HOLY CROSS COLLEGE

SEMESTER 2, 2016

Question/Answer Booklet

11 PHYSICS

Please place your student identification label in this box

Student Name SOLUTIONS

Student's Teacher ______________________

Time allowed for this paper

Reading time before commencing work: 10 minutes
Working time for paper: 3 hours

Materials required/recommended for this paper

To be provided by the supervisor
This Question/Answer Booklet
Data Sheet

To be provided by the candidate
Standard items: pens, pencils, eraser, correction fluid, ruler, highlighters

Special items: non-programmable calculators satisfying the conditions set by the School Curriculum and Standards Authority for this course

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 notes or other items of a non-personal nature in the examination room. 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 exam
Section One: Short answer	12	12	50	54	30
Section Two: Extended answer	7	7	90	90	50
Section Three: Comprehension and data analysis	2	2	40	36	20
			Total	180	100

Instructions to candidates

1. The rules for the conduct of examinations at Holy Cross College are detailed in the College Examination Policy. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer Booklet.

3. Working or reasoning should be clearly shown when calculating or estimating answers.

4. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.

5. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

    - Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
    - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

6. Answers to questions involving calculations should be ***evaluated and given in decimal form.*** It is suggested that you quote all answers to ***three significant figures***, with the exception of questions for which estimates are required. Despite an incorrect final result, credit may be obtained for method and working, providing these are ***clearly and legibly set out***.

7. Questions containing the instruction *"estimate"* may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. Give final answers to a maximum of *two significant figures* and include appropriate units where applicable.

8. Note that when an answer is a vector quantity, it must be given with magnitude and direction.

9. In all calculations, units must be consistent throughout your working.

Section One: Short response

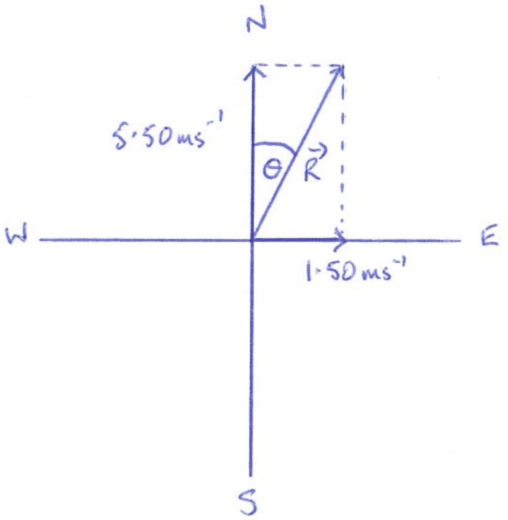
30% (54 Marks)

This section has **twelve (12)** questions. Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1

(5 marks)

Conall is sailing a boat North at 5.50 ms^{-1} when he enters a current travelling East at 1.50 ms^{-1}. Calculate Conall's resultant velocity once he enters the current. You must state the magnitude and direction of his resultant velocity.



$$\vec{R} = \sqrt{(5{\cdot}50)^2 + (1{\cdot}50)^2} \quad (1)$$

$$= 5{\cdot}70 \text{ ms}^{-1} \quad (1)$$

$$\tan\theta = \frac{1{\cdot}50}{5{\cdot}50} \quad (1)$$

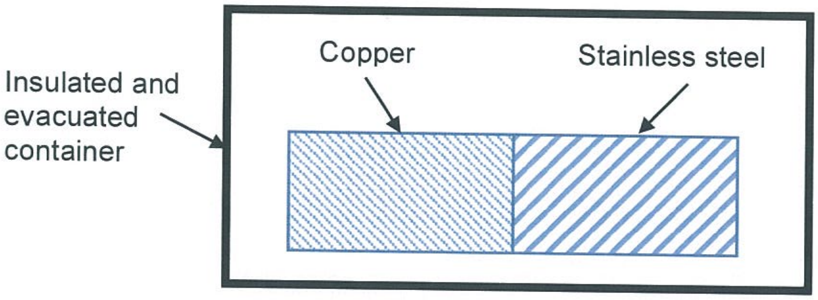
$$\Rightarrow \theta = 15{\cdot}3^{\circ} \quad (1)$$

$$\therefore \underline{\vec{R} = 5{\cdot}70 \text{ ms}^{-1} \text{ N } 15{\cdot}3^{\circ} \text{ E}} \quad (1)$$

Question 2

(5 marks)

A 1.00 kg copper block at 100 °C is placed in thermal contact with a 1.00 kg stainless steel block at 50 °C in an insulated and evacuated container. After several minutes, both blocks reach thermal equilibrium.



(a) Use the kinetic particle model to explain how thermal contact between the copper block and the stainless steel block leads to a nett heat transfer to the stainless steel block.

(3 marks)

- Cu is at a higher temperature so its particles have a higher average E_K. (1)
- The contact between the metals allows the Cu particles to impact the steel particles. (1)
- E_K is transferred from the Cu particles to the steel particles, causing the heat transfer to occur. (1)

(b) Explain why evacuating the container reduces the rate of heat loss from the blocks.

(2 marks)

- No convection currents can occur. (1)
- No conduction of heat to the outside can occur. (1)

Question 3

(5 marks)

An engineer heats a 43.0 kg aluminium engine block in a furnace to a temperature of 350 °C. He then plunges the block into 420 kg of water at 21.0 °C. Calculate the final temperature of the aluminium and water mixture when they have reached thermal equilibrium. You can assume that the water and aluminium mixture is an isolated system.

(The specific heat of aluminium is 900 $Jkg^{-1}{}^{o}C^{-1}$.)

$$Q_{lost} = Q_{gained}$$

$$\Rightarrow m_{Al} c_{Al} \Delta T = m_w c_w \Delta T \quad (1)$$

$$\Rightarrow (43.0)(9.00 \times 10^2)(350 - T_f) = (420)(4.18 \times 10^3)(T_f - 21.0) \quad (1)$$

$$\Rightarrow 1.355 \times 10^7 - 3.870 \times 10^4 \, T_f = 1.756 \times 10^6 \, T_f - 3.687 \times 10^7 \quad (1)$$

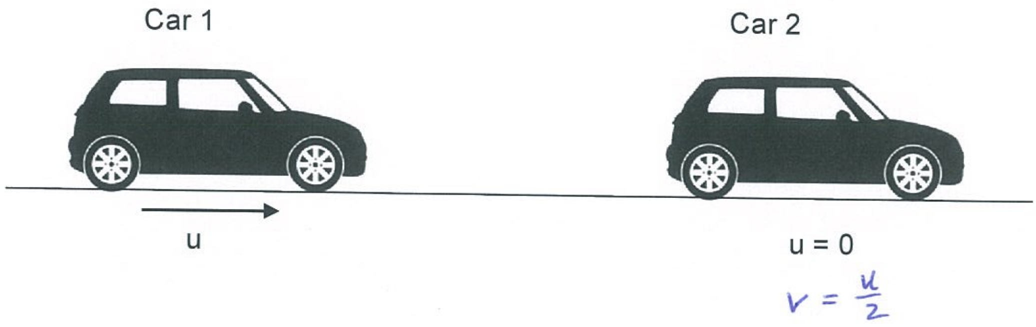
$$\Rightarrow 5.042 \times 10^7 = 1.795 \times 10^6 \, T_f \quad (1)$$

$$\Rightarrow \underline{T_f = 28.1\,^{\circ}C} \quad (1)$$

Question 4

(4 marks)

As shown in the diagram, Car 1 is moving to the right at an initial speed *u*. The car then impacts the rear end of Car 2, which is initially stationary. Both Car 1 and Car 2 have the same mass *m*. After the collision, both cars are effectively joined and move to the right at *half* of the initial speed of Car 1.



Determine if the collision is elastic or inelastic.

$\Sigma E_k (\text{initial}) = \frac{1}{2} m u^2$ (1)

$\Sigma E_k (\text{final}) = \frac{1}{2}(m+m)v^2$

$= \frac{1}{2}(2m)\left(\frac{u}{2}\right)^2$ (1)

$= \frac{mu^2}{4}$ (1)

$\therefore$ Collision is inelastic. (1)

Question 5

(5 marks)

Dolphins use high frequency clicks in the range of 40.0 kHz to 150 kHz for echolocation.

(a) If the speed of sound in water is 1480 ms^{-1}, calculate the wavelength of a 150 kHz click.

(2 marks)

$v = f\lambda$

$\Rightarrow \lambda = \frac{v}{f}$

$= \frac{1480}{150 \times 10^{3}}$ (1)

$= \underline{9.87 \times 10^{-3}\ m}$ (1)

(b) If a stationary dolphin emits a click and it takes 150 ms for the click to return to the dolphin from the sea floor, calculate the distance from the dolphin to the sea floor.

(3 marks)

$v = \frac{s}{t}$

$\Rightarrow s = vt$

$= (1480)(150 \times 10^{-3})$ (1)

$= 222\ m$ (1)

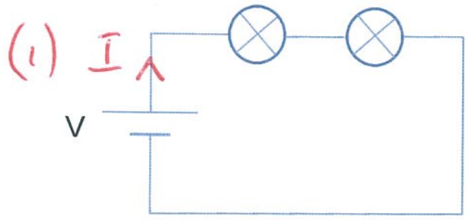
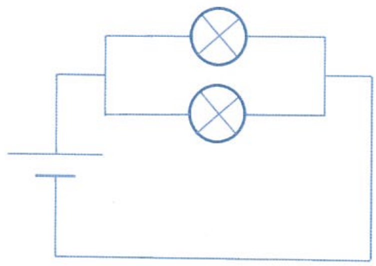
$d_{floor} = \frac{222}{2}$

$= \underline{111\ m}$ (1)

Question 6

(6 marks)

The diagram below shows a series circuit and a parallel circuit, which consist of a voltage source and two identical light bulbs. The effective resistance of each light bulb is R Ω. The resistance of the wires and the ammeter can be considered negligible.

Series Circuit	Parallel Circuit
	

(a) On the ***series circuit,*** use an arrow to indicate the direction of the conventional current.
(1 mark)

(b) Assuming that the voltage source and light bulbs are exactly the same in each circuit, which circuit will have the brighter light bulbs? Explain your answer. (5 marks)

SERIES $V_{bulb} = \frac{V}{2}$ $P_{series} = \frac{V^2}{R} = \frac{\left(\frac{V}{2}\right)^2}{R} = \frac{V^2}{4R}$ (2)

PARALLEL $V_{bulb} = V$ $P_{parallel} = \frac{V^2}{R}$ (2)

Since $P_{parallel} > P_{series}$, the bulbs in the parallel circuit are brighter. (1)

Question 7

(3 marks)

At the end of the last Apollo 15 moonwalk, Commander David Scott dropped a 1.32 kg geologic hammer and a 0.030 kg falcon feather from a height of 1.60 m above the surface of the Moon. He observed that when the feather and the hammer were dropped simultaneously, they both impacted the surface of the moon at the same time. Explain this observation.

- Since their is no air resistance on the moon, only gravity is acting. (1)
- $F_W(moon) = m g_{moon}$ and $\Sigma F = ma$.

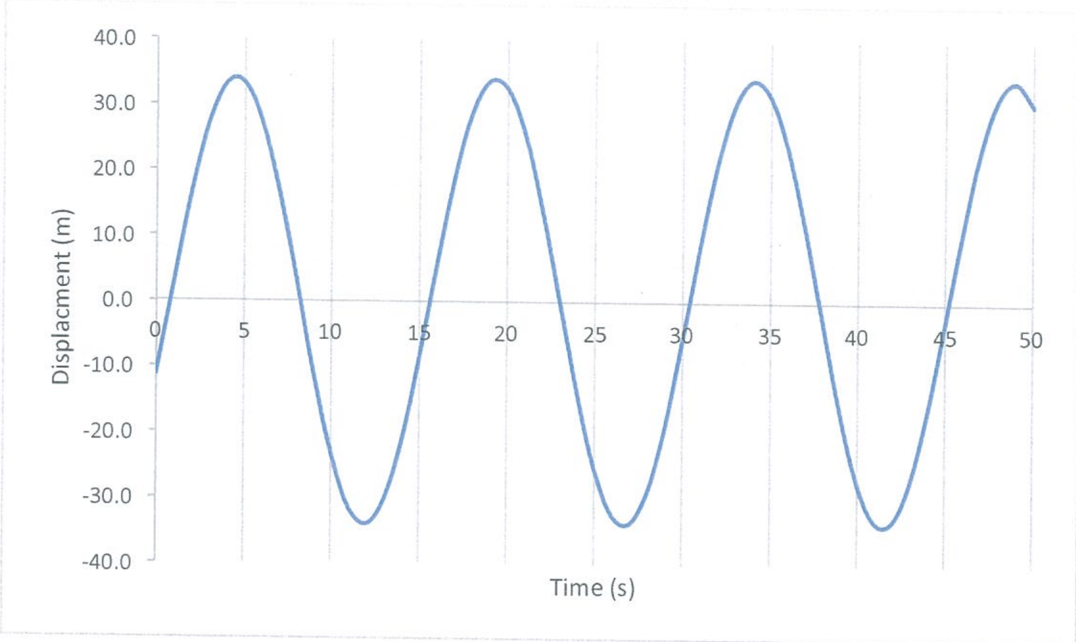
  $\Rightarrow a = g_{moon}$ (which is independent of the mass). (1)

$\therefore$ The feather and hammer fall at the same rate. (1)

Question 8

(5 marks)

In February 1933, the USS Ramapo, a 146 metre navy vessel, found itself in an extraordinary storm on its way from Manila to San Diego. The storm lasted 7 days and stretched from the coast of Asia to New York, producing strong winds over thousands of kilometres of unobstructed ocean. During the storm, the crew had time to carefully observe the nearly sinusoidal ocean waves. The plot shows a displacement-time graph of waves similar to that recorded by the USS Ramapo.



(a) Use the graph to determine the amplitude of the waves. (1 mark)

$a = 34 \pm 1$ m (1)

(b) Use the graph to determine the period of the wave. (1 mark)

$T = 15 \pm 1$ s (1)

(c) If the period of a wave is 15.0 s and its speed is 23.0 ms^{-1}, calculate its wavelength. (3 marks)

$V = f\lambda = \frac{\lambda}{T}$ (1)

$\Rightarrow \lambda = VT$

$= (23.0)(15.0)$ (1)

$= \underline{345 \text{ m}}$ (1)

Question 9

(6 marks)

A battery is connected in a series with a 1.20 Ω resistor. An ammeter measures a current of 6.00 A flowing through the resistor.

(a) Calculate the energy consumed by the resistor in a time of 2 minutes and 25 seconds.

(4 marks)

$$P = \frac{E}{t}$$

$$\Rightarrow E = Pt = I^2Rt \quad (1)$$

$$(1)$$

$$= (6{\cdot}00)^2(1{\cdot}20)(145) \quad (1)$$

$$= \underline{6{\cdot}26 \times 10^3 \text{ J}} \quad (1)$$

(b) List ***two*** energy transformations that occur in the circuit and state the circuit component in which they occur.

(2 marks)

Transformation 1

BATTERY - chemical energy → electrical energy. (1)

Transformation 2

RESISTOR - electrical energy → heat energy. (1)

Question 10 **(3 marks)**

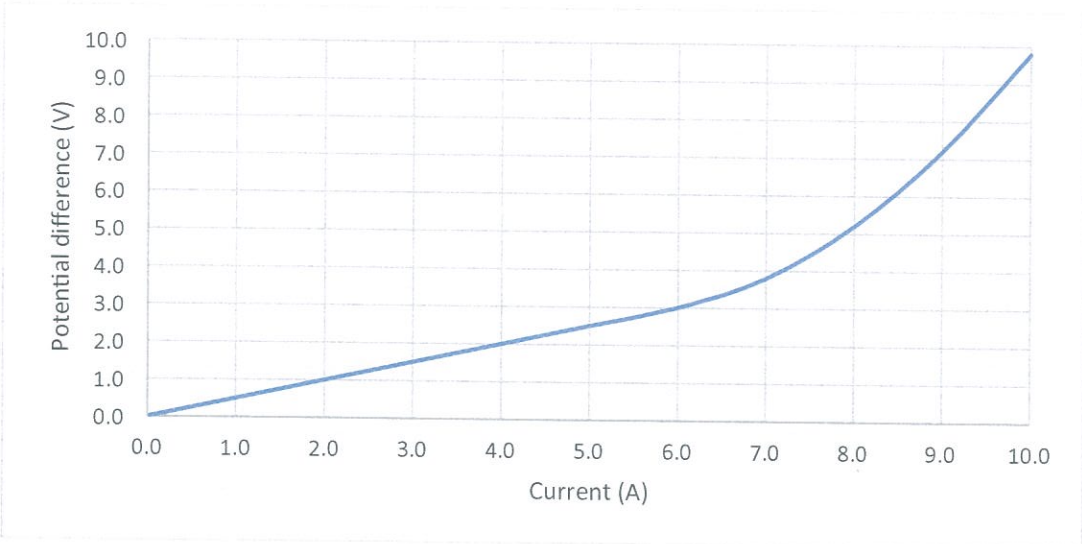
Explain how resonance occurs when a person is pushed on the swing.

- Swing has a natural frequency of movement. (1)
- The frequency of the small pushes matches the natural frequency of the swing. (1)
- Swing resonates, increasing the amplitude of each swing. (1)

Question 11

(4 marks)

Jack conducted an experiment to determine the resistance of a conductor. The results of his experiment are shown in the graph below.



(a) Between which **current** values is the conductor ohmic? Give your values to two significant figures. (2 marks)

0·0 A → 6·0 A (2)

(b) Calculate the power consumed by the conductor when the current is 3.0 A. Give your answer to two significant figures. (2 marks)

$P = VI$

$= (1{\cdot}5)(3{\cdot}0)$ (1)

$= \underline{4{\cdot}5\ W}$ (1)

Question 12

(3 marks)

An 87.0 kg patient is exposed to 1.20 x 10^2 TeV of alpha particle radiation during a medical procedure. Calculate the dose equivalent of radiation absorbed by the patient.

$$E = (1.20 \times 10^{14})(1.60 \times 10^{-19})$$
$$= 1.92 \times 10^{-5} \text{ J} \quad (1)$$

$$A.D. = \frac{E}{m}$$
$$= \frac{1.92 \times 10^{-5}}{87.0}$$
$$= 2.21 \times 10^{-7} \text{ Gy} \quad (1)$$

$$D.E. = A.D. \times QF$$
$$= (2.21 \times 10^{-7})(20)$$
$$= \underline{4.41 \times 10^{-6} \text{ Sv}} \quad (1)$$

End of Section One

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Section Two: Problem-solving

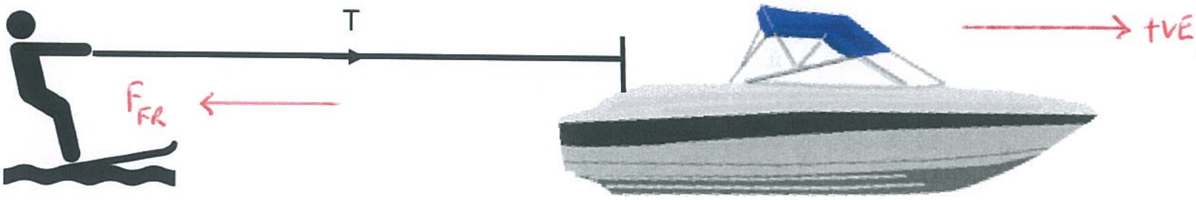
50% (90 Marks)

This section has **seven (7)** questions. You must answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 13

(15 marks)

The figure below shows a water skier being pulled to the right by a speedboat. The water skier and the boat are travelling in a straight line and the water skier is directly behind the boat. The mass of the person is 80.0 kg and the frictional force between the water skis and the water is 1.00×10^2 N. T is the tension in the rope.



The water skier has an initial speed of 12.8 ms^{-1} and is accelerated by the boat at 5.20 ms^{-2}.

(a) Calculate the time that it takes for the water skier to reach a final speed of 64.0 ms^{-1}. (2 marks)

$v = 64.0\,ms^{-1}$

$u = 12.8\,ms^{-1}$

$a = 5.20\,ms^{-2}$

$t = ?$

$s = ?$

$a = \frac{v-u}{t}$

$\Rightarrow t = \frac{v-u}{a}$ (1)

$= \frac{64.0-12.8}{5.20}$

$= \underline{9.85\,s}$ (1)

(b) Calculate the distance that the skier travels while being accelerated. (3 marks)

$v^2 = u^2 + 2as$ (1)

$\Rightarrow (64.0)^2 = (12.8)^2 + 2(5.20)s$ (1)

$\Rightarrow \underline{s = 3.78 \times 10^2\,m}$ (1)

(c) Calculate the work done by the boat while pulling the water skier a distance of 3.00 km at a constant speed of 64.0 ms^{-1}. (2 marks)

$W = \Sigma Fs$

$= (1.00 \times 10^2)(3.00 \times 10^3)$ (1)

$= \underline{3.00 \times 10^5 \text{ J}}$ (1)

(d) Calculate the power required to overcome friction when pulling the water skier at a constant speed of 64.0 ms^{-1}. (2 marks)

At constant speed: $F_{Forwards} = T = F_{Friction}$

$\therefore P = F v_{av}$

$= (1.00 \times 10^2)(64.0)$ (1)

$= \underline{6.40 \times 10^3 \text{ W}}$ (1)

(e) Calculate the tension in the rope if the rope is horizontal and the water skier is accelerated at 5.20 ms^{-2}. (3 marks)

Forwards +ve.

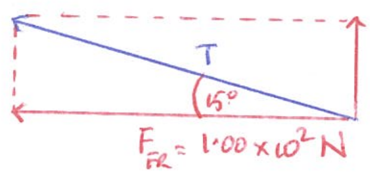
$\Sigma F = ma$

$\Rightarrow T - F_{Fr} = ma$ (1)

$\Rightarrow T = (80.0)(5.20) + (1.00 \times 10^2)$ (1)

$= \underline{516 \text{ N forwards}}$ (1)

(f) The angle of the ski rope is changed such that it now makes an angle of 15.0 ° to the horizontal. Calculate the tension in the rope if the friction force is 1.00 x 10^2 N and the boat travels at a constant speed. (3 marks)



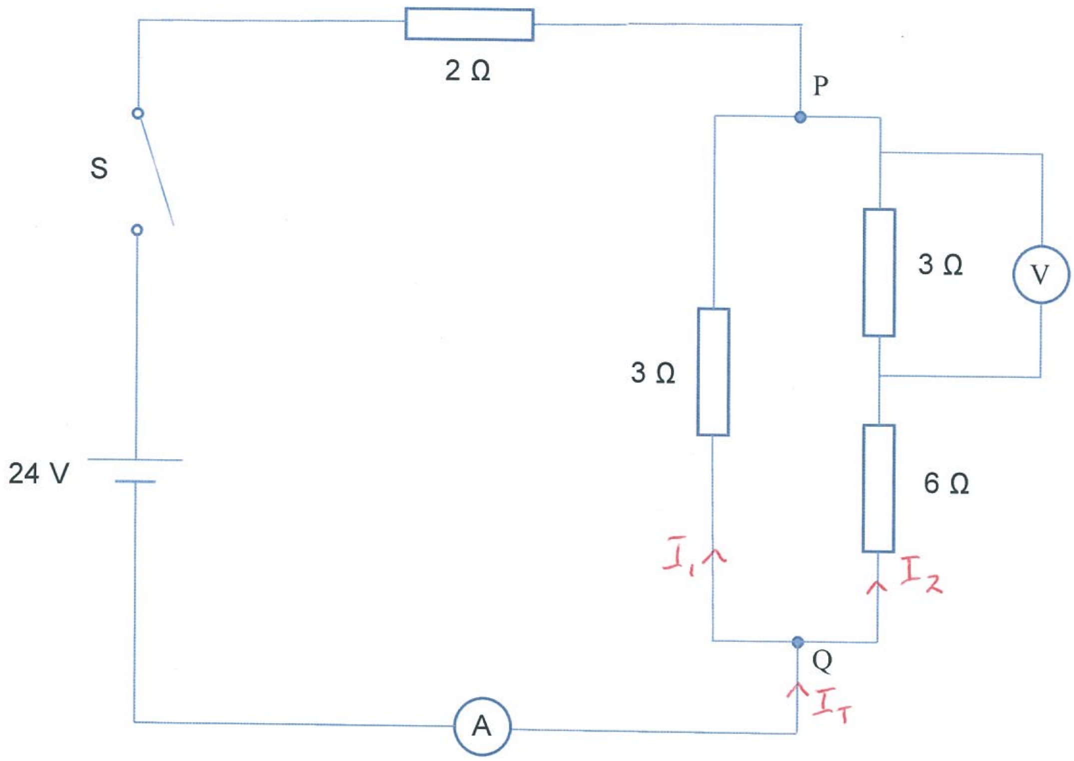
$\cos 15.0° = \dfrac{1.00 \times 10^2}{T}$ (1)

$\Rightarrow T = \dfrac{1.00 \times 10^2}{\cos 15.0°}$ (1)

$= \underline{104 \text{ N}}$ (1)

Question 14 **(13 marks)**

Alex set up the electrical circuit shown below for his physics investigation. The circuit is powered by a 24.0 V DC power source and has a single switch *S*.



(a) Calculate the total resistance of the circuit. (4 marks)

$$\frac{1}{R_{PQ}} = \frac{1}{3} + \frac{1}{9} \quad (1)$$

$$= \frac{4}{9} \quad (1)$$

$$\Rightarrow R_{PQ} = 2.25\ \Omega \quad (1)$$

$$R_T = 2.25 + 2$$

$$= \underline{4.25\ \Omega} \quad (1)$$

(b) Calculate the current recorded by the ammeter when the switch is closed. (2 marks)

$$V_T = I_T R_T$$

$$\Rightarrow I_T = \frac{24}{4.25} \quad (1)$$

$$= \underline{5.65\ A} \quad (1)$$

(c) If the current measured by the ammeter is 5.65 A, calculate the electric charge delivered by the DC power source in 2 hours and 35 minutes. (3 marks)

$$I = \frac{q}{t}$$

$$\Rightarrow q = It \quad (1)$$

$$= (5.65)(155 \times 60) \quad (1)$$

$$= \underline{5.26 \times 10^4\ C} \quad (1)$$

(d) If the voltage drop between P and Q is 12.7 V,

(i) calculate the voltage drop recorded by the voltmeter. (2 marks)

$$V_{PQ} = I_2 R$$

$$\Rightarrow I_2 = \frac{12.7}{9}$$

$$= 1.41\ A \quad (1)$$

$$V_{3\Omega} = I_2 R$$

$$= (1.41)(3.0)$$

$$= \underline{4.23\ V} \quad (1)$$

(ii) calculate the power consumed by the 6.00 Ω resistor. (2 marks)

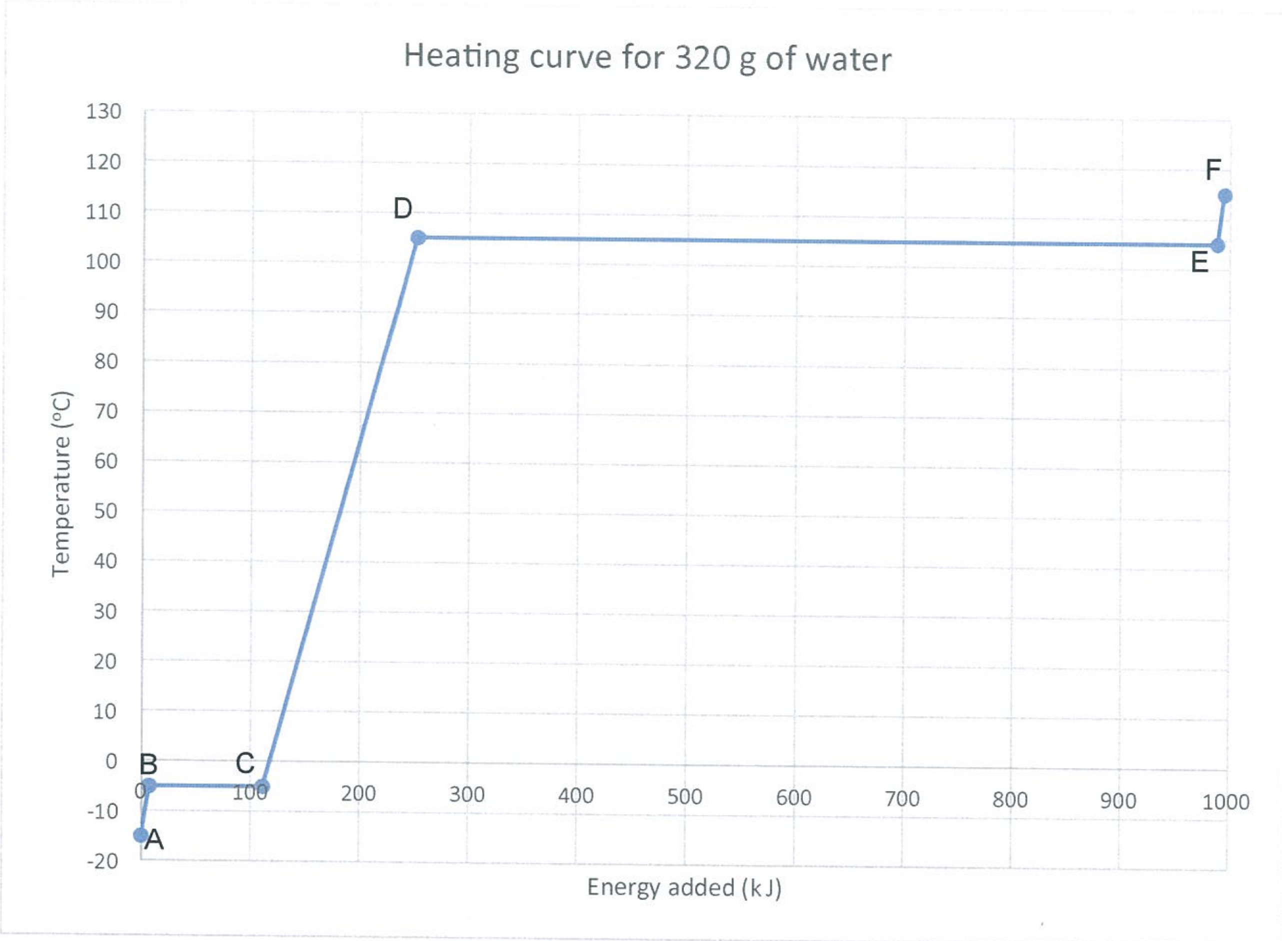
$$P_{6\Omega} = I_2^2 R$$

$$= (1.41)^2(6.0) \quad (1)$$

$$= \underline{11.9\ W} \quad (1)$$

Question 15 **(12 marks)**

To investigate the properties of salt water, Lia heated 320 g of frozen salt water at -15.0 °C to a temperature of 115 °C in an insulated container. Her results are shown in the heating curve below.



(a) Explain why the temperature of the salt water is constant between points D and E. You must refer to the kinetic particle model and the internal energy of the salt water. (4 marks)

- Between D and E, the salt water is boiling. (1)
- As there is no change in temperature, the average E_K of the particles remains constant. (1)
- The added energy is moving the particles further apart. (1)
- This increases the E_P of the particles. (1)

(b) Calculate the latent heat of vaporisation of the salt water from the graph. (4 marks)

$$Q_{phase\ change} = 990 - 250$$
$$= 740\ kJ \quad (\pm 10\ kJ) \quad (1)$$

$$Q = mL_v$$
$$\Rightarrow L_v = \frac{Q}{m} \quad (1)$$
$$= \frac{740 \times 10^3}{0.320} \quad (1)$$
$$= \underline{2.3 \times 10^6\ J\ kg^{-1}} \quad (1)$$

(c) Calculate the specific heat of salt water from the graph. (4 marks)

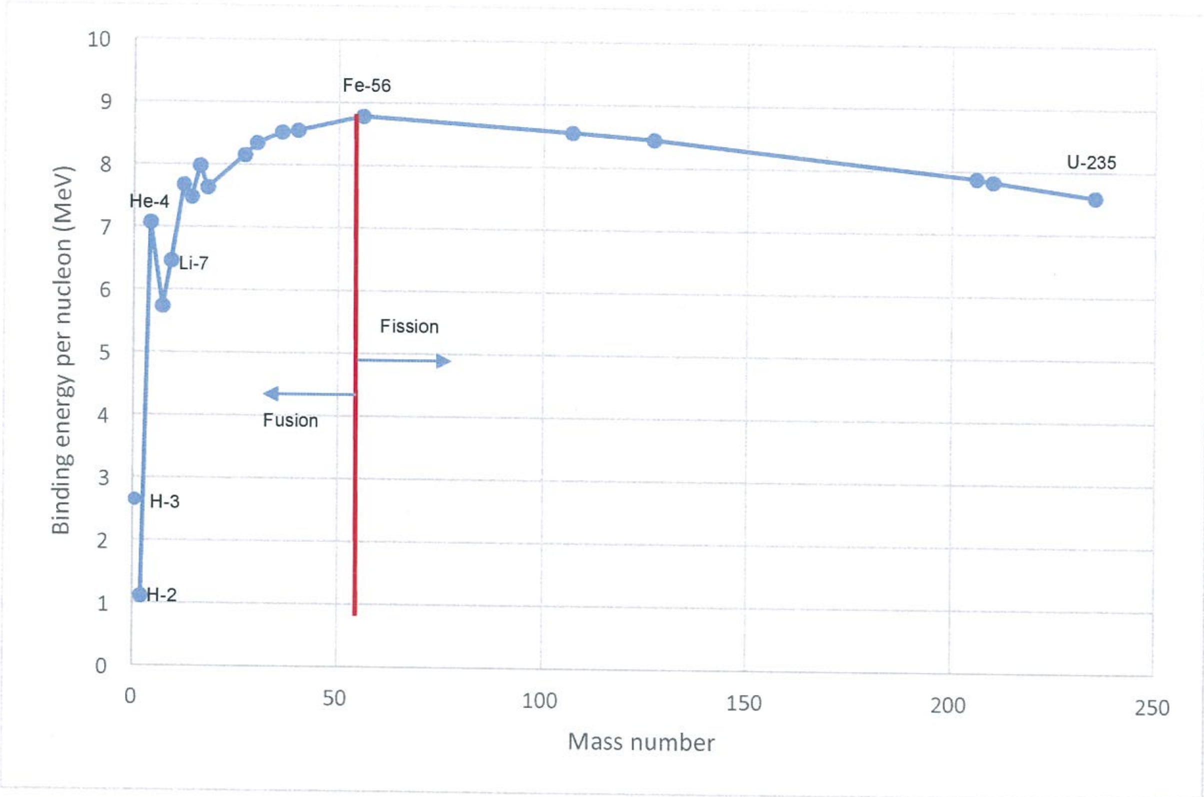
From the graph: $\Delta T = 105 - (-5)$
$$= 110\ °C \quad (1)$$

$$Q = 250 - 110$$
$$= 140\ kJ \quad (1)$$

$$Q = m_{sw} c_{sw} \Delta T$$
$$\Rightarrow c_{sw} = \frac{140 \times 10^3}{(0.320)(110)} \quad (1)$$
$$= \underline{4.2 \times 10^3\ J\ kg^{-1}\ °C^{-1}} \quad (1)$$

Question 16 **(11 marks)**

The figure below plots the binding energy per nucleon for elements of different mass numbers.



(a) Consider the Helium-4 and Lithium-7 nuclei. Which atom has the greater binding energy? Circle your answer below and provide an explanation. (3 marks)

Helium-4 **Lithium-7** (1)

Explanation

He-4 Binding energy = 4 × 7 = 28 MeV (1)

Li-7 Binding energy = 7 × 6.4 = 44.8 MeV (1)

∴ Li-7 is greater.

(b) Use the graph to explain why the fusion of two H-2 atoms to form He-4 will release energy. (3 marks)

- The H-2 atoms have a lower binding energy per nucleon than He-4, but it has a greater mass per nucleon. (1)
- Both H-2 and He-4 have the same number of nucleons. (1)
- Hence He-4 has less mass. (1)

(c) Calculate the binding energy for a $^{56}_{26}Fe$ nucleus in MeV where: (5 marks)
$m(^{56}_{26}Fe) = 55.92069$ u
$m(p^{+}) = 1.007276$ u
$m(n) = 1.008664$ u

Mass of protons = 26 × 1.007276 u = 26.189176 u (1)

neutrons = 30 × 1.008664 u = 30.259920 u

56.449096 u (1)

Mass defect = 56.449096 u − 55.92069 u

= 0.528406 u (1)

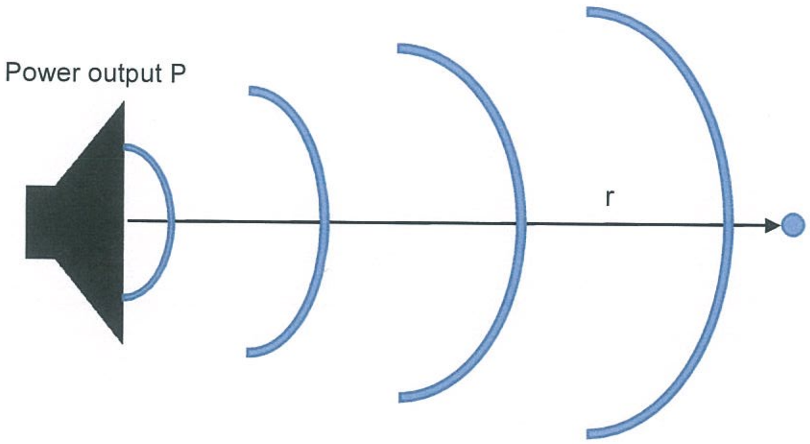
= 492 MeV (1)

Binding energy / nucleon = $\frac{492}{56}$

= 8.79 MeV / nucleon (1)

Question 17 **(17 marks)**

Jacqueline and Kieran set up an experiment to determine the power output of a loudspeaker. In this investigation, they measured the sound intensity $I\ (Wm^{-2})$ produced by the loudspeaker at several different distances $r(m)$ from it. Their experimental setup is shown below.



The equation that relates the power output of the speaker, the sound intensity and the distance from the speaker is:

$$I = \frac{P}{4\pi r^2}$$

where

- $I = sound\ intensity\ (Wm^{-2})$
- $P = power\ output\ of\ the\ speaker\ (W)$
- $r = distance\ from\ the\ speaker\ (m)$

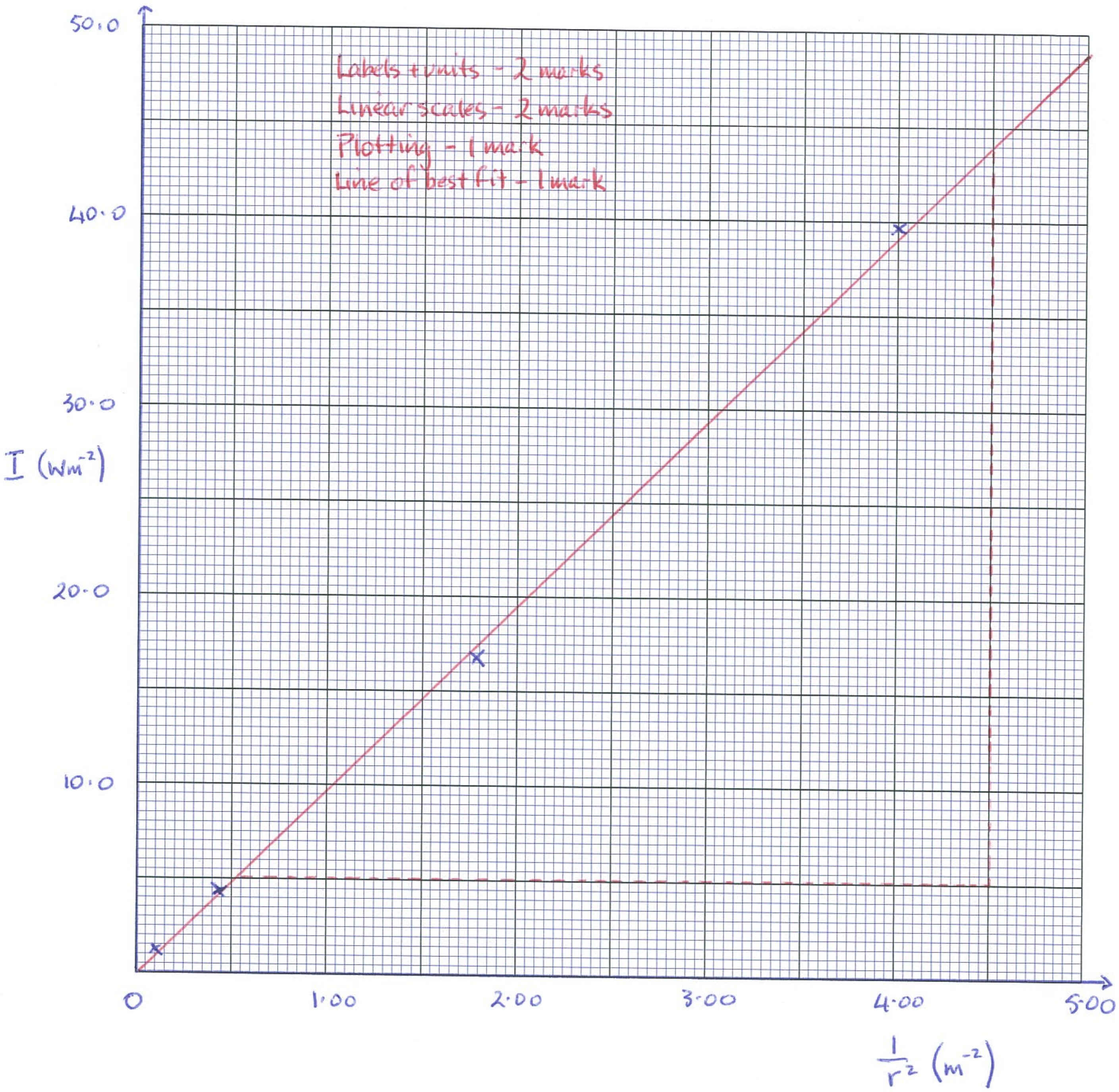
A table of results for this investigation is shown below.

r (m)	I (Wm^{-2})	$1/r^2\ (m^{-2})$
0.500	39.7	4·00
0.750	16.8	1·78
1.50	4.20	0·444
3.00	1.10	0·111

[1 mark each]

(a) Complete the last column in the table above. Give your answers to three significant figures. (4 marks)

(b) On the graph paper provided, plot $1/r^2$ versus sound intensity I. Plot $1/r^2$ on the *x*-axis and sound intensity on the *y*-axis. You must label your axes. (5 marks)



(c) Add a line of best fit to your graph. (1 mark)

(d) Using your line of best fit, determine the sound intensity 0.900 m from the speaker. (2 marks)

When $r = 0.900\,m$: $\frac{1}{r^2} = \frac{1}{(0.900)^2} = 1.24\,m^{-2}$ (1)

$\therefore$ $\underline{I = 12\ Wm^{-2}}$ (from graph) (1)

(e) Determine the gradient of your line of best fit. You must show your rise and run on the graph. (3 marks)

$$\text{gradient} = \frac{(44.0 - 5.0)}{(4.50 - 0.52)} \quad (1) \quad [\text{Rise + run on graph - 1 mark}]$$

$$= \underline{9.80 \text{ Wm}^{-2}} \quad (1)$$

(f) The sound intensity equation can be written as: $I = \frac{P}{4\pi} \times \frac{1}{r^2}$

Use the gradient of the line of best fit that you calculated in part (e) to calculate the power of the source P.

(If you did not calculate the gradient, use a value of 9.90 W.) (2 marks)

$$\text{gradient} = Ir^2 = \frac{P}{4\pi}$$

$$\Rightarrow P = 4\pi \times \text{gradient}$$

$$= 4\pi \times 9.80$$

$$= \underline{123 \text{ W}}$$

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Question 18 **(13 marks)**

Jack drops a small rubber ball from a height of 1.50 m above flat ground. The mass of the ball is 0.120 kg. Air resistance can be neglected for each of the following questions.

(a) Which of the following statements correctly describes the applied forces as the ball impacts the ground? Circle the correct answer and provide an explanation below.

(i) The force that the ball applies to the ground is ***greater than*** the force that the ground applies to the ball.

(ii) The force that the ball applies to the ground is ***less than*** the force that the ground applies to the ball.

(1) (iii) The force that the ball applies to the ground is ***equal to*** the force that the ground applies to the ball.

(3 marks)

Explanation

- Newton's 3rd law ⇒ for every action, there is an equal and opposite reaction. (1)
- As the ball doesn't bury into the ground, the force of the ground on the ball must equal the force of the ground onto the ball. (1)

(b) Calculate the velocity of the ball as it impacts the ground. (3 marks)

↓ +ve

$v = ?$

$u = 0 \text{ ms}^{-1}$

$a = 9.80 \text{ ms}^{-2}$

$t = ?$

$s = 1.50 \text{ m}$

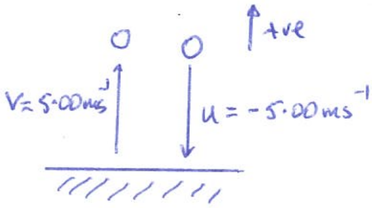
$v^2 = u^2 + 2as$ (1)

$= 0 + 2(9.80)(1.50)$ (1)

$\Rightarrow v = \underline{5.42 \text{ ms}^{-1} \text{ down}}$. (1)

(c) The ball is dropped again from a different height and impacts the ground with a speed of 5.00 ms^{-1}. If the collision that the ball makes with the ground is elastic and the impact time is 0.0100 s, calculate the magnitude of the average force that the ball applies to the ground.

(3 marks)



$$I = Ft = m\Delta v = \Delta p$$

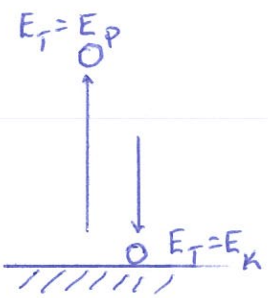
$$\Rightarrow F = \frac{m \Delta v}{t} \quad (1)$$

$$= \frac{(0.120)(5.00-(-5.00))}{(0.0100)} \quad (1)$$

$$= \underline{1.20 \times 10^{2} \text{ N down}} \quad (1)$$

(d) A 46.0 g golf ball is dropped and impacts the ground with a velocity of 7.00 ms^{-1}. The golf ball then rebounds to a height of 1.75 m above the ground. Calculate the efficiency of the impact.

(4 marks)



At impact: $E_T = E_K = \frac{1}{2}mv^2$

$$= \frac{1}{2}(0.0460)(7.00)^2$$

$$= 1.127 \text{ J} \quad (1)$$

At height: $E_T = E_P = mgh$

$$= (0.0460)(9.80)(1.75)$$

$$= 0.7889 \text{ J} \quad (1)$$

$$\% \text{ efficiency} = \frac{0.7889}{1.127} \times \frac{100}{1} \quad (1)$$

$$= \underline{70.0\%} \quad (1)$$

Question 19 **(9 marks)**

Carbon-14 is a radioactive isotope of carbon that undergoes beta decay. It is used for the radiocarbon dating of archaeological objects such as boomerangs and bone.

(a) Explain what is meant by the term 'isotope'. (2 marks)

(1)

ISOTOPE: atom with the same number of protons as the "parent" atom but with a different number of neutrons. (1)

(b) Write the equation for the beta decay of Carbon-14. (3 marks)

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \bar{\nu} \quad (1)$$

(1) (1)

(c) Carbon-14 has a half-life of 5,730 years. Calculate the percentage of Carbon-14 that remains in a boomerang, which is 11,500 years old. (4 marks)

$$n = \frac{t}{t_{1/2}} = \frac{11500}{5730} \ (1) = 2.01 \ (1)$$

$$N = N_0 \frac{1}{2^n} = 100\left(\frac{1}{2^{2.01}}\right) \ (1) = \underline{24.8\%} \ (1)$$

End of Section 2

Section Three: Comprehension

20% (36 Marks)

This section contains **two (2)** questions. You must answer both questions. Write your answers in the space provided. Suggested working time for this section is 40 minutes.

Question 20

(18 marks)

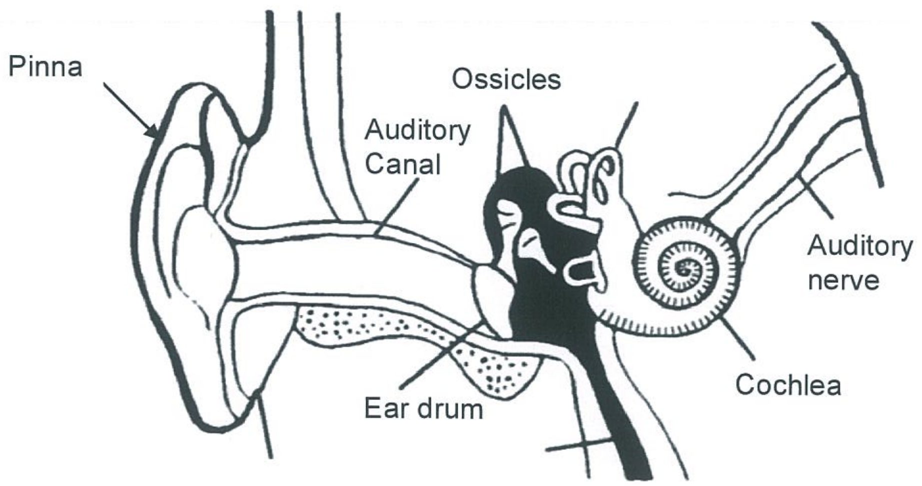
The Ear

The human ear is used for both hearing and balance and acts as transducer, which converts sound energy to a nerve impulse that is sent to the brain. The ear allows us to detect pressure variations in the air, which are less than one-billionth of atmospheric pressure. It is able to detect these pressure variations within a range from 20 Hz to 20 kHz.

The ear comprises the outer ear, middle ear and inner ear, and each part has a different function. When a sound wave is produced it travels at 340 ms^{-1} from the source and spreads out in three dimensions. The large area of the pinna collects the sound and focuses it down the auditory canal. The auditory canal acts as if a pipe closed at one end and resonance occurs within its length. The peak sensitivity of the ear to sound occurs at 3700 Hz, which corresponds to the fundamental resonant frequency of the auditory canal.

The sound travels down the auditory canal to the ear drum. The sound vibrates the ear drum, which vibrates the ossicles that are the three bones of the middle ear and the smallest bones in the body. The ossicles further amplify the sound.

The vibrating bones of the middle ear produce longitudinal waves in the fluid of the cochlea in the inner ear. The cochlea transforms the energy of the waves into nerve impulses, which are transmitted to the brain.



(a) Vibration of the bones in the middle ear produces longitudinal waves in the cochlea. Explain how longitudinal waves are different from transverse waves. (2 marks)

LONGITUDINAL: particles vibrate parallel to the direction of movement of the wave. (1)

TRANSVERSE: particles move perpendicular to the direction of movement of the wave. (1)

(b) If sound enters the auditory canal with a frequency of 20.0 kHz, how many sound waves enter the ear in 25.0 ms. (2 marks)

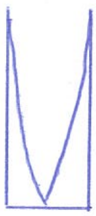
$$\# \text{waves} = f \times t$$
$$= (20.0 \times 10^{3})(25.0 \times 10^{-3}) \quad (1)$$
$$= \underline{5.00 \times 10^{2} \text{ waves}} \quad (1)$$

(c) Calculate the wavelength of sound vibrating at the fundamental resonant frequency of the auditory canal. You can assume that the speed of sound is 340 ms^{-1}. (3 marks)

$f = 3700$ Hz (from article) (1)

$$v = f\lambda$$
$$\Rightarrow \lambda = \frac{v}{f}$$
$$= \frac{340}{3700} \quad (1)$$
$$= \underline{9.19 \times 10^{-2} \text{ m}} \quad (1)$$

(d) Calculate the effective length of the auditory canal. If you did not calculate an answer for the previous question, assume that the wavelength that corresponds to the fundamental frequency is 92.0 mm. (2 marks)



$l = \frac{\lambda}{4}$

$$l = \frac{\lambda}{4} \quad (1)$$
$$= \frac{9.19 \times 10^{-2}}{4}$$
$$= \underline{2.30 \times 10^{-2} \text{ m}} \quad (1)$$

(e) Calculate the frequency of the third harmonic. (1 mark)

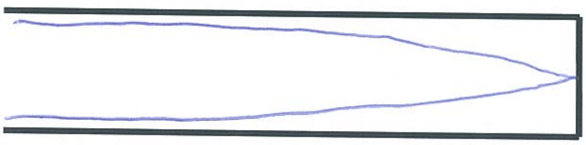
$f_3 = 3f_1$

$= 3 \times 3700$

$= \underline{1.11 \times 10^4 \text{ Hz}}$ (1)

(f) The figures below represent the auditory canal. Draw the ***particle displacement*** for the first and third harmonics of the auditory canal.

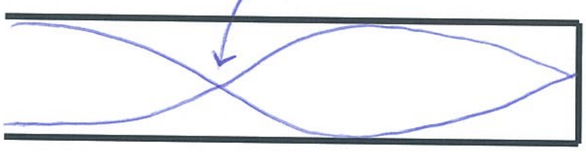
First harmonic (2 marks)



[Correct shape - 1 mark
Position of nodes - 1 mark.]

Third harmonic (2 marks)

node (1)



(g) On the diagram above for the third harmonic, label the nodes. (1 mark)

(h) Explain how standing waves are formed in the auditory canal. (3 marks)

- Sound at the resonant frequency enters the ear. (1)
- The sound wave is reflected from the eardrum and constructively interferes with the incoming sound wave. (1)
- The constructive interference of the two waves forms the standing wave. (1)

Question 21 **(18 marks)**

Plutonium Injection Experiments

On May 14 1945, Albert Stevens was injected with 131 kBq of plutonium without his knowledge or consent. He was unknowingly one of 18 test subjects that took part in the plutonium human injection experiments. The aim of the experiments was to develop a tool to calculate the level of uptake of plutonium by the body from the urine and faeces excreted by the test subjects. The tool would then be used to determine if a worker using plutonium metal had received a dosage at or over the safe limit (Moss and Eckhardt, 1995).

Stevens checked into the University of California Hospital in San Francisco with a stomach ulcer that was so large that it was misdiagnosed as terminal cancer. As he was thought to have only a very short time to live, the doctors secretly injected him with a mixture of plutonium isotopes Pu-238 and Pu-239 to observe their effects. The half-life of Pu-238 is 87.7 years and that of Pu-239 is 24,100 years. Both elements are alpha emitters.

Approximately 10 years after the injection, it was noted that the bones in his lower spine had suffered significant degeneration. Similarly to radium, plutonium was also observed to accumulate in and damage bones. Testing showed that the plutonium remained in his body for the remainder of his life; however, the levels of plutonium slowly decreased because of radioactive decay and biological elimination.

Stevens died of heart disease 20 years after the initial injection at the age of 79. Since his injection, scientists calculated that he had accumulated an equivalent dose of 64 Sv and as a result, he survived the highest known accumulated radiation dose in human history.

Reference: Moss, W., Eckhardt, R., 1995. The Human Plutonium Injection Experiments, *Los Alamos Science*. Radiation Protection and the Human Radiation Experiments (23): 177–223.

(a) Plutonium was first produced by deuterium (H-2) bombardment of U-238, which produces Np-238 and several neutrons. Np-238 then undergoes spontaneous decay to produce Pu-238.

(i) Determine the number of neutrons produced by the deuterium bombardment of U-238. (1 mark)

$$^{238}_{92}U + ^{2}_{1}H \rightarrow ^{238}_{93}Np + 2\,^{1}_{0}n$$

$\therefore$ 2 neutrons (1)

(ii) Using a nuclear equation, determine the type of spontaneous decay that Np-238 undergoes to produce Pu-238. (2 marks)

$$^{238}_{93}Np \rightarrow ^{238}_{94}Pu + ^{0}_{-1}e + \bar{\nu} \quad (1)$$

$\therefore$ β decay (1)

(b) Explain why giving Stevens a dose of only Pu-239 would have caused his lifetime dose equivalent to be significantly smaller than if he was given an equivalent mass of Pu-238.

(3 marks)

- Pu-239 has a longer half-life than Pu-238. (1)
- Hence there were fewer decays of Pu-239. (1)
- As they are both α emitters and have the same quality factor, the dose equivalent for Pu-239 would have been less. (1)

(c) Explain why plutonium in the human body is difficult to detect with a Geiger counter.

(2 marks)

- Plutonium emits α particles. (1)
- α particles can't penetrate the skin to reach the geiger counter. (1)

(d) Write the equation for the alpha decay of Plutonium-238. (2 marks)

$${}^{238}_{94}Pu \rightarrow {}^{234}_{92}U + {}^{4}_{2}He$$

[Correct symbols - 1 mark
Correct numbers - 1 mark]

(e) A fission reaction involving Plutonium-239 is shown below. Calculate the energy released by this reaction. Give your answer in Joules. The mass of the reactants and products involved in the reaction are given below. (4 marks)

$$^{239}_{94}Pu + {}^{1}_{0}n \rightarrow {}^{91}_{38}Sr + {}^{146}_{56}Ba + 3{}^{1}_{0}n$$

$m\left(^{239}_{94}Pu\right) = 3.968266\times10^{-25}\ kg$
$m(^{1}_{0}n) = 1.674929\times10^{-27}\ kg$
$m(^{91}_{38}Sr) = 1.509109\times10^{-25}\ kg$
$m\left(^{146}_{56}Ba\right) = 2.422442\times10^{-25}\ kg$

Mass of reactants $= 3.968266\times10^{-25} + 1.674929\times10^{-27}$
$= 3.985015\times10^{-25}$ kg (1)

Mass of products $= 1.509109\times10^{-25} + 2.422442\times10^{-25} + 3(1.674929\times10^{-27})$
$= 3.981799\times10^{-25}$ kg (1)

Mass defect $= (3.985015 - 3.981799)\times10^{-25}$
$= 3.216\times10^{-28}$ kg (1)

$E = mc^2$
$= (3.216\times10^{-28})(3.00\times10^{8})^2$
$= \underline{2.89\times10^{-11}\ J}$ (1)

(f) If each instance of a fission reaction releases 3.20 x 10^{-11} J of energy, calculate the number of reactions required to produce 50.0 MW of power for a time of one hour and fifty minutes. (4 marks)

$P = \frac{E}{t}$
$\Rightarrow E = Pt$ (1)
$= (50.0\times10^{6})(110\times60)$ (1)
$= 3.30\times10^{11}$ J (1)

reactions $= \frac{3.30\times10^{11}}{3.20\times10^{-11}}$
$= \underline{1.03\times10^{22}}$ (1)

End of Questions

Additional working space

Additional working space

Additional working space

End of examination