise around both wires)
- showing the relative magnetic field strength (more lines/density around P)
- showing the cancelation of field lines between P and Q
- showing the null point closer to Q than it is to P.

Question 11 b)

Poorly done by many candidates. A large number of candidates substituted 1m for the length and calculated the Force instead of calculating the Force per unit length. Even though this results in the correct numerical value, it does not show the correct calculation and produces the incorrect units.

Question 11 c)

Well done by the majority of candidates. Some forgot to add direction, or to recognise that the two fields are in the same direction and should therefore be added together.

Criterion 7: Section C (Waves)

Question 12 a)

This was well done by most candidates. On rare occasions, candidates failed to recognise that the refracted index was provided and that they were 'working backwards' to find the incident angle.

Question 12 b)

Part i) was poorly done by a surprisingly large number of candidates. Those that drew a dashed normal line at the prism-air boundary fared much better than those that didn't do so. The most common error was drawing the refracted ray bending away from the normal but not crossing the normal line.

In part ii), many repeated their error from part i). Partial marks were awarded for evidence of understanding that the two colours would refract to differing degrees. The most common error was showing the red ray refracting more strongly than the blue.

Question 12 c)

This was moderately well done overall. Full marks required an acknowledgement of the impact of less refraction at both boundaries.

Question 12 d)

This was very well done by most candidates. Minimal penalty was imposed on those who used the incorrect refractive index (1.54).

Question 12 e)

Few candidates received full marks for this question. Most made a link between critical angle and angle of incidence, but many incorrectly asserted that a lack of total internal reflection implied that there was no internal reflection at all.

Question 13 a)

Most candidates did part i) of the question well. The most common errors were failing to calculate the string tension from the hanging mass and using the hanging mass itself as the value for string tension. Many candidates also rounded intermediate values excessively, which led to calculation errors.

Surprisingly, even with credit for an error carried forward, many candidates did not successfully calculate the frequency of the second overtone in part ii). The most common errors were:

- dividing instead of multiplying
- confusing the second overtone with the second mode of vibration
- treating the string as a closed-ended pipe.

Question 13 b)

This was generally very well done. Candidates are reminded to use the given value from a) if they were unsuccessful in calculating their own value, and to use their own value if they were successful.

Question 13 c)

This was also well done by a significant number of candidates. Most recognised that the need for a least tensioning mass implied the lower of the two frequencies from part b). The most common error was not recognising the speed of the wave changes – many candidates used the same value as in part a).

Question 14 a)

Most candidates answered this question correctly. Teachers should be careful to distinguish between coherent light and in-phase double-slit sources.

Question 14 b)

Both parts were well done by the majority of candidates.

Question 14 c)

This was generally well done.

Question 14 d)

Those who answered part c) correctly generally managed to answer this question successfully as well.

Question 15 a)

Most candidates answered this question correctly.

Question 15 b)

Most candidates answered this question correctly.

Question 15 c)

This question was not well done by large number of candidates. Many attempted to use the wave equation, rather than the given information. Others based their value on the amplitude of the wave, rather than the separation of the buoys. Most candidates who answered correctly were able to also supply suitable reasoning.

Question 15 d)

Many candidates received partial marks for error carried forward from other parts. Those who answered parts b) and c) correctly usually also answered this question correctly.

Question 15 e)

Most candidates answered this question correctly. The quality of reasoning varied significantly.

Question 16 a)

Most candidates answered this question correctly.

Question 16 b)

Most candidates demonstrated an understanding of the working of polarised sunglasses, but relatively few were confident in identifying the respective polarisations of the reflected light. Full marks required identifying that:

- reflections from the water surface are horizontally polarised
- that the glasses are designed to absorb (or 'cancel' horizontally polarised light)
- that reflections from windows are vertically polarised, and so
- the glasses won't absorb the light reflected by the window.

Candidates were not required to explore the possibility of up-down reflections in a vertical window, but allowances were made in cases where it was clear that the candidate had considered a range of possibilities for the polarisation of light reflected from a window (the orientation of the window and the direction of the reflection are both important).

Question 16 c)

Few candidates were awarded full marks for this question.

Most candidates identified that there would be no difference between what the observer sees with the glasses at 0° rotation and at 180° rotation.

A significant subset of those candidates described what would happen as the glasses were rotated through the 0° to 180° range.

Relatively few candidates identified the vertical polarisation of the scattered light, which then enabled them to ascertain that the scattered light would be minimally filtered at 0° , maximally filtered at 90° , and minimally filtered again at 180° .

Question 17 a)

This was very well done by a significant majority of candidates. Scaling errors in the second diagram were the most common source of error.

Question 17 b)

This was also well done by a significant majority of candidates. The most common error was failing to calculate the correct wavelength. Some candidates used the speed of light for the wave speed, and others were unable to come up with a wave speed at all.

Question 17 c)

Many candidates received partial marks for only discussing the higher-frequency fundamental mode of the child's ear, which is due to its shorter length (and hence shorter corresponding wavelength).

For full marks, candidates also needed to discuss the sensitivity of the adult ear, which is due to resonance of the ear canal at the fundamental frequency and first overtone.

Criterion 8: Section D (Twentieth Century)

Question 18 a)

This question was done well. Many candidates converted their answers to Celsius, which was unnecessary. Explicitly stating a range as an answer was preferred but not required for full marks.

Question 18 b)

This question was also done well. Full marks required mathematical support of the justification (for example, calculation of peak wavelength of the sun and comparison of temperature range to temperature of the sun).

Question 19 a)

This was done well by most candidates. A number of candidates misinterpreted the question and attempted to find the mass defect of each isotope from their subatomic particles and then combine these mass defects. Candidates are encouraged to look at the mark allocation to a question to determine if their approach is likely correct. Both positive and negative answers were accepted here.

Question 19 b)

This was also well done by most. Error was carried forward from part a) if a logical and clearly elucidated process of calculation was shown. No deductions were made for significant figures here. Error was carried forward from a) frequently.

Question 19 c)

Relatively few candidates attempted this part. A number of distances were accepted in calculating the force, including 4fm, 5.5fm and 1fm. A charge separation of 3fm was not accepted. Candidates are encouraged to double check their calculations with respect to the formula sheet, as a number of students did not square the radius in their calculation. A number of candidates also incorrectly calculated the charges of each particle based on mass rather than atomic number. Overall, when attempted, this question was done quite well.

Question 20 a)

Part i) was done well. Most candidates were able to successfully answer this question. Alternative units were accepted (e.g. Ns, Jsm⁻¹). In part ii), most candidates did not consider the vector nature of momentum and were deducted accordingly.

Question 20 b)

This question proved challenging to many students but was well done by those who had practised conservation of momentum questions in Compton Scattering. The correct answer could be obtained in this question by simply adding the two momenta from part a) together, without showing reasoning. Due to the “show that” nature of the question, that approach only gained 2 marks. Markers required clear indication of the law of conservation of momentum being applied correctly to gain full marks.

Question 20 c)

This question proved challenging for many candidates. Concluding that energy was either conserved because the two values were close or not conserved because they were not exactly equal were both accepted.

Question 20 d)

The best answer to this question is relativistic effects, hence this was accepted despite not being an assessable concept under the course document. Students who correctly calculated the energy values in part c) to show the final energy being higher than the initial energy were able to answer this question more frequently.

Question 21 a)

Generally done well. The most common errors were:

- listing antineutrinos as a product
- indicating X as the product without including the mass and charge
- unbalanced equations
- providing equations (e.g., $A = A_0 e^{-\lambda t}$) from the Information Sheet, rather than the decay equation.

Question 21 b)

Many candidates failed to match the decay constant with the half-life units (e.g., day⁻¹ with a half-life in days). There were also many calculation errors.

Question 21 c)

Many candidates rearranged the formula incorrectly and calculated $A = \frac{e^{-\lambda t}}{A_0}$ or failed to match the decay constant to the half-life units. There were many calculating errors.

Question 22

Many candidates missed out on part marks due to not including full (or any) working. Many answers were quoted in eV when joules were required and vice versa. There was a lot of unnecessary converting between joules and electron volts in calculations.

Question 22 a)

Many candidates miscalculated $\frac{2.10}{1.60 \times 10^{-19}}$ or used Planck's constant.

Question 22 b)

Many candidates read this question incorrectly and identified more energy level transitions than necessary, missing some of the three required answers. Many also missed the 3.19 to 2.10 eV transition.

Question 22 c)

Many candidates multiplied by Planck's constant or missed the transition from 3.19 to 2.10 eV.

Question 22 d)

Many candidates stated that the energy of the scattered electrons corresponded directly to the difference in energy levels as stated in c).

Question 22 e)

Many candidates used 10 eV instead of 5.13 eV and some candidates calculated the energy of the photon as being 10 eV - 5.13 eV.

Question 22 f)

Many candidates interpreted “two energy levels” as two energy transitions and incorrectly identified a second pair of energy levels, most commonly $n_5 - n_3$.

Question 23 a)

Many candidates incorrectly identified 200 nm as being in the x-ray spectrum.

Question 23 b)

There was a lot of unnecessary conversion between joules and electron volts. Candidates should take care to match Planck’s constant to the units of energy used.

Question 23 c)

Candidates are reminded that the stem given at the beginning of the question relates to all subsequent parts of the question, unless stated otherwise. Many candidates forgot this, which impacted their interpretation of this part.

Many candidates discussed bremsstrahlung radiation, or answered the question relating the change in energy to a change in frequency of the incoming photons, rather than it being constant. Many also incorrectly stated that not all energy is transferred from the photon to the photoelectron.

Question 23 d)

This question was generally done well. The most common error being the use of $E = 2.01$ eV.

Attach your candidate label here

Solutions

PHYSICS

PHY415115

Section **A** Newtonian Physics

Pages: 12

Questions: 5

Information Sheet: 1

Preparation time for this exam: 15 minutes

Suggested working time: 45 minutes

Instructions:

- Answer **all** questions and **all** items within each question.
- Write your answers in the spaces provided in this exam paper.
- A spare diagram has been provided at the end of this section. Indicate in the box provided if you have used the spare diagram.
- TASC-approved scientific calculators can be used throughout the exam.
- The Physics Information Sheet can be used throughout this exam.
- The exam is **three (3) hours** in length. The suggested working time for this section is **approximately 45 minutes**.
- All answers must be written in **English**.
- You **must** make sure your answers address the listed criterion.

Marker use	
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Question 1

Marker use

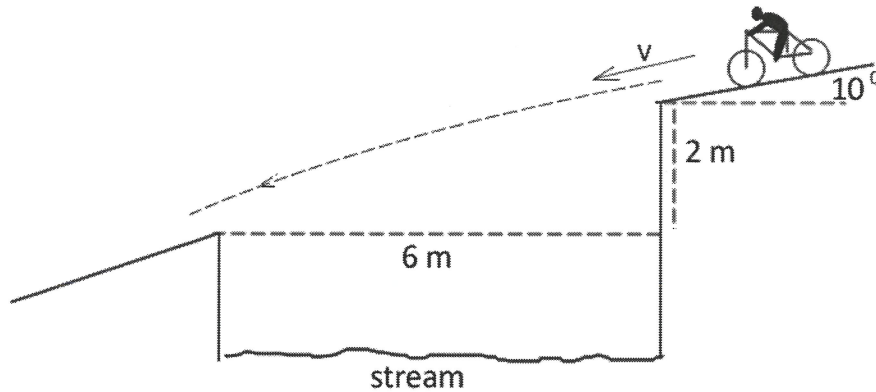


Figure 1

A mountain-bike stream crossing is shown in Figure 1.

The crossing is 6 m wide horizontally. Vertically the rider falls 2 m.

The start ramp is at -10° to the horizontal.

a) If the rider's speed is 52 km h^{-1} when leaving the ramp, calculate the components of the velocity.

i. Horizontally

$$u_H = \frac{52}{3.6} \cos 10^\circ = 14.23 \approx 14.2 \text{ ms}^{-1} \text{ left.}$$

/1

ii. Vertically

$$u_V = 14.44 \cdot \sin 10^\circ = 2.507 \approx 2.51 \text{ ms}^{-1} \text{ down.}$$

/1

b) Does the rider cross the river? Justify your answer.

$\text{horizontally: } a=0$ $\therefore s = ut$ $\therefore t = \frac{s}{u} = \frac{6}{14.23}$ $= 0.4216 \text{ s}$	$\text{vertically: } \Delta s = ut + \frac{1}{2}at^2$ $\therefore \Delta s = 2.507 \times 0.4216$ $+ \frac{1}{2} \times 9.81 \times 0.4216^2$ $= 1.929 \text{ m.}$ $\Delta s < 2 \text{ m}$ $\rightarrow \text{the rider crosses.}$
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/3

Total
Q1
/5

Question 2

A hockey ball of mass 0.160 kg is travelling from left to right at 5.00 m s⁻¹. It is struck at an angle of 73.6° to the ball's initial motion with a force of 10.7 N for a duration of 0.110 s, as shown in Figure 2.

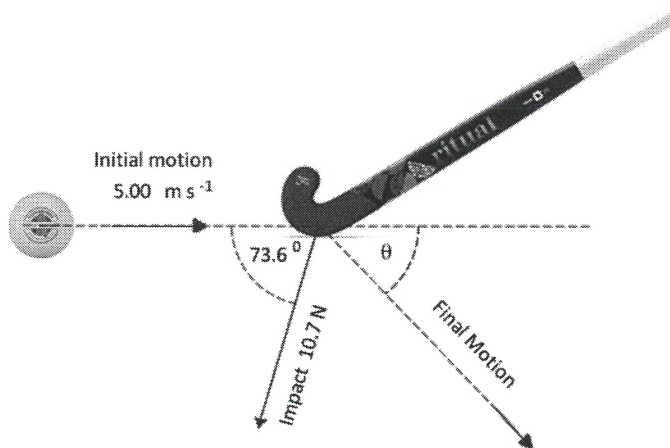


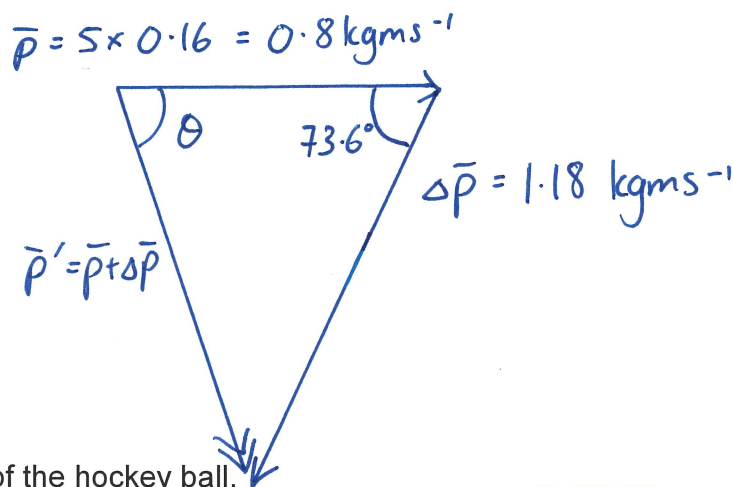
Figure 2

a) Show that the change of momentum of the ball has a magnitude of 1.18 kg m s⁻¹.

$$F = \frac{\Delta p}{\Delta t} \therefore \Delta p = F \Delta t = 10.7 \times 0.110 = 1.177 \approx 1.18 \text{ kgms}^{-1}$$

/1

b) Draw a labelled vector diagram that will enable the final motion of the ball to be calculated.



/3

c) Calculate the final speed of the hockey ball.

$$p' = \sqrt{0.8^2 + 1.177^2 - 2 \times 0.8 \times 1.177 \times \cos 73.6^\circ} = 1.222 \text{ kgms}^{-1}$$

$$\therefore v' = \frac{p'}{m} = \frac{1.222}{0.160} = 7.638 \approx 7.64 \text{ ms}^{-1}$$

/3

Question 2 continues

Question 2 continued

Marker use

d) Calculate the deflection angle, θ , as shown in Figure 2.

$$\frac{\sin \theta}{1.177} = \frac{\sin 73.6^\circ}{1.222} \quad \therefore \theta = \sin^{-1} \left(\frac{1.177 \times \sin 73.6^\circ}{1.222} \right)$$
$$= 67.5^\circ$$

/2

Total
Q2
/9

Question 3

Marker use

In 1665, Newton first thought about gravity at his home by comparing the falling of apples to the motion of the Moon.

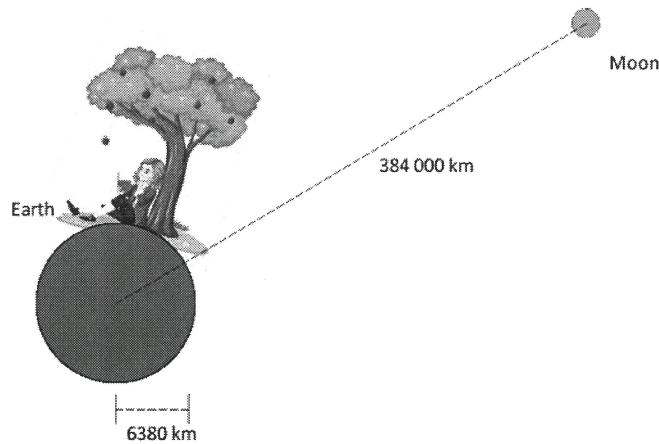


Figure 3

The Earth has a radius of 6 380 km while the Moon is 384 000 km from Earth's centre.

Objects fall at the surface of Earth at a rate of 9.81 m s^{-2} .

The Moon completes one orbit around Earth every 27 days and 8 hours.

a) Calculate the orbital speed of the Moon in m s^{-1} assuming a circular orbit.

$$v = \frac{2\pi r}{T}$$

$$r = 3.84 \times 10^8 \text{ m}$$

$$T = (27 \times 24) + 8 = 656 \text{ hours}$$

$$\therefore T = 656 \times 3600 = 2.362 \times 10^6 \text{ s}$$

$$\therefore v = \frac{2 \times \pi \times 3.84 \times 10^8}{2.362 \times 10^6} = 1021 \text{ ms}^{-1}$$

$$= 102 \times 10^3 \text{ ms}^{-1}$$

/3

b) Calculate the magnitude of the centripetal acceleration of the Moon in its orbit.

$$a_c = \frac{v^2}{r} = \frac{1021^2}{3.84 \times 10^8} = 2.715 \times 10^{-3} \text{ ms}^{-2}$$

$$\approx 2.71 \times 10^{-3} \text{ ms}^{-2}$$

/2

Question 3 continues

Question 3 continued

Marker use

- c) From the results of part a) and b), show that gravity's acceleration follows an inverse square law.

$$\text{Moon: } F_g = F_c \quad \left| \quad g = \frac{GM}{r^2} \Rightarrow GM = gr^2 \right.$$

$$\therefore g = a_c$$

$$\therefore g = 2.715 \times 10^{-3} \text{ N/kg, Moon: } GM = 2.715 \times 10^{-3} \times (3.84 \times 10^8)^2$$

$$\text{Earth's surface } g = 9.81 \text{ N/kg.} \quad \left| \quad = 4.003 \times 10^{14} \right.$$

$$\text{Earth: } GM = 9.81 \times (6.38 \times 10^6)^2 = 3.993 \times 10^{14}$$

(GM constant $\rightarrow g \propto \frac{1}{r^2}$)

The International Space Station (ISS) is at a mean altitude of 420 km above the Earth's surface.

- d) Calculate the acceleration of ISS.

$$\text{Use } GM = 4.00 \times 10^{14} \text{ (from c)}$$

$$a_c = g = \frac{GM}{r^2} = \frac{4.00 \times 10^{14}}{((6380 + 420) \times 10^3)^2}$$

$$= 8.65 \text{ ms}^{-2} \text{ centrally.}$$

/3

/2

Total Q3

/10

Question 4

Two of the three stars in the Alpha Centauri star system are fairly close to each other. These are Alpha Centauri A and Alpha Centauri B, henceforward referred to as Star A and Star B.

Star A has a mass of 2.19×10^{30} kg while Star B has a mass of 1.79×10^{30} kg. They are separated by a distance of 3.00×10^{12} m on average.

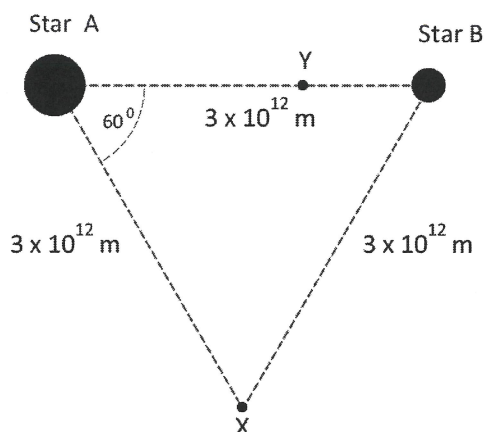


Figure 4

a) Point X forms an equilateral triangle with Star A and Star B.

i. Calculate the gravitational field strength of Star A, g_A at point X.

$$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 2.19 \times 10^{30}}{(3 \times 10^{12})^2} = 1.623 \times 10^{-5}$$

$\approx 1.62 \times 10^{-5} \text{ N/kg towards A}$

/2

ii. Calculate the gravitational field strength of Star B, g_B at point X.

$$g = \frac{6.67 \times 10^{-11} \times 1.79 \times 10^{30}}{(3 \times 10^{12})^2} = 1.327 \times 10^{-5}$$

$\approx 1.33 \times 10^{-5} \text{ N/kg towards B}$

/2

iii. Calculate the **magnitude** of the total gravitational field strength at point X.

$\theta = 120^\circ$

$$\therefore g_{tot} = \sqrt{1.623^2 + 1.327^2 - 2 \times 1.623 \times 1.327 \times \cos 120^\circ} \times 10^{-5}$$

$$= 2.559 \times 10^{-5} \approx 2.60 \times 10^{-5} \text{ N/kg.}$$

/3

Question 4 continues

Question 4 continued

Marker use

- b) Calculate the distance from Star A to point Y from Figure 4, between the stars where the total gravitational field is zero.

$$g_{\text{tot}} = g_A + g_B = 0$$

$$\therefore |g_A| = |g_B|$$

$$\therefore \frac{GM_A}{r_A^2} = \frac{GM_B}{(3 \times 10^{12} - r_A)^2}$$

Cancel G, rearrange, $\sqrt{\quad}$ both sides:

$$\therefore (3 \times 10^{12} - r_A) \sqrt{M_A} = r_A \sqrt{M_B}$$

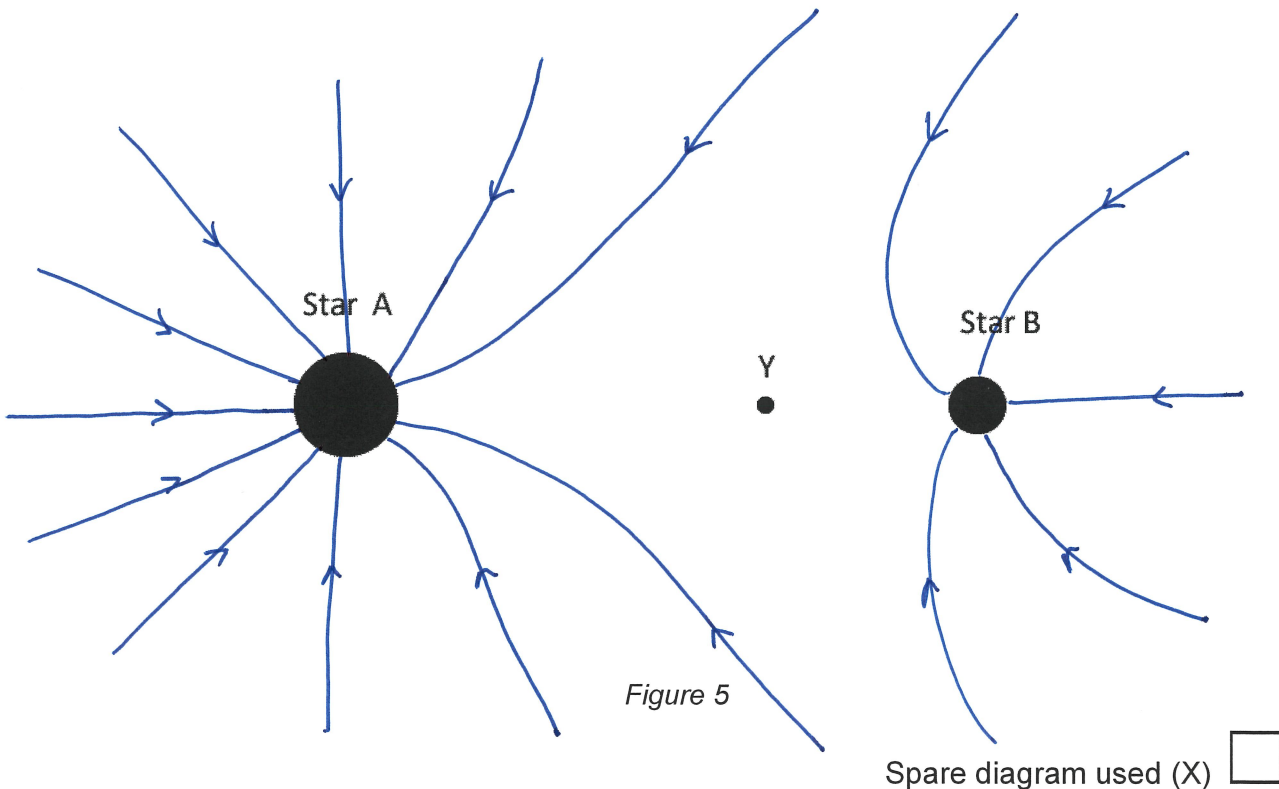
$$\therefore 3 \times 10^{12} \sqrt{M_A} = r_A (\sqrt{M_A} + \sqrt{M_B}) \quad | \times 3$$

$$\therefore r_A = \frac{3 \times 10^{12} \sqrt{2.19}}{\sqrt{2.19} + \sqrt{1.79}} \times \frac{\sqrt{10^{30}}}{\sqrt{10^{30}}}$$

$$= 1.576 \times 10^{12}$$

$$\approx 1.58 \times 10^{12} \text{ m.}$$

- c) Sketch the gravitational field around the two stars on Figure 5.



/2

Total Q4

/12

Question 5

A Blackhawk helicopter hovering in place generates a downward cylinder of air moving at an average speed of 18.0 m s^{-1} . The rotor blades are 8.20 m long.

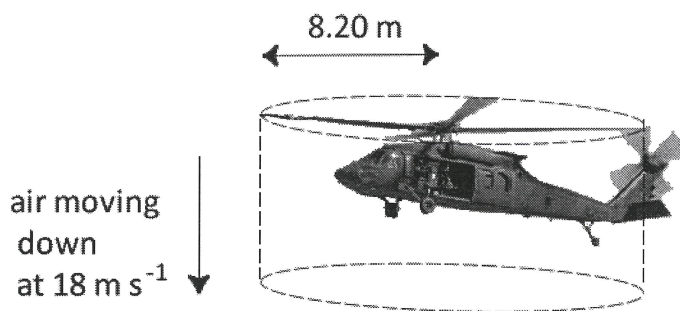


Figure 6

Consider a time period of 1 second, during this time stationary air is given momentum downwards.

a) We wish to calculate the change in momentum of this air per second.

i. Show that the volume of air driven down in 1 second is $3.80 \times 10^3 \text{ m}^3$.

$$\begin{aligned} \text{Cylinder volume: } \pi r^2 \times h &= \pi \times 8.2^2 \times 18 \\ &= 3802 \\ &\approx 3.80 \times 10^3 \text{ m}^3 \end{aligned}$$

/2

ii. If the density of air is 1.29 kg m^{-3} , calculate the mass of this air.

$$\begin{aligned} \text{mass} &= \text{volume} \times \text{density} = 3802 \times 1.29 \\ &= 4905 \approx 4.91 \times 10^3 \text{ kg} \end{aligned}$$

/1

iii. Calculate the change of momentum of the air caused by the helicopter blades.

$$\begin{aligned} \Delta p &= m \cdot \Delta v \\ &= 4905 (18 - 0) \\ &= 88290 \approx 8.83 \times 10^4 \text{ kgms}^{-1} \text{ downwards.} \end{aligned}$$

/2

b) Given the helicopter is stationary, calculate the mass of the helicopter.

$$\begin{aligned} F_g &= F_{\text{air}} \\ \text{and } F &= \frac{\Delta p}{\Delta t} \end{aligned} \left. \vphantom{\begin{aligned} F_g &= F_{\text{air}} \\ \text{and } F &= \frac{\Delta p}{\Delta t} \end{aligned}} \right\} \therefore mg = \Delta p \\ \therefore m &= \frac{\Delta p}{g} = \frac{88290}{9.81} = 9000 \text{ kg.}$$

/2

Question 5 continues

Question 5 continued

Marker use

- c) While the helicopter is hovering, the engines are operating at 1800 kW. Calculate the percentage of the engines' power transferred to the air.

$$\begin{aligned} E_{k(\text{air})} &= \frac{1}{2} mv^2 & E_{\text{engines}} &= 1800 \text{ kJ (1 sec)} \\ &= \frac{1}{2} \times 4905 \times 18^2 \\ &= 794.6 \text{ kJ} & \therefore \text{transfer \%} &= \frac{794.6}{1800} \times 100 \\ & \text{(in 1 sec.)} & &= 44.1 \% \end{aligned}$$

/2

Spare Diagrams

Question 4 c)



Figure 5

End of Section A

Total
Q5
/9

Attach your candidate label here

Solutions

PHYSICS

PHY415115

Section **B** Electromagnetism

Pages: 16

Questions: 6

Information Sheet: 1

Suggested working time: 45 minutes

Instructions:

- Answer **all** questions and **all** items within each question.
- Write your answers in the spaces provided in this exam paper.
- A spare diagram has been provided at the end of this section. Indicate in the box provided if you have used the spare diagram.
- TASC-approved scientific calculators can be used throughout the exam.
- The Physics Information Sheet can be used throughout this exam.
- The exam is **three (3) hours** in length. The suggested working time for this section is **approximately 45 minutes**.
- All answers must be written in **English**.
- You **must** make sure your answers address the listed criterion.

Marker use

C6

/ 45

Question 6

Marker use

Air is usually an insulator as the gases are covalent molecules. However, if a sufficiently strong electric field is applied, molecules can be ionised leading to lightning.

Consider a column of rising air from which a thunderstorm forms. The base of the thundercloud is usually negative.

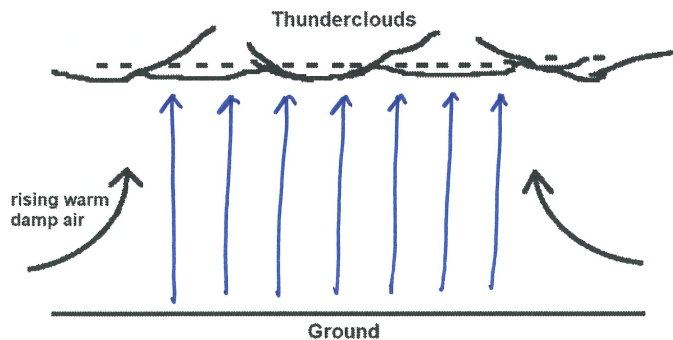


Figure 7

Spare diagram used (X)

a) What charge will tend to form on the ground.

..... Positive charge.

/1

b) Sketch the average electric field between the cloud and the ground on Figure 7.

The electric field strength at which air becomes ionised is between 2 to 3 MV m⁻¹. This value depends on moisture content and other variables.

/1

c) Lightning tends to form from sharp points on the ground. Suggest why, using the Figure 8 diagram and the known ionising field strength.

/2

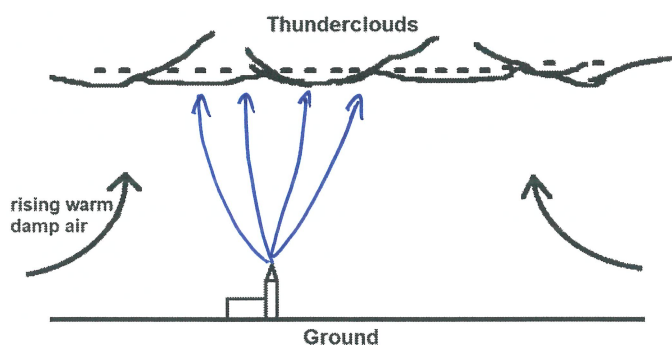


Figure 8

{ Charge will concentrate in a pointed object.
 { Pointed object shown is also closer to the cloud.
 → larger field strength makes ionisation (lightning) more likely

Question 6 continues

Question 6 continued

Marker use

- d) Why might a person's hair standing on end under a thundercloud be an indication of danger to the person?

..... Indicates a build-up of charge on the person's
 head. Stronger local field \rightarrow more chance of

/1
 lightning.

During a thunderstorm, a particular lightning strike travelled 5.0 km long cloud to ground. It lasted 20 milliseconds and carried an estimated current of 30 kA.

- e) Calculate the minimum potential difference of the cloud relative to the ground.

..... $E = 2 \text{ MV m}^{-1}$ (min. of 2-3 range)
 $d = 5000 \text{ m}$.
 $V = Ed = 2 \times 10^6 \times 5 \times 10^3 = 1.00 \times 10^{10} \text{ V} = 10 \text{ GV}$

/2

- f) Calculate the charge transferred.

..... $Q = It = 30 \times 10^3 \times 20 \times 10^{-3}$
 $= 600 \text{ C}$

/1

- g) Calculate the minimum energy released in the strike.

..... $E = VQ$
 $= 1 \times 10^{10} \times 6 \times 10^2$
 $= 6.00 \times 10^{12} \text{ J or } 6 \text{ TJ}$.

/2

Total
 Q6

/10

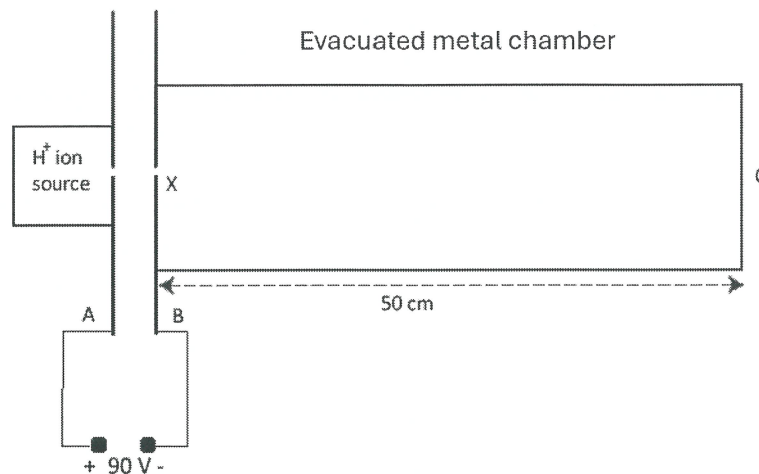


Figure 9

Positive H⁺ ions are injected at a hole, X, into an evacuated metal chamber as shown in Figure 9 above.

90 V are placed across the plates A and B.

Holes at A and B allow the ions to freely move into the metal cylinder and arrive at C 50 cm from X.

a) Explain why acceleration occurs between A and B.

Potential difference exists → electric potential → kinetic energy
 [OR] → electric field → accelerating force

/1

b) Explain why no acceleration occurs between X and C.

No pot. diff. exists between X and C
 → hence no electric potential or electric field
 [OR] Faraday cage → no field → no force.

/2

c) Calculate the kinetic energy in joules of an ion when entering at X.

$$E_k = \Delta E_p = Vq$$

$$= 90 \times 1.6 \times 10^{-19}$$

$$= 1.44 \times 10^{-17} \text{ J}$$

/2

Question 7 continued

Marker use

A timing system is set up between X and C to measure the ion traverse time.

- d) If an ion takes $3.80 \mu\text{s}$ to move from X to C, calculate the speed of the ion.

$$v = \frac{s}{t} = \frac{0.5}{3.80 \times 10^{-6}} = 1.316 \times 10^5$$
$$\approx 1.32 \times 10^5 \text{ ms}^{-1}$$

- e) Calculate the mass of the H^+ ion using your answers from part c) and d).

$$E_k = \frac{1}{2}mv^2 \quad \therefore m = \frac{2E_k}{v^2} = \frac{2 \times 1.44 \times 10^{-17}}{(1.316 \times 10^5)^2}$$
$$= 1.66 \times 10^{-27} \text{ kg}$$

/1

/2

Total
Q7
/8

Question 8

Marker use

A simple linear motor can be constructed by placing a metal roller on top of rails 12 cm apart immersed in a magnetic field of 0.3 T. A current is then passed through the rails and roller.

Consider the Figure 10 diagram below.

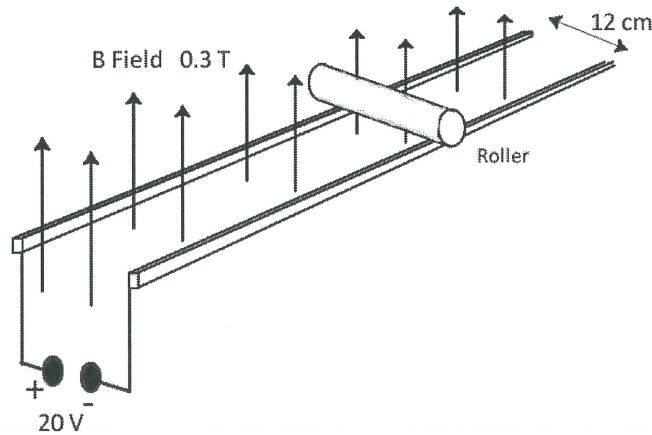


Figure 10

20 V is placed across the roller via the rails. The roller has a resistance of 0.5 Ω.

a) Calculate the initial current through the roller.

$$I = \frac{V}{R} = \frac{20}{0.5} = 40 \text{ A}$$

/1

b) What is the initial magnitude and direction of the force on the roller?

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

$$= 40 \times 0.12 \times 0.3 \times \sin 90^\circ$$

$$= 1.44 \text{ N along rails, towards the voltage source.}$$

/2

As the roller gains speed, an induced emf is created across it which will cause opposition to its motion.

c) Ignoring mechanical friction, calculate the speed at which the roller will cease accelerating.

$$a = 0 \Rightarrow \text{balanced forces} \Rightarrow \text{induced emf} = 20\text{V}$$

$$\therefore v l B \sin \theta = 20 \quad \therefore v = \frac{20}{0.12 \times 0.3 \times 1} = 555.6$$

$$\approx 556 \text{ ms}^{-1}$$

/2

Question 8 continues

Question 8 continued

Marker use

d) What is the current through the roller at this maximum speed? Justify your answer.

No current at this speed.
Induced emf = supplied voltage
 \therefore net voltage = 0 \therefore current = 0.

/2

Total
Q8
/7

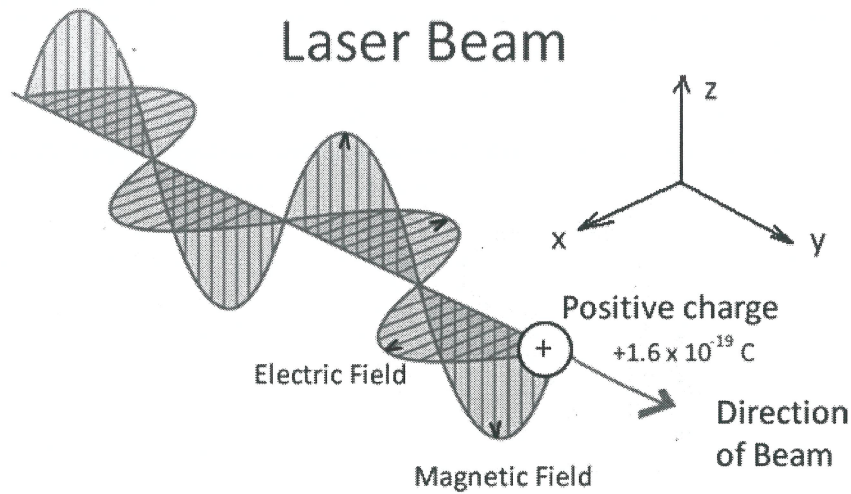


Figure 11

A laser beam of light can be considered as two rapidly changing electric and magnetic fields at right angles to each other.

Consider the beam interacting with a stationary positive charge of value $+1.6 \times 10^{-19} \text{ C}$ as shown in Figure 11.

a) State the formula that can be used to determine the force on the charge:

i. Due to the electric field.

$F_E = Eq$

/1

ii. Due to the magnetic field.

$F_B = vIB \sin \theta$

/1

b) As the beam strikes the charge, identify the axis (x, y or z) along which the positive charge will:

i. Accelerate due to the electric field.

the x-axis.

/1

Question 9 continued

Marker use

- ii. Accelerate due to the magnetic field given the motion from part b) i. Justify your answer.

the y-axis. RHR, with B field in the z-direction and velocity in the x-direction.

/2

- c) If the charge is negative instead of positive, will the direction of the acceleration due to the magnetic field be different to part b) i. and ii.? Answer **yes** or **no** and explain your reasoning.

No difference.
Opposite charge causes change of direction of x-axis motion. This change, together with opposite charge, result in the same motion due to F_B .

/2



$$\begin{aligned} & (qvB\sin\theta) \\ & = \\ & (-q)(-v).B\sin\theta) \end{aligned}$$

Figure 12

Comets often have a tail of ions pointing directly away from the Sun.

- d) Using your answers to parts a), b) and c), explain how light can cause the ion tail to point away from the Sun.

Beam of light is coming from the sun. Light causes oscillatory motion due to E field (b), but motion due to magnetic field is consistently in the direction of the beam (c).

/1

OR

Photons from the sun impart momentum to the ions. Momentum is in the direction of the beam.

Total Q9

/8

Question 10

Marker use

A sheet of metal is pulled out of a magnetic field as in the Figure 13 diagram. An eddy current is formed as a result.

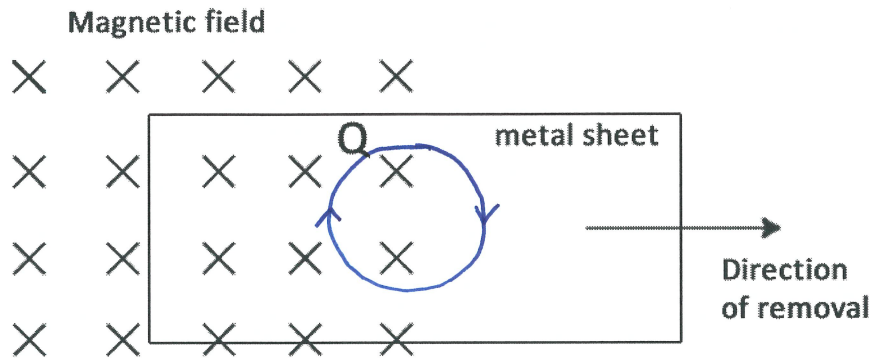


Figure 13

Spare diagram used (X)

a) Will the region of Q be positive or negative? Justify your answer.

Positive. RHR, with velocity to the right and B field into the page → positive charges are forced upwards.

/2

b) Sketch on the Figure 13 diagram the resulting eddy current formed in the metal.

/2

c) Identify the transfer of energy occurring while the metal is being pulled out.

Kinetic energy transferred to sheet
 → electric potential energy created by charge separation
 → heat energy created by eddy currents.

/2

Total
 Q10
 /6

Question 11

Marker use

Two parallel wires, P and Q, are 20.0 cm apart and both carry currents **out** of the page. Wire P carries 25.0 A and Wire Q carries 5.00 A. The Figure 14 diagram below shows P and Q and the position of the point Y.

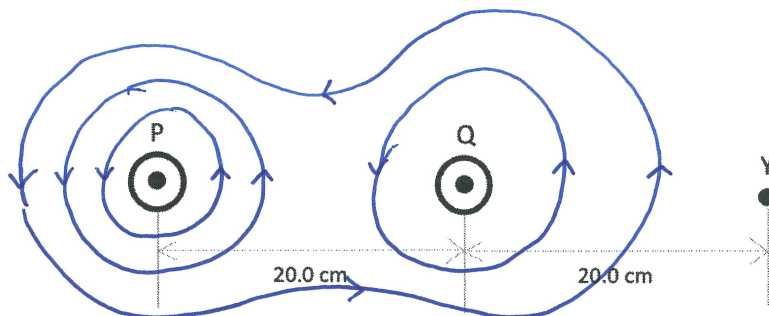


Figure 14

Spare diagram used (X)

a) On the Figure 14 diagram sketch the magnetic field in the region around Wire P and Wire Q.

/2

b) Calculate the force per unit length that Wire P exerts on Wire Q.

$$\frac{F_Q}{l} = \frac{k_B I_1 I_2}{r} = \frac{2 \times 10^{-7} \times 25 \times 5}{0.2} = 1.25 \times 10^{-4} \text{ N/m}$$

(attractive)

/2

c) Calculate the magnetic flux density at the point Y.

$$B_P = \frac{k_B I_P}{r_P} = \frac{2 \times 10^{-7} \times 25}{0.4} = 1.25 \times 10^{-5} \text{ T up.}$$

/2

$$B_Q = \frac{k_B I_Q}{r_Q} = \frac{2 \times 10^{-7} \times 5}{0.2} = 5.00 \times 10^{-6} \text{ T up.}$$

$$\therefore B_{\text{total}} = (1.25 + 0.5) \times 10^{-5} = 1.75 \times 10^{-5} \text{ T up.}$$

Total Q11

/6

Attach your candidate label here

Solutions

PHYSICS

PHY415115

Section **C** Waves

Pages: 16

Questions: 6

Information Sheet: 1

Suggested working time: 45 minutes

Instructions:

- Answer **all** questions and **all** items within each question.
- Write your answers in the spaces provided in this exam paper.
- A spare diagram has been provided at the end of this section. Indicate in the box provided if you have used the spare diagram.
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- All answers must be written in **English**.
- You **must** make sure your answers address the listed criterion.

Marker use	
C7	/ 45

Question 12

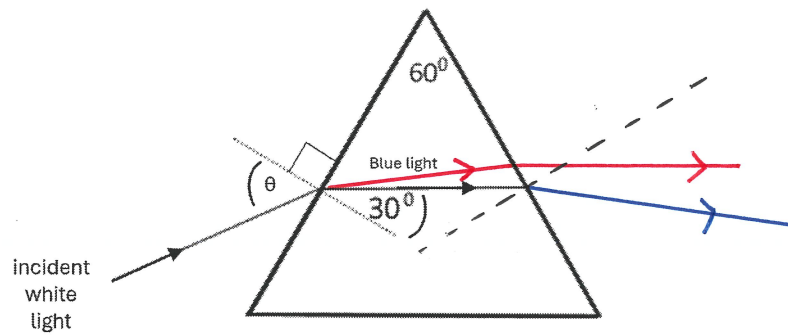


Figure 15

Spare diagram used (X)

A ray of white light strikes a 60° glass prism. Blue light is refracted to an angle of 30° . The prism has a refractive index of 1.58 for blue light.

- a) Calculate the angle of incidence, θ , of the white light.

$$1 \cdot \sin \theta = 1.58 \cdot \sin 30^\circ$$

$$\therefore \theta = \sin^{-1}(1.58 \cdot \sin 30^\circ) = 52.19^\circ$$

$$\approx 52.2^\circ$$

/2

The refractive index for red light is 1.54.

- b) Without calculation, sketch on the Figure 15:

- i. the path of the blue light as it leaves the prism
- ii. the path of the red light as it traverses and leaves the prism.

/1

/1

- c) Explain the path of the red light in part b) ii.

red has lower refractive index hence refracts to a lesser degree at both boundaries.

/1

- d) Calculate the critical angle of the blue light in the prism.

$$1.58 \sin \theta_c = 1 \cdot \sin 90^\circ$$

$$\therefore \theta_c = \sin^{-1}\left(\frac{1}{1.58}\right) = 39.27^\circ$$

$$\approx 39.3^\circ$$

/2

Question 12 continues

Question 12 continued

Marker use

- e) Would you expect all the refracted blue light to leave at the point in part b) i)? Give reasons for your answer.

Not all. $\theta_i < \theta_c$, and so total internal reflection does not occur. Light will refract out, but some internal reflection always occurs.

/2

Total
Q12
/9

Question 13

A wire is stretched between two bridges on a sonometer and is tensioned by a hanging mass as shown in Figure 16. The wire has a linear density of $2.00 \times 10^{-3} \text{ kg m}^{-1}$.

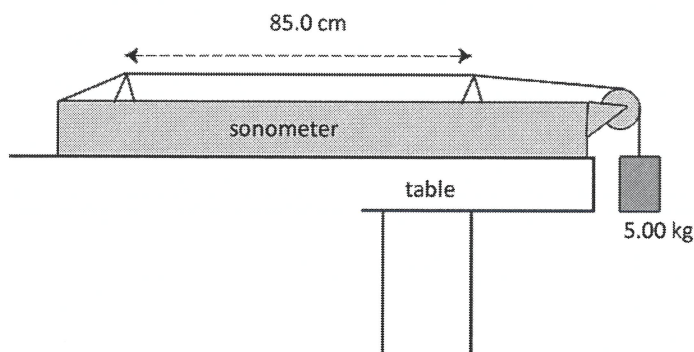


Figure 16

a) In one test, the bridges are 85.0 cm apart and tensioned with a 5.00 kg mass.

i. Show that the fundamental frequency of vibration of the wire is approximately 90 Hz.

$$\begin{array}{l}
 L = 0.85 \text{ m} \\
 \lambda = 2L = 1.7 \text{ m} \\
 T = F_g = mg \\
 \quad = 5 \times 9.81 \\
 \quad = 49.05 \text{ N}
 \end{array}
 \quad \left| \quad
 \begin{array}{l}
 v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{49.05}{2 \times 10^{-3}}} = 156.6 \text{ ms}^{-1} \\
 v = f\lambda \therefore f = \frac{v}{\lambda} = \frac{156.6}{1.7} \\
 \quad = 92.11 \\
 \quad \approx 92.1 \text{ Hz}
 \end{array}$$

/3

ii. Calculate the frequency of the second overtone.

$$\begin{array}{l}
 \text{second overtone} = \text{third harmonic} \\
 f = 3f_0 = 3 \times 92.11 = 276.3 \approx 276 \text{ Hz}
 \end{array}$$

/1

Question 13 continues

Question 13 continued

Marker use

A second identical wire is now also stretched 85 cm but is tensioned with a different mass. When the fundamental frequency of both are played together, the resulting tone "beats" with a frequency of 3.00 Hz.

b) What are the possible vibration frequencies of the second wire?

$$f_{\text{beat}} = |f_2 - f_1| \quad \therefore f_2 = f_1 \pm f_{\text{beat}}$$

$$= 92.1 \pm 3 \text{ Hz}$$

$$= 95.1 \text{ Hz or } 89.1 \text{ Hz}$$

/2

c) Calculate the least mass tensioning the second wire.

least mass \rightarrow least tension \rightarrow least speed \rightarrow least freq.

$$\therefore f = 89.1 \text{ Hz} \quad ; \quad v = \sqrt{\frac{T}{\mu}} \quad \therefore T = v^2 \mu$$

$$\lambda = 1.7 \text{ m} \quad ; \quad = 151.5^2 \times 2 \times 10^{-3}$$

$$\therefore v = f\lambda \quad ; \quad = 45.90 \text{ N}$$

$$= 151.5 \text{ ms}^{-1} \quad ; \quad T = mg \quad \therefore m = \frac{T}{g} = \frac{45.90}{9.81} = 4.68 \text{ kg}$$

/3

Total
Q13

/9

Question 14

Marker use

In a Young's Double Slit experiment, two coherent colours of light are passed through slits 0.2 mm apart. One is red light, wavelength 600 nm and the other blue light of wavelength 450 nm.

The resulting fringe pattern is observed on a screen 0.5 m from the double slit.

a) What is meant by the term "coherent" when applied to light?

Constant (or "consistent") phase relationship
(or "phase difference")

/1

b) Calculate the distance between each bright fringe for:

i. Red light

$$W = \frac{\lambda x}{d} = \frac{600 \times 10^{-9} \times 0.5}{0.2 \times 10^{-3}} = 1.5 \times 10^{-3} \text{ m} = 1.5 \text{ mm}$$

/1

ii. Blue light

$$W = \frac{\lambda x}{d} = \frac{450 \times 10^{-9} \times 0.5}{0.2 \times 10^{-3}} = 1.125 \times 10^{-3} \text{ m} \approx 1.13 \text{ mm}$$

/1

c) Show that antinodal fringes of light occur for both colours at points 4.5 mm on either side of the central bright spot.

antinodal fringes when distance = nW (integer n)
 $4.5 \text{ mm} = 3 \times 1.5 \text{ mm}$ (antinode for red)
 $4.5 \text{ mm} = 4 \times 1.125 \text{ mm}$ (antinode for blue)

/2

d) For the red light only, calculate how many wavelengths are in the path difference for the position in part c), 4.5 mm from the central bright spot.

antinode at nW corresponds to path difference = $n\lambda$
 $\therefore \text{P.D.} = 3\lambda$

/1

Total
Q14

/6

Question 15

Two buoys, A and B, are placed 60 m apart in an East – West line recording wave heights of ocean waves which are also travelling in an East – West direction as shown in Figures 17 and 18.



Figure 17

A plot of vertical displacement vs time for each of the two buoys is shown in Figure 18.

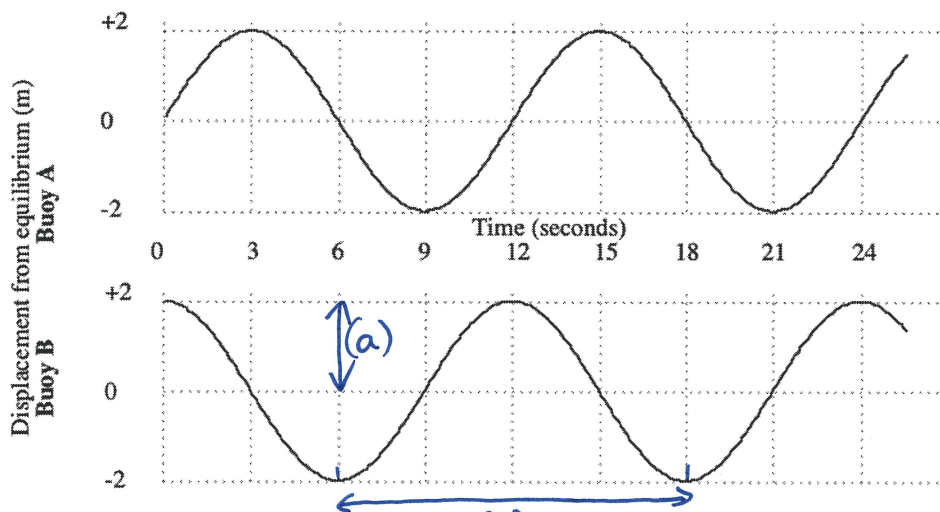


Figure 18

a) What is the amplitude of the wave?

2m.

/1

b) What is the period of the wave?

12 sec.

/1

Question 15 continued

Marker use

- c) Evaluate the wavelength of the wave. Give reasons for your answer.

Points A and B are 60m apart.
A is at equilibrium when B is at peak
→ separation is $\frac{1}{4} \times 2$. ∴ $\lambda = 4 \times 60 = 240\text{m}$.

/2

- d) Calculate the speed of the wave.

Peak travels 60m in 3 sec.
∴ $v = 60/3 = 20\text{ ms}^{-1}$.

/1

- e) Using Figures 17 and 18, which direction is the wave travelling? Give reasons for your answer.

Fig. 17 shows a peak at B, corresponding to time = 0 in Fig. 18. Peak arrives at A three seconds after B → wave is travelling east to west.

/2

Total
Q15

/7

Question 16

Many sunglasses are “polarised” meaning the lenses are made from a polarising filter. Consider unpolarised sunlight striking the surface of water as shown in Figure 19. The unpolarised light is shown in the diagram by an electric field component parallel to the surface of water by dots and the other component of equal value by arrows.

This light will be both reflected and refracted at the surface of the water.

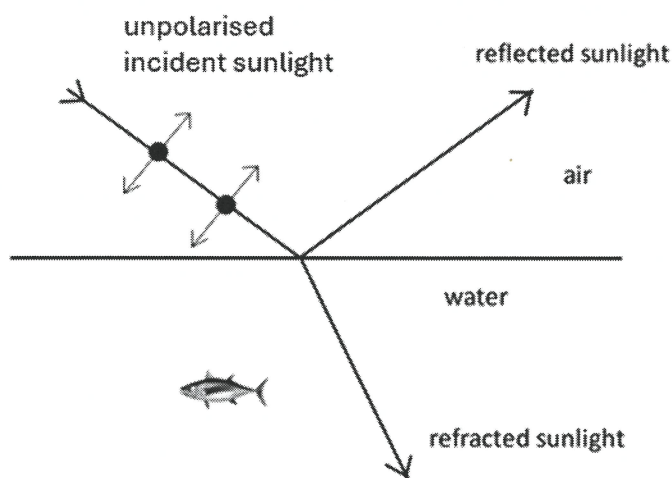


Figure 19

a) Circle **dot** or **arrow** as the main polarisation of the:

i. Reflected light **dot** arrow

ii. Transmitted light dot **arrow**

b) If the sunglasses reduce the reflected light from the water, are they good at reducing reflections from shop windows? Carefully explain your answer.

Sunglasses are aligned in a way that blocks horizontally polarised reflections from the water surface. Side-to-side reflections from a vertical shop window will be vertically polarised, so the glasses will be ineffective.

/1

/1

/3

Question 16 continues

Question 16 continued

Air scatters light. Consider an observer with polarised sunglasses looking at light from the Sun scattered by 90° .

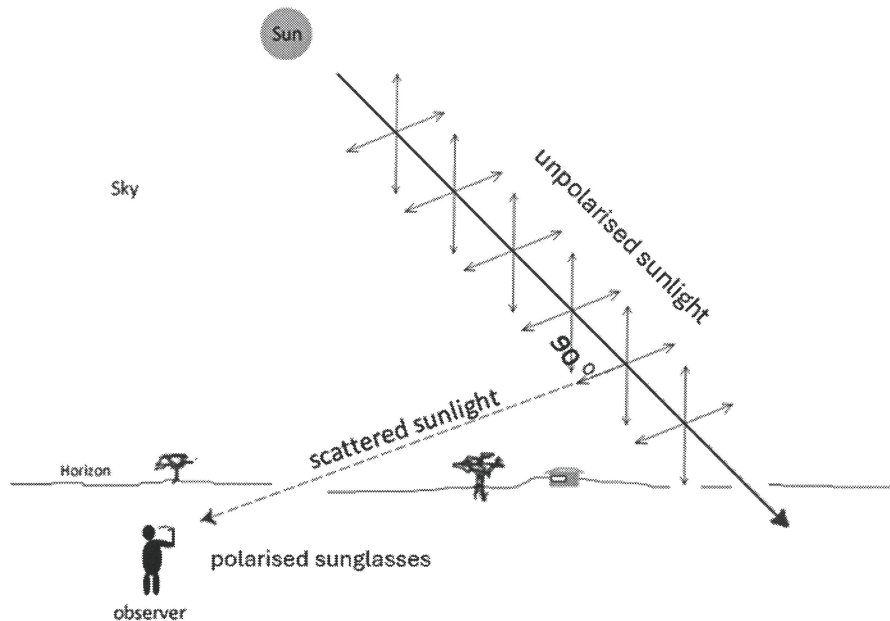


Figure 20

- c) Describe what will happen if the observer looks through polarised sunglasses at light that has been scattered by 90° , and then rotates the sunglasses through 180° .

Carefully explain your answer.

Scattered sunlight is polarised vertically. Sunglasses block horizontally polarised light when level.

So: at 0° rotation \rightarrow maximum transmission

at 90° rotation \rightarrow minimum transmission

at 180° rotation \rightarrow maximum transmission

Scattered light is bright, and 'hazy'. Observer will see bright + hazy \rightarrow dim + clear \rightarrow bright + hazy.

/3

Total
Q16

/8

Question 17

The human ear can be considered as a closed pipe (the ear canal to the ear drum) of approximate length 25 mm as shown in Figure 21.

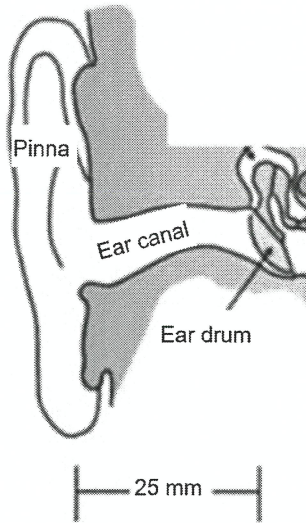


Figure 21

- a) Treating the ear as a closed pipe, sketch the fundamental and first overtone wave patterns in Figure 22.

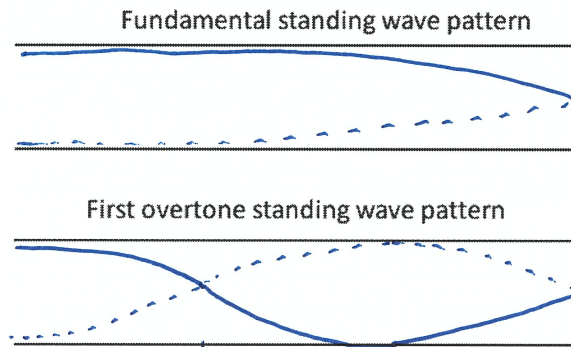


Figure 22

Spare diagram used (X)

- b) Calculate the fundamental frequency of a closed pipe of this length.

$$\begin{aligned}
 L &= \lambda/4 & v &= f\lambda \therefore f = v/\lambda \\
 \therefore \lambda &= 4L = 4 \times 25 \times 10^{-3} & &= 344/0.1 \\
 &= 0.1 \text{ m} & &= 3440 \text{ Hz} \\
 & & &\approx 3.44 \text{ kHz}
 \end{aligned}$$

Question 17 continues

Question 17 continued

Marker use

Adult human ears are most sensitive to frequencies between 2 kHz and 5 kHz and also 9 kHz to 12 kHz.

/2

Small children, however, are most sensitive to frequencies above 8 kHz.

c) Using parts a) and b), discuss this.

Adult ears: fundamental freq. in the 2-5 kHz range
first overtone has $f = 3f_0$
→ 9 - 12 kHz range.

Children: smaller ears → smaller L → smaller λ
→ higher frequency (fundamental)

Resonance amplifies sound, hence more sensitive to resonant frequencies.

Total
Q17
/6

Attach your candidate label here

Solutions

PHYSICS

PHY415115

Section **D** Twentieth Century

Pages: 12

Questions: 6

Information Sheet: 1

Suggested working time: 45 minutes

Instructions:

- Answer **all** questions and **all** items within each question.
- Write your answers in the spaces provided in this exam paper.
- A spare diagram has been provided at the end of this section. Indicate in the box provided if you have used the spare diagram.
- TASC-approved scientific calculators can be used throughout the exam.
- The Physics Information Sheet can be used throughout this exam.
- The exam is **three (3) hours** in length. The suggested working time for this section is **approximately 45 minutes**.
- All answers must be written in **English**.
- You **must** make sure your answers address the listed criterion.

Marker use

C8

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Question 18

Handheld remote thermometers measure the microwave emission peak emitted by warm bodies. They are sensitive to the range of $7.5 - 14 \mu\text{m}$ wavelengths.



Figure 23

- a) Calculate the range of temperatures for which the thermometers are most likely to be accurate.

$$\lambda_p T = 2.90 \times 10^{-3}$$

$$7.5 \mu\text{m} : T = \frac{2.90 \times 10^{-3}}{7.5 \times 10^{-6}} \quad 14 \mu\text{m} : T = \frac{2.90 \times 10^{-3}}{14 \times 10^{-6}}$$

$$= 387 \text{ K} \quad = 207 \text{ K}$$

- b) Would these sensors be likely to provide accurate readings of the temperature of the Sun's surface – approximately 5800°C ? Justify your answer.

$$\lambda_p = \frac{2.9 \times 10^{-3}}{5800 + 273} \quad \lambda_p \ll 7.5 \mu\text{m}$$

$$= 477 \text{ nm} \quad \therefore \text{unlikely to provide accurate readings.}$$

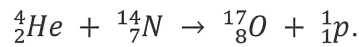
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Question 19

Marker use

In 1917, Rutherford observed that α particles from a source striking nitrogen produced a long-range radiation subsequently recognised as the proton. The reaction is as follows:



The masses of the particles are:

$${}^1_1\text{p} = 1.007276 \text{ u}$$

$${}^{17}_8\text{O} = 16.999131 \text{ u}$$

$${}^{14}_7\text{N} = 14.003074 \text{ u}$$

$${}^4_2\text{He} = 4.001506 \text{ u}.$$

a) Calculate the mass difference in the reaction.

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$$\Delta m = m_{\text{products}} - m_{\text{reactants}}$$

$$= (16.999131 + 1.007276) - (14.003074 + 4.001506)$$

$$= 0.001827 \text{ u}.$$

b)

i. Is energy released or absorbed in this reaction?

absorbed ($m_{\text{products}} > m_{\text{reactants}}$)

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ii. Calculate the value of this energy in MeV.

$$E = mc^2 = 0.001827 \times 931 \text{ MeV}$$

$$= 1.70 \text{ MeV}$$

/1

Question 19 continues

Question 19 continued

Marker use

The size of a nitrogen nucleus is about 3×10^{-15} m (3 fm).

- c) Calculate the force of repulsion between a nitrogen nucleus and the α particle at a separation of 4 fm and use this to argue for the existence of a nuclear force.

$$Q_N = +7 \times 1.6 \times 10^{-19} \text{ C}$$

$$Q_\alpha = +2 \times 1.6 \times 10^{-19} \text{ C}$$

$$F_E = \frac{k_E Q_N Q_\alpha}{r^2} = \frac{9 \times 10^9 \times 7 \times 1.6 \times 10^{-19} \times 2 \times 1.6 \times 10^{-19}}{(4 \times 10^{-15})^2}$$

$$= 201.6 \approx 202 \text{ N.}$$

Very large repulsive force, relative to tiny particles.

\therefore A very strong force (nuclear strong force) is required to bind them together.

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Question 20

Marker use

A photon with a wavelength of 2.484×10^{-11} m strikes an electron and is scattered at an angle of 180° from its original direction. After scattering, its wavelength is 2.967×10^{-11} m.

a) Calculate the momentum of:

i. The incident photon.

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{2.484 \times 10^{-11}} = 2.669 \times 10^{-23} \approx 2.67 \times 10^{-23} \text{ kgms}^{-1} \text{ forwards}$$

/1

ii. The reflected photon.

$$p = \frac{6.63 \times 10^{-34}}{2.967 \times 10^{-11}} = 2.235 \times 10^{-23} \approx 2.24 \times 10^{-23} \text{ kgms}^{-1} \text{ backwards}$$

/1

b) Show that the speed of the electron after the collision is 5.4×10^7 m s⁻¹ (0.18c).

$$\begin{aligned} \Delta p &= \bar{p}_f - \bar{p}_i = p_f + (-p_i) \\ &= (2.669 + 2.235) \times 10^{-23} \\ &= 4.904 \times 10^{-23} \text{ kgms}^{-1} \\ v &= \frac{p}{m} = \frac{4.904 \times 10^{-23}}{9.11 \times 10^{-31}} = 5.383 \times 10^7 \approx 5.38 \times 10^7 \text{ ms}^{-1} \text{ forwards.} \end{aligned}$$

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c) Show that energy appears not to be conserved in this collision.

$$\begin{aligned} E_\gamma &= hc/\lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 2.484 \times 10^{-11} = 8.007 \times 10^{-15} \text{ J} \\ E_\gamma' &= 6.63 \times 10^{-34} \times 3 \times 10^8 / 2.967 \times 10^{-11} = 6.704 \times 10^{-15} \text{ J} \\ E_e' &= \frac{1}{2}mv^2 = \frac{1}{2} \times 9.11 \times 10^{-31} \times (5.383 \times 10^7)^2 = 1.320 \times 10^{-15} \text{ J} \\ E_{total}' &= (6.704 + 1.320) \times 10^{-15} = 8.024 \times 10^{-15} \text{ J} \\ E_\gamma &= E_{total} \neq E_{total}' \quad (8.007 \times 10^{-15} \neq 8.024 \times 10^{-15}) \end{aligned}$$

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d) Suggest the effect that has not been taken into account in the energy calculation.

Relativistic effects OR $E_e \neq 0$ (as assumed above)
 Not a closed system (energy transferred to/from system from elsewhere)

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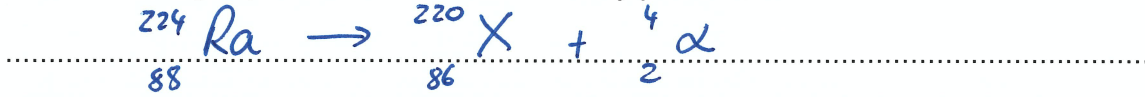
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Question 21

Marker use

In nuclear medicine, $^{224}_{88}\text{Ra}$ has been used for treating a condition called ankylosing spondylitis, a type of arthritis. It has a half-life of 3.823 days and is an α particle emitter. Typically a sample of activity of 6.0 MBq is injected into the patient.

- a) Write the decay equation in terms of the decay product, X.



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- b) Calculate the number of atoms injected into the patient.

$$A = \lambda N$$

$$\therefore N = \frac{A}{\lambda} = \frac{6 \times 10^6}{\frac{0.693}{3.823 \times 24 \times 60 \times 60}}$$

/2

$$= 2.86 \times 10^{12} \text{ atoms.}$$

- c) After 10.0 days, what is the activity of the remaining sample of radium $^{224}_{88}\text{Ra}$?

$$A = A_0 e^{-\lambda t} = 6 \times 10^6 \times e^{-\frac{0.693}{3.823} \times 10}$$

$$= 9.79 \times 10^5 \text{ Bq.}$$

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Total
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Question 22

Sodium atoms are bombarded with electrons in a vacuum tube. Some of the energy levels of atomic sodium are shown in Figure 24.

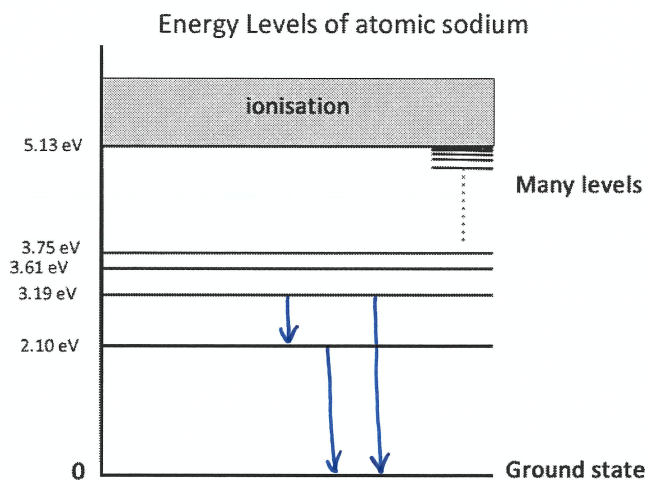


Figure 24

Spare diagram used (X)

- a) Calculate the minimum energy to excite an electron from a ground state atom in joules.

$$E = 2.10 - 0 = 2.10 \text{ eV}$$

$$= 2.1 \times 1.6 \times 10^{-19} = 3.36 \times 10^{-19} \text{ J}$$

/1

The atoms in ground state are bombarded with electrons at 3.30 eV.

- b) Show on Figure 24, possible transitions as the atom reverts to ground state.

/2

- c) Calculate the possible photon energy or energies in joules associated with these transitions.

/2

$$3.19 - 2.10 = 1.09 \text{ eV} = 1.74 \times 10^{-19} \text{ J}$$

$$2.10 - 0 = 2.10 \text{ eV} = 3.36 \times 10^{-19} \text{ J}$$

$$3.19 - 0 = 3.19 \text{ eV} = 5.10 \times 10^{-19} \text{ J}$$

Question 22 continues

Question 22 continued

Marker use

- d) Calculate the possible energies (in eV) of the scattered electrons.

$$3.30 - 3.19 = 0.11 \text{ eV}$$

$$3.30 - 2.10 = 1.20 \text{ eV}$$

$$3.30 - 0 = 3.30 \text{ eV (not a required answer)}$$

/2

- e) If sodium atoms are bombarded with 10 eV electrons, calculate the frequency of the highest energy photon that sodium will emit.

largest transition : 5.13 eV \rightarrow 0 eV.

$$E = hf \therefore f = \frac{E}{h} = \frac{5.13}{4.14 \times 10^{-15}} = 1.24 \times 10^{15} \text{ Hz}$$

/1

Sodium emits photons of yellow-orange light very strongly at a wavelength of 589 nm.

- f) Which two energy levels in Figure 24 are responsible for this wavelength?

$$\text{transition } E = hc/\lambda = 4.14 \times 10^{-15} \times 3 \times 10^8 / 589 \times 10^{-9} = 2.11 \text{ eV}$$

the 0 and 2.10 eV levels.

/2

Total
Q22

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Question 23

Marker use

Light of wavelength 200 nm falls on a clean aluminium surface in a photoelectric tube.

a) In what region of the electromagnetic spectrum is this light?

ultraviolet

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The work function of aluminium is 4.2 eV.

b) Calculate the maximum kinetic energy of any emitted photoelectrons in eV.

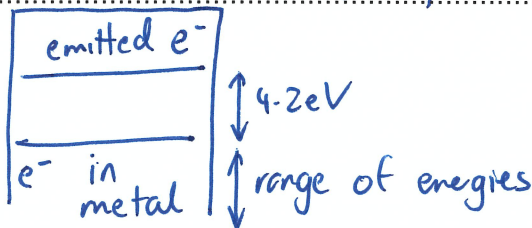
$$\begin{aligned}
 E_{kmax} &= hf - W \\
 &= \frac{hc}{\lambda} - W \\
 &= \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{200 \times 10^{-9}} - 4.2 \\
 &= 6.21 - 4.2 \\
 &= 2.01 \text{ eV}
 \end{aligned}$$

/2

The range of energies of photoelectrons varies from 0 eV up to the maximum value.

c) Explain why this range of kinetic energies exists. Use a diagram if necessary.

Work function (W) is the minimum energy required to emit a photoelectron. Most electrons require more than this, hence less energy remains as E_k .



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d) Calculate the minimum photon frequency required to eject photoelectrons from aluminium.

$$\begin{aligned}
 E = 4.2 \text{ eV} &= hf \quad \therefore f = \frac{4.2}{4.14 \times 10^{-15}} \\
 &= 1.01 \times 10^{15} \text{ Hz}
 \end{aligned}$$

/2

Total Q23

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