Mechanics Coursework

Simulating Asteroid Impact

In this experiment the ball bearings will be the free falling objects which will simulate a meteorite or asteroid impact. Any object which is allowed to free fall in the Earth's gravitational field will experience an acceleration (*g*) equal to 9.8 m/s^2. In order to determine the velocity of the ball bearing at the moment of impact, two equations are needed. The equation,

$$(1)\ v_f = v_i - gt$$

states that the final velocity, v_f, is equal to the initial velocity, v_i, minus the acceleration due to gravity, *g*, multiplied by the amount of time, *t*, it takes the object to fall. During this experiment you will be unable to accurately measure the fall time. Because of this, another equation is needed to determine the final velocity.

$$(2)\ d = v_i t - 0.5gt^2$$

Equation (2) allows you to calculate the distance, *d*, an object will fall within the Earth's gravitational field, if the amount of fall time is known. It should be noted that *d* is negative (-) for objects moving towards the Earth. In other words a falling object has a negative displacement. For objects moving away from the Earth, *d* will be positive (+). Notice that time, *t*, is still a part of equation (2). By substitution, we can eliminate *t* and can then calculate v_f based solely on the distance the object falls.

The initial velocity in these experiments is equal to zero, since the ball bearing is not moving prior to being released. This then simplifies the equations (1) and (2) to:

$$(3)\ v_f = -gt$$

$$(4)\ d = -0.5gt^2$$

By manipulation of equation (3) we get

$$(5)\ t = -v_f / g$$

Substituting equation (5) into equation (4) results in the following:

$$(6)\ d = -0.5g(-v_f / g)^2$$

Simplification of equation (6) results in:

$$(7)\ v_f^{\,2} = -(2dg)$$

$$(8)\ v_f = (-2dg)^{0.5}$$

By using equation (8), if you know the distance the free falling object has moved, you can calculate its impact velocity. Velocity is measured in meters per second.

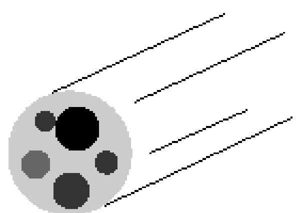
To calculate the amount of energy released during the impact, the following equation is used:

$$(9)\ E = mv^2$$

E is the energy release in joules (J), *m* is the mass of the falling object in kilograms and *v* is the impact velocity in meters per second. For example, if a 10 kg meteorite hit the Earth with an impact velocity of 10 m/s, the energy released would be:

$$(10)\ \ E = 10kg(10m/s)^2 = 1000J$$

Craters



The sky is falling, the sky is falling!

-- Chicken Little

Prelab

Answer these questions:

- What factors could affect an impact crater's shape and size?
- What effect do you expect varying these factors will have on the craters?
- Explain how you could test these hypotheses.

Overview

- Evaluate parameters affecting crater formation.
- Find the size of the asteroid/comet that killed the dinosaurs.
- Make your own series of craters, to observe the "geological" results.
- Look at and evaluate images of craters on other planets/heavenly bodies.

Introduction

One look at the surface of the Moon should convince you that "empty space" is not so empty after all. There is actually a wide range of objects floating between the planets, from tiny particles to asteroids that can be a hundred miles across, debris left behind when the planets were formed. These objects can be perturbed from their orbits (by a close passage by a planet, a passing star, any number of things) and onto paths that cross ours -- or any other planet or moon. When that happens, a collision occurs and an impact crater is formed.

Directions

We will be doing two activities with craters in this lab. For both you need a box of sand (the planet surface) and a small ball bearing (the 'asteroid' or 'comet'). The box of sand will have two components, a thick base made of white sand and a thin layer on top made of colored sand. Smooth the surface of the white sand and sprinkle a light covering layer of colored sand on top. This layer of colored sand lets you see where the ball bearing pushes the white sand up to the surface as crater ejecta. This enables you to easily measure the crater diameter and to see the changes in crater morphology that result when using heavier ball bearings dropped from larger heights.

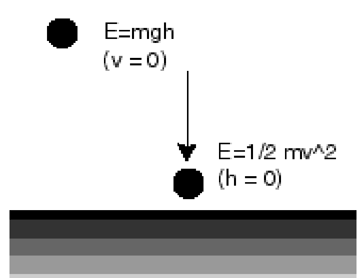
Activity 1:

The size of a crater is related to the energy of the impacting object (the asteroid). This makes sense -- as the energy of the asteroid increases, it releases more energy on impact, making a bigger crater. The relationship is not linear however, but rather some form of *power law*:

$$\mathbf{D = k * E^n}$$

where **E** is the energy of the asteroid (kinetic and potential) and **D** is the diameter of the crater. Also, **k** is an unknown constant, and **n** is some unknown factor that describes how the diameter of the crater depends on the energy of the asteroid. We want to find out what **n** and **k** might be by looking at our scaled version of asteroids and craters.

By dropping the ball bearings from different heights, we can find out how the diameter of the crater scales with energy. The energy of the ball bearing when it hits the sand can be determined by conservation of energy:



So the kinetic energy of the ball bearing on impact is equal to its potential energy before it is released, **E = mgh**. Here **m** is the mass of the ball bearing (in kg), **g** is the gravitational acceleration = 9.81 m/s^2, and **h** is the height of the ball bearing above the sand (in meters). If we drop the ball bearing from different heights, we get different values of energy on impact and different crater diameters.

Record the crater diameter made when you drop the ball bearing from various heights in Table 1. Try to get as large a range in height as you can, and don't take measurements from very low heights (less than 2 cm). Once you have a table of height and crater diameter, convert the heights into energy using **E = mgh**. To find the mass of the ball bearing, measure its diameter. The ball bearing is made of steel, which has a density of approximately 8000 kg/m3, and has a volume given by **V=4/3πR^3**. You can now figure out its mass (density = mass/volume).

Now you have a table of crater diameter as a function of energy. By graphing these, we can find the value of 'n' in the expression above. However, since this is a power law relationship (**n** is in the exponent) a simple graph of diameter vs. energy would make it very hard to find **n**. The graph would be a curvey line, instead of a straight one (a straight line would result if there was a linear relationship). So, instead plot **log(diameter) vs. log(energy)**. This plot will look like the data points are along a nice straight line, and now the slope of this line is **n**. Make sure you plot the log of each of the values, on normal graph paper. If you don't remember how logs work, or don't understand why plotting log(D) vs. log(E) will make a straight line, ask your instructor for a more explanation.

Draw a "best-fit" line through the data points on the graph. Remember, a best-fit line is a straight line that comes close to, but probably not through, as many points as possible. Find the slope of this line. Mark the two places on your line that you used to find the slope. This slope is equal to **n** in the equation above. If you decide to use your graphing calculator to find the best-fit line, remember you still have to hand in a graph of your data points and your best fit line so that your instructor can see it.

So we know **n** from the slope on the graph. We also need to know the constant **k** in the equation relating crater diameter and impact energy. To find **k**, you will use one of your data points. Pick a data point that is close to your best-fit line (one that you think is a good value), and plug **D**, **E**, and your value for **n** into the equation $\mathbf{D = k\,E^n}$. Now you can solve that equation for the value of **k**. For example, suppose you dropped a 0.03kg ball bearing from a height of 2m. This give you an impact energy of E = mgh = (0.03kg) * (9.81m/s^2) * (2m) = 0.59Joules. And suppose that when you dropped the ball bearing, you measured the crater diameter to be 5cm = 0.05m, and also your graph had given you a slope = n = .25. Then,

D = 0.05m, E = 0.59Joules, and n = 0.25,

plugged into the equation $\mathbf{D = k\,E^n}$

$$k = D / (E^n) = 0.05 / (0.59\text{^}0.25) = 0.057 .$$

Now, go and put all this knowledge to work in the Activity #1 Questions!