Christ Church Grammar School

Science Department
Year 11 Physics

Semester 2 Examination, 2018

Question/Answer booklet

PHYSICS ATAR

SOLUTIONS

Student Name: ____________________

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time for paper: two and a half hours

Materials required/recommended for this paper

To be provided by the supervisor

Question/Answer booklet
Formulae and Data booklet

To be provided by the candidate

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

Special items: non-programmable calculators approved for use in the WACE examinations

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	Percentage achieved
Section One: Short Answer	10	10	50	52		33	
Section Two: Problem Solving	6	6	70	72		46	
Section Three: Comprehension	2	2	30	34		21	
						100	

Instructions to candidates

1. Write your answers in this Question/Answer booklet. preferably using a blue/black pen. Do not use erasable or gel pens.

2. Answer the questions according to the following instructions.

   Section One: Answer all questions. Show all calculations clearly in the space marked Workings for questions where calculations are applicable. Marks will be awarded principally for the relevant physics content.

   Section Two: Answer all questions. Show all calculations clearly in the space marked Workings for questions where calculations are applicable. Marks will be awarded principally for the relevant physics content.

   Section Three: Answer all questions.

3. 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.

4. Additional working space pages at the end of this Question/Answer booklet are for planning or continuing an answer. If you use these pages, indicate at the original answer, the page number it is planned/continued on and write the question number being planned/continued on the additional working space.

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FINAL EXAMINATION 2018

Section One: Short Response

This section has **ten (10)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **50 minutes**.

Question 1 **(5 marks)**

A firework is launched straight up at 26.0 ms^{-1} from a 6.00 m high platform. It malfunctions and, after failing to explode, falls back down to the ground at the base of the platform. Calculate the maximum height the firework achieved above the ground and the speed it hits the ground with.

$v^2 = u^2 + 2as$ ½

$v^2 = 26.0^2 + 2 \times (-9.80) \times (-6.00)$ 1

$v = \pm 28.2\ ms^{-1}$ 1

$v^2 = u^2 + 2as$ ½

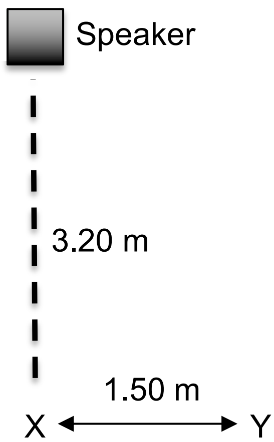
$0 = 26.0^2 + 2 \times (-9.80) \times s$ 1

$s = 34.49\ m$ 1

$Height = 34.49 + 6.00 = 40.5\ m$

Question 2 **(4 marks)**

A speaker is producing a 450.0 Hz sound which has an intensity of 1.50 W m^{-2} when 3.20 m directly in front of the speaker (Point X). Calculate the intensity of the sound at point Y in the diagram.



$s_Y = \sqrt{1.50^2 + 3.20^2} = 3.534\ m$ 1

$since\ I \propto \frac{1}{r^2},\ \ I_1 r_1^2 = I_2 r_2^2$ 1

$1.50 \times 3.20^2 = I_2 \times 3.534^2$ 1

$I_2 = 1.23\ Wm^{-2}$ 1

If student does not find the distance to Y, may give up to 2 marks total for going as far as possible using the inverse square law and the distance to X.

Question 3 **(4 marks)**

An 85.0 kg rugby player collides with a 76.0 kg rugby player. Both players were moving towards each other at 2.60 ms^{-1}. The players bounce off each other such that the heavy player moves away at 2.31 m s^{-1} and the lighter player moves at 2.89 m s^{-1} in the opposite direction. Use suitable calculations to determine whether the collision was elastic or not.

$KE\ before\ collision = \frac{1}{2} \times 85.0 \times 2.60^2 + \frac{1}{2} \times 76.0 \times 2.60^2 = 544\ J$ 1

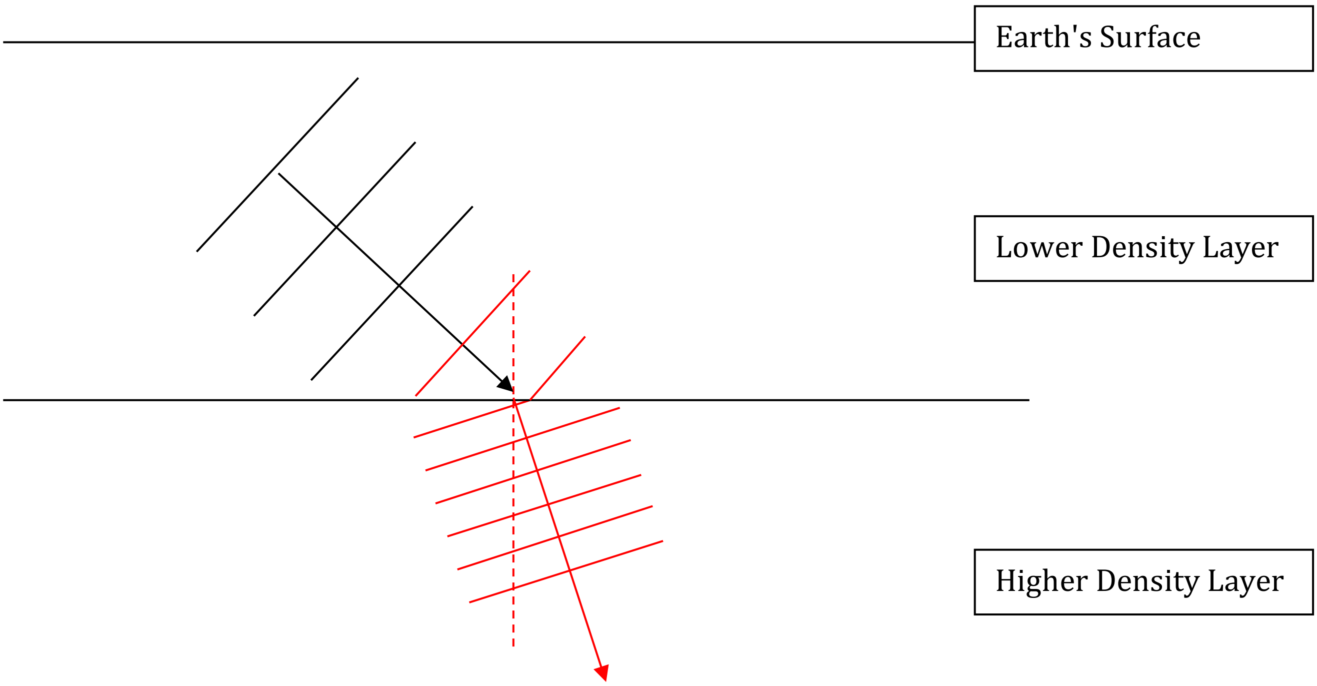
$KE\ after\ collision = \frac{1}{2} \times 85.0 \times 2.31^2 + \frac{1}{2} \times 76.0 \times 2.89^2 = 544\ J$ 1

The kinetic energy is conserved in the collision 1

Therefore, the collision is elastic 1

Question 4 **(3 marks)**

The P wave produced by an earthquake moves faster in lower density layers of the Earth. Show the behaviour of the P wave moving between layers of the Earth by completing the wave diagram below.



1 for refracting towards the normal
1 for wavefronts drawn perpendicular to ray
1 for wavelength change to match new speed
-1/2 if no normal or not fully completed

Question 5 **(4 marks)**

A 125 kg windsurfer takes advantage of a sudden increase in the wind speed, accelerating from 4.85 ms^{-1} to 7.40 ms^{-1} in 3.30 s. Calculate the force and power of the wind, applied to the wind surfer.

$F = ma = \frac{m(v-u)}{t}$ ½

$F = \frac{125\times(7.4-4.85)}{3.30} = 96.7\ N$ 1

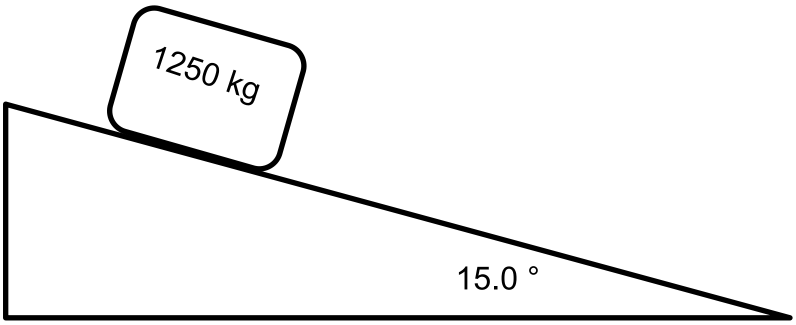
$\Delta E = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ ½

$\Delta E = \frac{1}{2}\times 125 \times 7.40^2 - \frac{1}{2}\times 125\times 4.85^2 = 1.952\times 10^3\ J$ 1

$P = \frac{E}{t} = \frac{1.952\times 10^3}{3.30} = 592\ W$ 1

Question 6 **(8 marks)**

A 1250 kg car travelling up an inclined road of 15.0°. It is observed to travel 65.0m while accelerating from 15.0 ms^{-1} to 20.0 ms^{-1} in a time of 3.71 seconds. During this time, a combined resistive force of 955 N between the car and the road exists.



(a) Calculate the increase in kinetic energy of the car during this 3.71 second period.

(3 marks)

$\Delta E = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ 1

$\Delta E = \frac{1}{2} \times 1250 \times 20^2 - \frac{1}{2} \times 1250 \times 15^2$ 1

= 109 kJ 1

(b) Using concepts of energy and work only, calculate the total power the engine must supply to the car in this 3.71 second period.

(5 marks)

W = (F_g x s) + ΔE_K + (F_F x s) 1

= 1250(9.8)sin(15) x 65 + 109,000 + 955(65) 1

= 377,159 J 1

$P = \frac{E}{t} = \frac{377 \times 10^3}{3.71}$ 1

$= 102\ kW$ 1

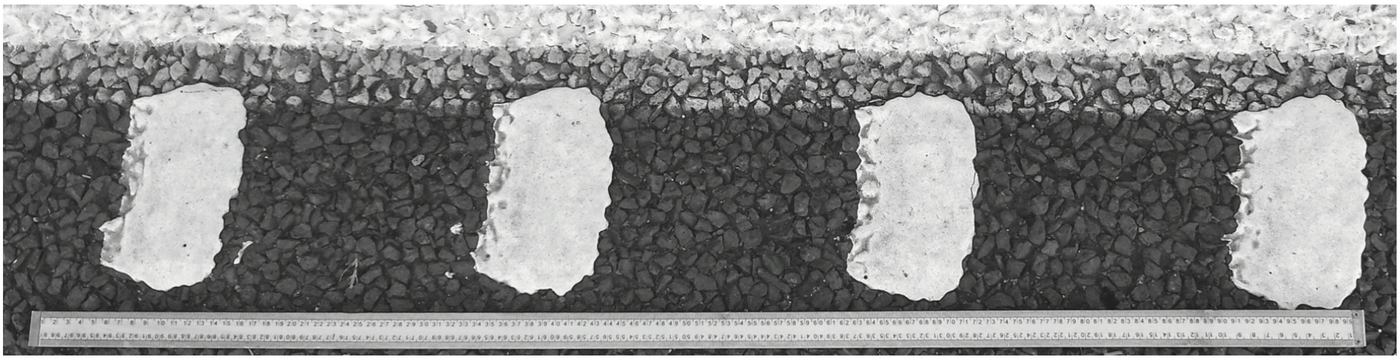
allow $\frac{377 \times 10^3}{4.00}$ 1

= 94.3 kW 1

as there was a misprint in the exam

Question 7 **(9 marks)**

Along the sides of some roads are rumble strips made of raised painted markers that are intended to get a driver's attention if a car strays across them. One part of a strip is photographed below. A metre ruler has been included to give an idea of scale.



(a) If there are 4 strips every 86.0 cm, calculate the frequency of the vibration if a car is travelling at 95.0 km/h.

(5 marks)

s = 0.86 / 3
= 0.287 m 1

v = 95 / 3.6
= 26.4 m/s 1

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

$$\therefore f = \frac{v}{s}$$ 1

$$= \frac{26.4}{0.287}$$ 1

= 92.0 Hz 1

If wavelength is used in place of s, to use f = v/λ in calculation of f, with no reference made to the relationship between period and frequency no carry through marks awarded.

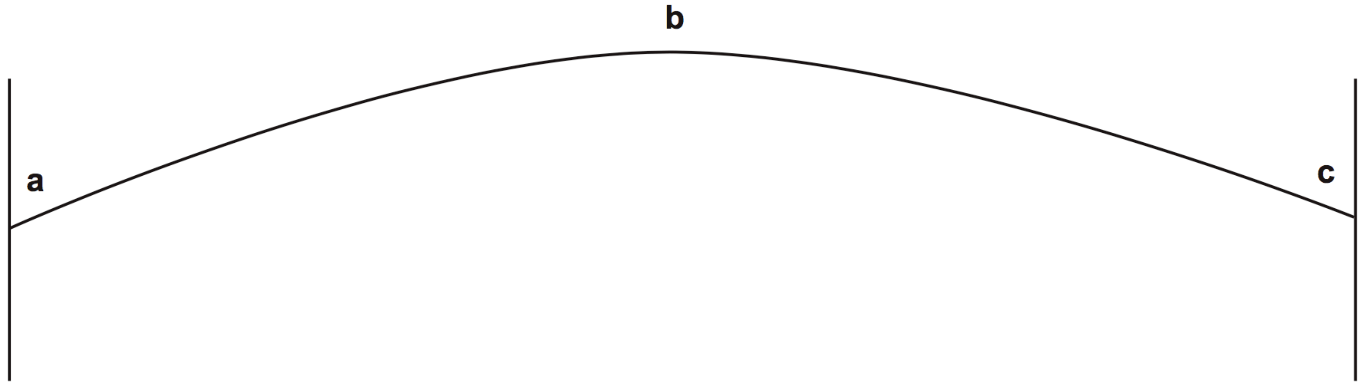
(b) An old car slows down to stop on the side of the road. As it crosses the rumble strip, the frequency of sound decreases along with the speed and the vibrations cause the dashboard to rattle. The intensity of vibration of the dashboard varies and becomes very loud at one particular frequency. Explain this phenomenon, using appropriate physics terminology and concepts.

(4 marks)

- Resonance.
- At a particular speed the driving frequency of the motion over the rumble strips
- matches the natural frequency of the dashboard
- The dashboard's vibrations will be reinforced at the resonance frequency.

Question 8 **(4 marks)**

The diagram below shows a string 0.250 m long vibrating in its fundamental mode between two fixed points. The string is vibrating with a frequency of 0.100 kHz.



(a) For each of the positions a, b, and c, indicate whether these are particle nodes or antinodes (1 marks)

a. Node

b. Antinode

c. Node

(b) Calculate the speed of the wave travelling through the string. (3 marks)

$\lambda = 2L = 2 \times 0.250 = 0.500$ m 1

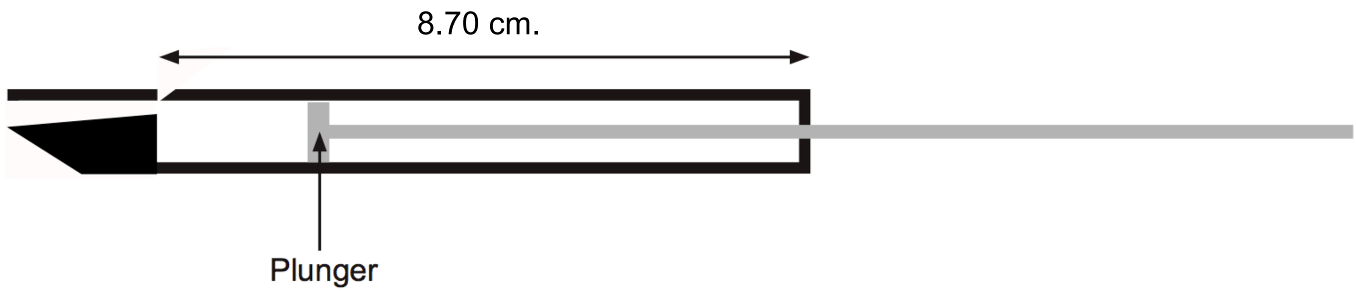
$v = f\lambda$ ½

$= 100 \times 0.500$ ½

$= 50.0\ ms^{-1}$ 1

Question 9 **(5 marks)**

The diagram below shows a section lengthwise through a bird whistle capable of making sounds over a large range of frequencies. The frequency can be changed by moving the plunger inside the whistle. The longest length of the whistle is 8.70 cm



Calculate the distance moved by the plunger when changing the fundamental note from 18.0 kHz to 21.0 kHz. Take the speed of sound in air to be 346 ms^{-1}.

Whistle is a closed end pipe, f = v/4L 1

When f = 18,000 Hz L = 346/4×18,000 = 0.0048 m 1

When f = 21,000 Hz L = 346/4 × 21,000 = 0.0041 m 1

Distance moved = 0.0048 – 0.0041 1

= 0.000687 m (0.69 mm) 1

Question 10 **(6 marks)**

A cricket ball has a mass of 165 g and is travelling at 50.0 ms^{-1} at 40.0° below the horizontal when it strikes an unobservant fielder on the head during a T-20 match at the WACA, as he is signing autographs. The ball is brought to rest in a time of 5.00×10^{-3} seconds.

(a) Calculate the total impulse the ball **delivers to the fielder's head**

(3 marks)

^^ impulse of the fielder's head

$I = Ft = \Delta p = m(v-u)$ 1

$= 0.165(0-50)$ 1

$= -8.25$ Ns (in the direction of balls initial velocity) 1

(accept 40.0° below horizontal)

-1/2 marks if no direction

(b) Calculate the average force the ball exerts on the fielder's head.

(3 marks)

$I = \Delta p = F\Delta t$ 1

$-8.25 \text{ Ns} = F \times 5.00 \times 10^{-3} \text{ s}$ 1

$F = -8.25/(5.00 \times 10^{-3})$

$F = 1650$ N towards the fielder's head 1

(accept 40.0° below horizontal)

-1/2 marks if no direction

End of Section One

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Section Two: Problem-Solving

This section has **six (6)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **70 minutes**.

NAME:______________________________________

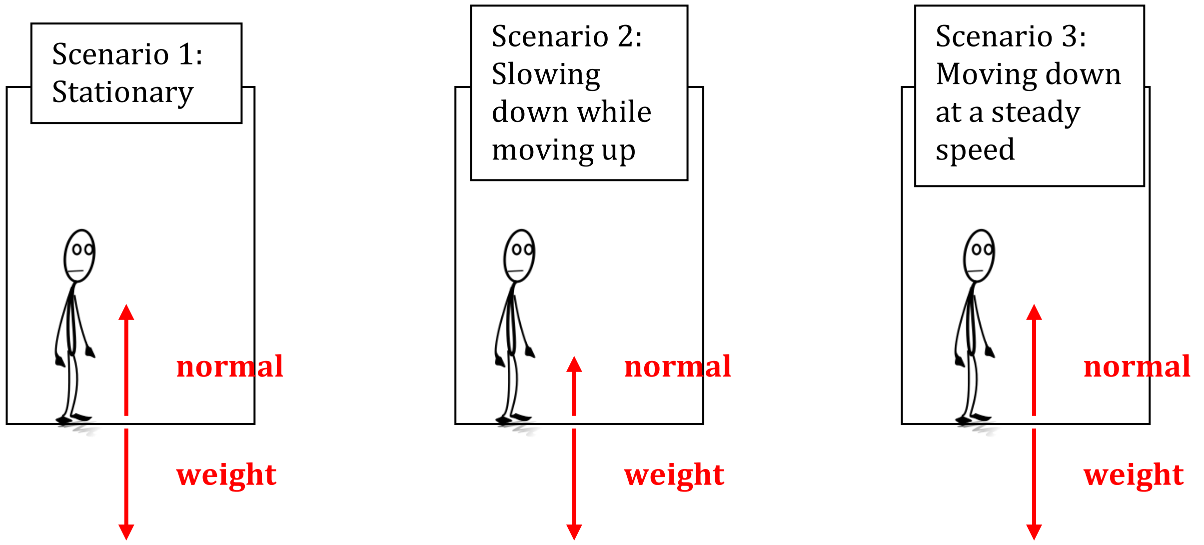
TEACHER: SFZ JRM
(please circle)

Question 1 **(16 marks)**

In the early 1900s, it was common practice for elevators to be operated by a bell hop; a person who would manipulate hand controls to determine both the speed and direction of the elevator. A 60.0 kg bell hop is bored and decides to play around with the elevator controls.

(a) Draw a free body diagram showing a labelled weight force and normal force that would be acting on the bell hop for each scenario the elevator is found in below. For clarity, draw the forces in the white space next to each bell hop, not over the bell hop.

(3 marks)



1 for weight force remaining consistent between all scenarios
1 for normal force matching magnitude of weight for scenario 1 and 3
1 for normal force being smaller than weight in scenario 2
If all the above is correct, but no labels assigned, may award 2 out of 3 marks.

(b) Calculate the weight of the bell hop.

(1 mark)

W = mg ½

= 60 x - 9.8 = 588 N Down ½

(c) Calculate the magnitude of the normal force acting on the bell hop in scenario 2 if the acceleration of the elevator is 3.20 m s^{-2}.

(3 marks)

$\sum F = ma = W + N$ (treating up as positive)

$ma = W + N$ 1

$N = ma - W$

$N = 60.0(-3.20) - (-588)$ 1

$= 396\ N$ 1

(d) The elevator itself has a 485 kg mass. Calculate the tension in the cable supporting the elevator with the bell hop inside if the elevator was stationary.

(3 marks)

$\sum F = 0 = W + T$ 1 (treating up as positive)

$T = -W$

= - (485 + 60) (-9.8) 1

= 5340 N Upwards 1

e) Explain whether the tension in the cable would increase, decrease or remain the same as the elevator begins to accelerate upwards, compared to when it was stationary. State and refer to one of Newton's laws of motion in your answer.

(3 marks)

- According to Newton's second law, a mass will experience an acceleration proportional to the net force acting upon it. OR

  Newton's 1st Law of inertia, an unbalance force will cause a mass to accelerate.

- The elevator, as it starts to move up from rest, will be experiencing an acceleration upwards.

- To have a net force also up, the tension needs to increase so that it is greater than the weight force acting down. (must mention weight force constant or T>W for full mark)

(f) Describe why the bell hop would feel weightless if the cable supporting the elevator breaks.

(3 marks)

- Both the elevator and bell hop fall together with the same acceleration

- so there is no normal force applied to the bell hop by the floor of the elevator.

- The sensation of weight comes from the surface pushing up on the bell hop's feet; no force means no sensation of weight.

Question 2 **(13 marks)**

An organ is a musical instrument that operates on the resonance of both open and closed pipes of varying length. A keyboard of white and black keys, similar in appearance to those on a piano, are used to activate wind that passes through the pipes, causing them to vibrate at their natural frequencies. A full-size organ spans 5 octaves from the lowest note to the highest note across the keyboard. In music, an octave is the separation between two notes if one note has either double or half the frequency of the other.

(a) Explain why pipes of varying length and type (open/closed) are required to produce different notes.

(3 marks)

- Each note is a specific frequency of a sound wave (required)

  then
- The pipes will resonate when the wavelength of the sound fits nicely in the pipe/ Only certain frequencies will cause a pipe to resonate.
- The resonating wave wavelength depends on the length of the pipe and its type
- The equations $\lambda = \frac{2L}{n}$ and $\lambda = \frac{4L}{(2n-1)}$ for open and closed pipes respectively, show length (L) and pipe type affects the resonating wavelength
- The frequency of the wave in the standing wave pattern depends on the wavelength as $f = v/\lambda$

(3 marks based on accuracy and reasoning of explanation; not all statements are required)

(b) A full-sized organ can produce notes as low as 8.00 Hz. Take the speed of sound in air to be 346 ms^{-1}.

(i) Calculate the shortest length of pipe able to produce this note.

(3 marks)

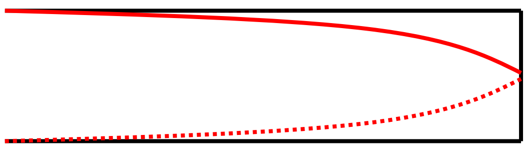
$$f = \frac{v}{\lambda} = \frac{346}{8.00} = 43.25\ m \quad 1$$

$$\lambda = \frac{4L}{(2n-1)} \quad \therefore L = \frac{\lambda}{4} \quad 1$$

$$L = \frac{43.25}{4} = 10.8\ m \quad 1$$

(ii) Draw the particle displacement envelope inside this pipe when producing this note.

(1 mark)



(iii) Calculate the highest frequency this full-sized organ will produce when activating a key on the other end of the keyboard.

(1 mark)

keyboard spans 5 octaves

$$f = 8 * 2^5 = 256\ Hz$$

½ ½

(c) Show that the wavelength of **any** harmonic of an open pipe can also be produced by a closed pipe of equal length resonating at twice the harmonic of the open pipe.

(3 marks)

For a closed pipe:

$\lambda_c = \frac{4L}{n'}$ ½

where $n' = (2n - 1)$ is the harmonic

For an open pipe:

$\lambda_o = \frac{2L}{n}$ ½

$\lambda_c = \lambda_o$ 1

$\frac{4L}{n'} = \frac{2L}{n}$

$n' = 2n$ 1

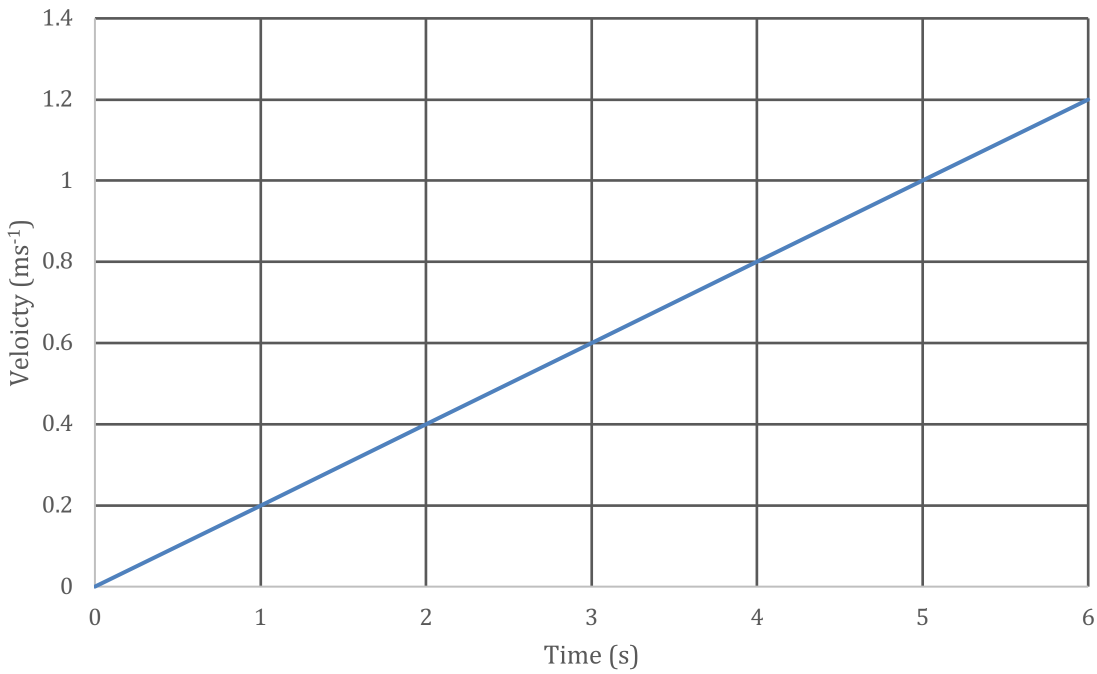
(d) On hot days, the organ can sound slightly out of tune. Suggest a reason for this.

(2 marks)

- Hotter air has a faster speed of sound
- The increased speed affects the frequency of the standing waves $f = v/\lambda$

Question 3 **(10 marks)**

A 0.850 kg remote-controlled car is powered by a 2.00 W electric motor. Its operator, standing next to the car, pushes the control stick forward to its maximum position, causing the car to accelerate along the flat path away from the operator. The car's velocity for the first 6.00 s of its journey is shown below.



(a) Calculate the acceleration of the car by analysing the graph.

(2 marks)

$$a = gradient = \frac{rise}{run} = \frac{1.2 - 0}{6 - 0} \quad 1$$

$$= 0.20\ ms^{-2} \quad 1$$

If used an equation of motion (1 mark only)
-1/2 marks if units incorrect or omitted

(b) Calculate the distance covered by the car in the 6.00 s by analysing the graph.

(2 marks)

$$\Delta s = area = \frac{1}{2} 6 \times 1.2 \quad 1$$

$$= 3.6\ m \quad 1$$

If used an equation of motion (1 only)

(c) Calculate the efficiency of the car's motor.

(3 marks)

$\Delta E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.850 \times 1.2^2 = 0.612\ J$ 1

$E_{motor} = Pt = 2.00 \times 6.00 = 12.0\ J$ 1

$efficiency = \frac{E\ out}{E_{in}} \times 100 = \frac{0.612}{12.0} \times 100 = 5.1\ \%$ 1

OR

$P_{useful} = \frac{\frac{1}{2}mv^2}{t}$

= 0.102 W

$efficiency = \frac{P\ out}{P_{in}} \times 100 = \frac{0.102}{2} \times 100 = 5.1\ \%$

(d) At the 6.00 s mark, the operator released the control stick and the car slowed down, coming to a complete stop 4.40 m from the operator. Calculate the average frictional force acting on the car during its deceleration.

(3 marks)

Distance while slowing down:

$s = 4.40 - 3.60 = 0.80\ m$ 1

$W = \Delta E = Fs$ 1

$F = \frac{\Delta E_k}{s} = \frac{0.612}{0.80} = 0.76\ N$ 1

or

F = m a $a = \frac{v^2 - u^2}{2s}$

$= \frac{0 - 1.2^2}{2(0.8)}$ 1

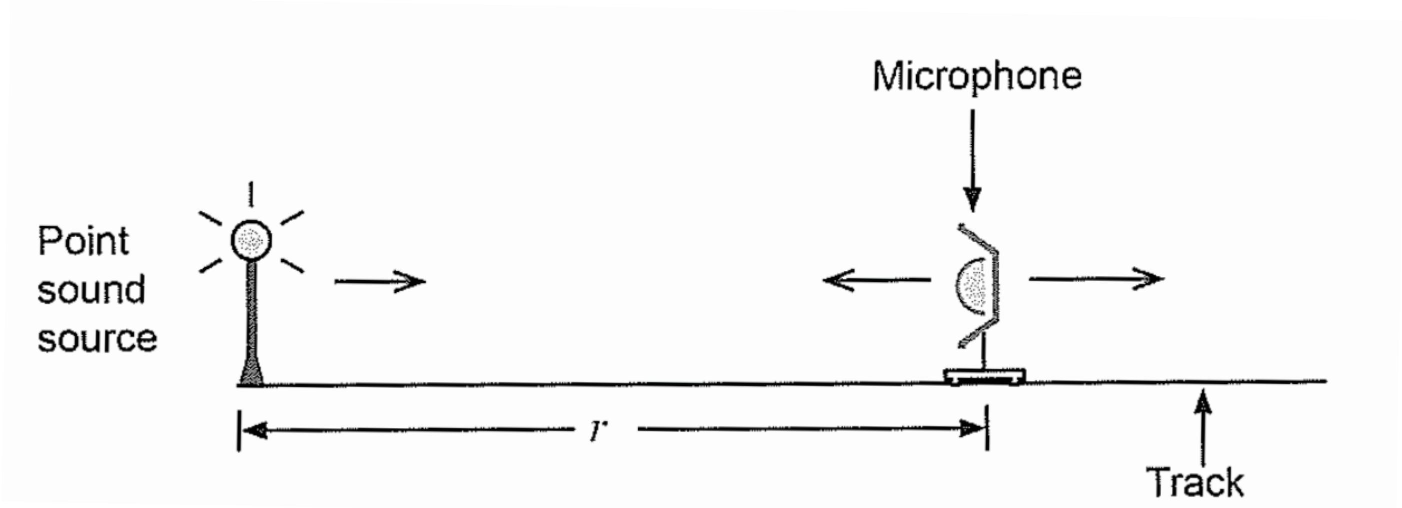
$= 0.90\ ms^{-2}$

F = 0.85(0.9) = 0.765 N 1

Question 4 **(8 marks)**

Sound intensity is defined as sound per unit area, $Intensity = \frac{Power}{Area}$; $I = \frac{P}{4\pi r^2}$

Hence, the further from a source, the more area the sound is spread across, and the less intense a sound appears to a person. A student was asked to verify the formula I = P/A. The experimental set-up was as follows:



A student used a microphone to monitor the level of intensity of the sound at various distances. As the student moved the microphone along the track, the values were recorded in a table as follows:

Intensity, I ($\times 10^{-4}$ Wm^{-2})	Distance from speaker (m)	$^1/_{r^2}$ (m^{-2})
48	0.50	**4.0**
10	1.0	**1.0**
5	1.5	**0.44**
3	2.0	**0.25**
2	2.5	**0.16**

(a) Complete the last column in the table, expressing the values to the correct significant figures. (2 marks)

The following page shows a linearised graph of the proportionalities between intensity and distance.

(b) Using the graph on the following page, calculate the gradient. Show all working and include units in your answer.

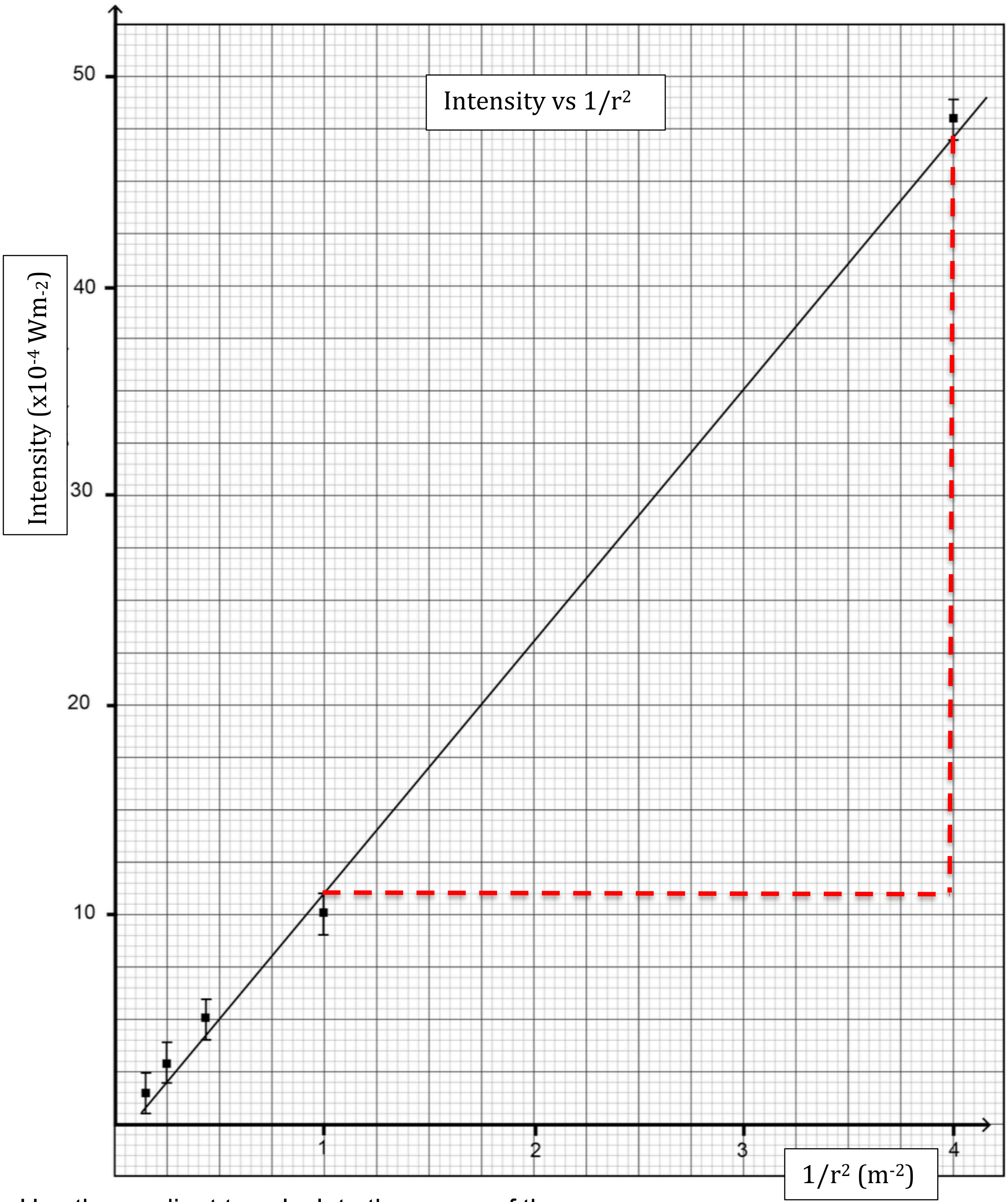
(3 marks)

Uses two points from line of best fit to calculate the gradient

gradient = $\frac{(47-11)\times 10^{-4}}{4-1} = \frac{36\ Wm^{-2}}{3\ m^{-2}}$ 1

$= 1.2 \times 10^{-3}$ W 1

-1/2 mark if units omitted or incorrect.
-1 mark if order of magnitude omitted



(c) Use the gradient to calculate the power of the source.

(3 marks)

$$I = \frac{P}{4\pi r^2} = \frac{P}{4\pi} \cdot \frac{1}{r^2}$$

1

gradient = $\frac{P}{4\pi}$

P = gradient.4π 1

= 1.2 x10^{-3} (4π) = 1.5 x10^{-2} W 1

Question 5 **(12 marks)**

A car accelerates from rest to 30.0 ms^{-1} East at a constant rate in 7.00 seconds. 12.00 seconds later, while still travelling at 30.0 ms^{-1}, the car is required to come to rest at an intersection. While it is decelerating at a constant rate, it covers a distance of 120.0 m.

(a) Calculate the car's initial acceleration.

(2 marks)

$a = \frac{v-u}{t}$ ½

$= \frac{30-0}{7}$ ½

= 4.29 ms^{-2} East 1

-1/2 marks if direction incorrect or omitted

(b) Calculate the car's total displacement.

(3 marks)

$\sum S = S1 + S2 + S3$ ½

= ½ at^2 + vt + 120 ½

= ½(4.29)(7^2) + (30)(12) + 120

= 105 + 360 + 120 1

= 585 m East 1

-1/2 marks if direction incorrect or omitted

(c) Calculate the car's acceleration in the last 120.0 m.

(2 marks)

a = $\frac{v^2-u^2}{2s}$ ½

= $\frac{0^2-30^2}{2(120)}$ ½

= 3.75 ms^{-2} West 1

-1/2 marks if direction incorrect or omitted

(d) Calculate the time take to decelerate in the last 120.0 m.

(2 marks)

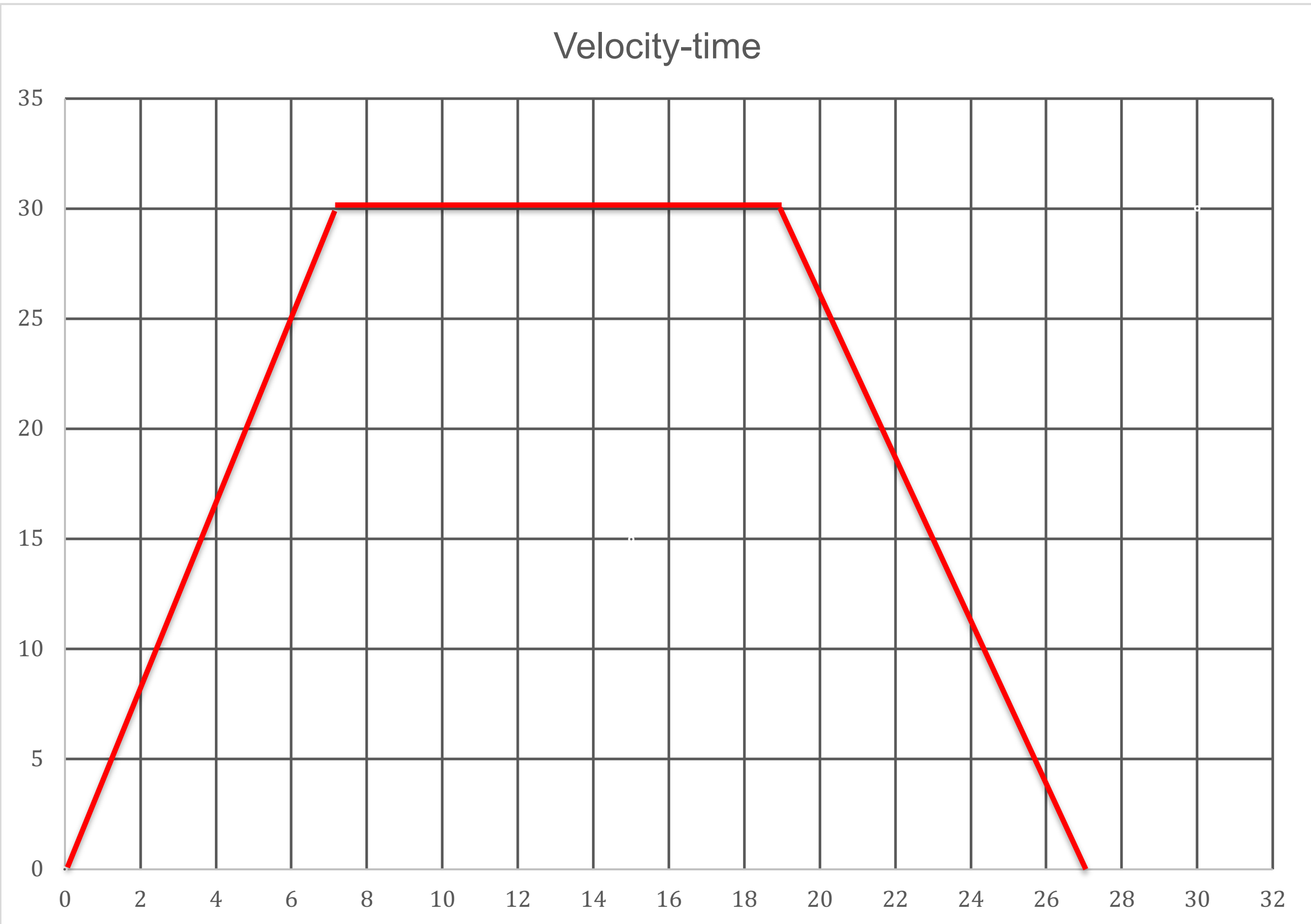
$t = \frac{v-u}{a}$ ½

$= \frac{0-30}{-3.75}$ ½

= 8.00 s 1

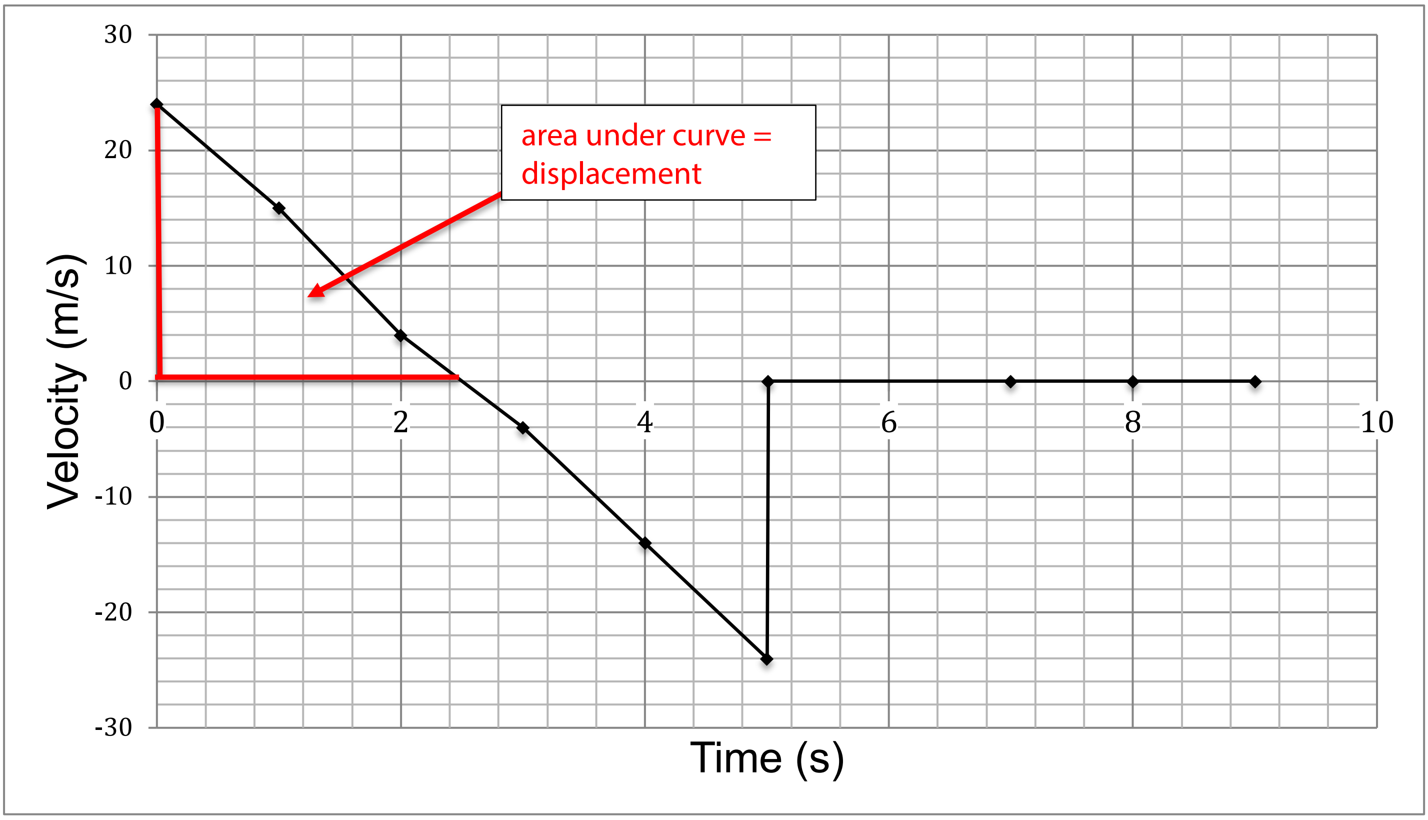
(e) Complete the velocity-time graph below for the cars entire journey.

(3 marks)



Question 6 **(13 marks)**

Students at a school are investigating the effects of gravity by throwing a 0.250 kg ball up in the air. They use motions capture software to plot the object's velocity against time. They receive the following graph.



(a) Use the graph to calculate the acceleration due to gravity. Show all working. (3 marks)

Uses two points from line of best fit to calculate the gradient 1

gradient = $\frac{24.0-0}{2.5-0} = \frac{24\ ms^{-1}}{2.5\ s}$ 1

= 9.60 ms^{-2} 1

-1/2 marks if units incorrect or omitted

(b) Use the graph to calculate the maximum displacement of the ball. (2 marks)

Area under = 1/2(2.5)(24) 1

= 3.0 x10^1 m 1

(c) Use an appropriate equation of motion to calculate the final displacement of the ball.

(3 marks)

t = 5 (from graph)

$s = ut + 1/2\ at^2$ 1

$= 24(5) + 1/2(-9.8)(5^2)$ 1

$= -2.5\text{m}$ 1

OR

$s = ut + 1/2\ at^2$

$= 24(5) + 1/2(-9.6)(5^2)$ (from graph)

$= 0\ \text{m}$

(d) Using concepts of conservation of energy, calculate the maximum height of ball.

(3 marks)

$\sum Ei = \sum Ef$ ½

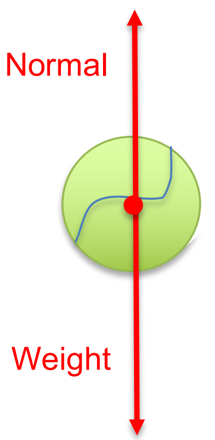
$½\ mu^2 = mgh_f$ ½

$½\ (0.25)(24\text{^}2) = (0.25)(9.8)\ h_f$ 1

$hf = 29.4\ \text{m}$ 1

(e) On the diagram below, draw the forces acting on the ball between the 5 and 9 seconds.

(2 marks)



-1 mark if not equal in magnitude

End of Section Two

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Section Three: Comprehension

This section has **two (2)** question. Answer **all** questions. Write your answers in the space provided.

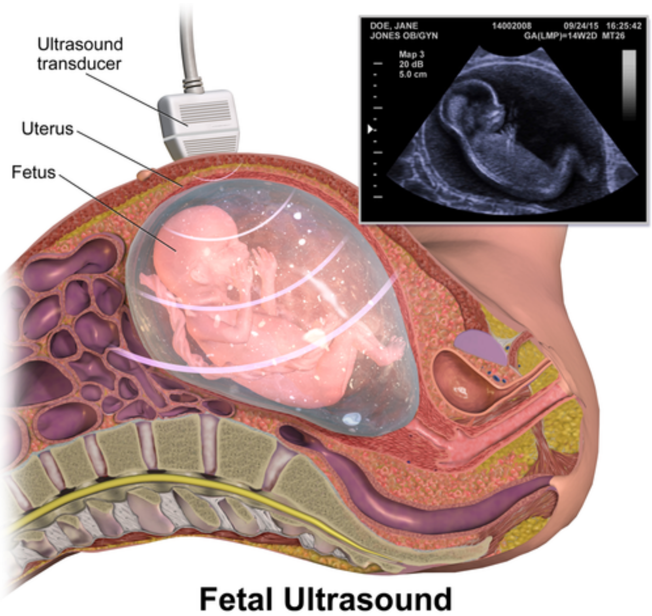
Suggested working time for this section is **30 minutes**.

NAME:____

TEACHER: SFZ JRM
(please circle)

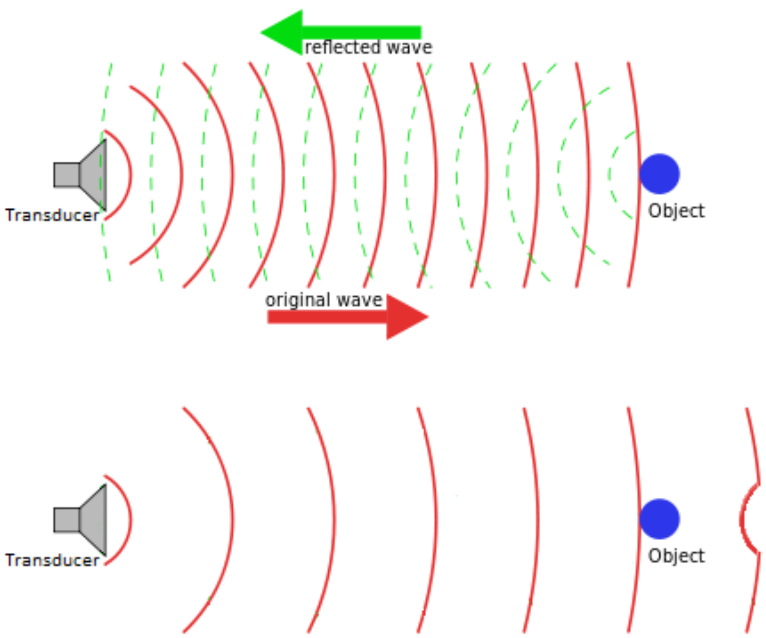
Question 1: The Medical Use of Ultrasound **(18 marks)**

The term ultrasound refers to sound vibrations with a frequency higher than is perceptible by humans; in the range of 20.0 kHz or more. As with all sound, ultrasound waves will undergo reflection and refraction at boundaries between mediums as well as undergoing interference. Ultrasound's wave behaviours allow for it to be used as a non-invasive, safe imaging technique for medical diagnosis; The most common being to monitor foetal development.



Fetal Ultrasound

An ultrasound wave is produced within a device called a transducer which houses a piezoelectric material that vibrates in response to an electric current. The wave is directed into the body where it reflects or refracts at the boundary between different tissue layers (e.g. between fat and muscle or blood and arterial walls). Reflected waves are detected by the piezoelectric material in the transducer, converted into a current and interpreted by software to form an image.



When using a wave to form an image it is important that the wavelength is similar or smaller than the size of the features that need to be distinguished. If the wavelength is larger than the feature, the wave tends to bend around the feature instead of being reflected (see image on left). Monitoring foetal development requires observation of features as small as one millimetre wide. This is why the 'ultra' part of ultrasound is required – it has a small enough wavelength to reveal the necessary details.

Can we keep increasing the frequency to obtain clearer images? Unfortunately, the energy of the wave is absorbed easily by body tissues at higher frequencies. This limits how deep a high frequency wave can penetrate into the body before it must reflect, otherwise it will be absorbed before returning to the transducer. Thus, higher frequencies have low penetration but clearer images while low frequencies have higher penetration but lower clarity. The right frequency to use will be one that maximises clarity while still being able to reach deep enough into the part of the body needing to be imaged.

As stated earlier, the ultrasound will reflect and refract at the boundary between tissue layers. How much of the wave reflects and how much refracts depends on the difference between the acoustic impedance of each layer. The acoustic impedance (Z) is the resistance the ultrasound wave encounters moving through tissue. As the difference in acoustic impedance between the layers increases, the fraction of the wave that reflects also increases. The fraction of the amount reflected can be calculated using:

$$reflection\ fraction = \left(\frac{Z_2 - Z_1}{Z_1 + Z_2}\right)^2$$

Where Z_1 and Z_2 are the acoustic impedance of tissue layer 1 and tissue layer 2 respectively.

A similar observation can be made with audible sounds. An echo heard from a canyon wall occurs because the difference in acoustic impedance between the air and the dense rock is large, causing the sound to be reflected back. However, sound waves moving through different density layers of air mostly refracts because the layers have similar impedances.

(a) Calculate the maximum wavelength of an ultrasound passing through air. Give your answer to a suitable number of significant figures. Take the speed of sound in air to be 346 ms^{-1}.

(3 marks)

$\lambda = \frac{v}{f}$ 1

$= \frac{346}{20.0 \times 10^3}$ 1

$= 0.0173\ m$ 1

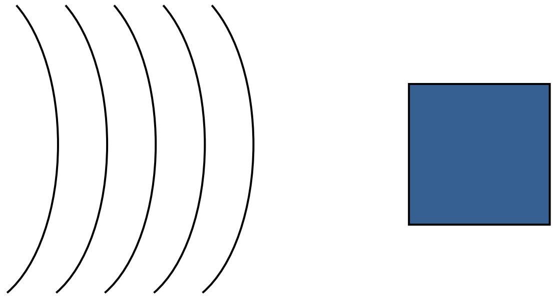
(b) Describe the role of a transducer in a medical ultrasound.

(2 marks)

- Produces and transmits the ultrasound wave
- Detects the reflected ultrasound wave

(c) In the diagram below, is it possible for the incident wave to reflect off the object that is in the path of the wave? Justify your answer by referring to information available in the diagram and article.

(2 marks)



- Yes,
- the wavelength (distance between wavefronts) is small compared to the width of the object

(if indicate length/size as opposed to width, -1/2 mark)

(d) Typically, a 2.50 MHz wave is used for a medical ultrasound of a foetus.

(i) What is the size of the smallest feature required to be distinguished when monitoring a foetus?

(1 mark)

1 mm

(ii) Via a suitable calculation, estimate the speed of sound inside the womb where the foetus is located.

(3 marks)

Take wavelength to be 1 mm = 1.00×10^{-3} m

$v = \lambda f$ 1

$= 1.00 \times 10^{-3} \times 2.50 \times 10^{6}$ 1

$= 2.5 \times 10^{3}\ ms^{-1}$ 1

(e) Describe why increasing the frequency of the ultrasound waves is not always the best option to produce useful medical images.

(2 marks)

- Increasing the frequency will reduce the penetrative power of the wave
- The wave may not be able to image deep enough into the body to be of use

(f) The table below shows the acoustic impedance of mediums relevant to ultrasound medical imaging.

Medium	**Impedance ($\times 10^6$ kg m^{-2} s^{-1})**
Air	0.0004
Skin	1.99
Fat	1.38
Kidney	1.65

(i) Calculate the fraction of an ultrasound wave that is reflected at the boundary of fat and kidney tissue.

(3 marks)

$$reflection\ fraction = \left(\frac{Z_2 - Z_1}{Z_1 + Z_2}\right)^2$$ 1

$$reflection\ fraction = \left(\frac{1.65 \times 10^6 - 1.38 \times 10^6}{1.38 \times 10^6 + 1.65 \times 10^6}\right)^2$$ 1

$$= 7.94 \times 10^{-3}$$ 1

(ii) A special gel is placed on the transducer so that when it is placed on the skin of the patient there is no air between the transducer and the skin. Suggest a reason why this is important.

(2 marks)

The difference in impedance between air and skin is large enough to cause almost all the wave to reflect at the boundary.

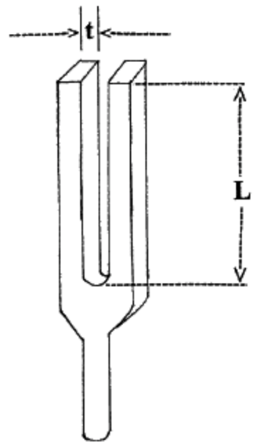
OR

The gel has a similar impedance as the skin, so the wave can penetrate into the body instead of reflecting at the skin layer.

Question 2: Tuning Forks **(16 marks)**

A tuning fork has two metal tines that flex alternately toward one another and away from one another. The natural frequency of a vibrating system is determined by its physical shape and material of construction. In the case of a tuning fork, the length of the tines determines the natural frequency as well as the material of which it is made.

The equation that can be used to predict the fundamental resonant frequency of a tuning fork is given by:



$$f = \frac{(1.194)^2\pi}{8L^2}\sqrt{\frac{EK^2}{\rho}}$$

Where: L is the length of the tine (m)
E is Young's Modulus of the material ($kg.m^{-1}s^{-2}$)
ρ is the density of the metal (kgm^{-3})
K is the radius of gyration of the bar = $\frac{t}{\sqrt{12}}$ (s)
t is the thickness of the tine (m)

The speed of sound in the metal bar, v, can be substituted for v = $\sqrt{\frac{E}{\rho}}$

(a) Rewrite the equation for frequency, substituting the equation for v.

(1 mark)

$$f = \frac{(1.194)^2\pi}{8L^2} v.\sqrt{K^2}$$

Or

$$f = \frac{(1.194)^2\pi}{8L^2} v.K$$

A group of students conducted an experiment with a set of steel tuning forks to determine the values of m and B. They placed tuning forks of differing frequency near to a microphone connected to a cathode ray oscilloscope. They then struck each of the tuning forks in turn with a small rubber mallet. The tuning forks used were all made from stainless steel and had a tine thickness (t) of 1.00 cm.

The period of each tuning fork was then measured from the oscilloscope screen. The results from this experiment are given below.

L (m)	F(Hz)	$1/L^2$ (m^{-2})
0.19	261	28
0.17	330	35
0.16	392	39
0.15	440	44
0.13	532	59

(b) Process the data so that you are able to plot a graph of f vs $\frac{1}{L^2}$

-1/2 if unit not included in column, -1/2 mark if data not in 2 sig fig (2 marks)

(c) On the following page, plot a graph of f vs $\frac{1}{L^2}$ including a line of best fit.

(5 marks)

(d) Calculate the gradient of the graph.

(3 marks)

Uses two points from line of best fit to calculate the gradient 1

gradient = $\frac{432.5-100}{45-12} = \frac{332.5\ Hz}{33\ m^{-2}}$ 1

= 10 Hz.m^2 1

-1/2 marks if units incorrect or omitted

(e) Use your answer from (d) to determine the value of v, the speed of sound in the stainless steel tuning fork.

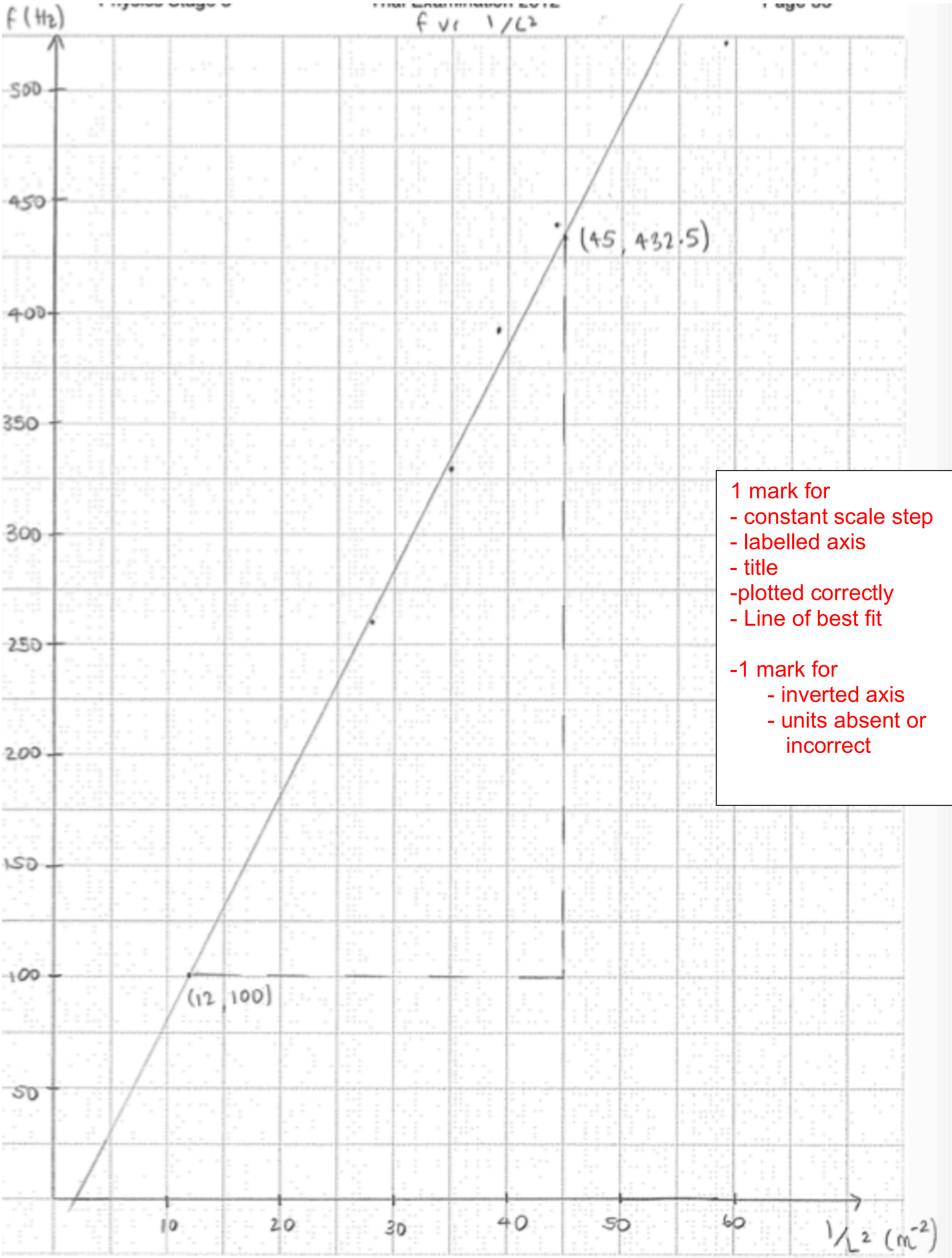
(3 marks)

$$gradient = \frac{(1.94)^2\pi}{8} v.K$$ 1

$$10.1 = \frac{(1.194)^2\pi}{8} v.\frac{0.01}{\sqrt{12}}$$ 1

$$v = \frac{10.1(8)\sqrt{12}}{(1.194)^2\pi(0.01)}$$

= 6.25 x10^3 ms^{-1} 1



1 mark for
- constant scale step
- labelled axis
- title
- plotted correctly
- Line of best fit

-1 mark for
- inverted axis
- units absent or incorrect

(f) The accepted value for the speed of sound in stainless steel is 5.80 x10^3 ms^{-1}. Determine the percentage error in your result.

(2 marks)

% error $= \frac{measured - accepted}{accepted} \times 100$ ½

$= \frac{6250 - 5800}{5800} \times 100$ ½

= 7.76 % 1

End of Section Three