Cratering (Part 2)

Post-Lab Assignment

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Data Collection & Processing

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 <u>one or two paragraphs</u>, 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 <u>supported</u> 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.

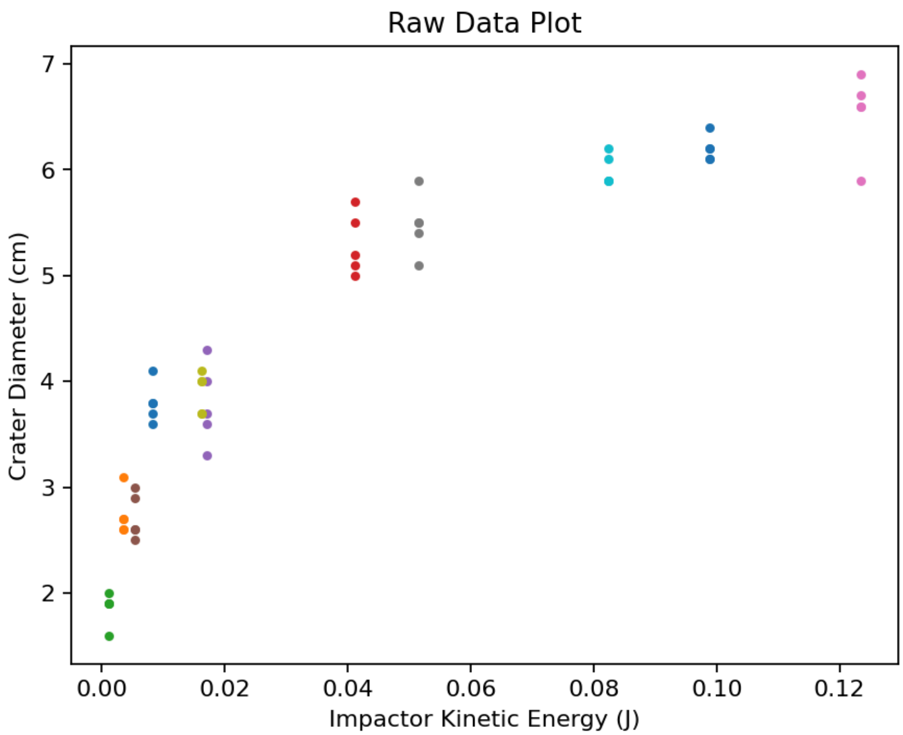
NOTE: You may focus on work done in today's part, but you will likely need to draw some from work done in Part 1 to provide further context.

Our raw data from Part 1 and Part 2 is summarized as follows in the following data table:

Height (cm ± 0.05 cm)	*Trials (#)*	*Diameter Measurement (cm ± 0.1 cm)*		
		Mass (g ± 0.1g)		
		8.4	*3.5*	*1.1*
10.0	*1*	*3.7*	*2.6*	*2.0*
	2	*3.8*	*2.7*	*1.9*
	3	*4.1*	*2.7*	*1.6*
	4	*3.6*	*3.1*	*1.9*
	5	*3.8*	*2.6*	*1.9*
50.0	*1*	*5.5*	*3.3*	*2.6*
	2	*5.7*	*3.6*	*2.5*
	3	*5.2*	*4.3*	*2.6*
	4	*5.0*	*4.0*	*2.9*
	5	*5.1*	*3.7*	*3.0*
*100.0**	*1*	*5.9*	-	-
	2	*6.1*	-	-
	3	*5.9*	-	-
	4	*5.9*	-	-
	5	*6.2*	-	-
*120.0**	*1*	*6.1*	-	-
	2	*6.2*	-	-
	3	*6.2*	-	-
	4	*6.1*	-	-
	5	*6.4*	-	-
150.0	*1*	*5.9*	*5.5*	*4.0*
	2	*6.6*	*5.4*	*4.1*
	3	*6.6*	*5.9*	*4.0*
	4	*6.7*	*5.5*	*3.7*
	5	*6.9*	*5.1*	*3.7*

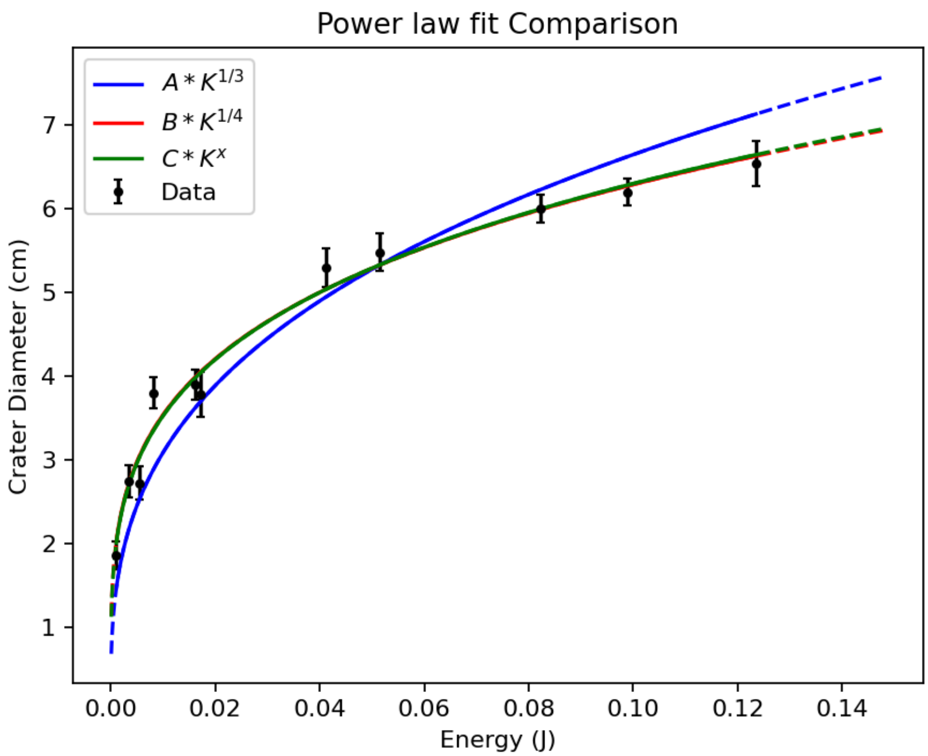
*: These two trials were added during Part 2 to ensure that there is sufficient data in all ranges of Kinetic Energy, as previously there was a gap of data in between the 0.06J and 0.10J range. Initially, our Chi-squared value was < 1, which prompted us to do more trials.

Graphing the raw data on a graph, we get the following:



Visually, it seems that there is some sort of power or logarithmic relationship between the impactor's kinetic energy and the crater diameter.

And when fitted using power fits for kinetic energy to the exponent of ¼, ⅓, and a K^n fit, we get the following:



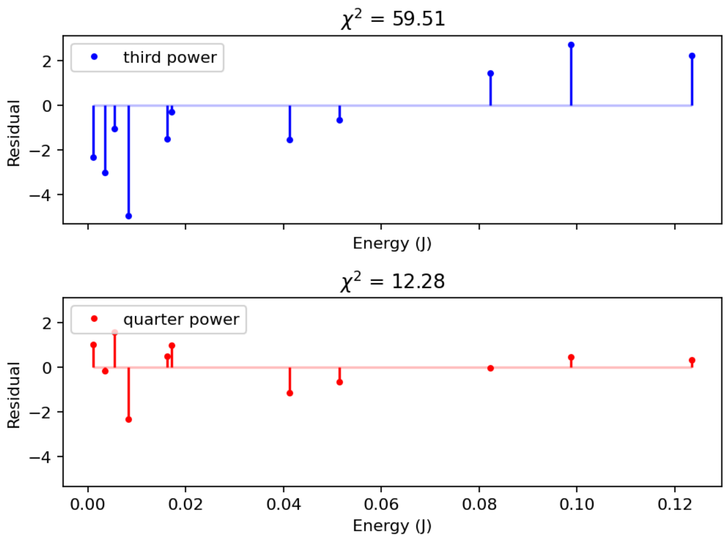
With the following fits:

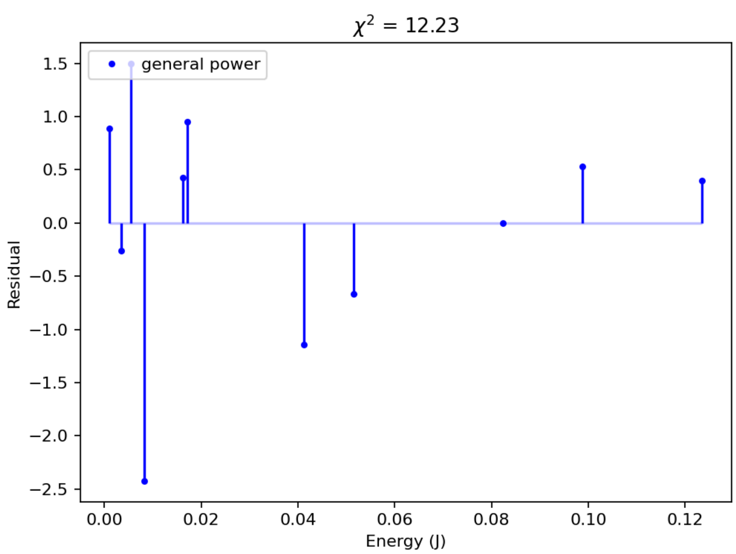
```
FIT: D = A*K^(1/3)
-----
Converged with chi-squared: 59.51
Number of degrees of freedom, dof: 10
Reduced chi-squared (chi-squared/dof): 5.95

Parameter    | Best fit values:          | Uncertainties in the best fit values:
A            | 14.3223                   | 0.1822

FIT: D = B*K^(1/4)
-----
Converged with chi-squared: 12.28
Number of degrees of freedom, dof: 10
Reduced chi-squared (chi-squared/dof): 1.23

Parameter    | Best fit values:          | Uncertainties in the best fit values:
B            | 11.1846                   | 0.1417
```

```
FIT: D = C*K^x
-----
Converged with chi-squared: 12.23
Number of degrees of freedom, dof: 9
Reduced chi-squared (chi-squared/dof): 1.36

Parameter    | Best fit values:          | Uncertainties in the best fit values:
C            | 11.2685                   | 0.4133
x            | 0.2524                    | 0.0111
```

The Chi-Squared value of 5.95 for the power fit of ⅓ indicates that the data from the experiment disagree with the model, as the data points appear to have more scatter than expected given the uncertainties in the data. As the uncertainties we have used are calculated using the standard error equation $SE = \frac{\sigma}{\sqrt{n}}$, it is rather unlikely that the high Chi-Squared value is due to the uncertainty of the data being too small, as the error accounts for more random errors beyond measurement uncertainty.

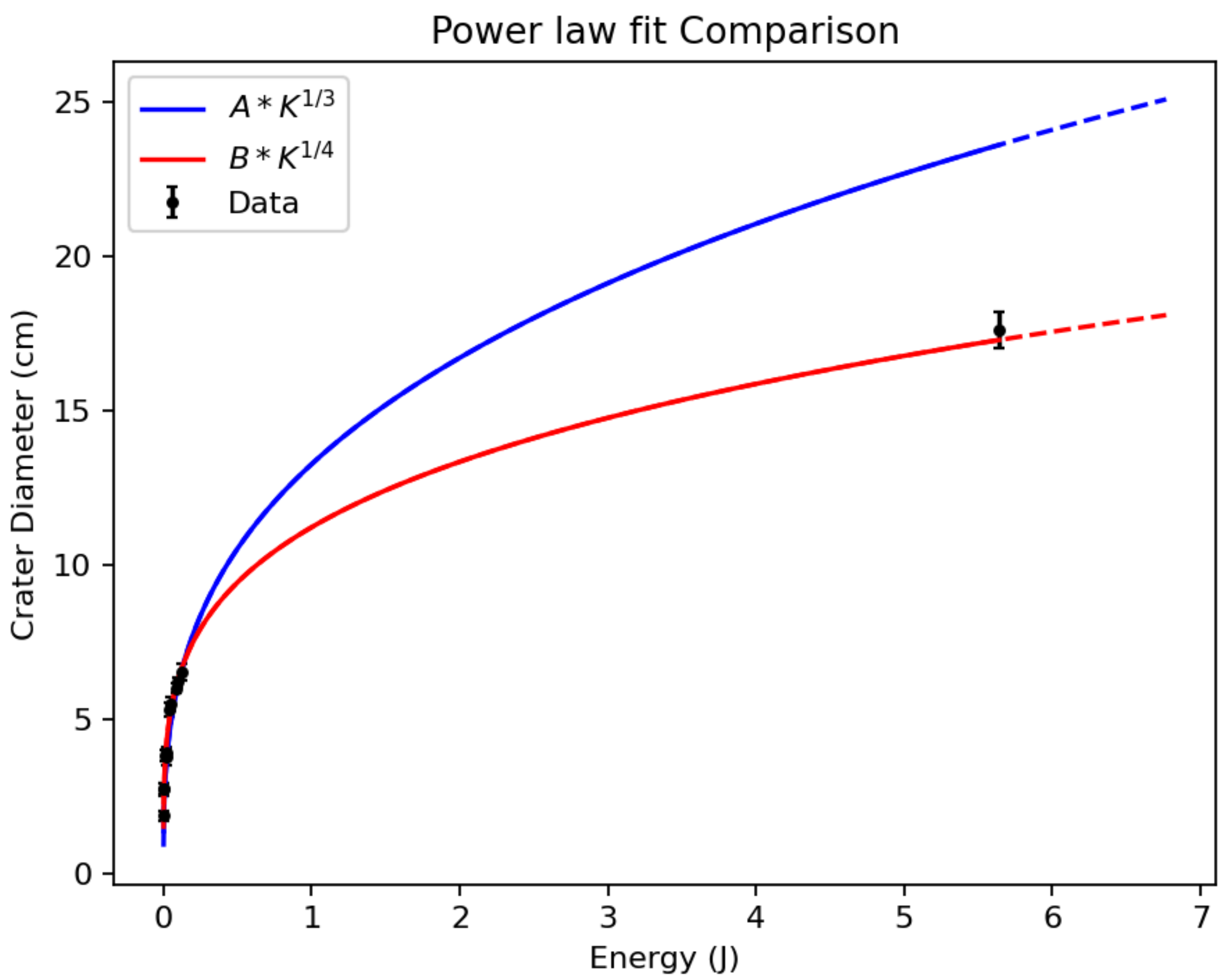
The ¼ fit, with its Chi-squared value of 1.23, implies that the data is in agreement with the model, as the data scatter appears to align with the relationship in this power fit. With the general power fit suggesting a relationship of 0.2524, which is only 0.0024 away from the ¼ relationship, it implies that the ¼ model is the most applicable to the results of the experiment.





The residual graphs seem to support this conclusion. The quarter power fit and general power fits have residuals that are both randomly greater or lower than the value of the fit, whereas the residual graph for the third power fit has groupings of values that are significantly lower or significantly greater than the predicted value of the model.

Adding the 8.67m trial to the fit, we get the following:



By observation, it appears that the 8.63m data value aligns with the ¼ power fit, as the predicted value falls within the range of uncertainty of the actual (average) value. The ⅓ relationship appears not to align with the data.

```
print( general-power prediction: , b_gen, +/- , db_gen, cm )

Enter an energy (in J) to see what your models predict for the crater diameter: 5.6410858
1/3-power prediction:  25.49576536599417  +/-  0.3242732946811734 cm
1/4-power prediction:  17.23704560766189  +/-  0.2184002530250408 cm
general-power prediction:  17.438646654970448  +/-  0.6396835561771812 cm
```

The predicted value of the ¼ power fit is 17.2cm, which, compared to the mean value of 17.6 in the experiment, only has an absolute difference of 0.4 cm, which is marginal compared to the height and scale of this trial.

It appears that the only uncertainty within this experiment is random error, as indicated by the fluctuations in the residuals, which are sometimes greater than and sometimes less than the predicted value. However, there are likely also systematic errors, such as the impact of drag on the ball, the effect of which can't be determined without information about the actual relationship between kinetic energy and crater size. As all data values internalize systematic errors and affect all data values equally, a power fit would systematically be affected by the systematic error and this influence cannot be discerned without actual theoretical numbers or data from experiments accounting for this error somehow (e.g., by performing it in a vacuum).

Applying the Model to Earth Craters

Given the relationship is $D = 11.19(K)^{1/4}$, the fit can be arranged to $K = (\frac{D}{11.19})^4$ so that it is a function for K.

Sedan Crater

Given the 390m diameter, we would get a predicted KE value of $1.48 \times 10^6 \pm 0.38 \times 10^6$ J. The known value is 4.4×10^{12} J, suggesting that it is not of the same order of magnitude, as there is a difference in magnitude 10^6. I speculate that this is probably because the dominant model that should be applied to nuclear explosions should not be the ejection, but rather other possibilities, such as heating, communion or seismic waves, or a combination of the aforementioned. A significant amount of heat is generated during an explosion, so our ejection model likely does not account for the thermal energy of the explosion. Another possibility is that some of the unaccounted-for systematic errors (e.g., drag) have a lesser component compared to in our small-scale experiment.

Chicxulub Crater

For this crater with a diameter of 100-150km (I will take this as 125 ± 25km), the predicted KE value is 1.56×10^{16}J, which also has a similar difference in magnitude of around 10 to the power of 6 or 7 with other predicted values like 3×10^{23}J. Likely for similar reasons for the Sedan crater, it is perhaps that different models are more dominant here or that systematic errors that are significant in our experiment are not as substantial in real life applications.

Check this out!

On December 24, 2021 a meteorite struck Mars near where the NASA InSight Lander is operating. Devices on the craft detected seismic waves that scientists at first thought were due to an earthquake (marsquake?), but satellite imagery from NASA's Mars Reconnaissance Orbiter later showed a new impact crater on the surface consist with the location of the source of the waves.

There are no questions to answer, but you might enjoy this summary of the recent study (published October 22, 2022): https://www.jpl.nasa.gov/news/nasas-insight-lander-detects-stunning-meteoroid-impact-on-mars.