Physics (Standard Level)

Internal Assessment

How is the crater, formed by the drop of the ball on sand, is affected by the height of the initial drop?

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Introduction

In 2014 Russian society was perplexed with mysterious gigantic crates that were discovered in Siberia, northern part of Russia. Nobody could clearly explain the origins of those craters, what could be a reason for formation of not single, but a set of craters all over Siberia.

For present moment, scientist were able to explain such phenomenon with a link towards weather anomalies, unusually warm weather in recent years[1]. The initial theory, however, implied the possibility of meteors and asteroids falling in that area.

Whilst this theory was still alive for a long time, I questioned myself on a subject of correlation and relationship between sizes of the craters and physical properties and parameters of the meteors that caused eruption and construction of such. To explore this question, I set up an experiments in a much smaller scale with sand as a substitute for the surface of the Eartha and ball as one for the meteor. I assumed that a meteors that are coming from different heights would have different impacts on the earth and thus creating craters of different diameters. To explore this topic, the following procedures were taken.

Design

Research Question:

How is the crater, formed by the drop of the ball on sand, is affected by the height of the initial drop?

[1] Liesowska, Anna. "Solved? How Scientists Say Mystery Craters Were Formed in Northern Siberia." <i>RSS</i>. Siberian Times, 10 July 2015. Web. 22 Feb. 2016. <http://siberiantimes.com/science/casestudy/news/n0302-startling-changes-revealed-in-mystery-craters-in-northern-siberia/>.

Background:

The conservation of Energy law is a fundamental concept of physics. It states that in the enclosed system, the total energy is conserved hence can be neither created nor destroyed.[2]

When object is dropped down from a particular height, its kinetic energy transforms into potential energy. Therefore, with a reference to the surface density that the object hits in the end, energy that the object carries yields into crater in the surface. With KE=PE, KE = mgh. Having a constant mass of the object and ‘g’ being a gravitational potential constant, height, h, would be left the only variable that has an impact on the energy that the object hits the surface with.

The impact on the surface can be investigated by measuring the diameter ob the crater formed.

$$\mathrm{E} = \mathrm{mgh} = \frac{1}{2}\mathrm{mv}^2$$

$\mathrm{E} \propto \mathrm{h}$

with $m = V\rho$, $m \propto V$

Having a ball as an object dropped, we can assume that crater formed has a volume of hemisphere (half of sphere). Volume of sphere is

$V(s) = \frac{4}{3}\pi r^3$, hence

$$\mathrm{V(hs)} = \frac{2}{3}\pi\left(\frac{\mathrm{D}}{2}\right)^3$$

$$\mathrm{V(hs)} = \frac{\pi \mathrm{D}^3}{12}$$

[2] "Conservation of Energy." <i>Conservation of Energy</i>. NASA, n.d. Web. 22 Feb. 2016. <https://www.grc.nasa.gov/www/k-12/airplane/thermo1f.html>.

$V \propto D^3$

$E \propto D^3$

h ∝ D^3

Therefore diameter of the crater and height have exponential relation to each other.

Hypothesis:

The diameter of the crater is proportional to the height of the drop in cubic relation. With increase in PE of an object, KE would also increase and yield in increase of diameter size.

Variables:

Independent:

Height of the drop of the ball

Dependent:

Diameter of the crater formed

Controlled:

Mass of the ball

Diameter of the ball

Sand

Materials and Methodology:

Apparatus:

Box

White sand

Tennis ball

2 wooden rulers (30cm ± 0.5)

1 plastic ruler (15cm ± 0.5mm)

Camera

Scales (±0.1g)

Logger Pro

Methodology (Procedure):

1) A carton box was filled with a 4 cm sand layer
2) Surface of the sand was leveled to the flat state
3) The height was measured by a ruler and a ball was stationed to that height
4) The ball was dropped and the crater was created
5) The ball was carefully lifter from the crater
6) Diameter of the crater formed was measured be a ruler and recorded
7) The above procedure was repeated for 5 height values for 5 trial each

Results

Raw Data:

Mass, g	**Height, cm**	**Diameter, cm**				
		Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
38.3	15	4.8	4.6	4.7	4.5	4.5
	25	5.4	5.1	5.3	5.5	5.6
	35	6.5	7.3	7.0	6.7	6.5
	45	7.5	7.1	7.2	7.3	7.4
	55	8.0	8.0	8.1	7.9	7.9

Table 1. Raw data collection results

Processed Data:

Mass, g	**Height, cm**	**Diameter Average Value, cm**	**Relative uncertainty**
38.3	15	4.62	±0.15
	25	5.38	±0.25
	35	6.80	±0.40
	45	7.30	±0.20
	55	7.98	±0.10

Table 2. Processed data results

Sample Calculations:

Average values (as for h=25cm)

$D_{avg} = \frac{4.8+4.6+4.7+4.5+4.5}{5} = 4.62$

Uncertainties calculations (as for h=45cm)

$D_{rel} = \frac{7.5-7.1}{2} = \pm 0.20$

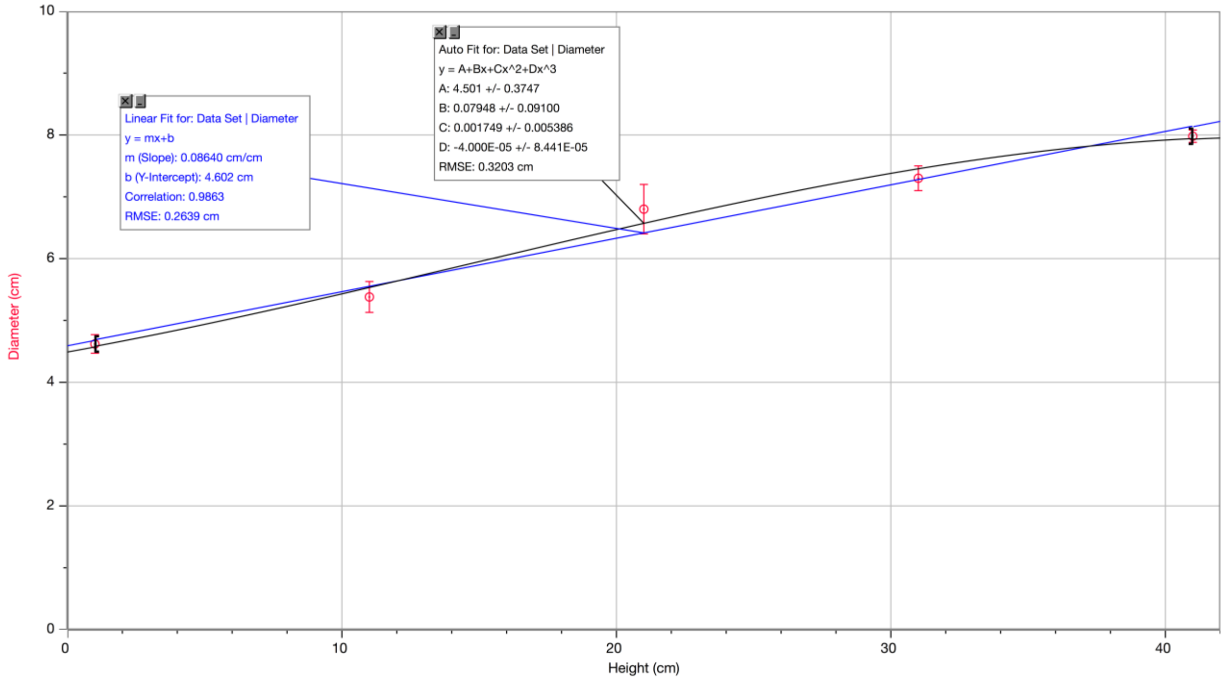

Figure 1. Height vs Diameter graph, which shows the exponential rise in value of the diameter over increase in height. The graph also shows the linear realtion between two variables with correlation coefficient close to the value of 1, which shows strong correlation between data points.

From the data obtained, the direct proportionality was proved. For the data points on graph, both linear and cubic fits were applied through the Logger Pro Software.

If following the cubic fit estimations, height-diameter relation function obtains a form of equation $y = ax^3 + bx^2 + cx + d$. Hence with the calculated values of a,b,c and d

D= $-4.00h^3 + 0.00174h^2 + 0.0794h + 4.50$,

where

D - diameter

h - height

a,b,c and d values - written down to 3 significant figures

The cubic fit does trespass all error bars of the data points, which shows relatively high accuracy of the data. We can observe exponential rise as the slope of the function gets less steeper with increase of height value. Root mean square error value (RSME) equals to 0.320, which indicates a strong correlation between data points. Thus it can be stated that diameter to height relation can be expressed through a cubic function.

However, the same data points also tend to follow linear relation simultaneously with the cubic one. Therefore linear fit was applied and following values were generated for the function y=mx+b.

D= 0.0864h +4.60

where

D - diameter

h - height

m,b values - written down to 3 significant figures

R, correlation coefficient, appeared to be equal to 0.983, which indicated towards high correlation between data values. RSME=0.263, which is another criteria for evaluation of relatively high correlation. RSME for the cubic fit, despite its individual strength, appears to be larger in value in comparison to linear fit. This proves that data tends to follow more linear relation rather than cubic one.

However, the hypothesis in the beginning states about cubic relation between eight and diameter. The disagreement between theoretical and experimental results can be partly credited to the small scale at which the experiment was performed.

Conclusion

The performed lab results did not confirm with the originally stated hypothesis. Unlike the predicted cubic relation of height to the diameter, formed by the ball released front his height to the sand, the experiment showed that obtained data is skewed more towards linear relationship. Therefore such relation can be described as follows: with an increase of initial height of the ball, diameter of the crater formed be this ball, will increase as well with a linear relation.

However, the results from this experiment can only be applicable towards situations of the same scale. Therefore if a relationship between meteor and its crater formed are to be determined, another series of experiments must be performed.

Evaluation

The experiment can be improved by:

- reducing random error value with implication of more trials for the same measurement
- reducing random error with smoothing sand after each from more carefully
- reducing systematic error with looking to ruler at the right angle, when taking measurements of the craters formed
- having wider range of height values or extrapolating graph, so that trend can be investigated more precisely

Bibliography

1. Ridenour, Louis N., and William Aaron Nierenberg. <i>Modern Physics for the Engineer</i>. New York: McGraw Hill, 1954. Print.
2. "Conservation of Energy." <i>Conservation of Energy</i>. NASA, n.d. Web. 22 Feb. 2016. <https://www.grc.nasa.gov/www/k-12/airplane/thermo1f.html>.
3. Liesowska, Anna. "Solved? How Scientists Say Mystery Craters Were Formed in Northern Siberia." <i>RSS</i>. Siberian Times, 10 July 2015. Web. 22 Feb. 2016. <http://siberiantimes.com/science/casestudy/news/n0302-startling-changes-revealed-in-mystery-craters-in-northern-siberia/>.

Appendix

Picture 1. Experiment setup

Picture 2. 15cm drop crater

Picture 3. 25cm drop crater

Picture 4. 35cm drop crater

Picture 5. 45cm drop crater

Picture 6. 55cm drop crater