

**ATAR course examination, 2022**

**Question/Answer booklet**

**PHYSICS**

**UNITS 1 & 2­**

Student Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Teacher: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Time allowed for this paper**

Reading time before commencing work: ten minutes

Working time: three hours

**Materials required/recommended for this paper**

***To be provided by the supervisor***

This Question/Answer Booklet

Formulae and Data booklet

***To be provided by the candidate***

Standard materials:pens (blue/black preferred), pencils (including coloured), sharpener,   
correction fluid/tape, eraser, ruler, and highlighters

Special items: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination, drawing templates, drawing compass and a protractor

**Important note to candidates**

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

**Structure of this paper**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Section | Number of questions available | Number of questions to be answered | Suggested working time  (minutes) | Marks available | Percentage of examination |
| Section One  Short response | 12 | 12 | 50 | 54 | 30 |
| Section Two  Problem-solving | 7 | 7 | 90 | 90 | 50 |
| Section Three  Comprehension | 2 | 2 | 40 | 36 | 20 |
|  |  |  |  | TOTAL | 100 |

**Instructions to candidates**

1. The rules for the conduct of the Western Australian external examinations are detailed in the *Year 12 Information Handbook 2021.* Sitting this examination implies that you agree to abide by these rules.
2. Write your answers in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.
3. You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.
4. When calculating or estimating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning.

In calculations, give final answers to three significant figures and include appropriate units where applicable.

In estimates, give final answers to a maximum of two significant figures and include appropriate units where applicable.

1. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

**Section One: Short response 30% (54 Marks)**

This section has **12** questions. Answer **all** questions. Write your answers in the spaces

provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 50 minutes.

**Question 1 (6 marks)**

In order to protect against household fires and electrocution, modern buildings are equipped with RCD’s and Circuit Breakers. By outlining how each device works and what they protect against, clearly explain why it is necessary to have both of these devices installed in order for residents to be fully protected.

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**Question 2 (4 marks)**

A kg truck travels North through an intersection at 3.00 m s-1 when it is hit by a   
 kg car travelling East. After the collision, the two cars move off together on a bearing of . Determine the speed of the car before the collision, supporting your answer with an appropriate diagram.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m s-1

**Question 3 (5 marks)**

In an egg-drop experiment, a group of High School students have fixed a parachute system to an egg before dropping it from a height of 3.00 m. They record the combined mass to be 90.0 g and the time for the egg to reach the ground to be 0.900 s. Determine the magnitude of the force of air resistance acting on the egg-parachute system, assuming this force to be constant throughout the drop.

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**Question 4 (4 marks)**

When fireworks explode, both light waves and sound waves are emitted, yet these two waves are very different in nature. Clearly state and explain two differences in the natures of light waves and sound waves.

Difference One: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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**Question 5 (4 marks)**

Kate and Kris are tuning their instruments to play a song together.

(a) Kate’s instrument is a pipe that is open at one end and closed at the other. Kate plays the instrument at its third harmonic. Sketch a wave envelope (either pressure variation or displacement) for the sound she produces in her instrument.

(1 mark)

(b) Kris’s instrument is a pipe that is open at both ends. Kris plays the at its third harmonic. Sketch a wave envelope for the pressure variation of the sound she produces in her instrument.

(2 marks)

(c) Given that Kate and Kris are producing sounds of the same frequency, if the length of Kate’s instrument is 0.320 m, determine the length of Kris’s instrument.

(1 mark)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m

**Question 6 (6 marks)**

“Whiskey Stones” are a popular alternative to using ice to cool drinks. They are made of solid granite, roughly the same size and shape as an ice cube, but approximately three times more dense than water and with approximately twice the specific heat capacity of water. Despite this, they are often considered a poor substitute for using ice to cool drinks.

(a) Explain why you would expect ice to lower the temperature of a drink more than you would   
expect Whiskey Stones to lower its temperature.

(2 marks)

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(b) State and explain the predominant method of heat transfer in drinks.

(2 marks)

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(c) Hence, considering this method of heat transfer and the difference in density between ice and Whiskey Stones, explain why you would expect ice to lower the temperature of a drink faster than you would expect Whiskey Stones to lower its temperature.

(2 marks)

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**Question 7 (4 marks)**

Many face masks carry a permanent electric charge that can attract droplets (and other small materials) towards a filter. Using the diagram below, explain how the droplet is attracted to the mask. As part of your answer, illustrate the charges on the droplet (it has been drawn oversized to allow you to more easily do so).

A person's face with a stethoscope around his neck

Description automatically generated with medium confidence

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Question 8 (3 marks)**

Fluorine-18 is a radioisotope with a half-life of 110 minutes. Determine the time it takes, in hours, for a sample containing 8.00 g of Fluorine-18 to only contain 2.00 g of Fluorine-18.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ hours

**Question 9 (3 marks)**

A basketballer is shooting a free-throw. They are standing a horizontal distance of 4.50 m from the ring, which is at a height of 3.00 m. If the basketballer shoots the 0.590 kg ball with a speed of 7.00 m s-1, from a height of 1.40 m, determine the speed of the ball as it passes through the ring.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m s-1

**Question 10 (5 marks)**

A child is sliding down a banister, as shown in the picture below.

Shape

Description automatically generated with low confidence

(a) Ignoring friction, draw and label the forces acting on the child in the diagram above.

(3 marks)

(b) After reaching the end of the banister, the boy is falling in mid-air. At this point in time, the net force on him would be (circle one):

(1 mark)

A) Zero

B) Less than his net force on the banister (but non-zero)

C) Equal to his net force on the banister

D) Greater than his net force on the banister

(c) The boy lands and stands stationary on the floor. At this point in time, the net force on him would be (circle one):

(1 mark)

A) Zero

B) Less than his net force on the banister (but non-zero)

C) Equal to his net force on the banister

D) Greater than his net force on the banister

**Question 11 (4 marks)**

Hwei is standing 3.00 m away from a speaker and hears the sound at an intensity of . Determine how far back she should walk if she wants to reduce the sound intensity to .

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m

**Question 12 (3 marks)**

A pot of boiling water will remain at during the entire time that the water is boiling, even though heat is clearly being transferred from the stove. Explain why this occurs.

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**Section Two: Problem-solving 50% (90 Marks)**

This section has **seven** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers

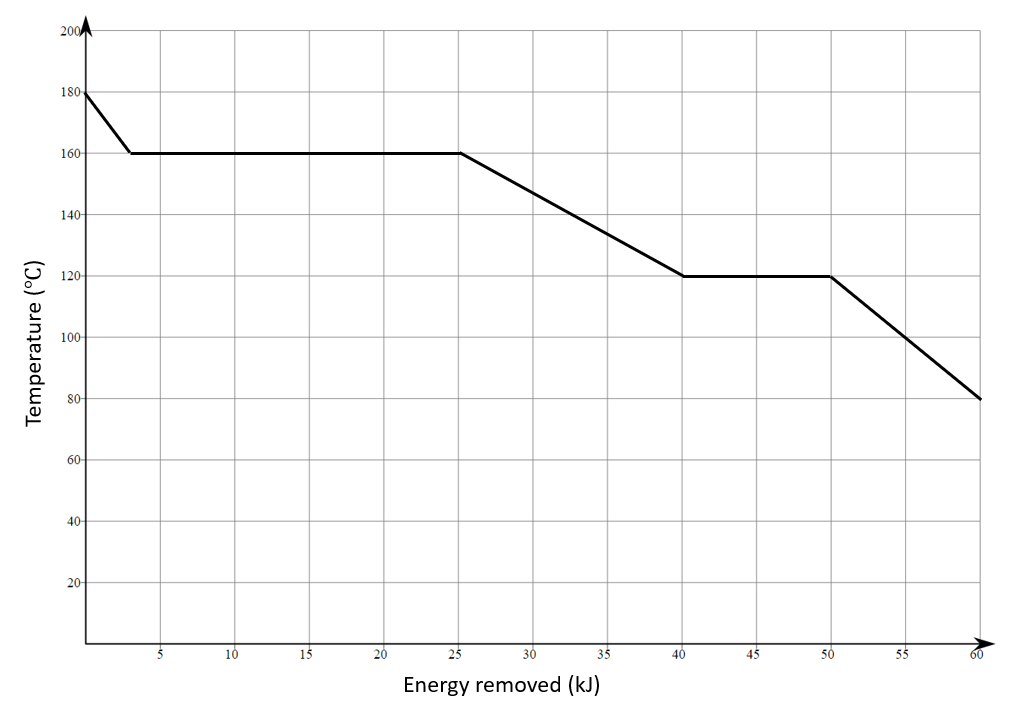
to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 90 minutes.

**Question 13 (12 marks)**

The cooling curve for a 35.0 g sample of a particular chemical is shown below.



(a) Determine the boiling point of the chemical, giving your answer in kelvin.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ K

(b) Determine the latent heat of fusion of the chemical.

(4 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ J kg-1

(c) Determine the specific heat capacity of the chemical in its liquid phase.

(4 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ J kg-1 K-1

(d) Without any further calculations, explain how you can deduce from the graph that the specific heat capacity is largest for the liquid phase.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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**Question 14 (17 marks)**

Sarah has just bought a bottle of orange juice. The juice is at a room temperature of , but Sarah would prefer it to be chilled to . She has poured herself a glass containing g of orange juice and intends to add ice, at , to cool the juice to the desired temperature.

(a) Given that orange juice has a specific heat capacity of , determine the amount of thermal energy that needs to be lost by the juice for it to be at the desired temperature.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ J

(b) Determine the mass of ice needed to cool the juice to the desired temperature.

(4 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ kg

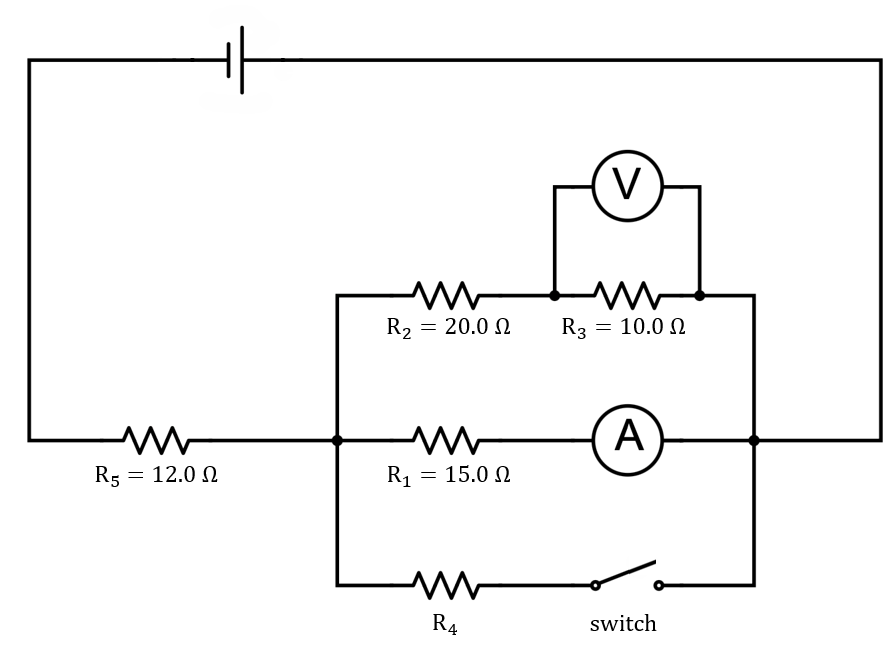
(c) The following day, Sarah uses orange juice from the fridge, which is already at a temperature of . She again pours herself a glass containing g of orange juice. Sarah quickly drinks a quarter of her orange juice then tops up the glass with room temperature water (at ) so that it once again contains g of drink. Determine the final temperature of the drink once it has reached thermal equilibrium.

(4 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Question 15 (17 marks)**

In the circuit below, the switch is currently open and the reading on the ammeter is 1.50 A.



(a) Draw an arrow indicating the direction of electron flow through .

(1 mark)

(b) Determine the number of electrons that pass through resistor during a three minute period.

(3 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ electrons

(c) Determine the power dissipated in .

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ W

(d) Determine the reading on the voltmeter.

(4 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ V

(e) Determine the voltage of the battery.

(3 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ V

(f) Suppose the switch is now closed. Clearly explain whether the reading on the ammeter will increase, decrease, or remain the same.

(4 marks)

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**Question 16 (15 marks)**

A common nuclear fission reaction is shown below, where the number of neutrons released has not been provided.

The masses of the above species are provided below.

|  |  |
| --- | --- |
| **Species** | **Mass (u)** |
| Neutron | 1.009 |
| Uranium-235 | 235.044 |
| Barium-141 | 140.914 |
| Krypton-92 | 91.926 |

(a) State the number of neutrons released through this reaction.

(1 mark)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ neutrons

(b) Show that the amount of energy released by each fission reaction is approximately J.

(5 marks)

(c) A typical nuclear power plant will use 3.00 kg of Uranium-235 each day. Determine the amount of energy such a power plant would produce in a day.

(3 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ J

(d) A member of the public is concerned that this nuclear process could become uncontrolled. Explain why the reaction has the potential for this to occur.

(3 marks)

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(e) A spokesperson for the power plant tries to reassure the public by saying that if the reaction is occurring at too high a rate then they can always insert moderators to slow down the reaction. Clearly explain why this statement is incorrect.

(3 marks)

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**Question 17 (11 marks)**

The velocity-time graph for an object, initially travelling towards the right, is shown below. Use the graph to answer the questions that follow, noting that the shape of the graph is circular between 7.00 and 9.00 seconds.

Chart, line chart

Description automatically generated

(a) State the time(s) at which the object changes direction.

(1 mark)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(b) State the time period(s) during which the object’s speed is increasing.

(1 mark)

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(c) Determine the acceleration of the object after four seconds.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m s-2 Direction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(d) Determine the displacement of the object after five seconds.

(3 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m Direction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(d) Determine the displacement of the object after nine seconds (providing your answer to three significant figures).

(4 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m Direction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Question 18 (15 marks)**

A kg undercover police car is travelling at m s-1 when another car speeds past it, travelling at a constant speed of km h-1. The police car immediately begins pursuing the second car, accelerating at a constant rate of m s-2.

(a) Determine the magnitude of the initial momentum of the police car.

(1 mark)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ kg m s-1

(b) Determine the police car’s speed after 2.00 s of accelerating.

(1 mark)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m s-1

(c) At the time when the police car’s speed matches that of the speeding car, determine the distance between them.

(5 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m

(d) Determine how long it takes for the police car to catch up to the speeding car (from the time the speeding car first passed the police car).

(3 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ s

(e) Determine the average power of the police car during its pursuit.

(3 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ W

(f) Once caught, the speeding car begins to slow down to a stop, braking at a constant rate of 7.00 m s-2. Determine the distance over which it brakes.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m

**Question 19 (10 marks)**

A new form of brachytherapy known as “diffusing alpha-emitters radiation therapy” aims to produce alpha-emitting radioisotopes at the site of a tumour. An initial source is implanted into the patient, which produces radioisotopes such as Radon 220, a known alpha-emitter. This technique hopes to treat large tumours of typical sizes such as 300 g by delivering an absorbed dose of approximately 70.0 Gy.

(a) Write the nuclear decay equation for Radon-220.

(2 marks)

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(b) State and explain two reasons why an alpha-emitter has been chosen for this application.

(4 marks)

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(c) Determine the energy delivered to a typical tumour.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ J

(d) Determine the equivalent dose delivered to a typical tumour.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Sv

**End of Section Two**

**Section Three: Comprehension 20% (36 Marks)**

This section has **two** questions. You must answer **both** questions. Write your answers in the spaces provided.  
  
When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.  
  
When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Suggested working time: 40 minutes.

**Question 20 (17 marks)**

A Year 11 Physics class is undertaking an experiment to determine the activity of a radioactive sample of Strontium-90 (decaying to Yttrium-90).

When Strontium-90 decays, it can be thought to emit radiation isotropically, meaning that the resulting particles of radiation are emitted in all directions, spreading out spherically. At a distance of from the source, the particles are thought to be spread over the surface of a sphere centred at the source (with surface area ).

A pair of glasses

Description automatically generated with low confidence

A radiation detector has a fixed area and will only detect the radiation incident on it. Therefore, the further the detector is placed from the source, the lower the activity it will detect. The students use a detector with a square detecting area of side length 3 cm.

(a) Write the nuclear decay equation for the radioactive source.

(2 marks)

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(b) Show that the detected activity (in becquerel), , is given by

where is the activity of the source (in becquerel), and is the distance from the

detector to the source (in metres)

(2 marks)

The students collected the data in the table below and have already begun the data manipulation process.

|  |  |  |
| --- | --- | --- |
|  |  |  |
| 0.100 | 100 | 26.5 |
| 0.150 | 44.4 | 11.8 |
| 0.200 |  | 6.6 |
| 0.250 |  | 4.2 |

(c) Complete the second column of the table above, including providing the correct units in   
 the header and the missing values correct to three significant figures.

(3 marks)

(d) Using the grid provided on the next page, plot a graph of against , with on the

vertical axis. Include a line of best fit.

(4 marks)

**A close up of a white wall

Description automatically generated**

A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and clearly indicate that you have redrawn it on the spare page.

(e) Clearly showing construction lines on your graph, determine the gradient of your line of

best fit.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Bq m2

(f) Use your gradient to determine the activity of the source.

(2 marks)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Bq

(g) The students took another measurement and found that the activity at the detector was

higher than expected. Assuming no mistakes were made and there were no errors

introduced by the measuring equipment, suggest a reason why this occurred.

(1 mark)

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(h) When the students compare their results to those from last year’s class, they find that all

of their measurements are lower. Assuming no mistakes were made and there were no

errors introduced by the measuring equipment (all of which is the same as that used last

year), explain why this occurred.

(1 mark)

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**Question 21 (19 marks)**

**Hunting techniques of the mustached bat**

Based on the research of Suga (1990)

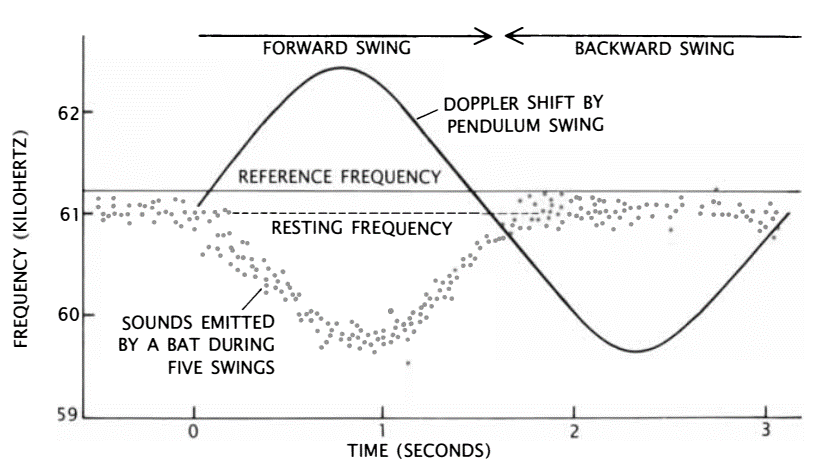
Some species of bat, such as the mustached bat, have developed advanced sonar techniques used for hunting other species. The mustached bat is not only able to use echolocation to determine the distance to its prey, but also to use the doppler effect to determine the speed of its prey. The doppler effect is a perceived change (commonly referred to as a doppler shift) in the frequency of a sound due to the relative motion of the source of the sound and/or whatever is hearing or recording the sound.

The mustached bat hunts by first releasing a high frequency sound and several of its harmonics. The sounds waves produced can effectively detect the location of any object larger than their wavelength. Of particular importance is the second harmonic. When the bat and its prey are both stationary, this harmonic has a frequency of 61.2 kHz. Mustached bats also have extremely sensitive hearing near this frequency and can detect frequency shifts as small as 0.01%. By detecting the shift in frequency of the returned echo, the bats can deduce the speed of their prey.

When flying towards its prey, the mustached bat also has the ability to compensate for its own movement in order to ensure that returned echoes still fall within its sensitive range of hearing. The bat’s motion will cause not only a doppler shift in its emitted sound, but also a doppler shift in its perceived frequency of the returning echo. The frequency of sound ultimately heard by the bat is given by

Note that will always be positive as mustached bats do not fly backwards.

The bats’ ability was observed by scientists, who placed a mustached bat on a swing and recorded the frequency of sound emitted by the bat. They clearly observed the bat’s emitted frequency of sound change to counteract the doppler shift caused by the forward swing.



*Figure taken directly from (Sugo, 1990)*

(a) Determine the fundamental frequency of sound emitted by the mustached bat when both

it and its prey are stationary.

(2 marks)   
  
  
  
  
  
   
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Hz

(b) Determine the wavelength of the second harmonic emitted by the mustached bat when   
both it and its prey are stationary.

(2 marks)   
  
  
  
  
  
   
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m

(c) State one reason why sound with this wavelength would be ideal for echolocation.

(1 mark)

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(d) Below is a simplified wavefront diagram showing the emitted sound waves of the

mustached bat as it approaches a stationary prey. Draw on the diagram to show three   
successive wavefronts that have reflected off the prey.

(2 marks)

A picture containing shape

Description automatically generated

(e) Considering both the article and the diagram from part (d), fully explain why the echo of the bat’s emitted sound will be perceived at a higher frequency when the bat is flying towards its prey.

(3 marks)

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(f) A stationary mustached bat detects its prey to be 30.0 m away. Determine the time

period between when the bat emitted a sound and when it heard its echo.

(3 marks)   
  
  
  
  
  
  
  
  
   
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ s

(g) Estimate the maximum speed of the swing used in the scientists’ experiment.

(5 marks)   
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
   
\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ m s-1

(h) Suggest an appropriate reason why there was no frequency compensation observed during the backwards swing for the scientists’ experiment.

(1 mark)

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Supplementary page

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Supplementary page

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Spare grid

**A close up of a white wall

Description automatically generated**

Suga, N. (1990). Biosonar and Neural Computation in Bats. *Scientific American*, *262*(6), 60–71. http://www.jstor.org/stable/24996825

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