Cratering (Part 1)

Post-Lab Assignment

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Course:	PHYS 13100 2
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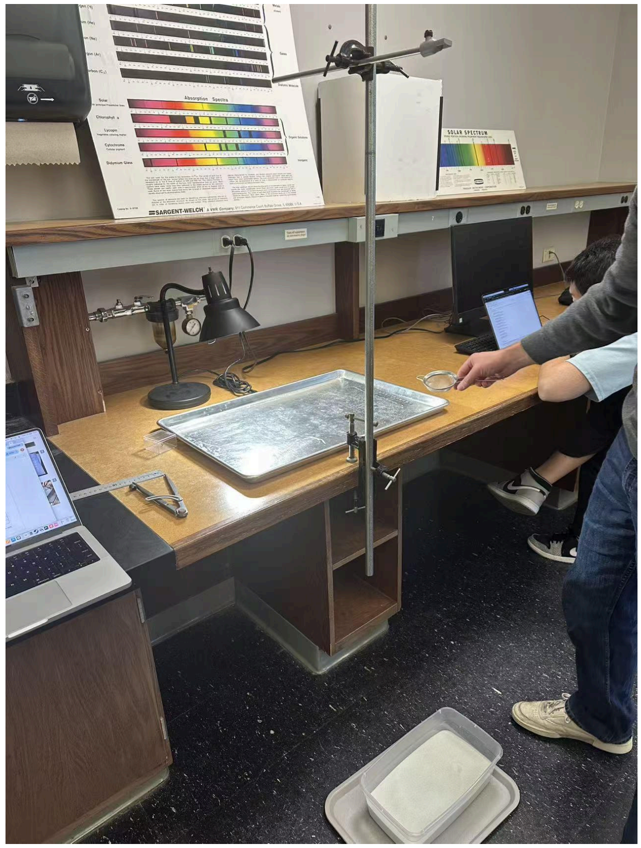
Goals/RQs

What is the relationship between the size of a crater and the kinetic energy expended to create it?

(More broadly) How can we use experimental data to compare the accuracy and efficacy of theories or models in relation to their respective real-world phenomena? How can assumptions and generalizations made in the experiment process impact its results?

Procedure & Setup



(Setup image by Ray of the highest height configuration)

Our general procedure for this experiment is as follows:

1. Set the height of the retort stand *relative to the surface/top of the sand* to 10 centimeters using a ruler or meter stick.
2. Place a mass of 8.4g underneath the end of the retort stand's arm, with a magnet above.
3. Release the mass by moving the magnet away from the arm.
4. Using a compass, then comparing its measurement with a ruler, measure the approximate maximum diameter of the crater created by the compass.
5. Resurface the sand's surface so that it is level using the rake and strainer.
6. Repeat steps 2-5 five times.
7. Repeat steps 2-6 with the masses of 3.5g and 1.1g
8. Repeat steps 2-7 at the retort stand heights of 0.5m and 1.5m

One of the main uncertainties with our procedure/setup is that we cannot consistently ensure the distance of the arm from the sand surface remains perfectly constant, as each trial causes the sand to shift slightly and results in inconsistent heights between trials. While we could re-measure the height in every trial, we feel that this itself would be a source of uncertainty due to the inaccuracy of the ruler when measuring the height (as the ruler has to "hover" over the sand so as not to sink into it).

Data

(Modified from original data table in lab notebook):

Table 1: Values for height = 10cm (± *0.05 cm)*

Mass (g ± 0.1g)	Diameter Measurement (cm ± 0.05cm)						
	1	2	3	4	5	Mean	Uncertainty
1.1	*3.7*	*3.8*	*4.1*	*3.6*	*3.8*	3.8	0.3
3.5	*2.6*	*2.7*	*2.7*	*3.1*	*2.6*	2.7	0.3
8.4	*2.0*	*1.9*	*1.6*	*1.9*	*1.9*	1.9	0.2

Table 2: Values for height = 50cm (± *0.05 cm)*

Mass (g ± 0.1g)	Diameter Measurement (cm ± 0.05cm)						
	1	2	3	4	5	Mean	Uncertainty
1.1	*2.6*	*2.5*	*2.6*	*2.9*	*3.0*	2.7	0.3
3.5	*3.3*	*3.6*	*4.3*	*4.0*	*3.7*	3.8	0.5
8.4	*5.5*	*5.7*	*5.2*	*5.0*	*5.1*	5.3	0.4

Table 3: Values for height = 150cm (± *0.05 cm)*

Mass (g ± 0.1g)	Diameter Measurement (cm ± 0.05cm)						
	1	2	3	4	5	Mean	Uncertainty
1.1	4.0	4.1	4.0	3.7	3.7	3.9	0.2
3.5	5.5	5.4	5.9	5.5	5.1	5.5	0.4
8.4	5.9	6.6	6.6	6.7	6.9	6.5	0.5

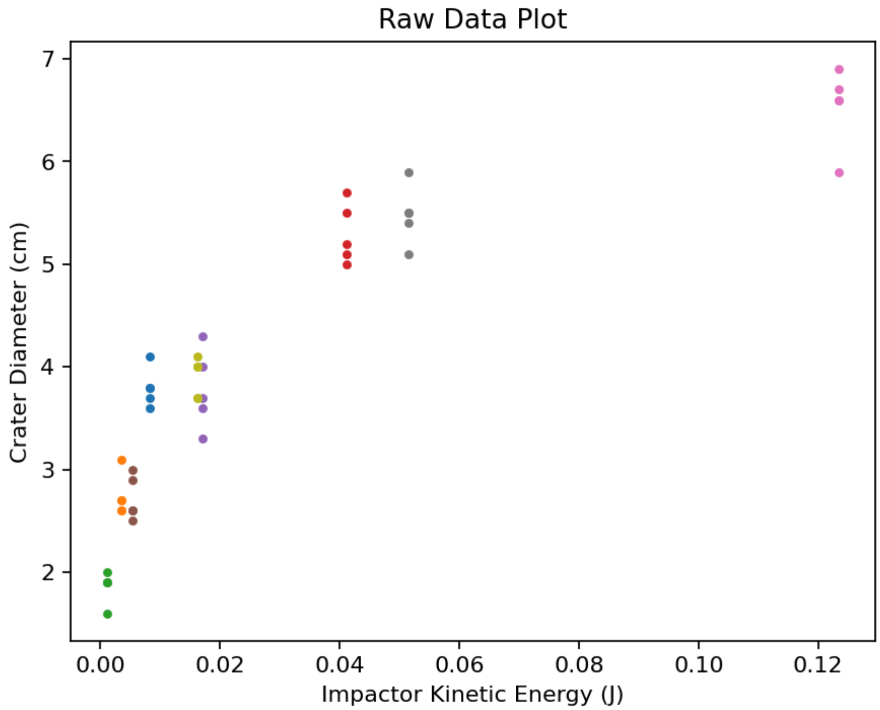
The uncertainty is derived from the formula $\frac{max-min}{2}$ for all combinations of height and mass. An uncertainty of 0.2cm (which is equivalent to 0.002m) seems to be appropriate given that with the assistance ot the light, the edges of the crater are relatively clear and discernible to a similar degree.

Given the heights and masses of the trials, the gravitational potential energy is computed in Google Colab:

```
Energy.append(0.0084*9.8*0.1)
Crater_Width.append([3.7,3.8,4.1,3.6,3.8])

Energy.append(0.0035*9.8*0.1)
Crater_Width.append([2.6,2.7,2.7,3.1,2.6])

Energy.append(0.0011*9.8*0.1)
Crater_Width.append([2.0,1.9,1.6,1.9,1.9])

Energy.append(0.0084*9.8*0.5)
Crater_Width.append([5.5,5.7,5.2,5.0,5.1])

Energy.append(0.0035*9.8*0.5)
Crater_Width.append([3.3,3.6,4.3,4.0,3.7])

Energy.append(0.0011*9.8*0.5)
Crater_Width.append([2.6,2.5,2.6,2.9,3.0])

Energy.append(0.0084*9.8*1.5)
Crater_Width.append([5.9,6.6,6.6,6.7,6.9])

Energy.append(0.0035*9.8*1.5)
Crater_Width.append([5.5,5.4,5.9,5.5,5.1])

Energy.append(0.0011*9.8*1.5)
Crater_Width.append([4.0,4.1,4.0,3.7,3.7])



for val in Energy:
  print(val)
for lst in Crater_Width:
  print(lst)
```

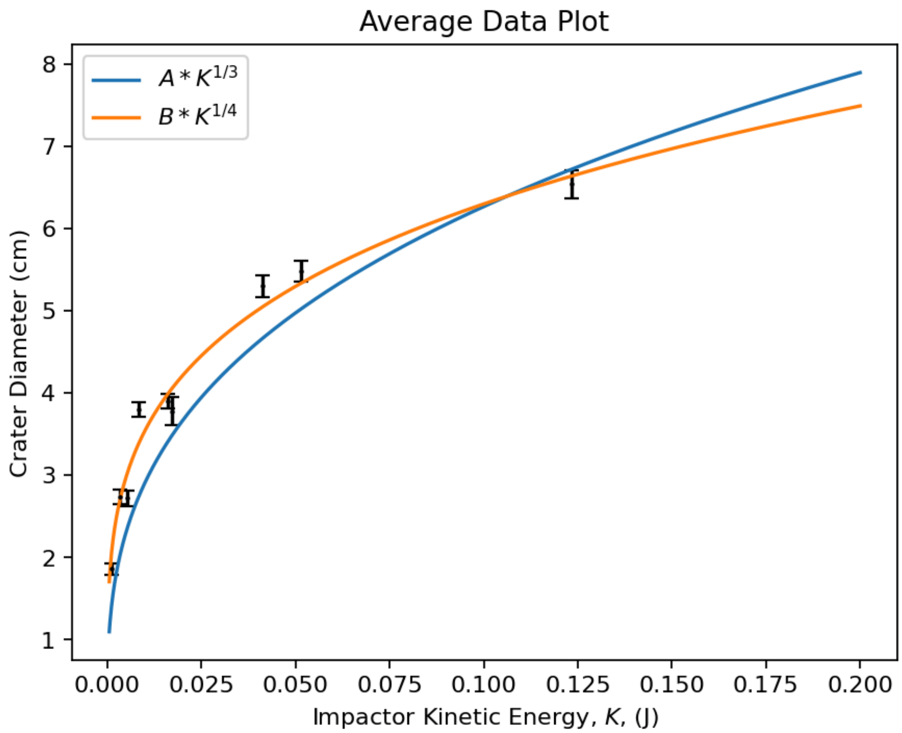
```
0.008232000000000001
0.0034300000000000008
0.0010780000000000002
0.04116
0.017150000000000002
0.005390000000000001
0.12348
0.05145000000000001
0.016170000000000004
[3.7, 3.8, 4.1, 3.6, 3.8]
[2.6, 2.7, 2.7, 3.1, 2.6]
[2.0, 1.9, 1.6, 1.9, 1.9]
[5.5, 5.7, 5.2, 5.0, 5.1]
[3.3, 3.6, 4.3, 4.0, 3.7]
[2.6, 2.5, 2.6, 2.9, 3.0]
[5.9, 6.6, 6.6, 6.7, 6.9]
[5.5, 5.4, 5.9, 5.5, 5.1]
[4.0, 4.1, 4.0, 3.7, 3.7]
```

In a data plot, the data points are as follows:



Some of the trials have some overlap because, for the given combination of height and mass, their gravitational potential energy is very close to each other. From the raw data plot, there is a logarithmic or some other power relationship between the impact kinetic energy and the crater diameter.

When the models are plotted on the graph, we get the following:



(A ~= 13.5, B ~= 11.20)

It appears that the ¼ power relationship matches the data better from observation, but this cannot be conclusively determined without some form of regression that can actually compare the model's fit with the data.

Conclusions (Partial)

The conclusion is your *interpretation* and *discussion* of your data.

- What do your data tell you?
- How do your data match the model (or models) you were comparing against, or to your expectations in general? (Sometimes this means using the t' test, but other times it means making qualitative comparisons.)
- Were you able to estimate uncertainties well, or do you see room to make changes or improvements in the technique?
- Do your results lead to new questions?
- Can you think of other ways to extend or improve the experiment?

In about one or two paragraphs, draw conclusions from the pendulum data you collected today. Address both the qualitative and quantitative aspects of the experiment and feel free to use plots, tables or anything else from your notebook to support your words. Don't include throw-away statements like “Looks good” or “Agrees pretty well”; instead, try to be precise.

Remember… your goal is not to discover some “correct” answer. In fact, approaching any experiment with that mind set is the wrong thing to do. You must always strive to reach conclusions which are supported by your data, regardless of what you think the “right” answer should be. Never should you state a conclusion which is contradicted by the data. Stating that the results of your experiment are inconclusive, or do not agree with theoretical predictions is completely acceptable if that is what your data indicate. Trying to shoehorn your data into agreement with some preconceived expectation when you cannot support that claim is fraudulent.

NOTE: We're leaving this week's experiment right in the middle – after you've taken data, but before we've fully explored the model. So, your conclusions are expected to be partial and incomplete. Maybe you will have to rely more on qualitative rather than quantitative data, or you will have to speak more towards what you plan to do next time than on what you've already done. That's all okay!

Roughly, the data collected fits the Ejection model better than the Deformation model when comparing the data plot with the graphed models manually fitted to the data. However, when graphed, not all error bars intersect with the manually fitted line, which suggests that the uncertainty may be even greater or that there are unaccounted variables influencing the experiment's results.

The minor experimental uncertainties and consistent values suggest that there is minimal random error in the data, indicating that the experiment yielded precise results. Notwithstanding this, I believe that there are unaddressed sources of systematic error that are not accounted for, which are likely also related to some of the inaccuracies in the data's matching of the model. Possible examples of systematic errors are drag/air resistance or potentially some sort of applied force from the magnet as it is taken away from the ball to release it.

These systematic errors are hard to quantify, as unlike random errors, which could be seen via the imprecision of results and thus could be quantified by a range of uncertainties, for example, systematic errors affect all values equivalently, such that their effects can’t really be seen unless the source of error is eliminated by adjusting methodology.

Questions

Consider the following questions:

- Think about the models we are testing…
    - What assumptions go into those models? (*About the type of impactor, about the sand, about the direction of impact, etc.*)
    - We test between “ejection” and “deformation” impacts. What other ways might energy be dissipated in an impact that we are not considering here?
    - We are dropping spherical balls and creating spherical craters. What do you think would happen if you dropped objects that were not spherical? (There is no right or wrong answer here, but justify your answer with an explanation of *why*.)
- Think about real craters produced on Earth (or the Moon or other planets)…
    - Could you apply the model (with the best fit parameters that you determined at the end of the lab) directly to such craters? (Why or why not?)
    - What might be different about these real craters from the ones we created today in lab? (Consider both differences in assumptions and differences in physical properties.)

For both of the models, some of the core assumptions include the assumption that the crater is circular, the impactor is “ideal” (i.e., constant density, perfectly spherical) and that energy is essentially conserved between the (gravitational) potential energy of the impactor and the kinetic energy it imparts on the sand. More specifically, the Ejection model seems to assume that the impacted material is not tightly bound, resulting in the material being ejected as the impactor hits, whereas the Deformation model doesn’t necessarily assume that the material is loosely-bound, but rather that it could be perfectly deformed. The actual process of cratering (specifically, the transfer of energy) probably involves a combination of both deformation and ejection, along with additional effects arising from the heat energy generated upon impact or the sound energy (in the form of waves).

The model with our best-fit parameters likely won’t be able to be directly applied to actual craters because, at the scale of actual craters, the errors arising from some of our assumptions will likely be significant. For example, actual meteors are very unlikely to have uniform density and material composition and are probably not perfectly circular. Additionally, it’s rather unlikely that a meteor will impact the ground at a perpendicular angle, as in our experiment, so the crater formed is also unlikely to exhibit properties such as being circular in nature and having a uniform diameter. The imperfections of the steel bearing, not being “perfectly” spherical, probably have less of an impact in our experiment than a meteor would in real life.