Christ Church Grammar School

Science Department
Year 11 Physics

Semester 2 Examination, 2020

Question/Answer booklet

PHYSICS UNIT 2

SECTION ONE

SHORT ANSWER

Fix student label here

SOLUTIONS

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

Three Question/Answer booklets
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: 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 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	8	8	50	48		30	
Section Two: Problem Solving	5	5	70	71		50	
Section Three: Comprehension	2	2	30	33		20	
						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.

Section One: Short Response **30% (48 marks)**

This section has **eight (8)** questions. Answer **all** questions. Write your answers in the space 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 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 **(4 marks)**

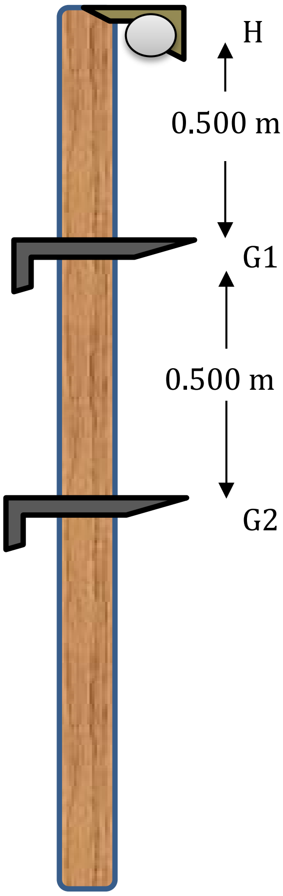
Calculate how much faster a 0.300 kg object must be travelling to have twice the energy of a 1.500 kg object travelling at a speed 'v'.

Description	Marks
$\frac{1}{2}m_1v_1^2 = 2\text{x } \frac{1}{2}m_2v_2^2$	1
$v_1^2 = \frac{2\text{x } \frac{1}{2}m_2 . v_2^2}{\frac{1}{2}m_1}$	1
$= \frac{2\text{x}(\frac{1}{2}1.5)}{\frac{1}{2}\ 0.3} . v_2^2$ $= 10\ v_2^2$	1
$v_1 = \sqrt{10}.\ v_2$ $= 3.16\text{x } v_2$	1
Total	4

Question 2 **(6 marks)**

A physics class was using the apparatus shown below to calculate the acceleration due to gravity. In the apparatus, photogates are placed 0.500 m apart and measure the time and speed of the steel ball though each gate as it falls under the influence of gravity. The times start the instant that a magnetic holder releases the steel ball. The data collected is recorded in the table below.

Using **two** different equations of accelerated motion, calculate two values for the acceleration due to gravity.

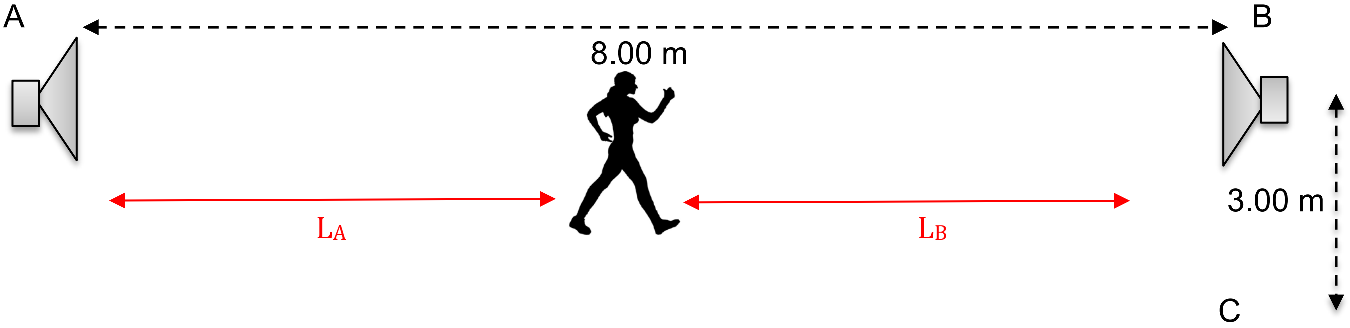


	Time(s)	Speed (m s^{-1})
Holder (H)	0.00	0.00
Gate 1 (G1)	-	3.12
Gate 2 (G2)	0.452	4.41

Description	Marks
Must chose two different equations from the possibilities below	
$a = \frac{v-u}{t} = \frac{4.41-0.00}{0.452}$	1
= 9.76 m s^{-2}	1
$a = \frac{v^2-u^2}{2s} = \frac{3.12^2-0^2}{2(0.500)}$ OR $\frac{4.41^2-3.12^2}{2(0.500)}$ OR $\frac{4.41^2-0^2}{2(1.00)}$	1
= 9.73 m s^{-2} = 9.71 m s^{-2} = 9.72 m s^{-2}	1
$a = \frac{2s}{t^2} = \frac{2(1.00)}{0.452^2}$	1
= 9.79 m s^{-2}	1
Total	6

Question 3 **(8 marks)**

A student sets up the following experiment in a large open area. She connects two speakers that are facing each other, as shown below. Both speakers are connected 8.00 m apart to the same signal generator and amplifier, which is producing a sound with a wavelength of 1.00 m.



(a) Show, through an appropriate calculation, how far she is from speaker B at this second region of quietness. The following equation may assist: Path difference = $n\lambda = |L_1 - L_2|$.
(4 marks)

Description	Marks
second region of destructive interference = 1.5 λ	1
$L_B + L_A = 8$ $L_A = 8 - L_B$	1
$1.5\lambda = L_A - L_B$ $= 8 - L_B - L_B$ $1.50(1.00) = 8 - 2L_B$	1
$L_B = 3.25$ m	1
Total	4
Note: Student must show substitution equation. If mental logic / limited mathematics is used, maximum 2 marks	

The student now walks 3.00 m down from speaker B perpendicular to the two speakers and stands at point C.

(b) Determine with a suitable calculation whether she will be in a loud or quiet region.
(4 marks)

Description	Marks
$L_{AC} = \sqrt{8^2 + 3^2} = 8.54\,m$	1
Path difference = 8.54 – 3 = 5.44 m	1
$n\lambda = 5.44 = n(1.00)$, n ≈ 5.5	1
She will be in a quiet region.	1
Total	4

Question 4 **(3 marks)**

Sometimes a tone from an instrument or an audio device will cause another object in the room to begin vibrating loudly. Name this phenomenon and explain its occurrence in this scenario.

Description	Marks
Resonance	1
Occurs when the driving frequency matches the natural frequency of the object.	1
This leads to a rapid increase in amplitude, and hence loud tone heard.	1
Total	3

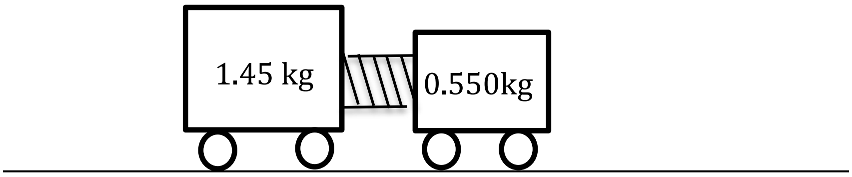
Question 5 **(4 marks)**

A 0.100 kg tennis ball is struck by a tennis racket and experiences an impulse of 3.00 N s West. If the initial speed of the tennis ball was 3.50 m s^{-1} East, calculate the final velocity of the tennis ball.

Description	Marks
$I = \Sigma F\Delta t = \Delta p = \Delta mv = m\Delta v$ - ← → +	1
- 3.0 = 0.1 (v – 3.5)	1
- 30. 0 = v – 3.5	1
v = -26.5 = 26.5 m s^{-1} West	1
Total	3

Question 6 **(8 marks)**

Two stationary carts are initially coupled together with a compressed spring between each cart. The spring is allowed to extend and the 0.550 kg cart is observed to travel away at a velocity of 2.40 m s^{-1} right.



(a) Using conservation of momentum, calculate the velocity of the 1.45 kg mass.

(3 marks)

Description	Marks
$m_c u_c = m_1 v_1 + m_2 v_2$ - ← → +	1
$v_2 = \frac{m_c u_c - m_1 v_1}{m_2} = \frac{0 - 0.55(+2.40)}{1.45}$	1
= 0.910 m s^{-1} left	1
Total	3

(b) Assuming no energy losses to the surroundings, calculate the energy contained within the spring when it is compressed. (If you could not complete (a), use v = 1.00 m s^{-1} left).

(3 marks)

Description	Marks
$\Sigma Ei = \Sigma Ef = ½ m_1 v_1^2 + ½ m_2 v_2^2$	1
$= ½(0.55)(2.42^2) + ½(1.45)(0.910^2)$	1
= 2.18 J (2.31 J)	1
Total	3

(c) State and explain the effect on the velocities if the coupled carts were initially travelling 1.00 m s^{-1} right as opposed to being stationary.

(2 marks)

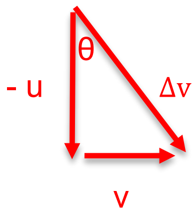
Description	Marks
Since momentum is conserved, and the sum of the initial and final is equal to mv	1
Both carts' final velocities would change by 1.00 m s^{-1} right.	1
Total	2

Question 7 **(9 marks)**

A car traveling at an initial velocity of 10.0 m s^{-1} North changes its velocity to 6.50 m s^{-1} East. With the aid of a scaled vector diagram calculate:

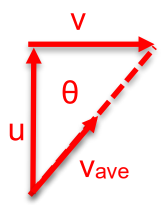
(a) The change in velocity of the car.

(4 marks)

Description	Marks
 $\Delta v = v - u = v + (-u)$	1
$\Delta v = \sqrt{10^2 + 6.5^2} = 11.9$ m s^{-1}	1
θ = tan^{-1}(6.5 /10) = 33.0	1
Δv = 11.9 m s^{-1} S 33.0° E	1
Total	4

(b) Assuming a uniform acceleration, calculate the average velocity of the car during this period.

(5 marks)

Description	Marks
	1
$v_{ave} = \frac{v+u}{2}$	1
$v_{ave} = \frac{\sqrt{10^2+6.5^2}}{2} = 5.96$ m s^{-1}	1
θ = tan^{-1}(6.5 /10) = 33.0	1
v_{ave} = 5.96 m s^{-1} N 33.0° E	1
Total	5

Question 8 **(6 marks)**

A student is investigating the intensity of sound at various distances from a musical instrument. At 1.40 m from the source, the intensity registers as 3.00 x10^{-4} W m^{-2} and the frequency is measured to be 448 Hz.

(a) Calculate how many pressure waves travel to the students in a time period of 0.560 seconds.

(3 marks)

Description	Marks
T = 1/f = 1/448 = 0.00223	1
n = 0.560 / 0.00223	1
= 251 waves	1
Total	3

(b) Calculate the distance from the source the student is to measure the intensity to be 30.5 mW m^{-2}. The following equation may be useful:

$$\frac{I_1}{I_2} = \frac{{r_2}^2}{{r_1}^2}$$

(3 marks)

Description	Marks
$\frac{I_1}{I_2} = \frac{{r_2}^2}{{r_1}^2}$, $r_2 = \sqrt{\frac{I_1}{I_2}{r_1}^2}$	1
$= \sqrt{\frac{3.00\times10^{-4}}{30.5\times10^{-3}}(1.40^2)}$	1
= 0.139 m	1
Total	3

End of Section One

Question 9 **(10 marks)**

Christ Church Grammar School is looking to go off-grid for their electricity. The majority of their electricity needs are supplied by solar panels but during cloudy days this needs to be supplemented with a diesel generator. Engineers in charge of this upgrade must minimise the noise disruption to classrooms when the generator is operating.

(a) State two things that the engineers could do to minimise the noise disruption.

(2 marks)

Description	Marks
Place the generator a far distance way from any classrooms.	1
Place the generator in a room **with adequate acoustic damping.** ← must be mentioned **low density/porous/large S.A.**	1
Total	2

All generators that are considered for this purchase are provided with a specified intensity which is "free field". this means that the sound is directly from the source and includes no reflection from outside objects.

(b) Explain why the engineers will need to increase the value of this intensity to use in their calculations.

(2 marks)

Description	Marks
Sound waves will reflect of surfaces such as walls and floors.	1
This reflection/reverberation can increase the intensity at certain locations	1
Total	2
"bounce off" = maximum 1.5 marks	

The engineers have been told that they must install the generator in an enclosed room to minimise the noise that reaches classrooms.

(c) Explain what sort of materials would likely be used in the walls of this room.

(3 marks)

Description	Marks
Walls should be of "anechoic" substances – Soft foam of varying/tapering sizes.	1
That can absorb the sound	1
And prevent it from being reflected or transmitted through the wall.	1
Total	3

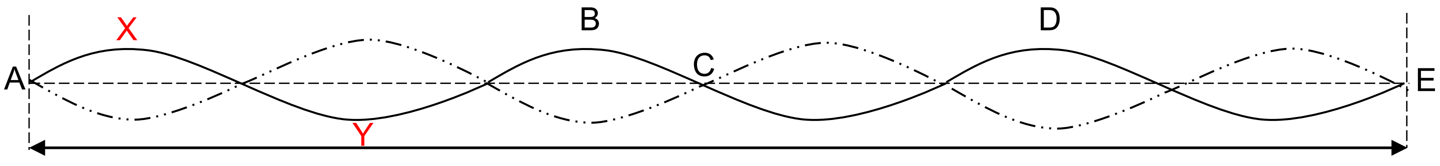
A diesel generator was purchased and installed on the campus grounds. In order to produce the required output voltage, the diesel generator must run within an operating range of between 3.00×10^3 and 3.08×10^3 rpm (revolutions per minute). It was discovered in early testing that one of the wall panels of the room began vibrating excessively when the generator was set to run at 3.00×10^3 rpm.

(d) State and explain one modification that the engineers could do to prevent this occurring. (3 marks)

Description	Marks
Any of the following	
Increase the operating frequency of the generator.	1
This will make the driving frequency different from the natural frequency of the wall panel	1
And prevent resonance occurring	1
Replace the wall panel with one with different acoustic properties.	1
This will cause the natural frequency to be different to the driving frequency of the generator.	1
And prevent resonance occurring	1
Brace the wall panel in certain locations.	1
This will prevent the panel from oscillating/changing its natural frequency	1
And prevent resonance occurring. (must mention resonance)	1
Total	3

Question 10 **(12 marks)**

When a note is played on a violin, the sound it produces consists of the fundamental frequency and many overtones. The diagram below shows the shape of the string for a stationary wave that corresponds to one of these overtones. The frequency of this overtone in 435 Hz.



Points A and E are fixed ends of the string. Points B, C and D are free to move.

(a) Describe the phase relationship between

i. A and B

(1 mark)

Description	Marks
out of phase by 90°	1
Total	1

ii B and D

(1 mark)

Description	Marks
in phase.	1
Total	1

(b) On the diagram above, label two points, X and Y, that are out of phase by 180 degrees.

(1 mark)

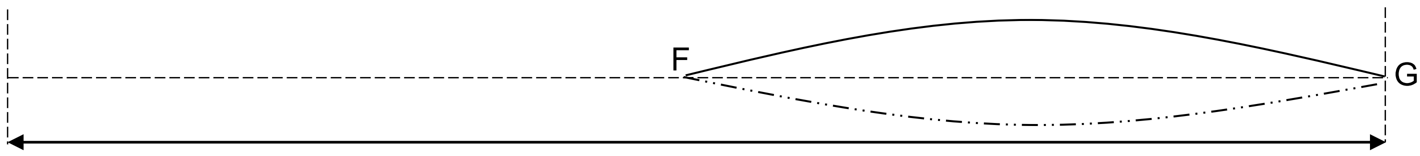
Description	Marks
selects and labels two points correctly	1
Total	1

(c) Calculate the speed of the wave on this string.

(3 marks)

Description	Marks
$f = \frac{nv}{2L}, n = 6.$	1
v = $\frac{2Lf}{n} = \frac{2(0.325)(435)}{6}$	1
= 47.1 m s^{-1}	1
Total	3

The violinist presses on the string at F to shorten the part of the string that vibrates. The diagram below shows the string between F and G vibrating in its fundamental mode. The distance between F and G is 240 mm.



(d) State the name given to the region midway between F and G

(1 mark)

Description		Marks
Particle Antinode	Antinode only = ½ mark.	1
	Total	1

(e) Calculate the wavelength of this stationary wave.

(2 marks)

Description	Marks
$\lambda = \frac{2L}{n}, n = 1, = 2L$	1
= 2(0.240) = 0.480 m	1
Total	2

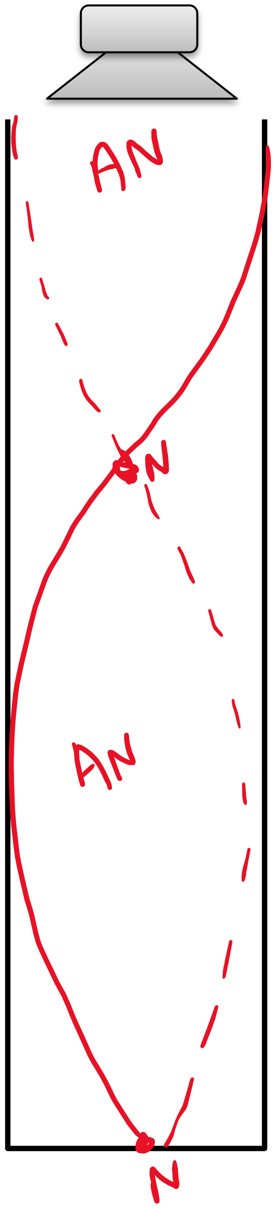
(f) Calculate the frequency of this fundamental mode, using the wave speed calculated in (c). If you could not complete (c), use v = 57.0 m s^{-1}.

(3 marks)

Description		Marks
$f = \frac{nv}{2L}, n = 1$		1
$= \frac{1(47.1)}{2(0.240)}$		1
= 98.1 Hz	(119 Hz)	1
	Total	3

Question 11 **(12 marks)**

A speaker is placed at the top of a closed end tube of length 0.800 m and the frequency slowly increased from 0 Hz until the 3rd loud tone was heard (n = 5). The speed of sound in air was recorded as 346 m s^{-1}. For this question, ignore any end error corrections.



(a) In the diagram to the right, sketch the particle displacement envelope of the 3^{rd} harmonic (n = 3), including all important features.

(1 mark)

Description	Marks
As shown in diagram.	1
Total	1

(b) Calculate the frequency of the 3^{rd} harmonic in the tube.

(3 marks)

Description	Marks
$f_n = \frac{nv}{4L}$, only odd numbered n values.	1
$= \frac{3(346)}{4(0.800)}$	1
= 324 Hz	1
Total	3
If n = 2, f = 216 Hz max 2 marks n = 5, f = 541 Hz max 2 marks if nv/2L, f = 649 Hz max 2 marks	

(c) Explain is what is meant by the term "particle displacement antinode".

(2 marks)

Description	Marks
The regions in the tube where the particle displacement	1
is its maximum from its equilibrium position.	1
Total	2

With the frequency remaining constant (n = 5), the tube is slowly filled with water and the sound Intensity is observed to decrease and then increase (n = 3).

(d) Calculate the effective length of the tube where this loud region would be heard.

(3 marks)

Description	Marks
distance between successive antinodes is $\frac{\lambda}{2}$	1
$\lambda = \frac{v}{f} = \frac{346}{541} = 0.640\ m$	1
L = 0.800 - $\frac{0.640}{2}$ = 0.480 m	1
OR	
$f_n = \frac{nv}{4L}$, only odd numbered n values set n = 3	1
L = $\frac{3(346)}{4(541)}$	1
= 0.480 m	1
Total	3

A group of students come in on another day when the air temperature in the tube was significantly higher.

(e) Explain, making reference to a suitable calculation, the effect this would have on the properties of the resulting waveform.

(3 marks)

Description	Marks
As the air temperature increases, the speed of sound in air increases.	1
Given $\lambda \propto v$, the wavelength of the sound will increase,	1
the 3rd harmonic would not be established in the 0.800 m column. OR the 3rd harmonic would occur at a longer effective length of the pipe	1
Total	3

Question 12 **(23 marks)**

When a spring is displaced from its equilibrium position it will experience a restoring force, which will act to return the spring to its equilibrium position. The restoring force is proportional to the 'stiffness' of the spring, which is known as the spring constant (k). The period of oscillation is the time for the spring to return to its original (displaced) position after it has been released.

The time period for such an oscillation is given by the formula:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Where: T = Period (s)
m = mass (kg)
k = the spring constant.

In a spring that is allowed to oscillate, there exists a *damping factor ζ* (zeta) that is a measure of how oscillations in a system decay after a disturbance. Depending on the amount of damping present, a system exhibits different oscillatory behaviour:

- Where the spring–mass system is completely lossless, the mass would oscillate indefinitely. This hypothetical case is called *undamped* $\zeta = 0$
- If the system contained high losses, for example if the spring–mass experiment were conducted in a thick fluid, the mass could slowly return to its rest position without ever overshooting. This case is called *overdamped* $\zeta > 1$.
- Commonly, the mass tends to overshoot its starting position, and then return, overshooting again. With each overshoot, some energy in the system is dissipated, and the oscillations die towards zero. This case is called *underdamped* $\zeta < 1$
- Between the overdamped and underdamped cases, there exists a certain level of damping at which the system will just fail to overshoot and will not make a single oscillation. This case is called *critical damping* $\zeta = 1$.

The following information was collected by a group of year 11 students:

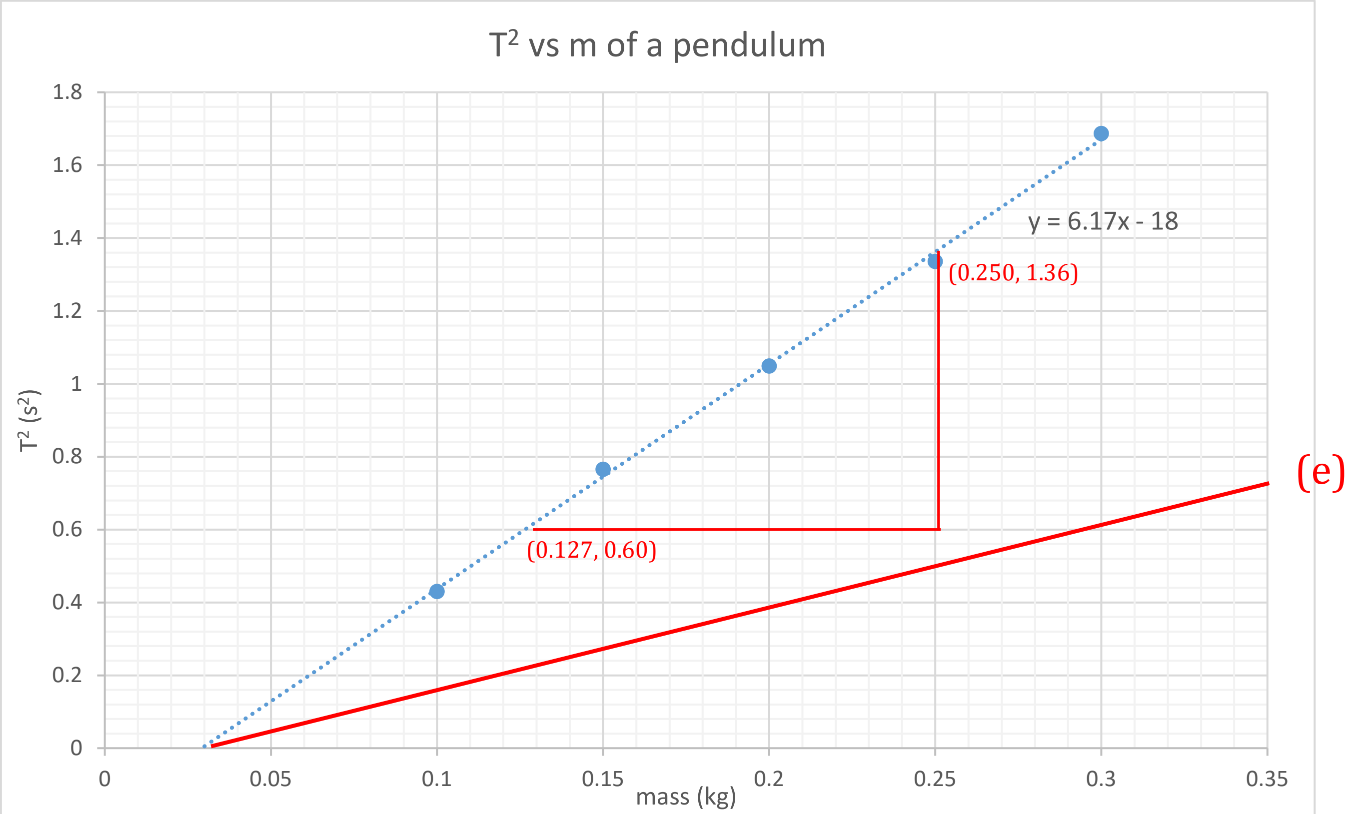
m (kg)	T(s) Trial 1 for 10 oscillations	T(s) Trial 2 for 10 oscillations	T(s) Trial 2 for 10 oscillations	T(s) Average time for 1 oscillation	$T^2 (s^2)$
0.100	6.50	6.53	6.66	0.656	0.430
0.150	8.78	8.75	8.73	0.875	0.766
0.200	10.22	10.25	10.24	1.024	1.049
0.250	11.53	11.57	11.58	1.156	1.336
0.300	13.20	12.89	12.89	1.299	1.687

(a) Process the data in the empty columns above so you are able to plot a graph of T^2 v m.
(3 marks)

Description	Marks
-1 marks for sig fig error. Not dividing T_{ave} by 10. Absent units for T^2	1
Total	3

(b) On the grid below, plot a graph of T^2 v m.

(5 marks)



(c) Calculate the gradient of the graph.

(3 marks)

Description	Marks
Appropriate lines drawn on graph	1
$m = \frac{y2 - y1}{x2 - x1} = \frac{1.36 - 0.60}{0.25 - 0.127}$	1
$= 6.18\ s^2\ kg^{-1}$	1
Total	3
allow 5.9 - 6.5 -1/2 marks for absent units.	

Question 12 continued

(d) Using the gradient, determine the spring constant of the spring used.

(3 marks)

Description	Marks
$T = 2\pi\sqrt{\frac{m}{k}}$, $T^2 = \frac{4\pi^2 m}{k} = \frac{4\pi^2}{k}.m$	1
k = $\frac{4\pi^2}{gradient} = \frac{4\pi^2}{6.18}$	1
= 6.39 kg s^{-2} -1/2 for absent marks (if axis inverted: 0.156 s^2 kg^{-1})	1
Total	3

(e) On the graph on the previous page, sketch the data you would expect for a stiffer spring. You do not need to provide any calculations.

(1 mark)

Description	Marks
Straight line with lower gradient. -1/2 marks for no label.	1
Total	1

(f) Given the method employed by the students, state and explain which suitable damping factor applies to this experiment.

(2 marks)

Description	Marks
Students must select a damping factor < 1 (underdamped) (do not allow undamped)	1
As student require the spring to oscillate at least 10 times to measure the time interval.	1
Total	2

Knowing that the spring has a possible $0 \leq \zeta \leq 1$, a student is concerned that by using 10 oscillations to calculate the period, this would introduce an error in the measurement of the period of the spring.

(g) Explain with reference to the properties of the spring, why this is not the case and what feature of the oscillation will change over time.

(4 marks)

Description	Marks
The equation of the period of the spring is stated as: $T = 2\pi\sqrt{\frac{m}{k}}$,	1
Neither the damping factor nor the amplitude of the spring is present in the equation and so will not affect the period of the spring. (or: The period of the spring will remain constant for all amplitudes of the springs oscillation)	1
OR	
As the physical properties of the spring has not changed, the natural frequency of the spring has not changed.	1
The period of the spring does not change.	1
AND	
The amplitude of the spring will reduce over time	1
As energy is removed from the system due to internal friction/air resistance.	1
Total	4

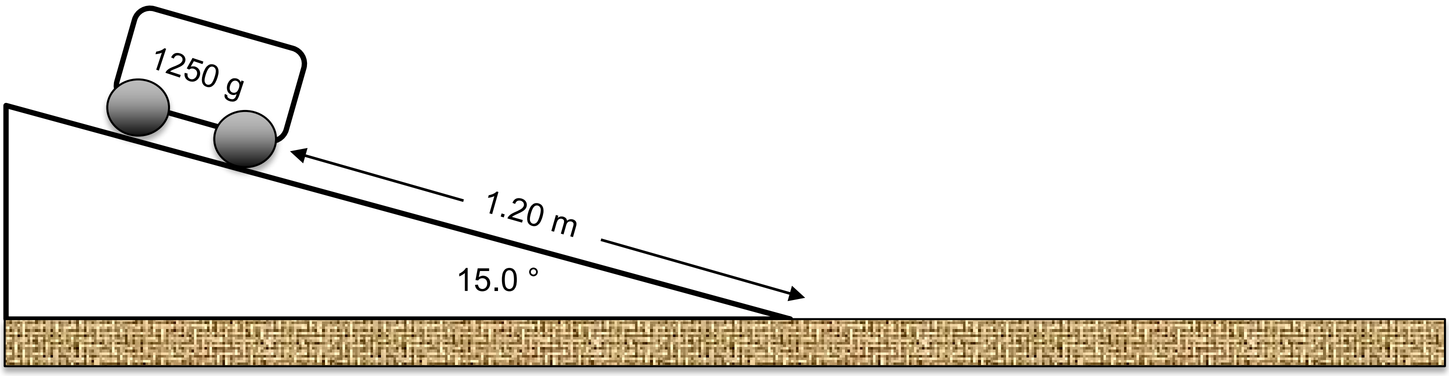
(h) By rearranging the original equation provided, show that the spring constant can also have units of [N m^{-1}] where 1 N = 1 kg m s^{-2}.

(3 marks)

Description	Marks
$T = 2\pi\sqrt{\frac{m}{k}}$, $T^2 = \frac{4\pi^2 m}{k}$, k = $\frac{4\pi^2 m}{T^2}$	1
= $\frac{[kg]}{[s]^2}$ = kg s^{-2}	1
N m^{-1} = kg m s^{-2}.m^{-1} = kg s^{-2} hence equivalent.	1
Total	3

Question 13 **(13 marks)**

A cart of mass 1250 g is allowed to accelerate from rest down a frictionless incline of angle 15.0° a distance of 1.20 m. It then travels along a horizontal surface where a frictional force of 4.55 N acts.



(a) Calculate the magnitude of the normal force of the surface and the force acting down the incline.

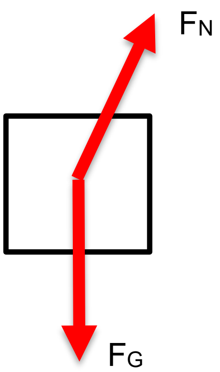
(4 marks)

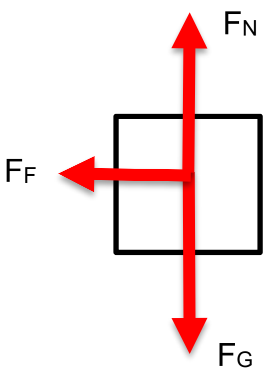
Description	Marks
$F_N = mg\cos\theta$ $= 1.25 \times 9.8\cos(15)$	1
$= 11.8$ N	1
$F_{II} = mg\sin\theta$ $= 1.25 \times 9.8\sin(15)$	1
$= 3.17$ N	1
Total	4

(b) On the diagrams below, draw a free body diagram showing the forces acting on the cart when:

i. on the incline ii. on the horizontal surface.

(2 marks)





(c) Using concepts of work and energy, calculate the speed of the cart as it leaves the incline.
(3 marks)

Description	Marks
$\Sigma Ei = \Sigma Ef, \quad E_p = mgh \quad E_k = \frac{1}{2}mv^2,$	1
$\frac{1}{2}mv^2 = mg(s \times sin15)$ $v = \sqrt{2 \times 9.8 \times 1.2 sin15}$	1
= 2.47 m s^{-1}	1
Total	3
if 0.972 s max 3 marks	

(d) Using concepts of Newton's Laws and accelerated motion, calculate the time that the cart is moving along the horizontal surface only.
(4 marks)

Description	Marks
$\Sigma F = ma, \quad a = \frac{\Sigma F}{m}$	1
$= \frac{-4.55}{1.25} = -3.64$	1
v = u + at, $t = \frac{v-u}{a} = \frac{0-2.47}{-3.64}$	1
= 0.679 s	1
Total	4

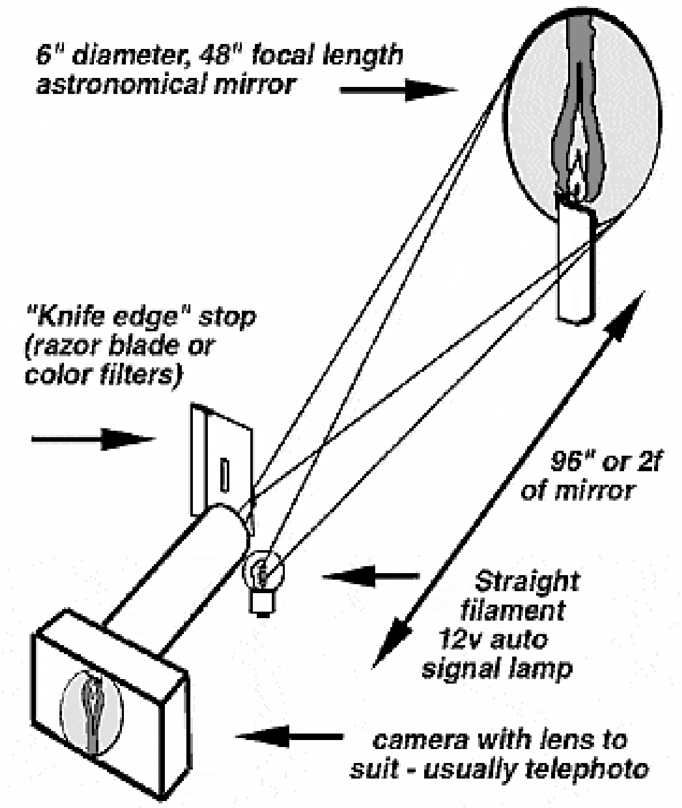
End of Section Two

Question 14 **(16 marks)**

Filming high speed bullets.

When bullets travel at supersonic speed (faster than the speed of sound), it becomes quite difficult and expensive to view their motion. One technique to film their motion is known and *Schlieren Optics* which takes advantage of the changes in the speed of light as it passes through regions of different air pressure. This can be caused by temperature fluctuations or by a fast-moving object that produces high pressure regions in front and low pressure regions behind it.

The setup requires a large parabolic mirror set up far enough away so the light source can be focused directly into the camera. A "knife edge" is then placed in front of the camera. This then allows any refracted light to be blocked from entering the camera and hence, be observed as a dark region in the image.

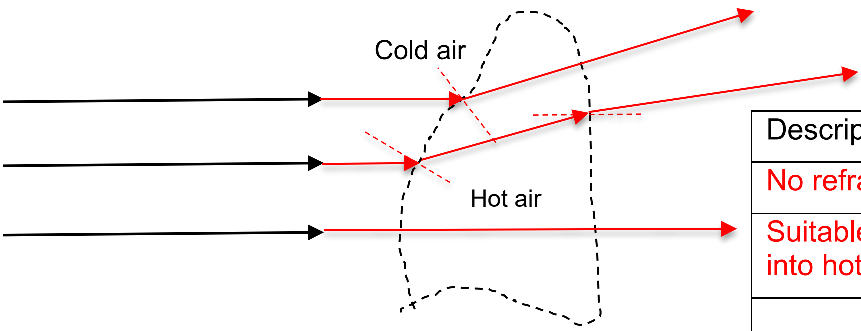


When light enters a region of high temperature it travels slightly faster than in the denser colder air. The difference in the light speed is very minimal, but this bending can be noticeable with large temperature differences such as the hot air rising from a campfire.

The diagram below shows a side on view of a temperature gradient above the candle with regions of differing temperature.

(a) Complete the ray diagram by sketching the path that the rays take as they pass by over the candle.

(2 marks)



Description	Marks
No refraction of lower ray	1
Suitable refraction in top two (ie: upwards into hot air and downwards exiting.	1
Total	2

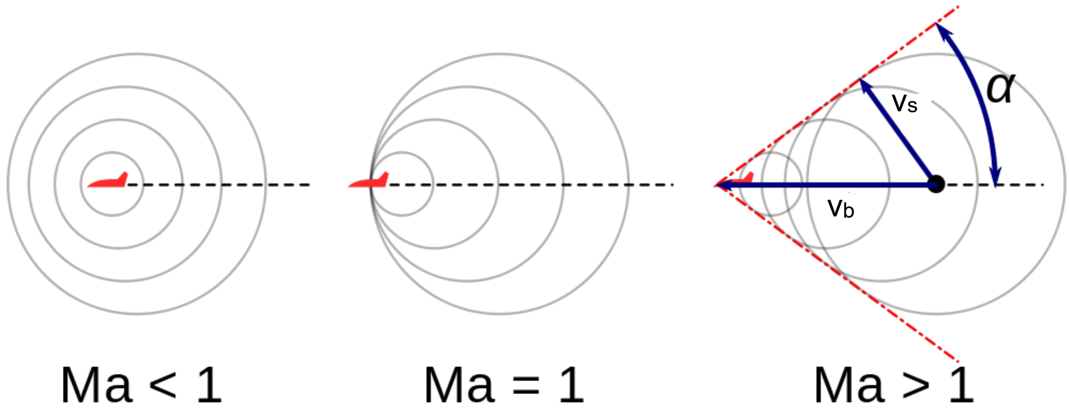
(b) State the definition of refraction.

(2 marks)

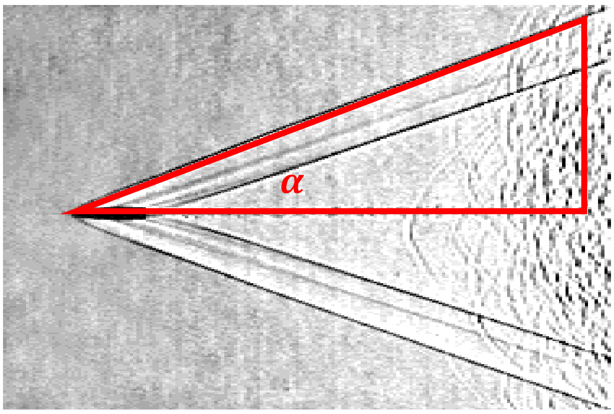
Description	Marks
The bending of a wave	1
as it travels into a medium of different wavespeed.	1
Total	2

High speed objects are given a Mach Number “Ma” which is a ratio of the object’s speed to the speed of sound. If a high-speed object is travelling supersonic (Ma > 1) it produces a cone of pressure caused by relative motion of the object through the medium. The angle of the cone when measured from the horizontal is known as the Mach angle (α), shown in the figure below. In a given time, the bullet travels forward a distance x = v_bt. In that same time period, the sound wave produced at the same point travels out radially a distance of v_st. Ma can then be determined by the following relationship:

$$Ma = \frac{1}{sin\alpha}$$



The cone of pressure of a fast-moving bullet can be seen using schlieren optics and a high-speed camera. Seen below is a 165 grain bullet (mass = 10.7 grams) fired at a super sonic speed in an environment where the speed of sound is 340 ms^{-1}.



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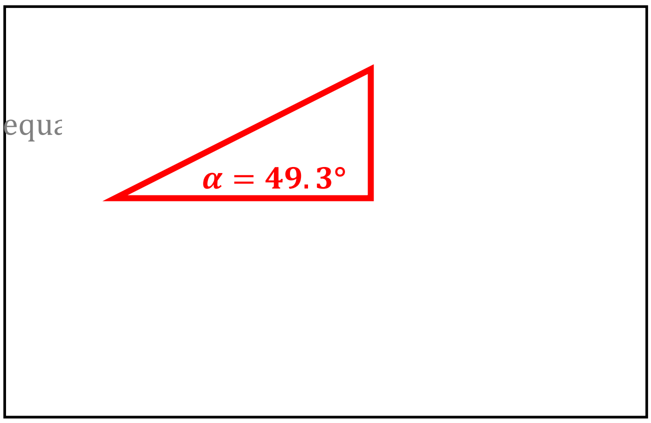

Question (e)

(c) By making use of the diagram above, estimate the Mach angle and calculate the Mach number. (3 marks)

Description	Marks
Measures angle on diagram = 20°, states to 2.s.f = 2.0 x10^{1} ° or sin α = opp/hyp (allow +/- 2°)	1
Ma = $\frac{1}{sin\alpha} = \frac{1}{sin20}$	1
= 2.9 (2.s.f)	1
Total	3

(d) Hence, calculate the speed of the 165 grain bullet.

(2 marks)

Description	Marks
v = Ma x 340 = 2.92 x 340	1
= 993 m s^{-1}	1
	1
Total	3

(e) In the box on the previous page, sketch the pressure wave produced by a bullet travelling at 450 m s^{-1}. Show all required working in the space below.

(4 marks)

Description	Marks
Ma = $\frac{vbullet}{340} = \frac{450}{340} = 1.32$	1
Sin$\alpha = \frac{1}{Ma} = \frac{1}{1.32}$	1
α = $\sin^{-1}\left(\frac{1}{1.32}\right)$ = 49.3°	1
Total	3
Correctly drawn in box	

(f) If the 165 grain bullet shown in the diagram was to be fired in an environment where the speed of sound was higher, state and explain the effect this would have on the Mach angle

(3 marks)

Description	Marks
assuming v_{bullet} remains constant,	1
Ma = $\frac{1}{sin\alpha}$ = $\frac{v_{bullet}}{v_{sound}}$	1
Hence, if v_{sound} increases, then sinα and hence Mach angle will increase.	1
Total	3

Question 15 **(17 marks)**

Falling Cupcakes

As objects fall, they increase their speed due to the downward pull of gravity. Air resistance opposes gravity's pull by resisting the downward motion of the object. The amount of air resistance depends upon a variety of factors, most noticeably, the object's speed. As objects move faster, they encounter more air resistance. When the amount of upward air resistance force is equal to the downward gravity force, the object encounters a balance of forces and is said to have reached a terminal velocity. The terminal velocity value is the final, constant velocity value achieved by the falling object.

A group of physics students are investigating the terminal velocity values obtained by falling cupcakes liners. They videotape the falling liners and use video analysis software to analyse the motion. The video is imported into the software program and the filter's position in each consecutive frame is tracked on (see Figure 1).

The software uses the position coordinates to generate graphs of the motion of the cupcake liners. Figure 2 shows the displacement versus time graph that resulted from the analysis of the motion of a single cupcake liner.

Figure 1

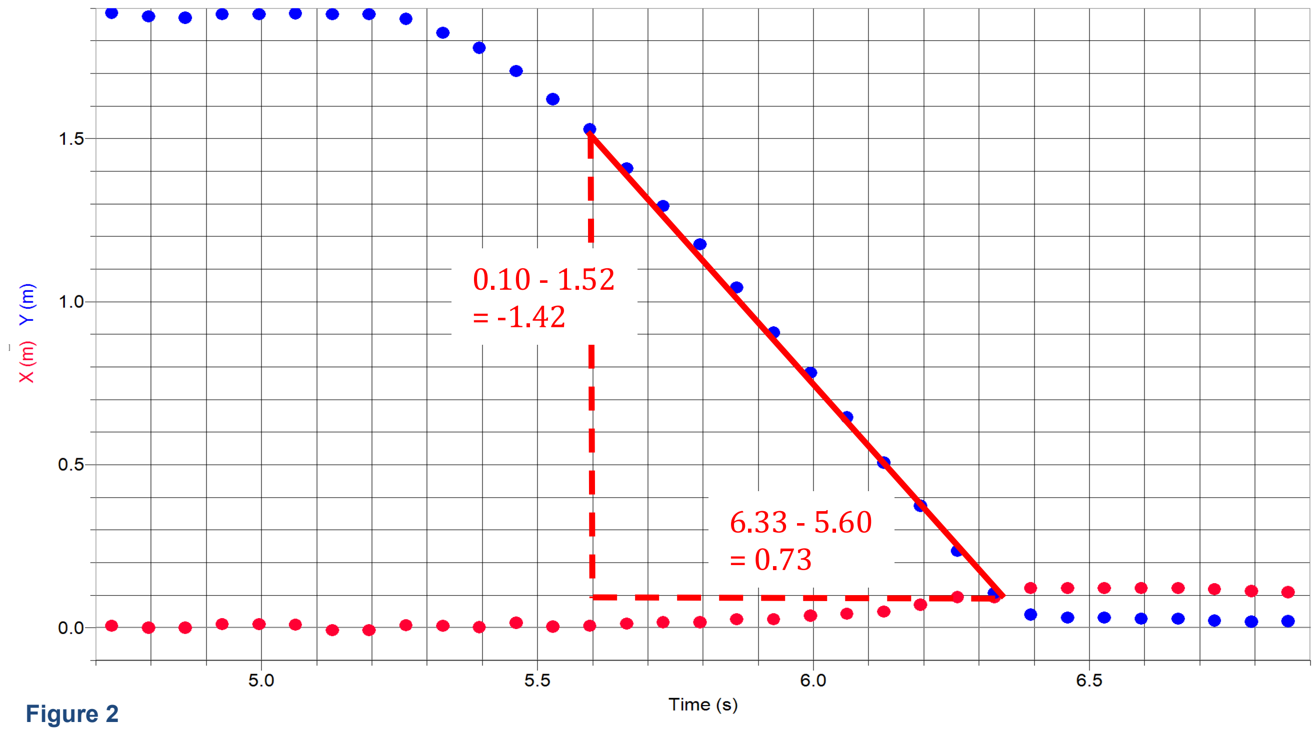

Figure 2

The lab group then investigated the effect of mass on the motion of the falling liners. They stacked varying numbers of liners tightly together and analysed the motion of the stacks of liners. They determined the terminal velocity of the stacks of liners. The students also measured the mass of the liners to determine their weight and used the value to determine the amount of air resistance encountered by the liners. Their results are plotted in Figure 3.

(a) Using the features of the graph in figure 2, show that the terminal velocity is 1.9 m s^{-1}
(3 marks)

Description	Marks
Determines gradient on graph (selects linear section of position-time graph)	1
m = $\frac{0.10 - 1.52}{6.33 - 5.60}$	1
= - 1.95 m s^{-1}	1
Total	3

One group of students conducted some further investigation and found an equation that describes the variables that affect the drag force of an object for a given speed.

$$F_D = \frac{1}{2}\rho v^2 A C_D$$

where:

F_D is the drag force [kg m s^{-2}]
ρ is the density of the fluid [kg m^{-3}]
v is the speed of the object relative to the fluid [m s^{-1}]
A is the cross-sectional area of the object relative to the fluid [m^2]
C_D is the drag coefficient that is unique for different shaped objects.

The terminal velocity as a function of mass is shown in Figure 3.

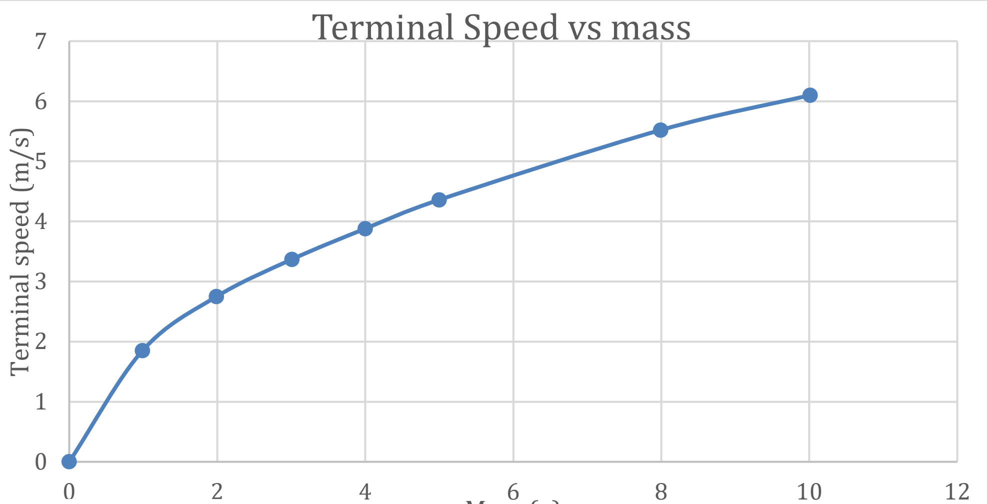

Figure 3

(b) State the mathematical proportionality between terminal velocity and mass and describe two different graphs that could be plotted to obtain a linear relationship between the two variables.
(2 marks)

Description	Marks
Graph shows a square root relationship	1
Students could plot v^2 vs m OR v vs $\sqrt{m}$	1
Total	2
No follow through given if relationship incorrect.	

(c) Derive an equation for terminal velocity that relates the variables of the falling cupcake liner once it has reached its terminal velocity.

(4 marks)

Description	Marks
$\Sigma F = 0 = W + F_D$	1
$mg = \frac{1}{2}\rho v^2 A C_D$	1
$v^2 = \frac{mg}{\frac{1}{2}\rho A C_D}$	1
$v = \sqrt{\frac{2mg}{\rho A C_D}}$	1
Total	4

(d) State what the students must plot and explain how they could analyse their graph to determine the drag co-efficient. State which additional variables they also need to measure.

(3 marks)

Description	Marks
$v^2 = \frac{2mg}{\rho A C_D}$ = $v^2 = \frac{2g}{\rho A C_D}$. M	1
Students must plot v^2 vs m and the gradient will be equal to $\frac{2g}{\rho A C_D}$	1
The students must measure the cross sectional area of the cupcake and the density of air.	1
Total	3
Marks awarded for v^2 vs F_D if appropriately explained.	

When the students dropped 12 cupcake liners, the video analysis provided a velocity-time graph shown in figure 4. The cupcake liners were released from rest at the 4.55 second mark and hit the ground at the 5.10 second mark, before they had reached their terminal velocity.

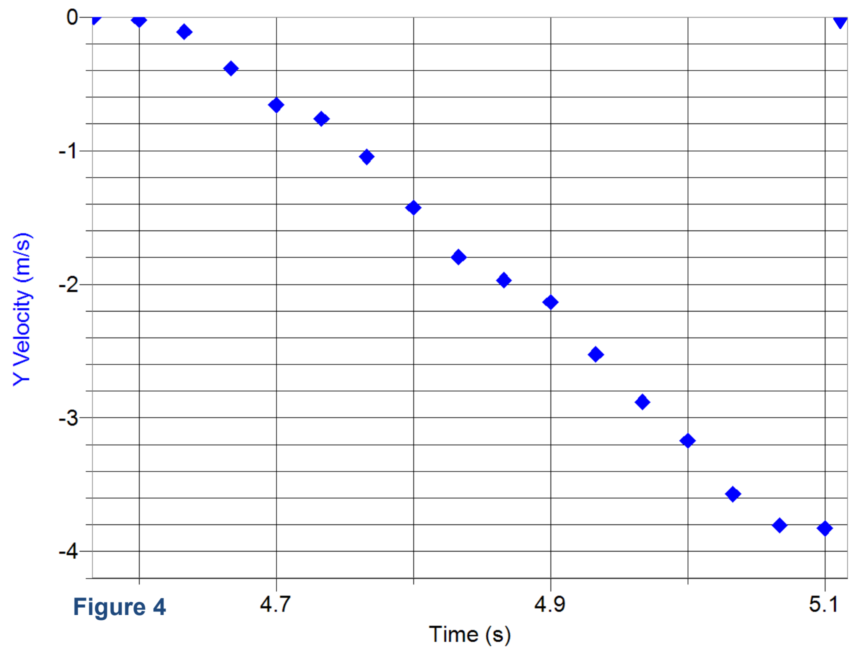

Figure 4

(e) Making reference to appropriate equations, state how students could modify their experiment in order to determine the terminal velocity of the stack of 12 liners.

(3 marks)

Description	Marks
Allow cupcakes to fall over a greater distance. This would allow cupcakes to reach its terminal velocity over a greater time	1
as $s = ut + 1/2\ at^2$, increasing s would increase t.	1
Given $v = u + at$, this would allow a greater v value	1
Total	3
Max of 2 marks for well justified explanation without equation	

(f) On the diagram below, draw a force diagram, showing the forces acting on stack of 12 cupcake liner from Figure 4 at t = 4.50 seconds and t = 5.00 seconds of the video.

(2 marks)

Description	Marks
t = 4.50 s Cupcake is in equilibrium, forces equal.	1
t = 5.00 s Cupcake is still accelerating. Upwards force is less than weight force.	1
Total	2
- ½ marks for missing / incorrect labels. No part marks other than that.	

End of Section Three