Craters in Sand

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This is one of our very simple experiments to get familiarized with the concept of uncertainty and how it can be quantified and expressed.

1 Experimental Method

Set up the apparatus as shown in Figure (1.a). 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. Use the mechanical ball dropper, shown in Figure (1.b), to drop the balls, one by one, into the sand container from a fixed height anywhere between 25 cm to 60 cm. The height is measured from the surface of the sand. Find the diameter D of the crater formed using a ruler, as shown in Figure (1.c). For each ball, take at least six replicate measurements of the diameter. Level up the sand after after taking each reading. Repeat the above process for different balls to get a range of kinetic energies of the impacting object.

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.
3. Make a comprehensive table showing the values of D, E, lnD, lnE and the uncertainties in these variables.
4. Plot a graph between lnD and lnE, showing uncertainties in both the dependent and independent variables.

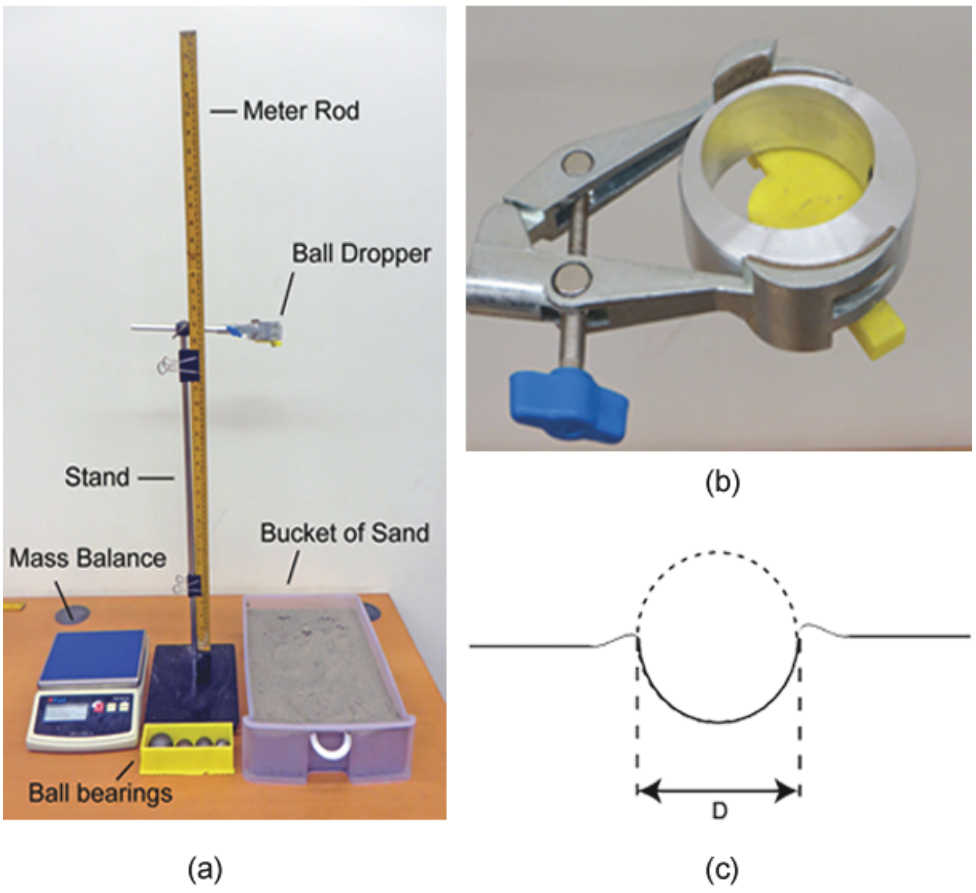

Figure 1: (a) Photograph of the apparatus. (b) Picture of the mechanical ball dropper (c) Cross section of the sand crater formed by falling ball into the sand container. The position of the peak of the crater wall is used to estimate its diameter.

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?

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).