Christ Church
Grammar School

Science Department
Year 12 2020

ATAR PHYSICS
SCIENCE INQUIRY SKILLS TEST 2020

Student Name:

SOLUTIONS

Teacher: JRM HKR

(Please circle)

Time allowed for this paper

Working time for paper: 50 minutes.

Instructions to candidates:

- You must include **all** working to be awarded full marks for a question. Answers should be expressed to 3 significant figures unless otherwise indicated.
- Marks may be deducted if diagrams are not drawn neatly with a ruler and to scale (if specified).
- Marks will be deducted for incorrect or absent units.
- **No** graphics calculators are permitted – scientific calculators only.

Mark:	/ 51
=	%

Question 1 **(55 marks)**

It is generally accepted that the world's landmine and improvised explosive device (IED) threat is reaching crisis level. Explosive devices have become the weapons of choice of many groups to incapacitate, maim or kill with an estimated 15 000 to 20000 annual casualties in open war and low-intensity conflicts.
Many experiments have been performed to study the blast induced biomechanical and molecular changes in tissues and cells. These studies look at primary blast injuries affecting hearing, the pulmonary and central nervous systems as well as the effects of trauma on individual cells. To be able to conduct valid experiments, researchers require sound experimental evidence to allow them to simulate explosion fragments and variables such as fragment velocity, size distribution and projection angle. Two of the major contributing injury mechanisms coming from the detonation of IEDs/landmines are **shock loading** and **fragment loading** coming from the casing and debris.

<u>Shock loading</u>
Upon detonation of a landmine/IED there is a high-frequency, high-pressure blast wave which penetrates the body, shattering bone and tissues within the body.
Experimental platforms investigating shock loading have been developed to apply low-intensity pulsed stimuli (forces) that replicate daily physical activities, such as walking, running or jumping. These occur under physiological strain rates, typically from 10^{-2} to 10^{0} s^{-1}. Blast loadings (forces) (as involved with landmines and IEDs), however, involve more impulsive events that occur under a broader range of strain rates, from 10^{1} to 10^{3} s^{-1} and beyond. A range of strain rates associated with different deformation processes is shown in Figure 1 below.

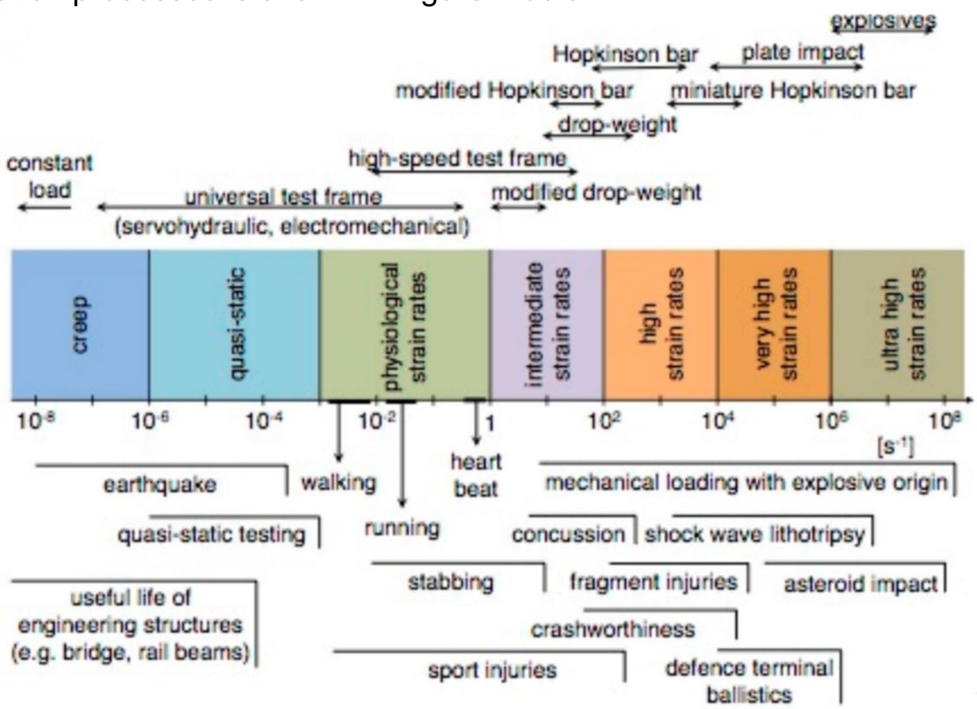


Figure 1. Deformation processes and experimental techniques associated with different ranges of strain rates.

(a) Explain what the strain rate represents in reference to the deformation process.

(1 mark)

Description	Marks
It represents the time over which a force is acting in the deformation process. *Strain rate* is the change in *strain* (*deformation*) of a material with respect to time.	1
Total	1

(b) Explain why the strain rate for walking is less than that for running (2 marks)

Description	Marks
When walking the foot is in contact with the ground for a longer period of time than for running.	1
The strain rate is inversely proportional to the time the force acts for.	1
Total	2

(c) Calculate the maximum order of magnitude difference in shock loading between walking and a blast loading. (2 marks)

Description	Marks
$= 10^{-2} : 10^{3}$	1
$= 1 : 10^{5}$	
Total	2

<u>Fragment loading</u>

As the detonation processes occur, the casing swells due to the high pressure developed by the expanding gaseous products. During this (very violent) acceleration, cracks initiate and propagate into the casing until fragments are formed, as shown in Figure 2 below.

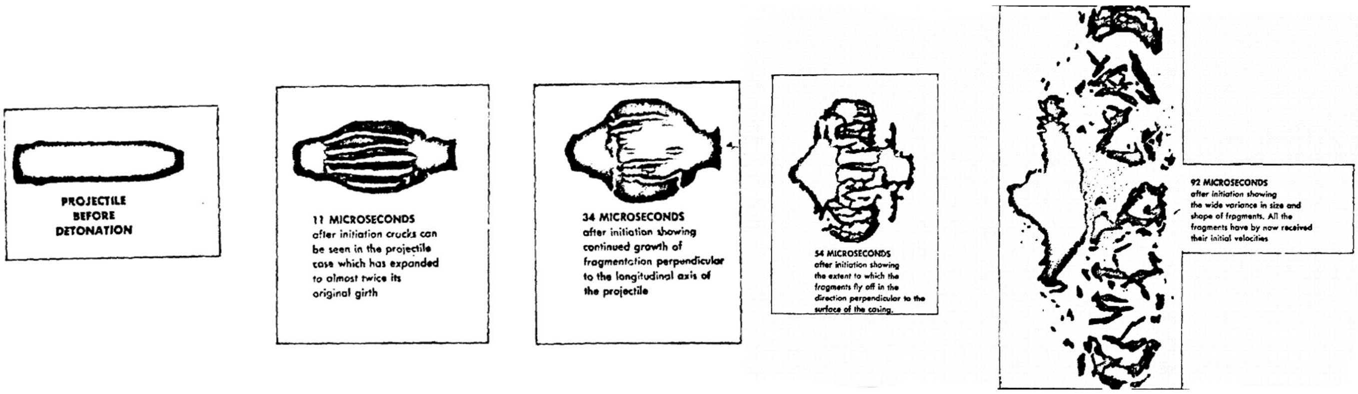


Figure 2. Detonation of a Projectile

As the energised fragments penetrate the body, they push through the soft biological tissue. When the explosive device is buried, the superheated, high-pressure gas bubble expanding in the soil breaks through the soil cap and jets soil and surrounding debris out at supersonic speed. This produces an additional violent stream of particles that extends the trauma.

Just before the casing fractures, the initial velocity imparted to the fragments can be predicted using the Gurney model.

The Gurney model is a set of mathematical formulae first developed in the 1940s by Ronald Gurney of the U.S. Army Ballistics Research Laboratory, which are extensively used in warhead engineering to predict how fast an explosive charge will accelerate surrounding metal fragments. The method makes several assumptions that simplify the problem.

1. The chemical energy of the explosive is assumed to be completely converted to kinetic energy upon detonation of the explosive.

2. The velocity profile of the product gases is linear and is constant throughout the metal thickness.

3. Gases after detonation are assumed to be equally dense everywhere and expand uniformly.

4. Rarefaction waves which are created behind the reaction zone are neglected.

Option 1			Option 2	
$v_0 \pm 5\%$ (mm/μs)	$\frac{1}{\sqrt{\frac{1}{\beta}+0.5}}$	$\beta \pm 0.02$	v_0^2 ($mm^2.\mu s^{-2}$) ($10^6\ ms^{-1}$)	$\frac{1}{\frac{1}{\beta}+0.5}$
0.7 ± 0.0	0.3 ± 0.0	0.07	0.5 ± 0.1	0.07 ± 0.02
1.1 ± 0.1	0.40 ± 0.02	0.17	1.2 ± 0.1	0.16 ± 0.02
1.4 ± 0.1	0.55 ± 0.02	0.35	2.0 ± 0.2	0.30 ± 0.02
1.9 ± 0.1	0.65 ± 0.01	0.54	3.6 ± 0.4	0.43 ± 0.02
2.2 ± 0.1	0.74 ± 0.01	0.76	4.8 ± 0.5	0.55 ± 0.01
2.6 ± 0.1	0.850 ± 0.007	1.13	6.8 ± 0.7	0.722 ± 0.013

Note: If students choose option 1: $\frac{1}{\sqrt{\frac{1}{\beta}+0.5}}$, error in β must be converted to % and then halved as per fractional index rule.

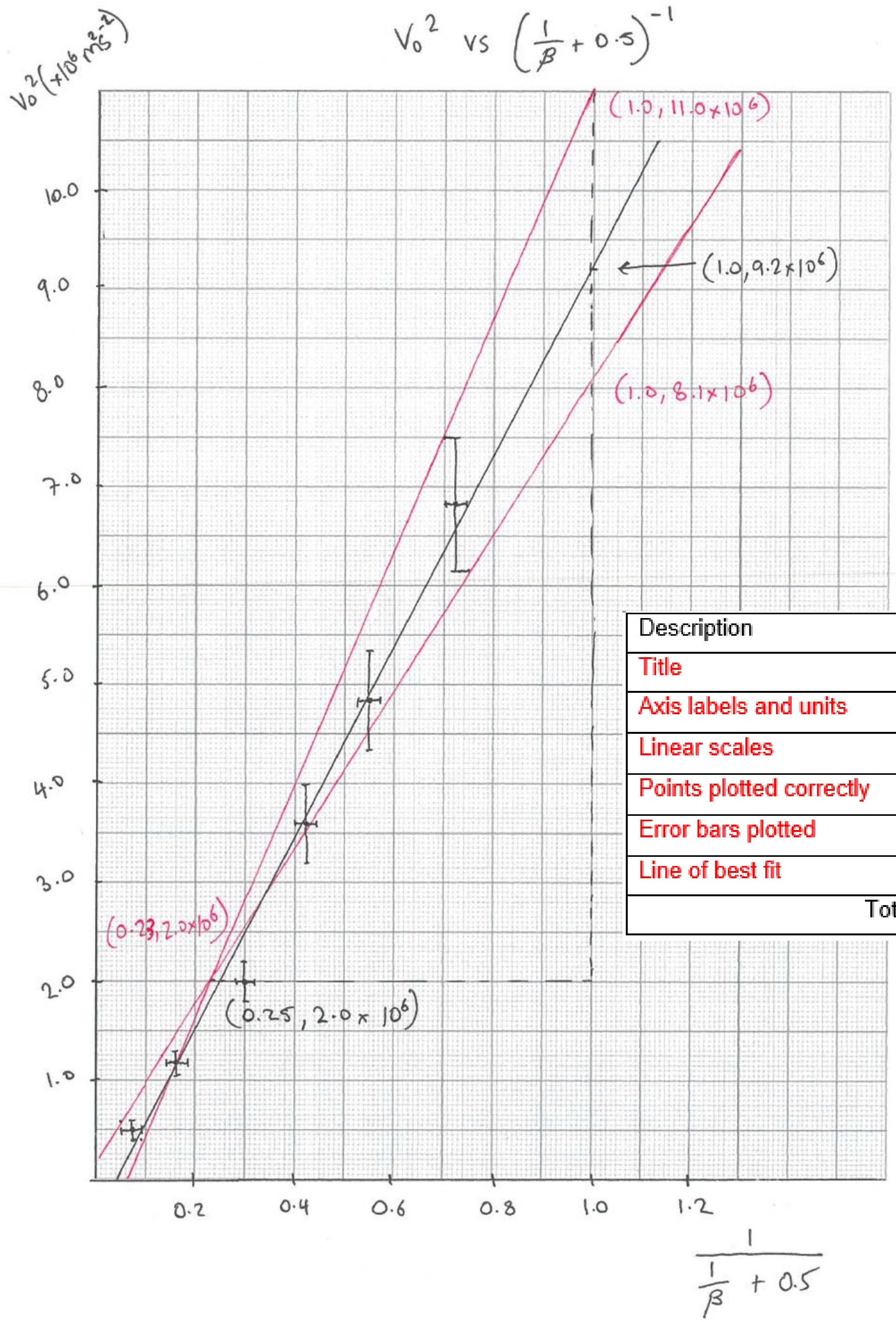
(d) State the variables that must be plotted (in the form 'y vs x') to obtain a linear relationship. (1 mark)

Description	Marks
v_0^2 vs $(\frac{1}{\beta}+0.5)^{-1}$ or v_0 vs . $\frac{1}{\sqrt{\frac{1}{\beta}+0.5}}$	1
Total	1

(e) Process the data in the table above to allow you to plot a linear relationship between the variables. Appropriate column labels and values of uncertainty must be included. (13 marks)

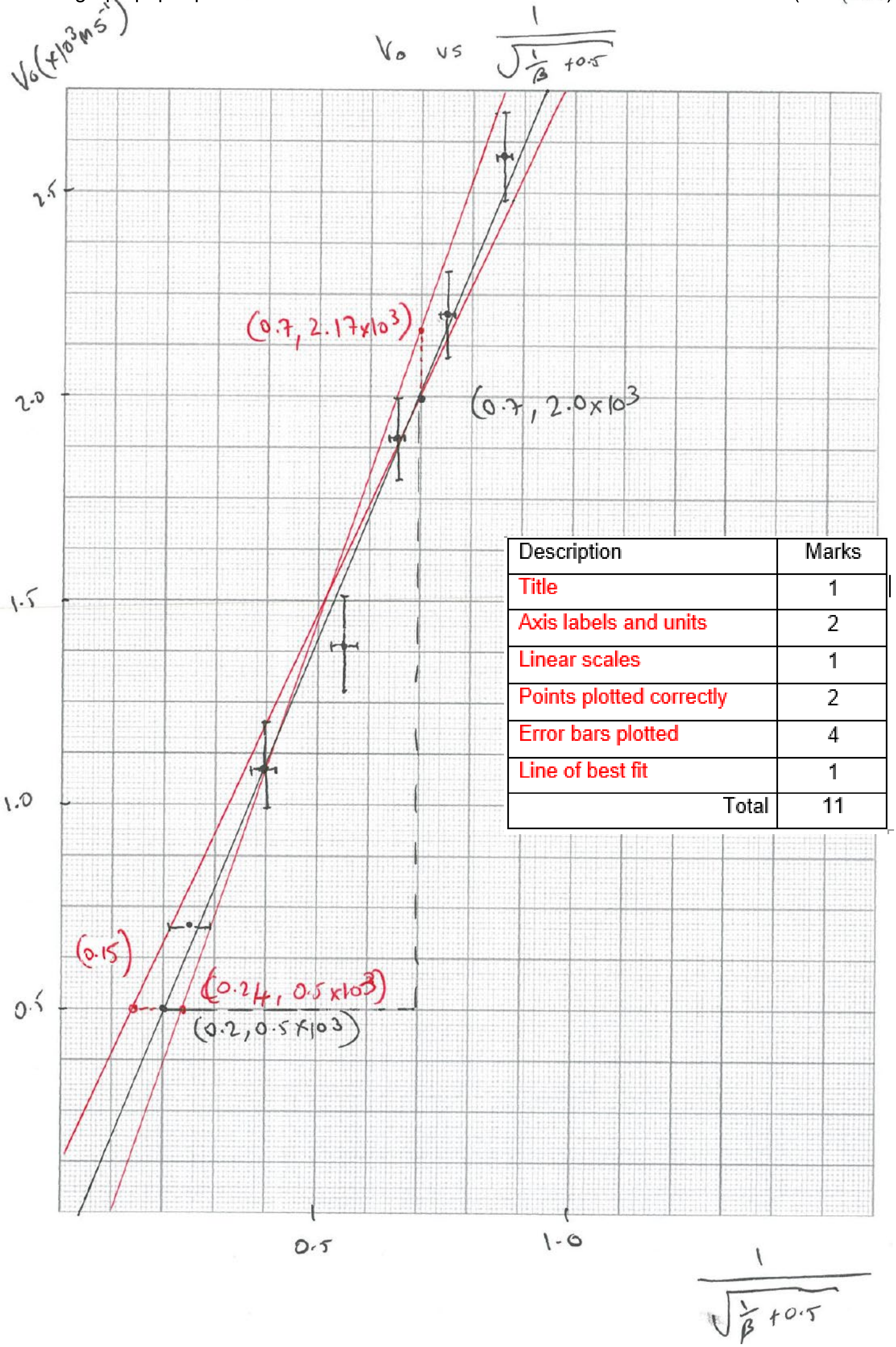
Description	Marks
Column labels and units	2
Correct significant figures	2
Correctly calculated values	4
Correct values for uncertainty	4
Values have been calculated in line with answer to (d) (1 mark)	1
Total	1
Note: If student plots v_0^2 vs β: maximum 11 marks If student does not complete 4th column: maximum 10 marks	

(f) Plot a linear relationship, including line of best fit and error bars, between the variables on the graph paper provided. (11 marks)



Description	Marks
Title	1
Axis labels and units	2
Linear scales	1
Points plotted correctly	2
Error bars plotted	4
Line of best fit	1
Total	11

(f) Plot a linear relationship, including line of best fit and error bars, between the variables on the graph paper provided. (11 marks)



Description	Marks
Title	1
Axis labels and units	2
Linear scales	1
Points plotted correctly	2
Error bars plotted	4
Line of best fit	1
Total	11

(g) Calculate the gradient of the line of best fit. (4 marks)

Description		Marks
$gradient = \frac{y2 - y1}{x2 - x1}$ $gradient = \frac{(9.2 - 2.0)\times 10^6}{(1.0 - 0.25)}$	$\frac{(2.0 - 0.5)\times 10^3}{(0.7 - 0.2)}$	1
$= 9.6 \times 10^6\ m^2s^{-2}$ or $9.6\ mm^2.\mu s^{-2}$	3.0 x103 ms-1	1
Triangle drawn clearly and correctly.		1
Must be to 2 sf		1
	Total	

(h) Calculate the uncertainty in the gradient of the line of best fit, through calculation of maximum and minimum gradients, and rewrite the gradient including the uncertainty. (7 marks)

Description		Marks
Lines of Best fit – upper and lower		1
$minimum\ gradient = \frac{(8.1 - 2.0)\times 10^6}{(1.0 - 0.25)}$	$= \frac{(2.17 - 0.5)\times 10^3}{(0.7 - 0.24)}$	1
$= 8.1\ mm^2.\mu s^{-2}$ (or $\times 10^6\ m^2s^{-2}$)	$= 3.6 \times 10^3$	1
$maximum\ gradient = \frac{(11.0 - 2.0)\times {10^6}^2}{(1.0 - 0.23)}$	$\frac{(2.0 - 0.5)\times 10^3}{(0.7 - 0.15)}$	1
$= 11.6\ mm^2.\mu s^{-2}$ (or $\times 10^6\ m^2s^{-2}$)	$= 2.7 \times 10^3$	1
$\frac{11.6 - 8.1}{2} =$		1
$9.6 \pm 1.7\ mm^2.\mu s^{-2}$ (or $\times 10^6\ m^2s^{-2}$)	$(3.0 \pm 0.5) \times 10^3\ m\ s^{-1}$	1
	Total	7

(i) State what the gradient represents.

(1 mark)

Description	Marks
2E or the Gurney constant squared or Gurney constant ($\sqrt{2E}$)	1
Total	1

(j) Using the gradient of the graph, calculate **E**, the specific energy of the explosive charge, used in this experiment. Include a value of uncertainty in your answer.

(4 marks)

Description	Marks
$9.6 \times 10^6 = 2E$ $E = 4.8 \times 10^6$ or $\sqrt{2E} = 3.0 \times 10^3$ m s^{-1} $E = 4.5 \times 10^6$	1
$\frac{1.7}{9.6} = 0.177$ $\frac{0.5}{3.0} = 0.167 \times 2$ $= 0.33$	1
$(0.177)(4.8 \times 10^6) = 0.8496 \times 10^6$ $0.33 \times 4.5 \times 10^6 = 1.499 \times 10^6$	1
$E = 4.8 \pm 0.8 \times 10^6$ m^2 s^{-2} $= 4.5 \pm 1.5 \times 10^6$ m^2 s^{-2}	1
Total	4

(k) If the chemical energy of the explosive is not completely converted to kinetic energy upon detonation of the explosive, state and explain any changes you would see to the gradient of the graph.

(3 marks)

Description	Marks
Kinetic energy of fragments would be lower and so would the peak initial velocity.	1
For a given value of $(\frac{1}{\beta} + 0.5)^{-1}$, which is set by the characteristics of the explosive, the value of v^2 would be lower	1
This would lead to a decrease in the gradient of the graph.	1
Total	3

The Gurney model gives the peak initial velocity for fragments. Figure 3 shows experimental data for the peak fragment speed vs the initial relative position along the casing of the fragment (i.e where on the casing the fragment came from).

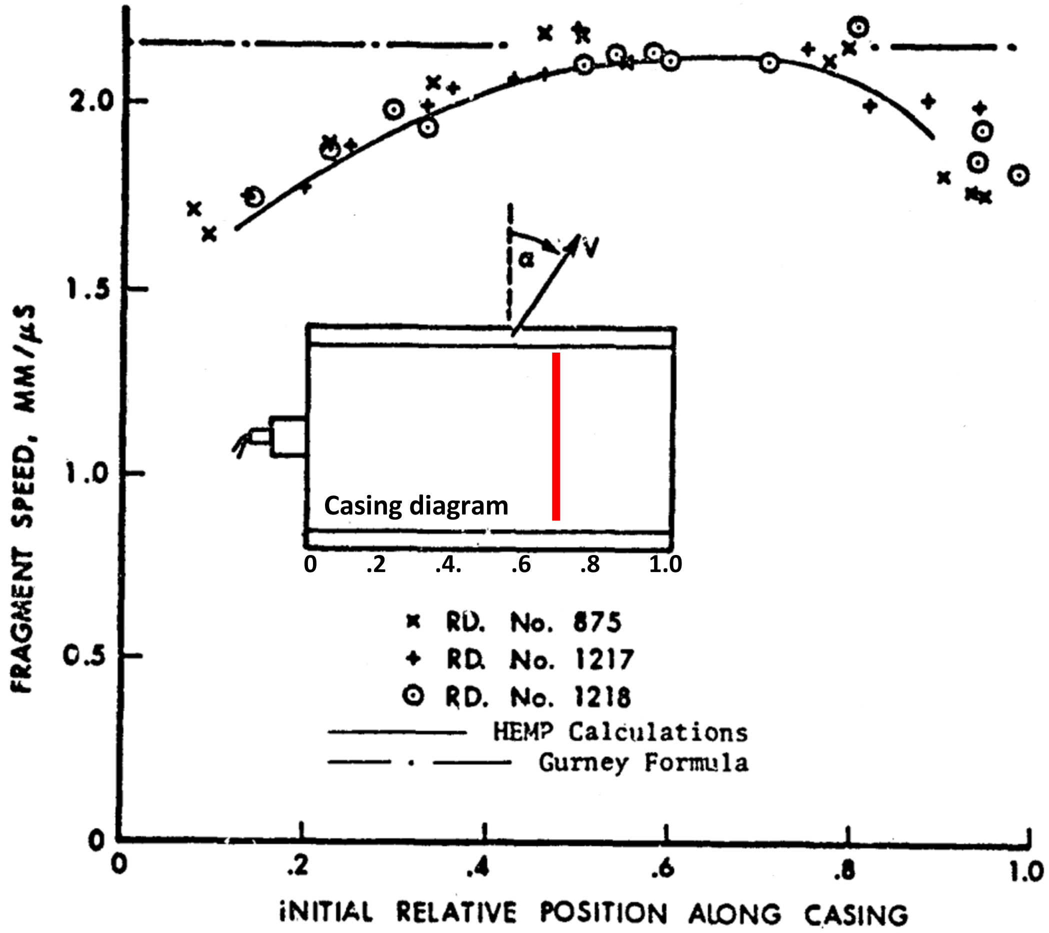


Figure 3. Peak fragment speed vs the initial relative position along the casing of the fragment for experimental data and HEMP (computer simulation) calculations.

(l) Making reference to the information provided in Figure 3 state how the peak initial velocity and initial relative position along the casing are related.

(1 mark)

Description	Marks
At the edges of the casing the peak velocity is less than in the centre of the casing.	1
Total	1

(m) On the diagram of the casing, on Figure 3, sketch the location where the experimental data, Gurney formula and HEMP Calculation indicate the fastest moving particles are emitted from.

(1 mark)

Description	Marks
Line is drawn on the casing in Figure 3 at 0.675 of the length	1
Total	1

END OF TEST