Craters in Sand (with a Magnetic Catcher)

Muhammad Sabieh Anwar
LUMS Syed Babar Ali School of Science and Engineering

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This is a simple experiment, where I would like to teach students how they can quantitatively study a power law and determine the exponent in the power lab. Students will also learn about making log plots, curve fitting and as a bonus, they will realize that craters on planetary surfaces are important and interesting objects to study!

1 Experimental technique

Setup the apparatus as shown in Figure 1. Find the masses of the available steel balls. Level up the sand by shaking the container vigorously then pour some water in the sand and use the trowel to break and level up its surface.

Connect the power supply to the magnetic catcher and also the digital multimeter. Turn on the power supply and set its voltage to approximately 15 V to hold the ball; whereas in order to release the ball, simply switch off the supply.

Drop the balls, one by one, into the sand container from a range of different heights between 25 cm to 95 cm. The heights are measured from the surface of the sand. Find the diameter D of the crater using a ruler or vernier calipers, as shown in part (b) of the figure. Take at least 3 replicate measurements of diameter at a specific height, so that we can find the mean and spread of the data for a partcular height and mass of the ball.

Caution: Turn on the supply only when it is required to hold the ball. When not in use, switch off the supply. This will prevent over-heating of the magnetic catcher.

1.1 Objectives

1. The diameter of the crater, D, and the kinetic energy, E, of the impacting ball are related through the relation $D = cE^n$, where E is the kinetic energy calculated by assuming that all the potential energy possessed by a ball at height h is transformed into kinetic energy before impact.

2. Determine the best value and the combined standard uncertainty in the kinetic energy, E, taking into account the uncertainties in the mass and the height of the ball.

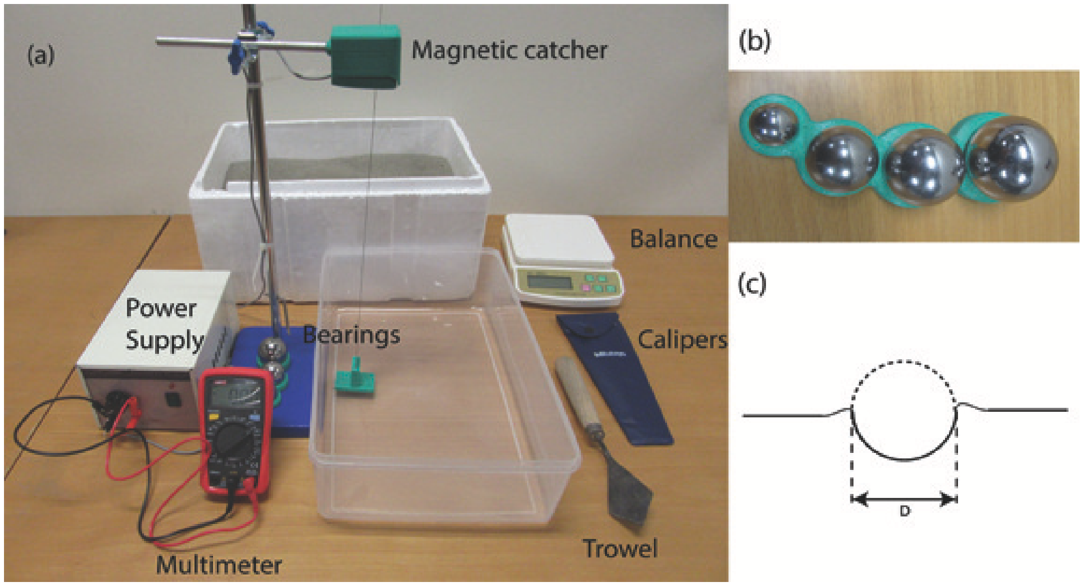

Figure 1: (a) Photograph of the crater formation experiment wiith (b) a closeup of the ball bearings and (c) the diameter D formed by the impacting ball bearing.

3. Make a comprehensive table showing the values of D, E, $\ln D$, $\ln E$ and the uncertainties in these variables.

4. Plot a graph between $\ln D$ and $\ln E$, showing uncertainties in both the dependent and independent variables.

5. Transfer uncertainties to the dependent variable.

6. Fit the equation $D = cE^n$ to your data using the technique of least-squares.

7. From the least-squares fitting of your data and the associated uncertainties, find the slope and its standard uncertainty.

8. Your goal is to find n which will specify the mechanism of crater formation [1]. For example, $n = 1/3$ implies that the dominant mechanism is the plastic deformation of the sand surface and $n = 1/4$ suggests that the craters are formed by the ejection of sand. What is the uncertainty in n?

9. Repeat the experiment for dry sand and compare your results.

References

[1] J.C. Amato, R.E. Williams, Crater formation in the laboratory: an introductory experiment in error analysis, Amer. J. Phys. **66**, 141 (1998).