Graphical user interface

Description automatically generated with low confidence

**ATAR Course Examination, 2023**

**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 | 13 | 13 | 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 2022.* 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 **13** 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 (3 marks)**

Complete the wavefront diagram below, showing the refraction of sound waves as they flow from the solid object into the surrounding gas. Draw at least five wavefronts.

A picture containing text, antenna

Description automatically generated

|  |  |
| --- | --- |
| At least five straight wavefronts drawn | 1 mark |
| Direction is bent towards the normal | 1 mark |
| Wavelength is consistent and shorter than for the solid | 1 mark |

**Question 2 (2 marks)**

Calculate the wavelength of sound produced in a string of length 0.750 m, vibrating at the fourth harmonic.

|  |  |
| --- | --- |
|  | 1 mark |
| m | 1 mark |

**Question 3 (6 marks)**

A g piece of lead at is placed into g of water at a room temperature of . The mixture reaches thermal equilibrium at a temperature of .

(a) Ignoring any heat exchange with the environment, use this information to determine the specific heat capacity of lead.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

(b) Considering that there likely would have been heat exchange with the environment, explain the effect this is likely to have on your calculation.

(3 marks)

|  |  |
| --- | --- |
| Since the lead/water system will be above room temperature, heat will have been lost to the surroundings | 1 mark |
| Without this heat loss, the equilibrium temperature would have been higher OR This will have been perceived as additional heat being transferred from the iron to the water | 1 mark |
| So the true specific heat capacity of lead should be larger than what was calculated | 1 mark |

**Question 4 (5 marks)**

Consider the circuit below.

A picture containing line, diagram, screenshot, plot

Description automatically generated

The voltage of the battery is measured to be V and the voltage drop over resistor is measured to be V. The resistance of is measured to be .

(a) Determine the voltage drop over resistor , including its absolute uncertainty.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
| i.e. | |

(b) Determine the current through , including its absolute uncertainty.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
| i.e. | |

**Question 5 (6 marks)**

Aaron is trying to determine the frequency of sound produced by a tuning fork. He holds the tuning fork above a tall, empty measuring cylinder and gradually fills the measuring cylinder with water. Aaron observes that he can hear the sound from the tuning fork loudly when the height of the water in the measuring cylinder is 11.0 cm and again when the height of the water in the measuring cylinder is 50.0 cm. This is depicted in the diagram below (not to scale). Use this information to determine the frequency of the tuning fork, assuming a room temperature of .

A picture containing line, rectangle, design

Description automatically generated

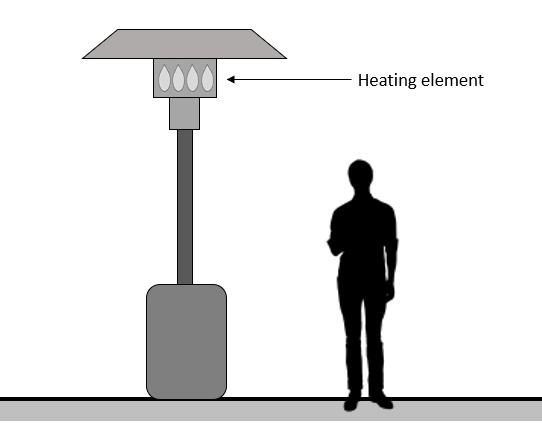
11.0 cm

50.0 cm

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
| m | 1 mark |
|  | 1 mark |
|  | 1 mark |

**Question 6 (5 marks)**

For safety reasons, the heating element for a patio heater is located near the top of the structure, however, this can reduce the effectiveness of the device for heating people.

****

(a) Explain, with reference to heat transfer via convection, why the position of the heating element is not ideally located.

(3 marks)

|  |  |
| --- | --- |
| Convection is a method of heat transfer in which hotter, less dense fluids rise, while cooler, more dense fluids fall | 1 mark |
| The heating element of the patio heater is positioned above the people using it | 1 mark |
| This means that hot air near the heating element will rise away from users due to convection (while cooler air takes its place) | 1 mark |

(b) Explain why air is not effective at conducting heat.

(2 marks)

|  |  |
| --- | --- |
| Conduction is a method of heat transfer in which heat is transferred through the collision of particles | 1 mark |
| Since the particles in a gases (such as in air) are so far apart from one another, they collide less frequently than particles in solids or liquids, making air a poor conductor of heat | 1 mark |

**Question 7 (3 marks)**

A 70.0 kg skateboarder, originally stationary, drops into a half-pipe of radius 3.00 m. Determine the speed of the skateboarder at the bottom of the half-pipe, ignoring any effects of friction or drag.

A picture containing ax, vector graphics

Description automatically generated

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

**Question 8 (3 marks)**

The ball pictured below is slowing down as it rolls across a rough surface, moving towards the right. On the diagram below, draw a labelled free body diagram of the forces acting on the ball.

Normal Force

**Shape, rectangle

Description automatically generated**

Friction

Weight

|  |  |
| --- | --- |
| Normal force, weight, and friction (can also include drag / air resistance) are included and labelled | 1 mark |
| Directions are correct, and the magnitudes of the normal force and weight are equal | 1 mark |
| No other forces are included | 1 mark |

**Question 9 (5 marks)**

Safety requirements dictate that radiation workers in Australia cannot receive more than an equivalent dose of mSv in a given year. Given that a kg worker has already been exposed to J of radiation from fast neutrons, determine how much additional energy they can be exposed to from slow neutrons before exceeding their annual limit. Assume that all exposures are to their whole body.

|  |  |
| --- | --- |
| Gy | 1 mark |
| Sv | 1 mark |
| Sv | 1 mark |
| Gy | 1 mark |
| J | 1 mark |

**Question 10 (3 marks)**

Carbon-14 is a naturally occurring radioisotope. Biological processes ensure a relatively constant amount of carbon-14 in living things, however, upon death this amount will then decrease as the carbon-14 undergoes radioactive decay with a half-life of 5730 years. Given that an animal fossil is found to contain 12.5% of the carbon-14 typically found in the living animal, determine how many years ago the animal is likely to have died.

|  |  |
| --- | --- |
| 3 half-lives  OR      Hence y | |
| Employs a reasonable method for determining the number of half-lives | 1 mark |
|  | 1 mark |
| y | 1 mark |

**Question 11 (5 marks)**

Ammeters are designed to have a very low resistance and should be connected in series with devices, as in the example circuit below.

A picture containing clock

Description automatically generated

(a) With reference to a relevant formula, explain why the ammeter is designed to have a very low resistance.

(2 marks)

|  |  |
| --- | --- |
| Since all components are in series | 1 mark |
| In order for the total resistance to be unchanged ( we require | 1 mark |

(b) Suppose that the ammeter was incorrectly connected in parallel to one of the globes, as in the diagram below.

Diagram

Description automatically generated

Compared to when the ammeter was connected in series, state how would you expect the brightness of each globe to change, justifying your answer.

(3 marks)

|  |  |
| --- | --- |
| The brightness of Y would decrease while the brightness of X would increase | 1 mark |
| Almost all of the circuit’s current would flow through the ammeter with almost none of the circuit’s current flowing through Y | 1 mark |
| Hence almost all of the circuit’s voltage will be provided to X | 1 mark |
| (accept other reasonable justifications) | |

**Question 12 (4 marks)**

A car travels at a constant velocity for 10.0 seconds. The driver then uses the brakes to bring the car to rest over the next 10.0 seconds, decelerating at a constant rate. Throughout this 20.0 second time period, the car travels a total distance of 260 m.

(a) Sketch a velocity-time graph for the car below.

(2 marks)

Chart

Description automatically generated

|  |  |
| --- | --- |
| As above for ( does not need to be indicated) | 1 mark |
| As above for | 1 mark |

(b) Determine the initial speed of the car.

(2 marks)

|  |  |
| --- | --- |
| (Trapezium area approach)  OR  (Composite area approach one)  OR  (Composite area approach two)  OR  (Motion formula approach) | 1 mark |
|  | 1 mark |

**Question 13 (4 marks)**

Ionisation smoke detectors rely on a radioactive sample of americium-241, a known alpha-emitter with a half-life of 432 years. In the absence of smoke, air molecules within the detector are ionised, creating a constant flow of current, however, in the presence of smoke this current is interrupted, triggering the alarm.

Explain two reasons why an alpha-emitter is more suited for this application than a gamma emitter.

|  |  |
| --- | --- |
| Alpha particles have a higher ionising ability than gamma rays | 1 mark |
| Hence they will ionise air molecules, allowing the smoke detector to work | 1 mark |
| Alpha particles have a lower penetrating ability than gamma rays | 1 mark |
| Hence they will not penetrate the casing of the smoke detector and so do not pose any exposure risk to people | 1 mark |

**End of Section One**

**This page has been left blank intentionally**

**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 14 (11 marks)**

Consider the thermal properties of acetone listed below:

|  |  |
| --- | --- |
| Melting point |  |
| Boiling point |  |
| Latent heat of fusion |  |
| Latent heat of vaporisation |  |
| Specific heat capacity of solid |  |
| Specific heat capacity of liquid |  |
| Specific heat capacity of gas |  |

(a) Express the melting point of acetone in kelvins.

(1 mark)

|  |  |
| --- | --- |
|  | 1 mark |

(b) Considering the kinetic particle model, explain why the latent heat of vaporisation is significantly larger than the latent heat of fusion.

(2 marks)

|  |  |
| --- | --- |
| The latent heat is the heat required for one kilogram of the substance (acetone) to change state | 1 mark |
| In changing from a solid to a liquid, attractive forces between acetone molecules are only partially overcome (and are still relatively strong), whereas in changing from a liquid to a gas, the remaining attractive forces between acetone molecules must be (virtually) completely overcome OR  In changing from a solid to a liquid, acetone molecules are only slightly separated, whereas in changing from a liquid to a gas, the acetone molecules are greatly separated | 1 mark |

(c) Vidhi prepares a 50.0 g sample of acetone at a room temperature of . She places the sample on an electric heater designed to deliver heat to the sample at a constant rate of 110 W. Determine the time taken for the sample to completely turn into a gas, assuming the heater is 100% efficient and no heat is lost to the surrounding environment.

(5 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

(d) Vidhi prepares a second room temperature sample of acetone. She places a thermometer in the sample and directs a small fan at the sample. Vidhi observes that some of the sample evaporates, causing the temperature of the remaining sample to decrease. Explain, with reference to temperature and particle energies, why the evaporation of some of the sample has caused this decrease in temperature.

(3 marks)

|  |  |
| --- | --- |
| Temperature is a measure of the average kinetic energy of particles in a substance | 1 mark |
| The evaporated particles will be those with the highest energy within the sample | 1 mark |
| When they are removed, the average kinetic energy of the remaining particles decreases, and hence so does the remaining sample’s temperature | 1 mark |

**Question 15 (15 marks)**

Leo is trying to determine the linear density of a string using the experimental set-up below.

A picture containing text, screenshot, table

Description automatically generated

pan

Using a 50.0 Hz motor, a pulley, and several masses to alter the tension in the string, Leo alters the length of the string between the motor and the pulley until he observes resonance in the length of string.

Leo knows that in order to achieve resonance, the following equation must hold:

where: is the linear density of the string (in kg m-1)

is the frequency the string is vibrating at (in Hz)

is the mean acceleration due to gravity on Earth (in m s-2)

is the vibrating string length (in m)

is the mass of the pan suspended from the pulley (in kg)

is the added mass suspended from the pulley (in kg)

Leo has collected the following data:

|  |  |  |
| --- | --- | --- |
| (kg) | (m) | (m2) |
| 0.030 | 0.130 | 0.0169 |
| 0.060 | 0.170 | 0.0289 |
| 0.090 | 0.200 | 0.0400 |
| 0.120 | 0.225 | 0.0506 |
| 0.150 | 0.240 | 0.0576 |

(a) Describe the experimental condition that would allow for resonance to occur.

(1 mark)

|  |  |
| --- | --- |
| The frequency of the motor matches the resonant frequency of the string | 1 mark |

(b) Complete the table, expressing the missing values to three significant figures.

(2 marks)

|  |  |
| --- | --- |
| Values | 1 mark |
| Significant figures | 1 mark |

(c) Using the grid and axes provided below, plot a graph of against , with plotted on the vertical axis. Include scales and labels for each axis, and a line of best fit.

(4 marks)

|  |  |
| --- | --- |
| Axes labelled correctly (including units) | 1 mark |
| Appropriate uniform scales used | 1 mark |
| Points plotted accurately | 1 mark |
| Reasonable line of best fit | 1 mark |

(d) Determine the gradient of your line of best fit. Clearly show your working and include units.

(3 marks)

|  |  |
| --- | --- |
| Uses two non-data points | 1 mark |
| Calculates value of gradient ( | 1 mark |
| Units of | 1 mark |

(e) Use the gradient to determine the linear density of the string. Show clear reasoning and working.

(3 marks)

|  |  |
| --- | --- |
| gradient = | 1 mark |
|  | 1 mark |
| (value will depend on students’ gradient) | 1 mark |

(f) Use the line of best fit to determine the mass of the pan. Show clear reasoning and working.

(2 marks)

|  |  |
| --- | --- |
| (y-value of) y-intercept = | 1 mark |
| kg  (should be consistent with students’ graph) | 1 mark |

**Question 16 (8 marks)**

Each power outlet in a home is designed to connect a device to the mains power supply by means of a set of wires that can carry current to and from the power outlet. It is often neglected that these wires also have resistance and hence there is power dissipated in them.

(a) Using formulae from your Formulae and Data Booklet, derive a formula for the power dissipated in a wire of resistance, R, with a current, I, flowing through it.

(2 marks)

|  |  |
| --- | --- |
| and | 1 mark |
|  | 1 mark |

(b) Considering this relationship, explain why connecting multiple devices to the same power outlet can be dangerous. As part of your answer, describe whether the devices are connected in series of parallel.

(4 marks)

|  |  |
| --- | --- |
| Devices are connected in parallel | 1 mark |
| Each device increases the total amount of current drawn by the power outlet | 1 mark |
| Hence, since , there is more power dissipated in the wires to and from the outlet | 1 mark |
| This power is in the form of heat, which may lead to a fire if it is too large | 1 mark |

(c) State a safety feature used to overcome this danger and briefly explain how it works.

(2 marks)

|  |  |
| --- | --- |
| Fuse or circuit breaker | 1 mark |
| Breaks the circuit if the current exceeds a given value (by melting in the case of a fuse) | 1 mark |

**Question 17 (18 marks)**

A 2.50 g penny is dropped from the top of a 300 m skyscraper. As the penny falls it is subject to air resistance, the force of which is proportional to its speed squared. During its fall, the penny reaches a terminal (constant) velocity of 20.0 m s-1 towards the ground.

(a) Explain why an object, if dropped for long enough, would reach a terminal velocity.

(3 marks)

|  |  |
| --- | --- |
| As its speed increases, so will the force of air resistance acting upon it | 1 mark |
| Eventually, the force of air resistance would be equal in magnitude to the object’s weight | 1 mark |
| By Newton’s First Law of Motion, the object would then maintain a constant (terminal) velocity | 1 mark |

(b) Draw two labelled free-body diagrams below, showing the forces acting on the penny during its fall when it has:

(3 marks)

(i) not yet reached terminal velocity (ii) reached terminal velocity

Weight

Air Resistance

Weight

Air Resistance

|  |  |
| --- | --- |
| Both diagrams include the weight and force of air resistance, with correct directions, labels, and ruled lines | 1 mark |
| The weight is the same size in both diagrams | 1 mark |
| In (i), the force of air resistance is smaller than the weight in magnitude In (ii), the force of air resistance is equal to the weight in magnitude | 1 mark |

(c) Determine the speed the penny would be expected to reach the ground at if no air resistance acted on the penny throughout its fall.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

(d) Hence determine the work done by air resistance on the penny.

(3 marks)

|  |  |
| --- | --- |
|  | 2 marks |
|  | 1 mark |

(e) After approaching at terminal velocity, the penny lands in the soil of a garden area, coming to rest 2.00 cm below the surface. Determine the average force that the penny struck the soil with.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

(f) Determine the time taken for the penny to come to rest from the moment it first hits the soil.

(3 marks)

|  |  |
| --- | --- |
|  | 2 marks |
|  | 1 mark |

(g) Explain why the impact force of the penny would have been significantly larger if it had landed on the pavement.

(2 marks)

|  |  |
| --- | --- |
| Given the work done on the penny is the same, the impact force is inversely proportional to the distance travelled in coming to rest | 1 mark |
| Since the penny would not travel very far into pavement, it would therefore have a very large impact force | 1 mark |

OR

|  |  |
| --- | --- |
| Given the change in momentum for the penny is the same, the impact force is inversely proportional to the time taken to come to rest | 1 mark |
| Since the penny would not have a long impact time with the pavement, it would therefore have a very large impact force | 1 mark |

**Question 18 (13 marks)**

Consider the circuit below, in which the current through is 3.00 A and the current through point C is 9.00 A.

Diagram, schematic

Description automatically generated

(a) Draw an arrow indicating the direction of conventional current through A.

(1 mark)

|  |  |
| --- | --- |
| Upwards arrow | 1 mark |

(b) Determine the resistance of .

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
|  | 1 mark |

(c) Determine the total resistance between B and C.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

(d) Determine the current through .

(2 marks)

|  |  |
| --- | --- |
| V | 1 mark |
|  | 1 mark |

(e) Determine the power output of the battery.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

(f) Determine how long it takes for electrons to pass through point A.

(3 marks)

|  |  |
| --- | --- |
| C | 1 mark |
|  | 1 mark |
| s | 1 mark |

**Question 19 (16 marks)**

Duncan throws a 145 g baseball upwards, from a height of 1.20 m above the ground, at a speed of 10.0 m s-1. After waiting a short while, he then throws a tennis ball upwards from the same height, in order to hit the baseball shortly after it has begun its descent. The tennis ball has an upward momentum of 0.670 kg m s-1 when it directly collides with the baseball, 1.15 s after the baseball was thrown.

(a) Determine the magnitude of the baseball’s displacement when it is hit by the tennis ball.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

(b) Determine the magnitude of the baseball’s momentum at the instant before it is hit by the tennis ball.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
| i.e. | 1 mark |

(c) Upon hitting the baseball, the tennis ball rebounds, travelling downwards with a momentum of 0.300 kg m s-1. Determine the speed of the baseball just after the collision. If you could not determine an answer to part (b), use a value of 0.200 kg m s-1.

(4 marks)

|  |  |
| --- | --- |
| kg m s-1 | 1 mark |
|  | 1 mark |
|  | 1 mark |
| () | 1 mark |

‘

(d) Determine the maximum height above the point of release that the baseball reaches. If you could not determine an answer to part (c), use a value of 5.50 m s-1.

(4 marks)

|  |  |
| --- | --- |
| The maximum height corresponds to | 1 mark |
|  | 1 mark |
|  | 1 mark |
| (6.56 m) | 1 mark |

(e) Determine the time taken for the baseball to fall from its maximum height to the ground. If you could not determine an answer to part (d), use a value of 6.00 m.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
| (1.21 s) | 1 mark |

**Question 20 (9 marks)**

The graph below shows an instant of pressure variation within a 35.0 cm pipe instrument, producing sound at a resonant frequency. The sound is being produced in air at .

**Diagram

Description automatically generated**

X

X

(a) For each end of the pipe, state whether it is an open end or a closed end.

(1 mark)

|  |  |
| --- | --- |
| Left end: Closed Right end: Open | 1 mark |

(b) State the wavelength of the sound.

(1 mark)

|  |  |
| --- | --- |
| 0.200 m | 1 mark |

(c) State which harmonic the pipe is resonating at.

(1 mark)

|  |  |
| --- | --- |
| The seventh harmonic | 1 mark |

(d) Place an ‘X’ on every point on the above graph corresponding to a compression.

(1 mark)

|  |  |
| --- | --- |
| As above (local maxima) | 1 mark |

(e) Determine the period of the sound wave.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
| Hz | 1 mark |
| s | 1 mark |

(f) On the grid below, sketch a graph showing the displacement of particles throughout the tube against their (average) distance along the tube for the instant shown in the graph on the previous page. You do not need to provide a scale for the vertical axis, however, consider a positive displacement to represent particles located to the right of their average position.

(2 marks)

Diagram

Description automatically generated with medium confidence

|  |  |
| --- | --- |
| Location of nodes and antinodes | 1 mark |
| Orientation | 1 mark |

**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 21 (19 marks)**

**Solar Panels**

Globally, Australia has the highest uptake of home solar systems with more than three million rooftop systems installed. Commercially available solar panels are currently capable of converting solar energy into electrical energy with an efficiency of up to 21.5%. These solar panels have a typical panel area of 1.60 m2.

Solar panels rely on light from the Sun travelling to Earth through the vacuum of outer space, a feat which other types of waves, like sound, are not capable of. Solar panels do not produce electricity at a constant rate though, due to both the rotation and revolution of the Earth. At the most obvious level, we would expect solar panels to only be effectively producing electricity during the daytime. However, the nature of Earth’s orbit impacts not only the duration of daylight hours for a given date, but also the distance between the Earth and the Sun and the angle that the Sun’s rays are incident on an area of the Earth.

Some key dates in the year when considering solar panels are:

* Perihelion (January 3), when the Earth is closest to the Sun
* Aphelion (July 3), when the Earth is furthest from the Sun
* Summer solstice (June 21 in the northern hemisphere; December 21 in the southern hemisphere), when the Sun has the greatest maximum angle of inclination and the duration of daylight is the greatest
* Winter solstice (December 21 in the northern hemisphere; June 21 in the southern hemisphere), when the Sun has the smallest maximum angle of inclination and the duration of daylight is the least

For Perth, the relevant data for the current year is shown in the table below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Date | Distance from Sun (m) | Maximum angle of inclination of Sun’s rays | Time of sunrise | Time of sunset | Minutes of daylight |
| January 3 |  |  | 5:15 | 19:26 | 851 |
| June 21 |  |  | 7:16 | 17:19 | 603 |
| July 3 |  |  | 7:17 | 17:23 | 606 |
| December 21 |  |  | 5:06 | 19:21 | 854 |

Diagram, schematic

Description automatically generated

Northern autumn/

Southern spring

Northern winter/

Southern summer

Northern spring/

Southern autumn

Northern summer/

Southern winter

**Aphelion**

**Perihelion**

*Figure 1: Key solar dates*

The figure above depicts the key dates referred to throughout the orbit of the Earth about the Sun, as well as indicating where on Earth the Sun’s rays will strike directly (with an angle of inclination of ). Due to the tilt of the Earth, in summer we experience more hours of daylight and more direct sunlight (i.e. the maximum angle of inclination of the Sun’s rays is greatest).

The greatest solar intensity for Perth (approximately 1000 W m-2) is experienced during the perihelion, however, due to the angle of the sun’s rays, the solar power incident on a panel is less than this amount. Solar panels can capture a greater proportion of the Sun’s rays when the angle of inclination of the Sun’s rays is greater. The figure below depicts a solar panel on a flat roof, with equally spaced rays incident upon it. As can be seen, less rays are incident on the solar panel for a smaller angle of inclination of the Sun’s rays.

A picture containing sketch, line, rectangle, parallel

Description automatically generated

*Figure 2: Solar rays incident on a flat solar panel for varying angles of inclination*

A close-up of a solar panel

Description automatically generated with medium confidence

In determining how much solar power can be collected, it is useful to consider the component of the length of the solar panel which is perpendicular to the Sun’s rays, which is the effective collecting length of the panel (as depicted on the right). The panel can always be oriented on the roof such that the effective collecting width is the full width of the panel, so only one dimension needs to be adjusted to account for the angle of the Sun’s rays.

*Figure 3: A panel’s effective length is the component of its length perpendicular to the Sun’s rays*

(a) Explain how light from the Sun is able to travel through space, despite sound waves not   
 being able to do so.

(2 marks)

|  |  |
| --- | --- |
| Light is an electromagnetic wave | 1 mark |
| It does not require a medium in order to propagate | 1 mark |

(b) Using information from the article and your Formulae and Data Booklet, determine the   
 time taken for light to travel from the Sun to the Earth on December 21.

(2 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |

For the questions that follow, consider a typical solar panel with the properties described in the text, installed on a flat roof in Perth.

(c) Show, with the use of a clear diagram, that

where is the effective collecting length of the solar panel;

is the full solar panel length; and  
 is the angle of inclination of the Sun’s rays.

(2 marks)

|  |  |
| --- | --- |
|  | |
| Draws an appropriate right-angled triangle with L, Leff, and labelled | 1 mark |
|  | 1 mark |

(d) Calculate the electrical power generated by a solar panel during the perihelion when the   
 Sun’s rays are at their maximum angle of inclination.

(4 marks)

|  |  |
| --- | --- |
|  | 4 marks  (1 mark for each correct factor) |

(e) Determine the percentage decrease in the greatest solar intensity for Perth during the aphelion compared to during the perihelion.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
| Hence a 6.47% decrease | 1 mark |

(f) Supposing the incident solar intensity was the same, determine the percentage decrease   
 in the solar power collected by the panel when the Sun’s rays are at their maximum angle   
 of inclination during the winter solstice, compared to when the Sun’s rays are at their   
 maximum angle of inclination during the summer solstice.

(3 marks)

|  |  |
| --- | --- |
|  | 1 mark |
|  | 1 mark |
| Hence a 41.9% decrease | 1 mark |

(g) Considering your answers to the previous two questions, explain whether a solar panel   
 installed in the northern hemisphere (at a similar distance from the equator as Perth) is   
 likely to be most effective in the northern summer or in the northern winter.

(3 marks)

|  |  |
| --- | --- |
| A solar panel in the northern hemisphere would be most effective in the summer | 1 mark |
| Since compared to winter, the decrease in electrical power produced due to the increased distance from the Sun (<10%) is significantly smaller than the increased electrical power produced due to the steeper maximum angle of inclination of the Sun’s rays (~40%) | 1 mark |

(h) State one additional factor presented in the text that would have a significant impact on   
 the effectiveness of solar panels in summer compared to winter.

(1 mark)

|  |  |
| --- | --- |
| The minutes of daylight | 1 mark |

**Question 22 (17 marks)**

**The boiling water reactor vs the liquid-metal fast-breeder reactor**

Uranium-235 is a fissile material that is commonly used in nuclear reactors. When the uranium-235 nucleus absorbs a slow-moving neutron, fission is induced. This leads to the splitting of the nucleus into daughter nuclei and a number of fast-moving neutrons. A large amount of energy is also released.

For example, after absorbing a slow-moving neutron, uranium-235 may commonly split into caesium-143 and rubidium-90, alongside the release of multiple neutrons and energy. Different nuclear reactors take different approaches to what may happen both to the neutrons and the energy released.

In a boiling water reactor (BWR), the focus is simply on using all of the available uranium-235 as fuel. In such a reactor, every neutron released by the fission of uranium-235 is intended to induce fission in another uranium-235 nucleus, unless absorbed by control rods. Water is used for the three purposes of acting as a coolant, a moderator, and the steam source for the turbine (which in turn produces electricity). Given the amount of energy produced in the reactor core, typical operating pressures of 70 times normal atmospheric conditions are used to prevent the water boiling, by raising its boiling temperature to .

Diagram

Description automatically generated

*Figure 1: The boiling water reactor.   
Taken directly from Hyperphysics (June 19 2015).*

The above is a relatively simple set-up and the fission of uranium-235 produces a significant amount of energy. However, this isotope of uranium only has a natural occurrence of 0.7%, with the remaining 99.3% of naturally occurring uranium being the isotope uranium-238. This means that the majority of mined uranium cannot be used as the fuel in this reactor.

However, while uranium-238 is not fissile itself, it can absorb a fast-moving neutron to form uranium-239, which can then decay (with a half-life of 23.5 minutes) into neptunium-239, which in turn can decay (with a half-life of 2.36 days) into plutonium-239, which is a fissile material.

The liquid-metal fast-breeder reactor (LMFBR) also uses uranium-235 as a fissile material. Unlike the BWR though, only one of the emitted neutrons is intended to continue the process of inducing fission in uranium-235. This is because the goal is for the remaining neutrons to be absorbed by uranium-238, which can in turn produce plutonium-239, increasing the amount of nuclear fuel available. The ratio of fissile (plutonium-239) nuclei produced to fissile (uranium-235) nuclei consumed throughout this process is termed the breeding ratio.

While water is still used as the steam source for the turbine, it cannot be used as the coolant for this type of reactor due to its effect on the neutrons in the reactor. Instead, liquid sodium, with a specific heat capacity of and a boiling point of , is used.

Diagram

Description automatically generated with medium confidence

*Figure 2: The* liquid-metal fast-breeder reactor. *Taken directly from Hyperphysics (June 19 2015).*

(a) Water is used as a coolant for the boiling water reactor but not for the liquid-metal fast-  
 breeder reactor. Explain why water cannot be used as the coolant for a breeder reactor.

(3 marks)

|  |  |
| --- | --- |
| Water acts as a moderator | 1 mark |
| Slowing down neutrons | 1 mark |
| However, a breeder reactor requires fast neutrons | 1 mark |

(b) Explain why the thermal properties of sodium make it an ideal coolant.

(4 marks)

|  |  |
| --- | --- |
| Liquid sodium has a large specific heat capacity | 1 mark |
| So can absorb large amounts of energy without significant changes in temperature | 1 mark |
| Sodium has a high boiling point | 1 mark |
| So does not require the system to be pressurised to prevent boiling | 1 mark |

(c) Write the nuclear equation for neptunium-239 decaying into plutonium-239.

(2 marks)

|  |  |
| --- | --- |
|  | |
| Balanced numbers | 1 mark |
| Appropriate symbols | 1 mark |

(d) Consider the fission of uranium-235 described in the second paragraph of the text.

1. Write the nuclear equation for this fission reaction.

(2 marks)

|  |  |
| --- | --- |
|  | |
| Correct reactants and products | 1 mark |
| Correct number of neutrons released | 1 mark |

1. Determine the energy produced by this fission reaction, using the following information:

|  |  |
| --- | --- |
| **Species** | **Mass (u)** |
| Neutron | 1.009 |
| Uranium-235 | 235.044 |
| Caesium-143 | 142.927 |
| Rubidium-90 | 89.915 |

(5 marks)

|  |  |
| --- | --- |
| u | 1 mark |
| u | 1 mark |
| mass defect u | 1 mark |
| MeV | 1 mark |
| J | 1 mark |

1. Determine the breeding ratio for a liquid-metal fast-breeder reactor that fully converts all uranium-235 nuclei to plutonium-239 through this fission reaction.

(1 mark)

|  |  |
| --- | --- |
| (or 2:1) | 1 mark |

Supplementary page

Question number: \_\_\_\_\_\_\_\_\_\_\_\_\_\_

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Spare grid

**A close up of a white wall

Description automatically generated**

Hyperphsyics. (June 19 2015). *Types of nuclear reactors* [Online], Available: <http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/reactor.html#c5>

WATP acknowledges the permission of the School Curriculum and Assessment Authority in providing instructions to students.