International Baccalaureate

Extended essay cover

SAMPLE C

Diploma Programme subject in which this extended essay is registered: PHYSICS

(For an extended essay in the area of languages, state the language and whether it is group 1 or group 2.)

Title of the extended essay: HOW DO CHANGES IN IMPACT VELOCITY OF A BALL BEARING AFFECT THE SIZE OF CRATERS LEFT IN A SAND LANDING AREA

Candidate's declaration

If this declaration is not signed by the candidate the extended essay will not be assessed.

The extended essay I am submitting is my own work (apart from guidance allowed by the International Baccalaureate).

I have acknowledged each use of the words, graphics or ideas of another person, whether written, oral or visual.

I am aware that the word limit for all extended essays is 4000 words and that examiners are not required to read beyond this limit.

This is the final version of my extended essay.

Candidate's signature: ______________________ Date: 22/11/08

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Supervisor's report

The supervisor must complete the report below and then give the final version of the extended essay, with this cover attached, to the Diploma Programme coordinator. The supervisor must sign this report; otherwise the extended essay will not be assessed and may be returned to the school.

Name of supervisor (CAPITAL letters) ______________________

Comments

Please comment, as appropriate, on the candidate's performance, the context in which the candidate undertook the research for the extended essay, any difficulties encountered and how these were overcome (see page 13 of the extended essay guide). The concluding interview (viva voce) may provide useful information. These comments can help the examiner award a level for criterion K (holistic judgment). Do not comment on any adverse personal circumstances that may have affected the candidate. If the amount of time spent with the candidate was zero, you must explain this, in particular how it was then possible to authenticate the essay as the candidate's own work. You may attach an additional sheet if there is insufficient space here.

The candidate showed excellent motivation and worked very well independently. He showed a good awareness of the reliability of his data and was careful to record measurements as accurately as possible.

I have read the final version of the extended essay that will be submitted to the examiner.

To the best of my knowledge, the extended essay is the authentic work of the candidate.

I spent 3 hours with the candidate discussing the progress of the extended essay.

Supervisor's signature: ______________________ Date: 22/11/08

Physics Extended Essay

How Do Changes In Impact Velocity Of A Spherical Ball Bearing Affect the Size of Craters Left In A Sand Landing Area?

Word count: 3996

Abstract Word Count: 299

- v. good effort weakened by a poor theoretical foundation better to undertake less experimentally but to investigate the theory more in-depth, getting a relevant basis using literature (which appears very late in the essay);
- the omission of a bibliography is very unfortunate;

A: Res.q is clear and correctly stated 2

B: Introduction lacks research on the topic, that eventually appears in the conclusion. 1

C: Data gathered is appropriate, plan is correct but unfortunately is not explained in detail. 3

D: There are some misunderstandings, from the derivation of hypothesis in experiment two (where volume doubling would not imply double depth & $\sqrt{2}$. radius) to velocity - heigh graph, which shows the expected theoretical relationship but is incorrectly interpreted as a consequence of air resistance 1.

E: the development ~~of~~ the essay is fluid and steps followed drive the investigation in the expected direction 3

F: Correct averages and graphs alternate with incorrect error calculation, some lines joining dots or some lack of reflection when obtaining the power equations. 2

G: Important mistakes here that do not allow to say that language is used consistently. Mass/weight, m/s^2 for velocity or m/s for acceleration 1

H: Conclusion is correct and incorporates a good comparison w/ expected theory but w/ mistakes 1

I: Presentation makes essay difficult to read w/ Key elements in the appendix that should've seen in body 2.

J: Correct 2 K: 3 (good effort)

Abstract

How Do Changes In Impact Velocity Of A Spherical Ball Bearing Affect the Size of Craters Left In A Sand Landing Area?

The research was divided into three experiments, each examining crater diameter and depth resulting from the impact of a ball bearing in sand. The key aspects of each were:

i. Varied impact speed with an the angle of incidence of 90° (the landing area was flat);
ii. Constant impact speed with a varied angle of incidence; and
iii. Constant impact speed, 90° incidence but with varying sand density.

I hypothesized that if impact speed doubles, crater diameters will increase by a factor of √2 and depths will double. However my experiments showed that while crater diameter could be described by an expression similar to my hypotheses [(20.6) x (impact speed $^{0.6}$)], crater depth was significantly different [(13.2) x (impact speed $^{0.2}$)].

I predicted that the craters would have an ovular shape when the angle of incidence was not 90°, with the oval becoming longer as the angle of incidence decreases but with the width (shortest diameter of the crater) of the oval remaining constant. I had problems with this experiment as there was no real trend to the lengths or depths of the craters. However they were ovular and the width remained constant.

I predicted that as sand density increases, depth of the craters will increase and the diameters of the craters will decrease. I hypothesized that as the density increases the craters will gradually change in shape from cones to vertical cylinders. My results showed Crater Diameter = 2e + 6(Sand Density)$^{-22.5}$ .Crater depth decreased with sand density, but not by a mathematically expressible trend. My main unresolved issue across all the experiments was the shape of the craters since they were not inverted cones.

Correct abstract.

* no bibliography included => 0 for presentation; not listed in Contents and not present at the end of essay before or after the appendix

Contents

vague

Appendix

appendix should be integrated in core of essay, in good part

figs + tables + graphs not listed in contents

- bibliography not listed in Contents
... no biblio included

1.0 Introduction:

The aim of this essay is to investigate how changes in impact velocity of a spherical ball bearing affect the size of craters left in a sand landing area.

I believed that there would be a relationship between impact speed and crater characteristics that might be described mathematically. Furthermore, the relationship between variables could be applied to much larger scenarios such as collisions of matter generating craters in space and this is why it is worthy of investigation.

My basic hypothesis was that the crater would be an inverted cone. Consequently my research was be divided into three experiments, each examining crater diameter and depth resulting from the impact of a ball bearing in sand. The key aspects of each were:

i. Variable impact speed with an the angle of incidence of 90° (that is when the landing area was flat);
ii. Constant impact speed with a varied angle of incidence; and
iii. Constant impact speed, 90° incidence but with varying sand density.

2.0 Planning

2.1 Theoretical Background

Investigating this question will involve physical laws on momentum, equations of uniform motion, gravity, conservation of energy and Newton's laws of motion. Classical physics provides us with five basic laws of motion that I have utilized for this investigation. The laws are set out below. The other critical factor is gravity which is constant at 9.81 ms^{-1} on the earths surface.

$v = u + at$ enables the calculation of final velocity of a body being accelerated over a given time, where

- u = initial velocity
- v = final velocity
- a = acceleration
- t = time

This equation enables the calculation of the impact speed of the ball bearing as described in Experiment 1 below

$KE = ½ mv^2$ describes the kinetic energy of a moving body, where

- m = mass
- v = velocity

This equation is the basis of my hypothesis.

I predicted the craters would be inverted cone shape with a slight rounded edge at the top. This is because I believed that as the ball impacts the sand it would violently deplace the sand grains until the energy from its motion is dissipated through the creation of movement of the sand grains it hits which then displace others or fly into the air. At initial impact a high amount of energy would be dissipated so the sand grains will move further. In addition the sand close to the surface will move more freely as there is little to hold it in place. As the ball bearing slows to a halt it will dissipate less energy so the grains will move less thereby creating an inverted cone with a lip. As shown in fig.2.

On the basis of $KE = \frac{1}{2} mv^2$ if the impact speed the same ball bearing doubles, the kinetic energy of the ball bearing also doubles. Therefore due to the law of conservation of energy, when the ball bearing collides with the sand all its kinetic energy will be transferred to the sand. I thought that if the ball bearing had twice as much energy, it would be able to remove twice as much sand from its landing area.

I assumed that the craters would always have the same cross sectional inverted cone shape. The volume of a cone is $1/3\pi r^2 h$, so volume is proportional to r^2 and h. Therefore if volume doubles when impact speed doubles, depth of the inverted cone should doubles (ie crater depth). Furthermore when height dropped from and volume double the radius (and hence diameter) will increase by a factor of $\sqrt{2}$. Even though the radius is half the diameter, the diameter will also increase by a factor of $\sqrt{2}$. Depth increases more than diameter because much more energy is needed to push particles up and out (to increase diameter) rather merely to be displaced (to increase depth) this is illustrated in fig.3.

explanations not v. clear; no research on the topic

3.0 Experiment One – Investigating Impact Speed

The first experiment varies the impact speed of the ball bearing whilst keeping the angle of incidence in the collision between the ball bearing and the sand constant at 90°. This is conducted by dropping the ball vertically onto the sand landing area, from different heights.

The experiment will be in two parts.

The preliminary part calculates the speed of the ball bearing at impact from different heights. The ball is dropped from eight different heights using an electromagnetic machine. An electronic timer is connected to the electro magnet and a landing sensor, enabling the time of the fall to be calculated to three decimal places. This approach aims to minimize human error. The most likely recording error is in ensuring the height from which the ball is dropped is accurately repeated in this experiments and those that follow. A realistic error margin would be +or- 1cm.

This is followed by the main part which measures the crater characteristics when the ball bearing is dropped. In this part the landing sensor is replaced with a sandpit. The ball is dropped from the same heights as above. The diameter and depth of the cones which are formed can be measured with a vernier caliper.

3.1 Hypothesis For Vertical Drop(Experiment One):
I predict that if impact speed doubles crater diameter will increase a factor of √2 and depths will double for the reasons set out above.

4.0 Experiment Two- Varying Angle Of Incidence
This experiment will investigate the consequences of changing the angle of incidence of impact.

In order to do this I could either project the ball bearing or change the angle of the sand landing area, as both would have the same effect. Changing the angle of the landing area gives much more accurate results with simpler mathematics because the angle of incidence is easily measured. The apparatus for this experiment is shown in fig.4.

In my results I will plot impact speed against angle of incidence (angle "x" in fig.4). Angle x can be calculated using simple trigonometry as both lengths "a" and "b" (see fig.4) can be measured and form the sides of a right angled triangle.

4.1 Hypothesis For Angular Landing Experiment (Experiment Two)
I predict that the craters in this experiment will have an oval shape, rather than the circular shapes in experiment one. Furthermore I believe that as angle "x" decreases the length (longest diameter of the craters) of the ovals will increase and depth will increase. The width (shortest diameter of the crater) of the ovals will remain constant. Furthermore I predict impact speed is proportional to the deepest depth of the crater multiplied by the longest diameter of the crater.

4.2 Reasoning Behind Hypothesis For Experiment Two
As the angle of incidence (angle "x") decreases, the landing area becomes steeper. On impact the sand displaced down the slope will slide further because it will be affected by gravity (or rather a vector thereof). This will result in the crater forming an ovular shape as shown in fig.5. The width will fluctuate but not change significantly since the ball bearing is always being dropped from the same height and there is only a slope in one direction, as shown in fig.6.The formula for the

volume of half an oval is $2/3\prod r_1 r_2 r_3$ [1] where r_1 is the deepest depth of the crater, r_2 is the widest diameter of the crater and r_3 is the shortest diameter of the crater. In this experiment if r_3 is relatively constant as I expect, $r_1 r_2$ is proportional to impact speed.

Depth of the craters will increase as the slope becomes steeper (angle "x"/angle of incidence decreases) because the steeper the slope, the more the ball bearing will slip down it on impact. This is shown in fig.7

5.0 Experiment Three- Changing Density/ Texture

This experiment varies the texture of the sand by increasing its density, by progressively adding more and more water to the sand. My six readings will be at 0ml, 250ml, 500ml, 1000ml, 1500ml, and 2000ml of water added. Water was chosen to increase density because it will spread evenly throughout the sand and has a convenient mass of $1 g/cm^3$. In this experiment the ball bearing is dropped from 175cm with three repeats at each density.

5.1 Hypothesis for Density Changing Experiment

As density of the substrate increases the grains of sand will be more difficult to displace. Therefore the depth of the craters will increase and the diameters of the craters will decrease. The craters will gradually change in shape as the density increases from originally being inverted cones to ending up as vertical cylinders.

5.3 Reasoning Behind Hypothesis For Experiment Three

Diameters will decrease as density of sand increases. This is because if density increases the mass of any given volume increases. An increase in mass results in it requiring much more energy to move the sand of any given volume. For instance if the mass of a sand granule multiplies by "x" then it will need to be give "x" times the amount of KE to move the same distance (Because $KE= ½ mv^2$). Since the same amount of energy is given whatever the density of the sand, the sand will move "x" times less far.

Depth of the craters will increase with density. This is because as the sand increases in density it will contain much more water. More water results in less loss of KE to friction as the ball bearing falls into the sand. This combined with the fact that very little sand will be lifted up and thrown to the edge of the crater (as the sand will be much heavier) will result in much deeper craters. The combined effect of increasing depth and decreasing diameter all as density increases will result in the craters changing from cones to cylinders. Shown in fig.8.

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[1] http://www.science.co.il/formula.asp

6.0 Variables:

To conclude my planning I have constructed a variable table for all three experiments:

	Independent Variables	Dependent Variables	Relevant Fixed Variables
Experiment One	Impact Speed	Crater Depth, Crater Diameter	Angle Of Incidence, Water Content and thus Density Of Sand, Heat Of Sand, Mass of Ball Bearing
Experiment Two	Angle Of Incidence	Crater Depth, Crater Diameter	Water Content and thus Density Of Sand, Impact Speed, Heat Of Sand, Mass Of Ball Bearing
Experiment Three	Water Content and thus Density Of Sand	Crater Depth, Crater Diameter	Angle Of Incidence Impact Speed, Heat Of Sand, Mass Of Ball Bearing

how thick is the sand layer?

heat of sand?

6.1 Controlling Fixed Variables

Sand Temperature- This is kept constant by using the same sand for all experiments, in the same room on the same morning so the value should not change. I will take the temperature of the sand at the start of every experiment.

Mass of Ball Bearing- This is fixed by using the same ball bearing for each experiment.

mass? value? diameter? or thickness of sand layer

Sand-water mixt

Water Content and thus Density of Sand- This is kept constant by using the same sand for experiments 1 and 2, this variable is controlled by measuring the mass of the sand before each experiment.

Can this be controlled?

Angle Of Incidence Between Sand And Ball Bearing**-** This is kept constant for experiments one and three because the sandpit landing will not move and neither will the machine dropping the ball bearings. Providing the sand is flat the angle will be vertical.

Impact Speed- Height dropped from should remain completely constant since the electromagnet dropping the ball bearings will not be moved in between readings. In my results I will give a (-+) 1cm to incorporate human error by myself in placing the electromagnet at the correct height between experiments. All experiments are on the same morning, so room temperature should not change enough to effect the speed with which the ball bearing falls, thus impact speed be the same from a given height.

Below is a table showing how I will measure all the readings which I need, the errors I need to take into account and how much of a margin I will give.

Reading	Method of Acquiring Reading	Possible Errors	Error Margins
Crater Depth	Vernier Caliper	Calibrator not placed in deepest part of crater	*
Crater Diameter	Vernier Caliper	Calibrator not placed across widest and shortest places	*
Height Dropped From	Tape measure	Human error in reading off height	(+-) 1cm
Time Taken To Fall	Electronic Timer	-	*
Impact Speed	Calculation incorporating Time taken to fall ($v^2 = u^2 + 2as$)	-	Calculated incorporating errors in height dropped from
Angle Of Incidence	Trigonometry after having measured raise in height of one side of sand pit	Height opposite side of triangle is measure incorrectly	(+-) 0.1 Degrees
Volume of Sand Container	Measuring then taking the product of the Length width and height of the container	The sand will not be completely flat on top of the sand landing area	(+-) 5cm³
Mass Of Sand Container	Scales	-	(+-) 10g
Density Of Sand Container	Dividing the mass of the container by the volume of the container	-	Calculated incorporating errors in volume and mass
Sand Temperature	Thermometer	Human error in reading off temperature	(+-) 2 Kelvin
Mass Of Ball Bearing	Scales	-	(+-) 0.2 grams

not an error per se but a range; $\Delta x \sim \frac{x_L - x_s}{n}$ uncertainty in the mean?

*Indicates an error will be calculated by taking an average of the three repeats. The error will be the difference between the largest and smallest of the repeat readings.

There is only error which I cannot account for in my experiments and this is that when the ball bearing falls it will still be in the crater. .I remove it using a magnet, potentially changing the shape of the crater. There is nothing I can do to incorporate this error into my results though it should not affect my overall pattern of results as the situation is the same for every single reading.

should be integrated here → Apparatus: Diagrams are shown in figures 9,10 and 11.

* How deep is the sand in the box?

11.3 Comparison with Previously Recorded Data:

Other physicists have investigated the causes of crater shapes, with the following conclusions:

We report on craters formed by balls dropped into dry, non-cohesive, granular media. By explicit variation of ball density "pb" diameter Db, and drop height H, the crater diameter is confirmed to scale as the 1/4 power of the energy of the ball at impact.

Still, geophysicists have developed a rule of thumb that both crater diameter and depth increase with impact energy according to a formula where energy is raised to the 1/4 power.

This seems very similar to my hypothesis as kinetic energy is proportional to v^2 and power of multiplied by the ¼ power equals $\sqrt{2}$. Consequently my results for in Experiment 1 showing power relationships of 0.21 and 0.55 are not to far from 0.25.

11.4 Unresolved Issues

Following my investigation there are still some unresolved issues which I would try to solve if I were to research this topic further:

- Why do the lines on the graphs look as if they would not pass through the origin? I think it may be because even f theoretically the ball were placed on the sand with no force it would still sink slightly. Thus even if impact speed is 0m/s there will still be a crater.
- Is there a common cross sectional shape for all craters? I predicted all craters formed where the ball was dropped perpendicular to the sand were inverted cones, this turned out to be proved wrong by my results.
- How is crater size affected by density? I feel even though I experimented on this aspect, it only culminated in three completely valid results. I like to investigate this area further.

11.0 Evaluation

Overall the results of the experiments were in line with the trends I expected, even if my initial hypotheses did not prove wholly accurate. However there are anomalies in my results and improvements to my method could have improved the accuracy of my results substantially and shed more light on unresolved issues. In addition I have become aware of data which has already been collected by professional physicists on this issue, with which my data could be compared. I will discuss all these areas in my conclusion.

11.1 Improvements to my method for data collection

If I were to repeat these experiments I would amend them to increase the accuracy of my results and to increase the relevance of the experiments to the research question.:

- More repeats would give a more accurate average and generated a more precise error range.
- Digital caliper as opposed to a vernier caliper would minimise any human error in measuring crater data.
- A greater range of impact speeds may unearth unknown trends, in particular the affect of the ball bearing reaching terminal velocity.
- Testing the wet sand with an angled landing would explore whether there was a relationship with the results of the wet sand with a flat landing area; and if the relationship was similar to that observed for dry sand (as shown in experiments 1 and 2).
- Investigate the relationship between other variables (such as mass or cross-section of ball) and crater size (in particular volume of craters).
- Vary the impact speed and the angle of incidence to assess whether the crater size was described by the formula for half an oval.($2/3\pi r_1 r_2 r_3$).

11.2 Anomalies and Errors:

My error bars were fairly accurate throughout the investigation however they could have had a more precise range if more repeats were conducted. There was only one substantial anomaly in my investigation and this was in my second experiment and causes a large kink in the graph. I feel this error is possibly due to an error in measuring the height which the side of the container was raised, resulting in the incorrect calculation of the angle of incidence.

10.0 Experiment Three:

The principal results to this experiment are shown in table 6 and graphed in Graphs 5 and 6. Graph 5 suggests that as density of sand increases the average depth of craters increases but not proportionately. Graphs 6 shows that as sand density increases the crater diameter decreases until the crater is no wider than the diameter of the ball bearing.

10.1 Analysis:

As I predicted, as sand density increases average depth of craters also increases, the reasoning behind this is explained in my planning section for experiment three.

My results for Crater Diameter vs. Sand density appear to be very uncorrelated, however if the last two results are removed, the points run perfectly through a power trend line showing Crater Diameter = (2e+[6(Sand Density)$^{-22.462}$]) this is again almost certainly linked to the power relationship between KE and impact speed. The reason I removed my last two results is that for these two readings the sand had reached the point where it had absorbed as much water as it could thus the sand at the top was very much liquid and thus simply fell into the crater onto the ball bearing, this is illustrated in fig.13

8.1 Analysis

Crater depth: I predicted that as height doubled crater depth would double. Graph 2 shows that this is not the case. For instance at an impact speed of 2 m/s the crater depth is approximately 15mm and only increases to 18mm at double the impact speed. The relationship is a power relationship whereby crater depth = 13.197x(impact speed)$^{0.2173}$. A power relationship is understandable as it may be related to the energy of the projectile, as when you double the ball bearing's speed it's KE increases by a factor of 4.

Crater Diameter: I predicted that as height doubled crater diameter would increase by a factor of √2. The Graph 3 suggests there is another power relationship whereby Crater Diameter = 20.621 x (Impact Speed)$^{0.5568}$. However this mathematical expression is reasonably close to my hypothesis. The table below shows the suggested crater depth is 20.6mm when the impact speed is 1m/s rising to 30.3mm at 2m/s (and so on), on the basis of the expression above. However this is only 4% different than my hypothesis predicted. The difference appears to increase as impact speed increases.

Impact Speed m/s	Suggested Crater Diameter mm	Hypothesised Crater Diameter mm	Difference
1	20.6		
2	30.3	29.2	4%
4	44.6	41.2	8%
8	65.6	58.3	13%

Nevertheless as the first hypothesis was clearly wrong must either mean that the ball bearing having twice as much energy does not necessarily remove twice as much sand, or the craters are not inverted cones.

9.0 Experiment Two:

The principal results to this experiment are shown in tables 4 & 5 and graphed in Graphs 4. The graph suggests that as the angle of incidence decreases (ie the ball bearing hits at a more oblique angle, the slope being steeper) crater depth increases.

9.1 Analysis:

I correctly predicted that as angle of incidence increased crater depth would decrease. However the crater is only about 19.4mm when the angle is 78° compared to 18.4mm at vertical, a change of only 5.4%. I had problems with the Carrying out of this experiment and I feel there are still unresolved issues, both of which are discussed in my evaluation.

Results and Analysis

7.0 Experiment One: Part 1 measuring Impact Speed

Supporting calculations for deriving Impact Speed are on tables 1 and 2. These tables also show the error in impact speed. Errors in all the results are calculated in the same way. The error is (plus or minus) the largest difference in two of the repeats i.e. the range of the repeats.

Table 1 shows the time taken for the ball bearing to fall. In order to calculate the average time I took a mean of three repeats.

Calculation of impact speed was done using the formula ($v=u + at$) e.g. when dropped from 100cm

Impact speed = original speed + (acceleration × time in freefall)
= 0m/s +(9.81m/s^2 × 451.33mS)
= 4.43 m/s

Error in impact speed (table two) was calculated by using the formula ($v^2=u^2-2as$) and incorporating the errors for height dropped from "s).

E.g. from 100cm $v = [\sqrt{2a} \times (s -+ 1)]/3$

$v = \sqrt{(19.62 \times 0.99)} = 4.41$
$v = \sqrt{(19.62 \times 1.00)} = 4.43$
$v = \sqrt{(19.62 \times 1.01)} = 4.45$

Thus the error in the range of the results here is 0.04 m/s which = (-+) 4%.

The line on Graph 1 is curved due to air resistance, showing that as height increases impact speed does not increase proportionately. This is because as height increases, the ball bearing is in flight longer so it accelerates to a higher speed and is therefore more affected by air resistance. The graph would intercept at the origin.

8.0 Experiment One: Part 2

The depth and diameter of craters in this experiment are shown in table 3 and 4 respectively, and graphed in Graphs 2 and 3. The graphs suggest that as impact speed of the ball bearing increases both crater depth and diameter increase too. The graphs describe a power relationship as follows:

Depth of Crater = 13.2 x (Impact Speed)$^{0.2}$

Diameter of Crater = 20.6 x (Impact Speed)$^{0.6}$

12.0 Research Question Conclusion

How Do Changes In Impact Velocity of a Ball Bearing and Sand Density Affect the Size and Shape of Craters Left In A Sand Landing Area When a Ball Bearing is dropped Into It?

Within this investigation I learnt that as impact velocity increases both crater depth and diameter increase with a power trend. When the ball bearing is dropped onto an angled landing area craters are an oval shape rather than circular. Increase in sand density reduces crater diameter with a negative power trend as crater depth increases. ✓

(it must be realized that meteor impact are explosive in character, not the case here for the ball bearing)

However article is about non-cohesive granular media; so ok; (... wet sand is cohesive)

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[i] UCLA Department of Physics & Astronomy, Los Angeles, CA 90095-1547
http://arxiv.org/PS_cache/cond-mat/pdf/0301/0301549v2.pdf

[ii] Physics review issue 12 September 2003.
http://focus.aps.org/story/v12/st8

dates of access?

—//—

- poor organization of the essay, makes it painful to read; poor quality of diagrams;
- language: equations not well written according to standards in a number of cases; some unit errors; lack of standard writing units eg MM for mm ...
- theory: poor, little effort along those lines, greater efforts put into hypothesis & speculative statements; some basic theory not well understood; greater time should have been devoted to the exploration of relevant articles of type listed above.

.. consequently the analysis is necessarily limited;

- efforts recognized, some personal input;

"a huge" appendix

Appendix

these diag. should be in the body of the essay.

- Over the following pages are my drawings/figures explaining the theories and showing the diagrams of my experiments followed by my results tables and graphs.

- how deep is the sand?
- radius of ball bearing

Fig.1 Set up for primary velocity calculation experiment:

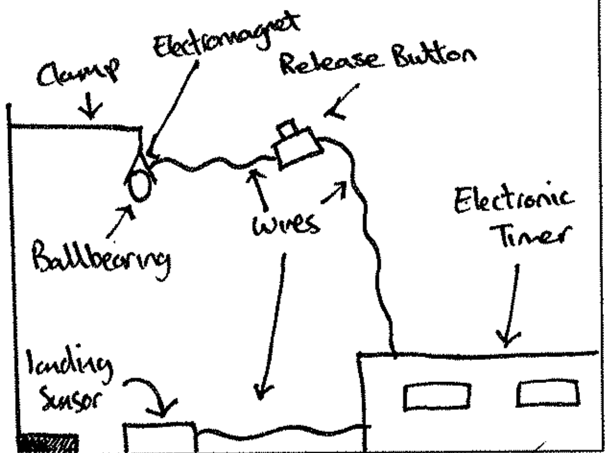


Fig.2

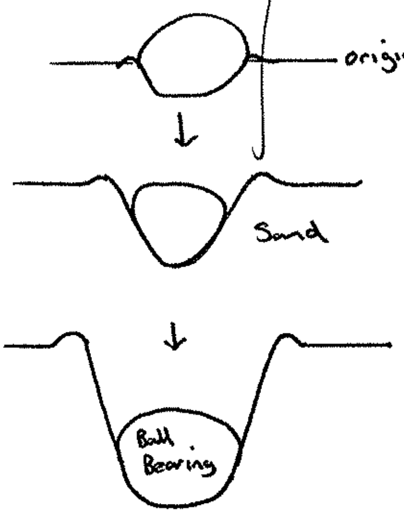


diagram not of good quality

Fig.3

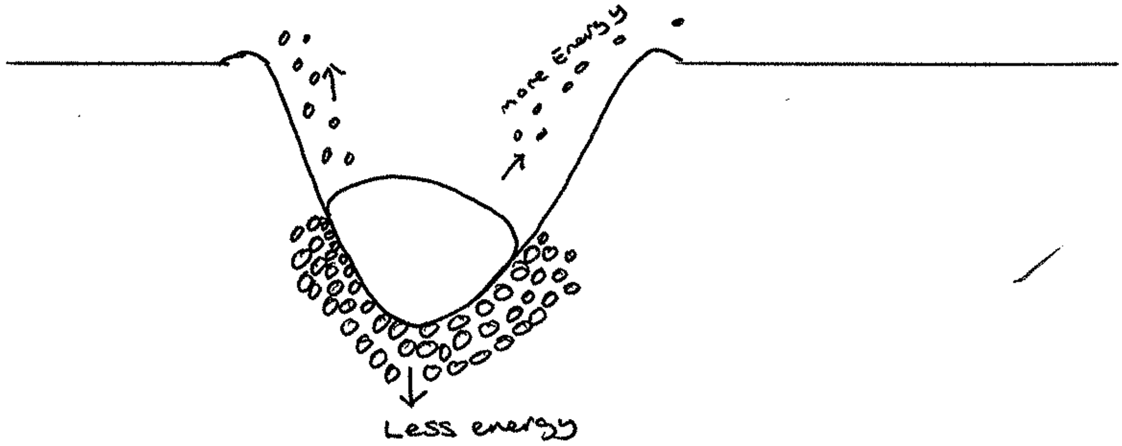


Fig.4

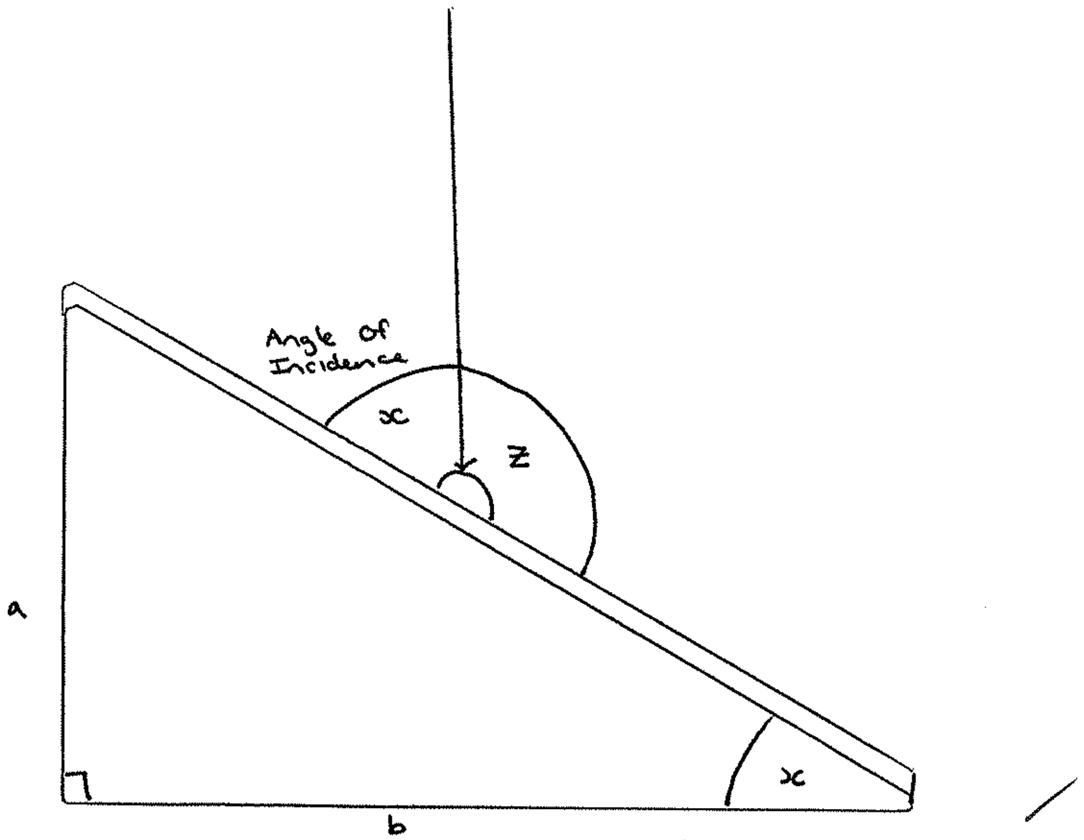


Fig.5

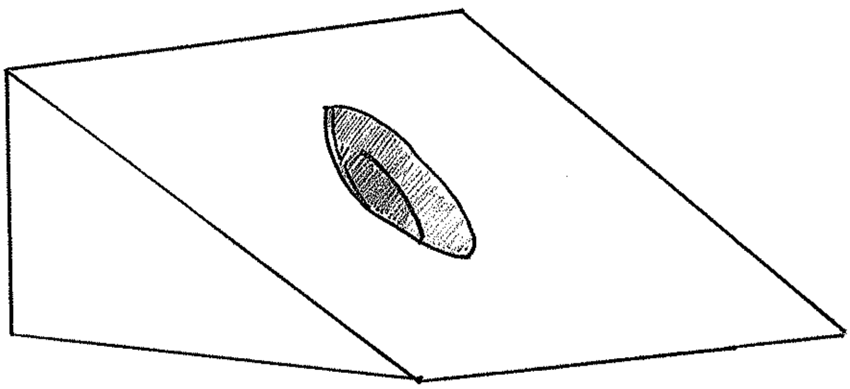


Fig.6

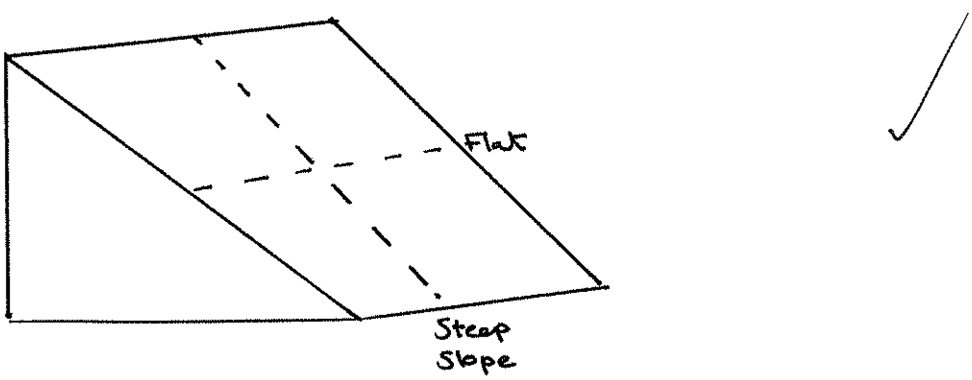


Fig.7

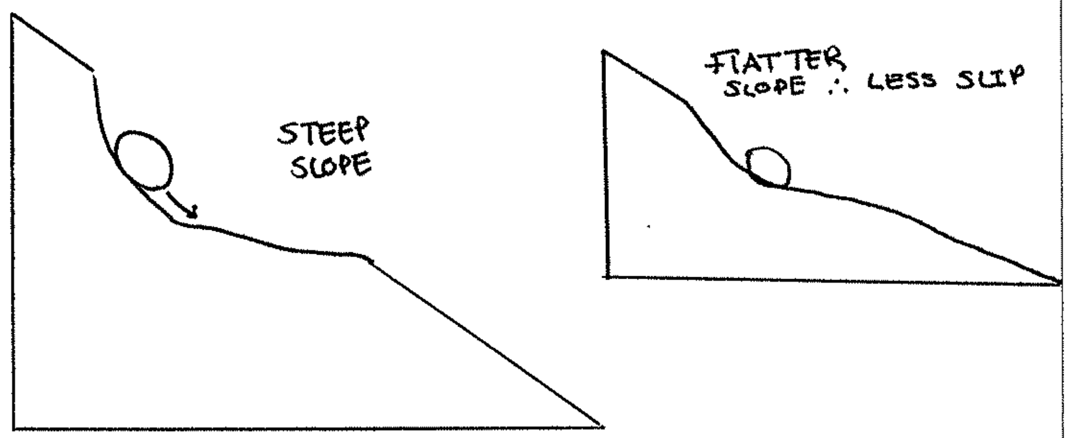


Fig.8

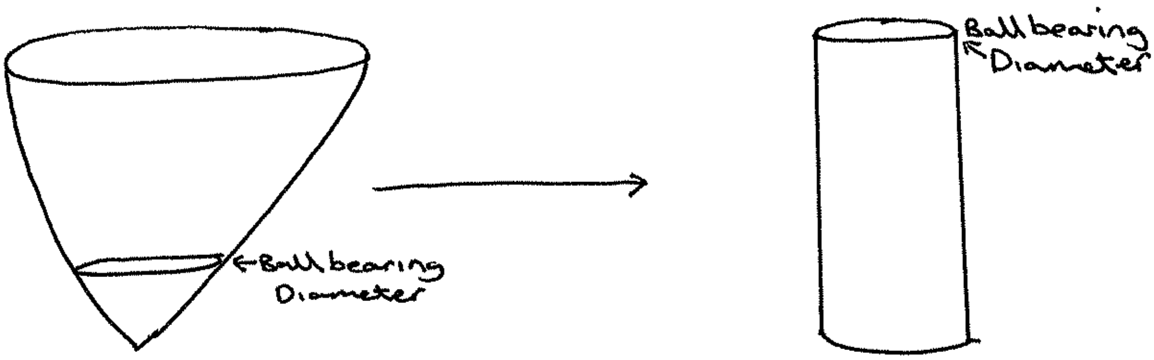


Fig.9 EXPERIMENT 1

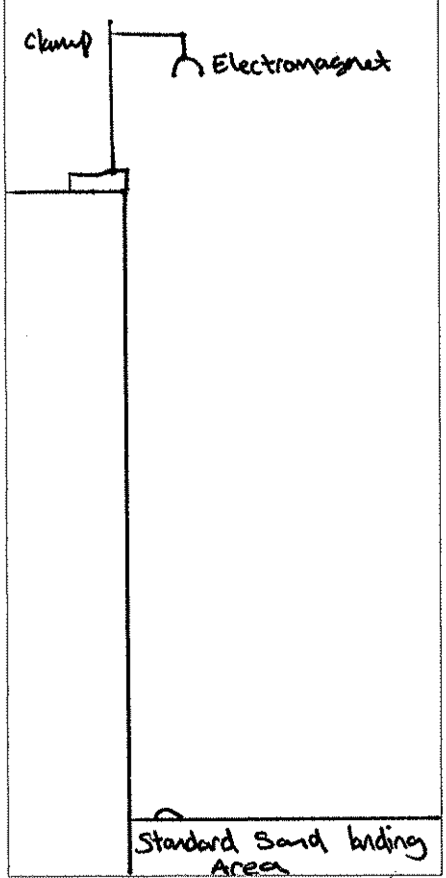


Fig.10 EXPERIMENT 2

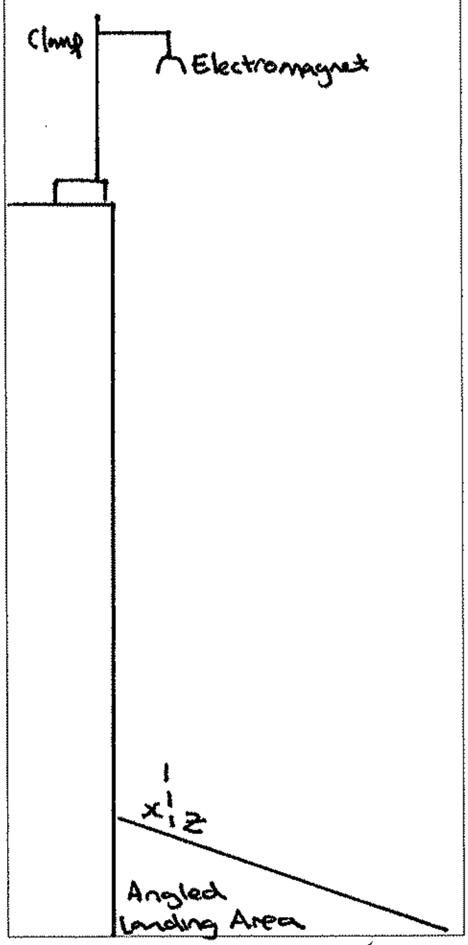


Fig.11 EXPERIMENT 3

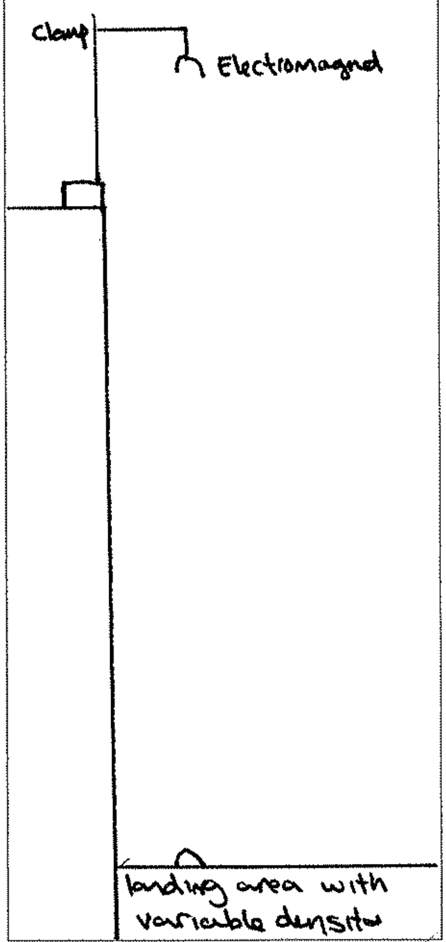
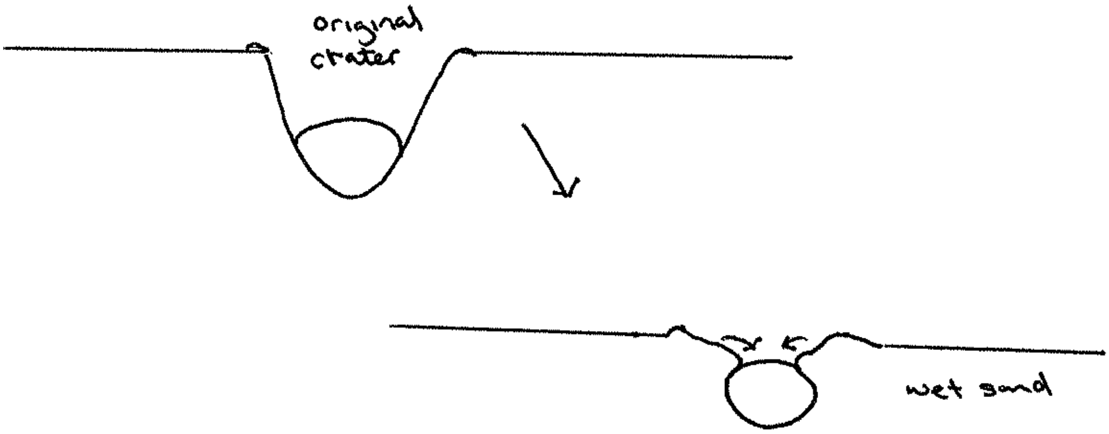


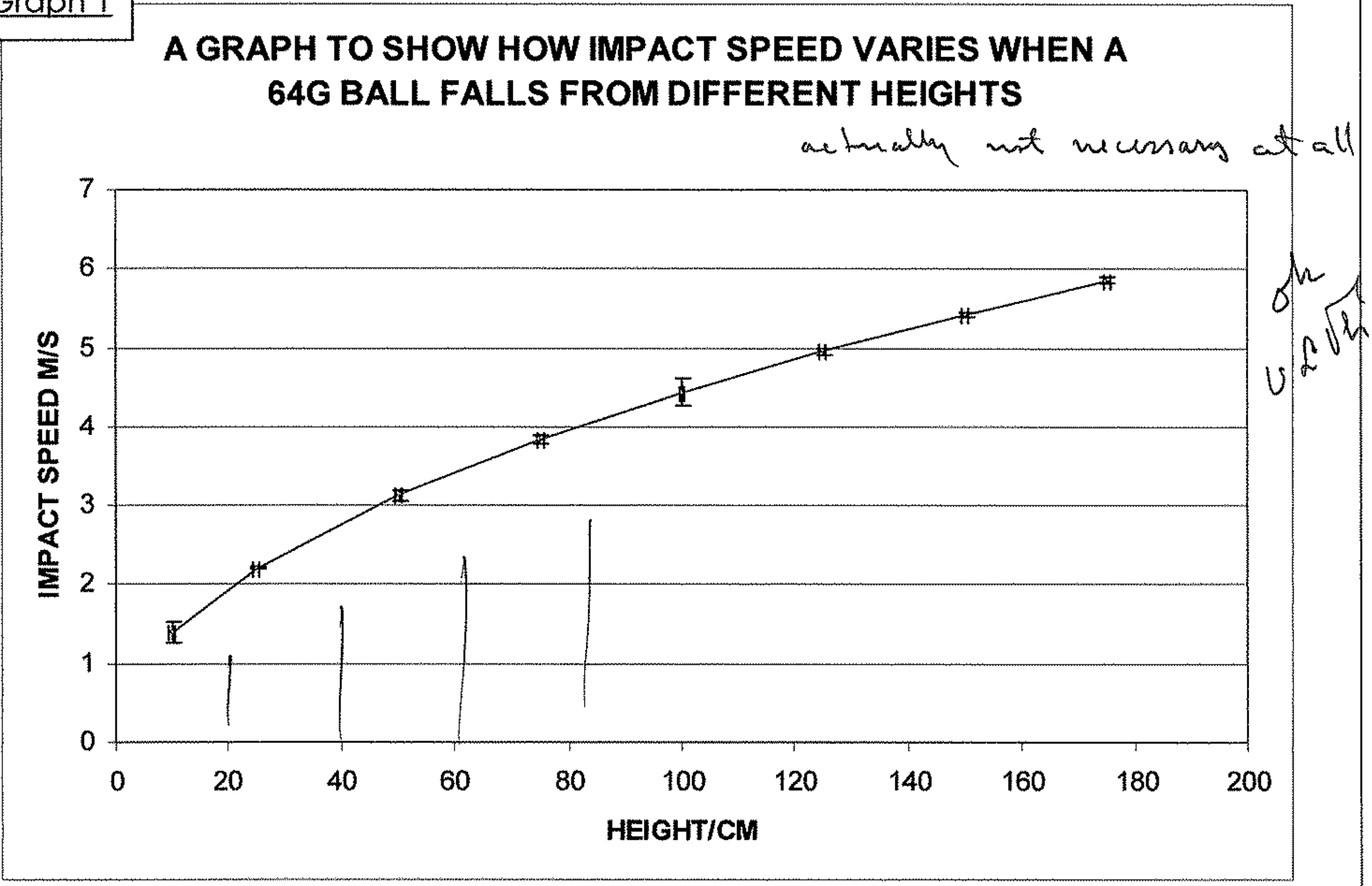
Fig.12

?

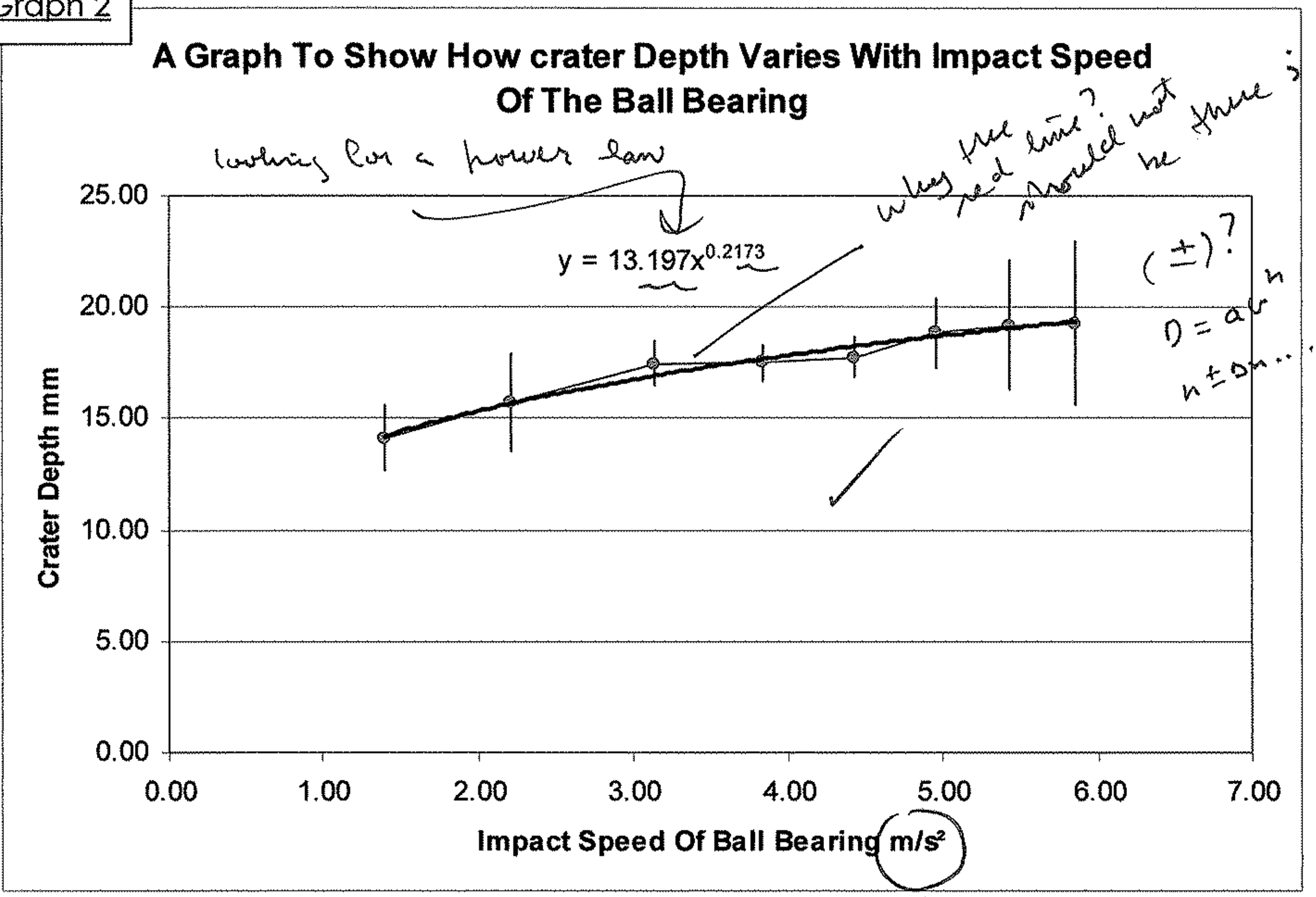
Fig.13



Graph 1



Graph 2



ms: millisecond

why 5 sig. fig.? why decimals here?

HEIGHT	TIME 1	TIME 2	TIME 3	AVERAGE TIME
/CM (-+ 1CM)	/mS ±?	/mS ±	/mS ±	/mS
10	152	146	148	148.67 → (149 ± 2)
25	227	226	226	226.33
50	312	314	314	313.33
75	392	392	390	391.33
100	453	450	451	451.33
125	508	509	507	508.00
150	561	558	559	559.33
175	601	605	610	605.33

Table 1 ✓

uncertainty in the mean ..

HEIGHT	TIME	ERROR IN TIME	IMPACT SPEED	ERROR IN IMPACT SPEED
/CM (-+ 1CM)	/mS	/mS	M/S	%
10	148.67	(-+)0.60	1.4	(-+)10.00
25	226.33	(-+)0.10	2.21	(-+)01.00
50	313.33	(-+)0.20	3.13	(-+)02.00
75	391.33	(-+)0.20	3.84	(-+)01.33
100	451.33	(-+)0.30	4.43	(-+)04.00
125	508	(-+)0.20	4.95	(-+)00.80
150	559.33	(-+)0.30	5.42	(-+)00.66
175	605.33	(-+)0.90	5.86	(-+)00.57

Table 2 ✓

too large

The only example shown on page 11 is wrong.

?

cm   m s⁻¹   mm   symbols not right (language)

HEIGHT	IMPACT SPEED	ERROR IN IMPACT SPEED	CRATER DEPTH 1	CRATER DEPTH 2	CRATER DEPTH 3	AVERAGE CRATER DEPTH	ERROR IN CRATER DEPTH
/CM	M/S	%	/MM	/MM	/MM	/MM	/MM
10.00	1.40	(-+)10.00	13.50	13.80	15.00	14.10	1.50
25.00	2.21	(-+)01.00	15.20	14.80	17.00	15.67	2.20
50.00	3.13	(-+)02.00	17.20	18.10	17.10	17.47	1.00
75.00	3.84	(-+)01.33	17.10	17.90	17.50	17.50	0.80
100.00	4.43	(-+)04.00	17.80	17.30	18.20	17.77	0.90
125.00	4.95	(-+)00.80	18.90	18.00	19.60	18.83	1.60
150.00	5.42	(-+)00.66	20.50	17.60	19.50	19.20	2.90
175.00	5.86	(-+)00.57	17.40	18.40	22.10	19.30	3.70

Table 3 ✓

temperature values? (see p 8 re temperature)

?

2 decimals (in mm): realistic?

Table 4

HEIGHT	IMPACT SPEED	ERROR IN IMPACT SPEED	CRATER DIAMETER 1	CRATER DIAMETER 2	CRATER DIAMETER 3	AVERAGE CRATER DIAMETER	ERROR IN AVERAGE CRATER DIAMETER
/CM	M/S	%	/MM	/MM	/MM	/MM	/MM
10.00	1.40	(-+)10.00	26.70	24.40	26.30	25.80	(-+)2.30
25.00	2.21	(-+)01.00	31.20	31.40	32.50	31.70	(-+)1.30
50.00	3.13	(-+)02.00	37.50	39.10	38.50	38.37	(-+)1.60
75.00	3.84	(-+)01.33	41.00	39.90	42.20	41.03	(-+)2.30
100.00	4.43	(-+)04.00	47.10	45.50	46.20	46.27	(-+)1.60
125.00	4.95	(-+)00.80	47.50	50.90	50.20	49.53	(-+)3.40
150.00	5.42	(-+)00.66	55.80	51.60	54.50	53.97	(-+)4.20
175.00	5.86	(-+)00.57	60.20	59.50	56.80	58.83	(-+)3.40

same remarks as before

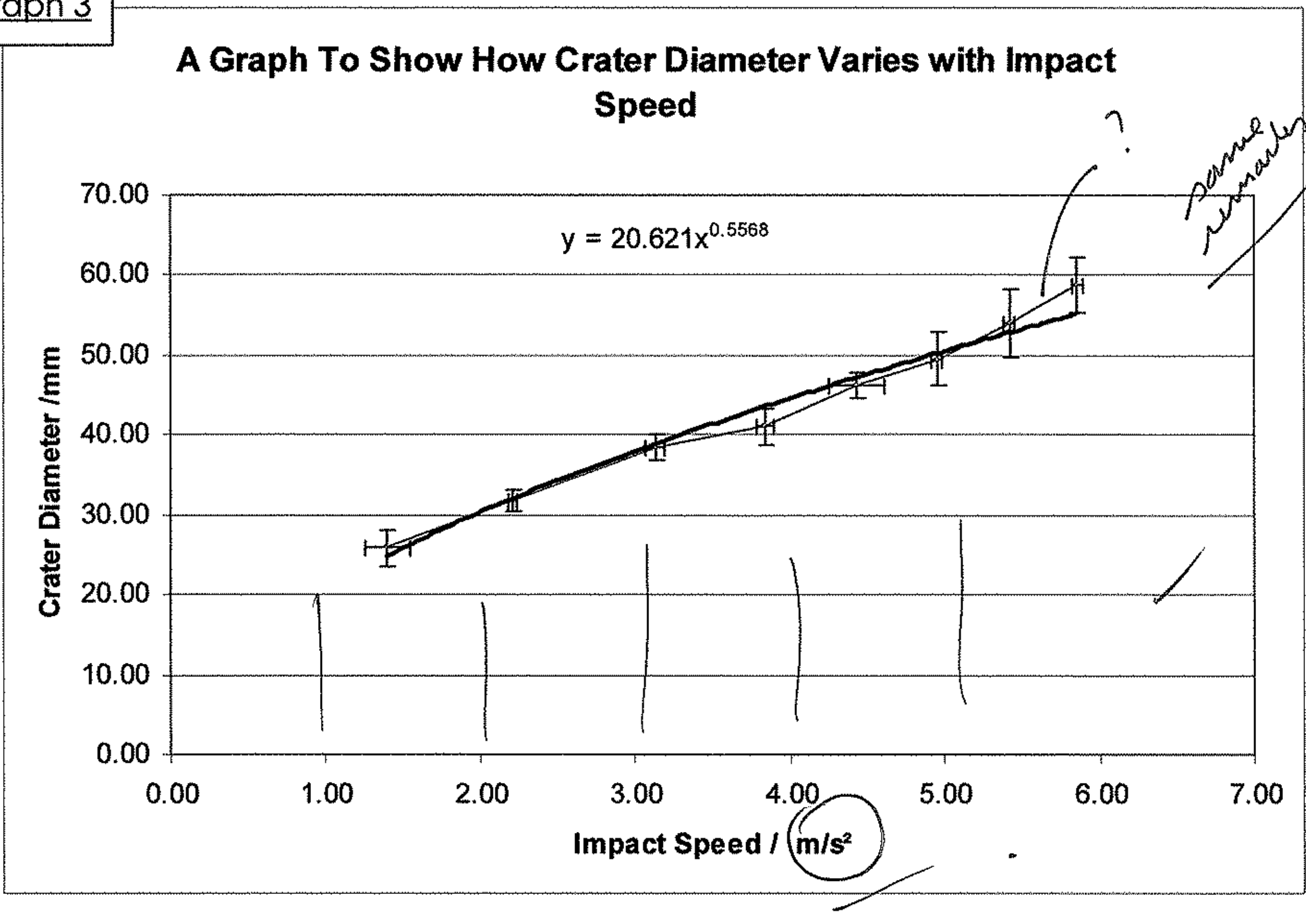
Table 5

IMPACT SPEED	ERROR IN IMPACT SPEED	HEIGHT OF BOX END	Z ANGLE	X ANGLE	MAXIMUM WIDTH	MAXIMUM LENGTH	MAXIMUM DEPTH
M/S	%	/MM	/DEGREES	DEGREES	/MM	/MM	/MM
5.86	0.5700	0	0	90	58	60.5	184
5.86	0.5700	33	5.1	86.7	55.8	59.6	185
5.86	0.5700	66	10.3	83.4	49.2	56.8	192
5.86	0.5700	99	15.5	80.1	46.3	53.9	193
5.86	0.5700	132	21	76.8	58.3	58.3	195

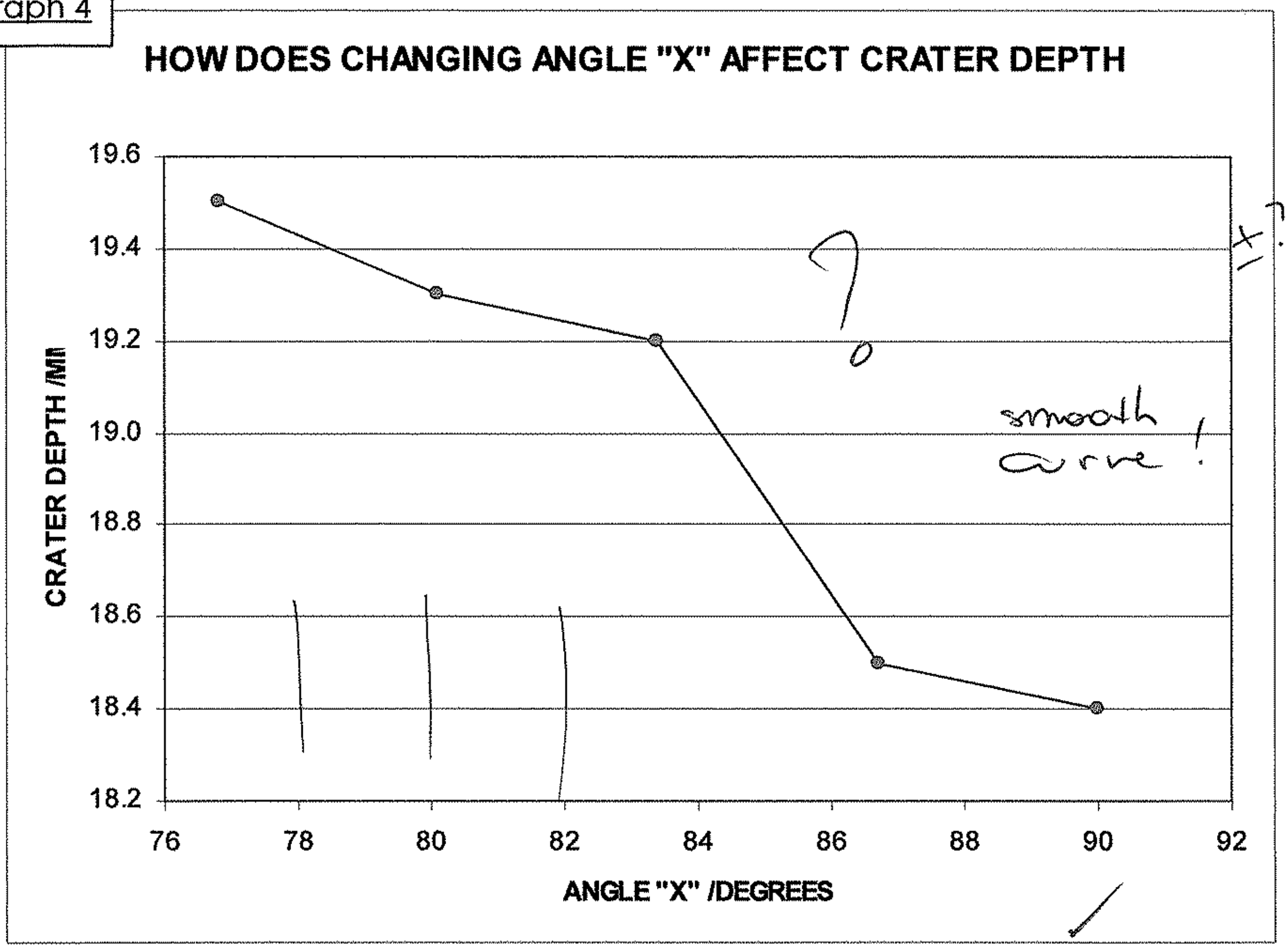
Table 6

WATER ADDED TO CONTAINED	DENSITY OF SAND	AVERAGE DEPTH	AVERAGE DIAMETER
/ML(-+) 25ML	/G/CM^3	/MM	/MM
250	1.77	19.5	5.83
500	1.81	24.8	3.51
1000	1.85	28.5	2.16
1500	1.95	37.5	1.90
2000	2.05	39.9	1.80

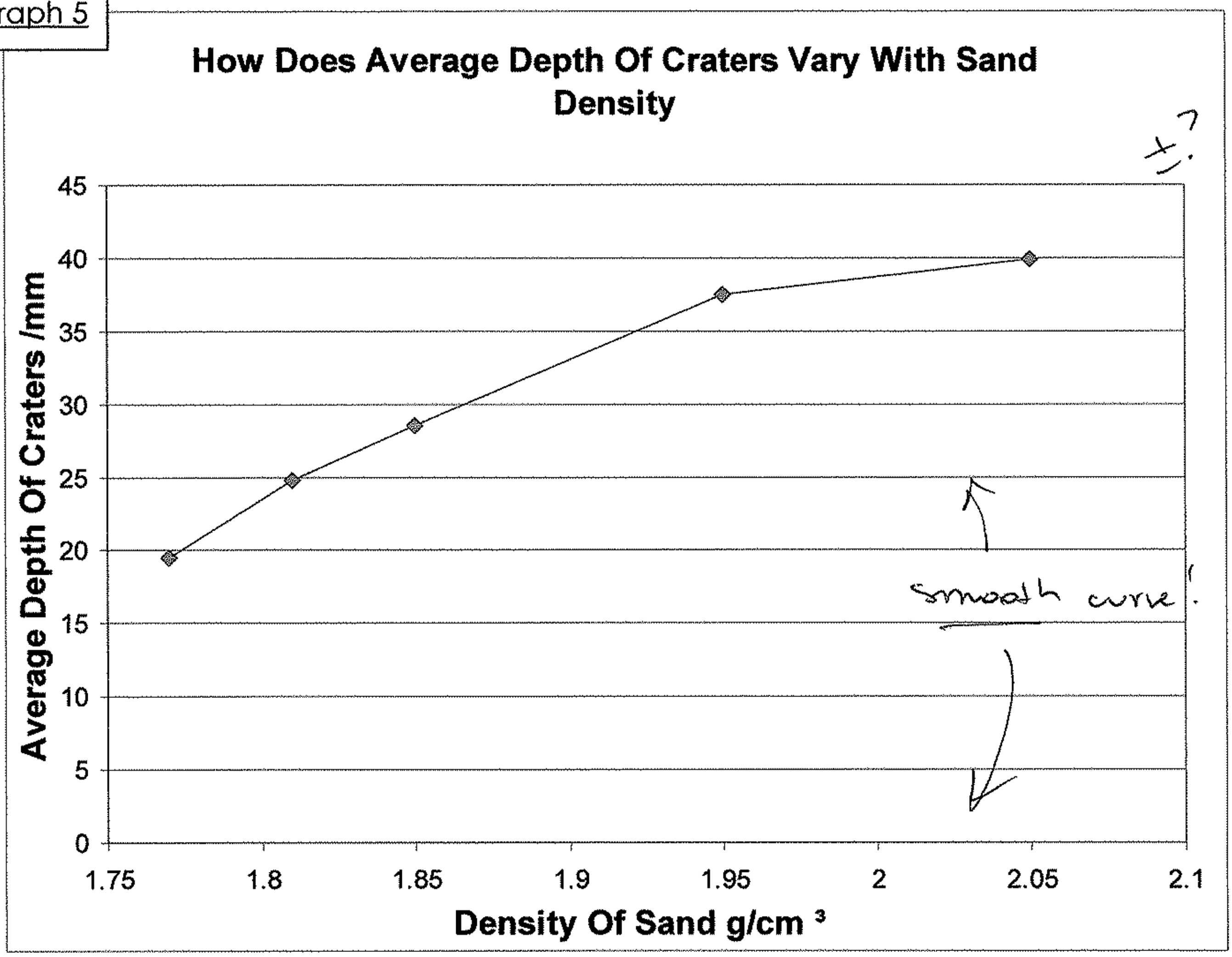
Graph 3



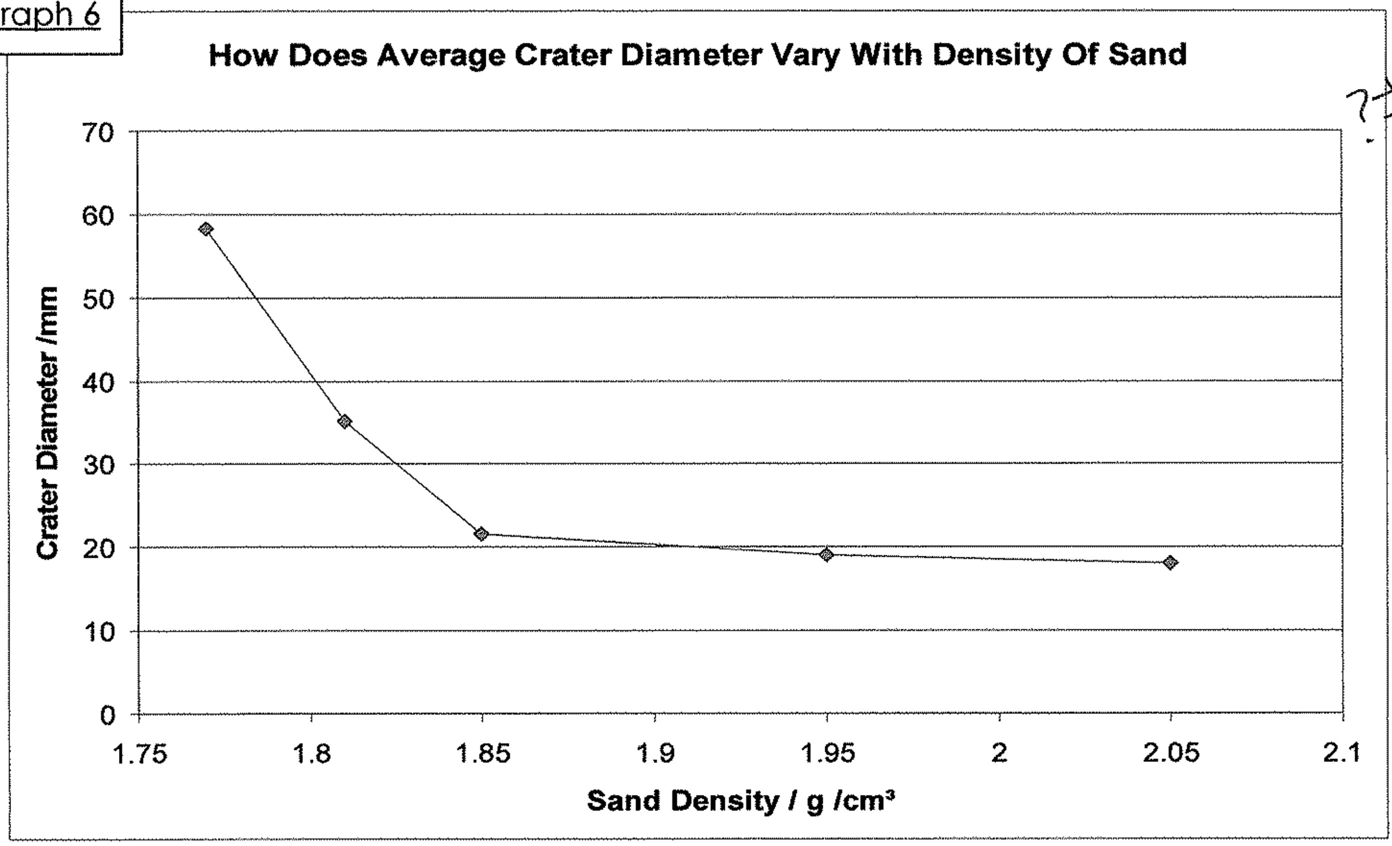
Graph 4



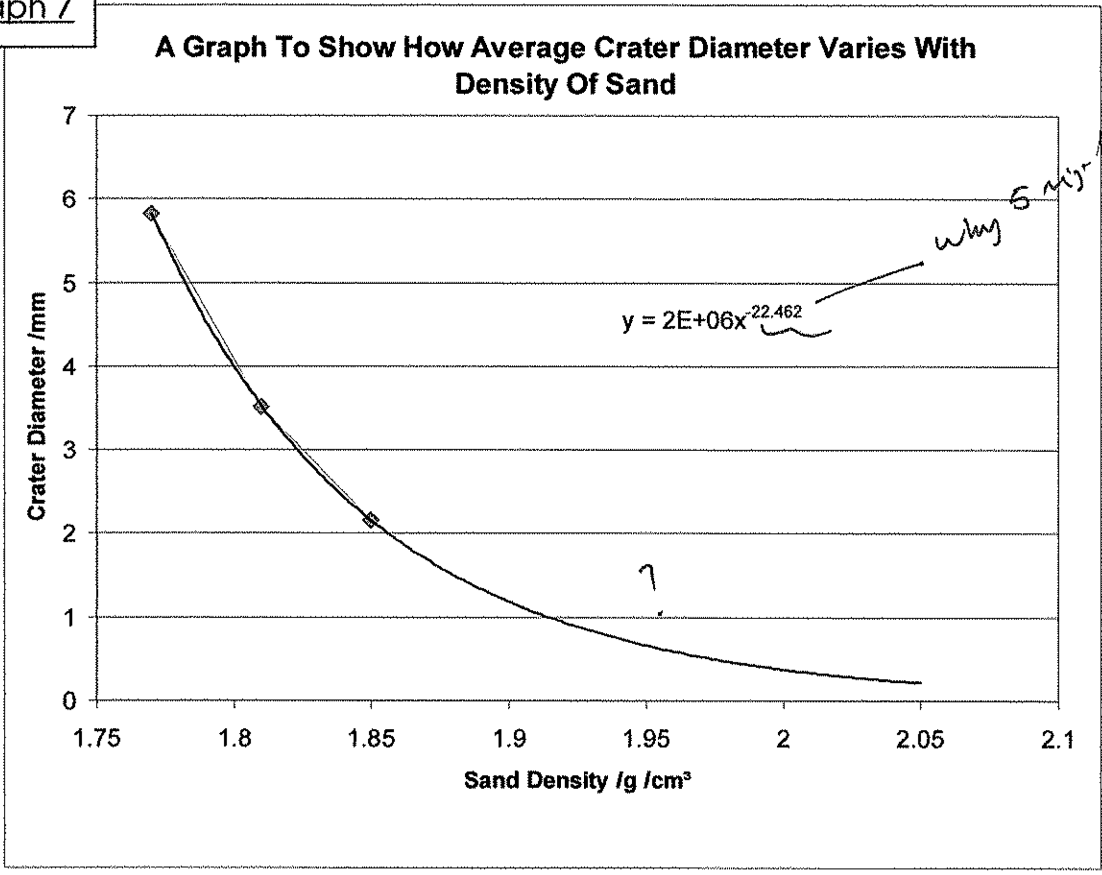
Graph 5



Graph 6



Graph 7



A Graph To Show How Average Crater Diameter Varies With Density Of Sand
y = 2E+06x-22.462
Crater Diameter /mm
Sand Density /g /cm³
0
1
2
3
4
5
6
7
1.75
1.8
1.85
1.9
1.95
2
2.05
2.1

Assessment form (for examiner use only)

Candidate session number	0	0							

Achievement level

Assessment criteria

	First examiner	maximum	Second examiner
A research question	2	2	2
B introduction	1	2	1
C investigation	3	4	3
D knowledge and understanding	1	4	1
E reasoned argument	3	4	3
F analysis and evaluation	2	4	2
G use of subject language	1	4	2
H conclusion	1	2	1
I formal presentation	2	4	0
J abstract	2	2	2
K holistic judgment	3	4	2
Total out of 36	21		19

twenty-one
FCD

Name of first examiner: ______________________ Examiner number: 4693
(CAPITAL letters)

Name of second examiner: ______________________ Examiner number: 0292
(CAPITAL letters)