

Name \_\_\_\_\_

Partners \_\_\_\_\_

## **COSMORPHOLOGY – May 2009**

### **THE FORMATION OF CRATERS**

**Purpose:** To model impact craters in the laboratory so that you can investigate what conditions control the size and appearance of craters. You will also determine a mathematical relationship between the controlling conditions and the size of an impact crater. You will use this mathematical relationship to predict the result of further experiments.

Impact craters are those craters which form when a meteorite strikes the surface of a planet. Such craters are found on all solar system objects which have solid surfaces. The occurrence and appearance of impact craters then tell us about the history of the cratering event. On the Earth impact craters are not easily recognized because of the intense weathering and erosion processes that wear away its surface.

Various geological clues and studies of the rocks returned from the Moon by the Apollo astronauts indicate that asteroid-sized chunks of matter were more abundant in the solar system some 3.9 billion years ago. During that era, considered to be the last stage of planetary accretion, the young planets were subject to intense bombardment by these objects. The Earth itself would have been struck many times, so that its crust was broken up and modified by the repeated impacts. Although plate tectonics, mountain building, weathering and erosion have all but hidden the craters formed on the Earth, the relatively unweathered lunar surface still bears testimony of this intense period of bombardment.

1. List all the factors you think might affect impact craters. Consider both the impactor and the surface being impacted.

In this lab, you will drop a selection of projectiles into trays of sand in order to investigate what properties of the projectile affect the resulting crater. The properties we will investigate are:

- a) The size of the impacting object
- b) Its mass
- c) The velocity of the projectile relative to the target when the impact occurs

You may have come up with other possibilities. This is good. We will attempt to investigate them near the end of the lab.

Fill a pan with sand to a depth of a few inches. Smooth the surface, then tap the pan to make the materials settle evenly.

### SIZE OR MASS

In order to determine if a particular property affects the resulting crater form, we must keep all other properties constant, otherwise we could not determine which property was causing the changes. Let's look at mass first. To do this properly, we need to make sure size and velocity remain constant (as much as possible). So, choose two balls with the same size and different masses. Record the size and mass of each ball in the table below.

To keep the velocity constant, we will drop the balls from a constant height. Because falling objects are affected by gravity, physicists can easily derive the impact velocity from the height. Drop the first ball into the sand. (Do not throw the ball or we will not be able to reproduce or determine the impact velocity.) Record the HEIGHT ABOVE THE SAND SURFACE from which the ball was dropped. Many experimenters find it easy to use a height with a round number. Because we have meter sticks, 100 cm is a commonly used value.

Observe the resulting impact crater feature. Record the diameter of this crater. Be certain to use the correct units! For best results, record the diameter to at least one decimal place. Repeat two more times, using the same ball from the same height, and recording the diameter of the resulting crater. Take the average of the three trials and record in the table.

Repeat this process for the other ball, remembering to always use the same height and recording all measurements in the table.

Composition	Size (in)	Mass (g)	Height (cm)	Crater diameter (cm)			
				Trial 1	Trial 2	Trial 3	Average

Ok, let's now look at size. We need to keep mass and velocity as constant as possible. We know how to keep velocity constant (drop from the same height), so choose two balls with the same mass (as close as possible) and different sizes. Drop the balls into the sand (from the same height) and record the data in the following table.

Composition	Size (in)	Mass (g)	Height (cm)	Crater diameter (cm)			
				Trial 1	Trial 2	Trial 3	Average

2. Does projectile size affect crater size?

3. Does projectile mass affect crater size?

4. Which matters more, size or mass?

### MASS

We have determined that changing the mass of the projectile will change the diameter of the impact crater. But, how exactly is crater diameter related to mass? In this section we will determine a relationship between the two quantities. Finding a mathematical relationship between related quantities is an incredibly useful tool in science because it allows us to make predictions. In this way, we can know what would happen in a given experiment without actually having to perform the experiment. Graphs are a useful tool for visually representing the mathematical relationship.

Choose six balls of the same composition but different masses. This time we will use a spreadsheet program (Excel) to assist with our graph and predictions. Open the file “cratering.xlsx” and enter the properties of your chosen balls in table 1. Drop each ball into the sand three times, always dropping every ball from the same height. Record your measurements in the spreadsheet (it will take the average for you). Do not change any values that are in **boldface**.

5. Based on the numbers you recorded, how does crater diameter depend on projectile mass? (ie, what happens to the crater diameter as the mass increases?)

6. The spreadsheet automatically produced a graph of crater diameter as a function of projectile

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mass (click on graph 1 at the bottom of the page). Describe what this graph looks like.

7. Here we will get a better idea of how projectile mass affects crater diameter (ie, the strength of the effect). If projectile mass is increased by a factor of 5 (from, say 10 g to 50 g), by what factor does the crater diameter increase? (parts a-c will help you answer this question if you're uncertain) A larger factor means a larger effect.
  - a. Write down the crater diameter that corresponds to a projectile mass of 10 g.
  - b. Write down the crater diameter that corresponds to a projectile mass of 50 g.
  - c. How many times larger is the crater diameter for a 50 g projectile than a 10 g?
  
8. Graphs are useful for predicting outcomes of experiments you have not yet performed. The spreadsheet is already set up to find a fit to the data you took. The mathematical relationship is shown by the black line. It should go close to all of your data points but may not go through all of them. What does that line predict the crater diameter should be for a projectile mass of 100 g?

### VELOCITY

Now we will determine how changing the impact velocity affects the crater diameter. So, now size and mass must be kept constant. This is easily accomplished by using the same ball in all experiments, so pick one of the six balls you used in the previous section. Record the size, composition, and mass of this ball in the spreadsheet. (You might need to switch back to "Sheet1".)

We will change the ball's impact velocity by changing the height from which it is dropped. The farther the ball falls, the faster it will be going when it hits the sand. The impact velocity is given by the formula:  $v = \sqrt{2gh}$ , where  $g$  is the acceleration of gravity (980 cm/s) and  $h$  is the height from which you drop the projectile.

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Drop the ball into the sand from the first height. Record the diameter of the crater in Table 2 in the spreadsheet (The first 5 heights are chosen for you and already recorded, choose a different height for the sixth trial). Repeat from the other heights, perform 3 trials for each height.

9. Again, the spreadsheet automatically created a graph of your data (click on “graph 2”). In what way does velocity affect crater diameter? (ie., describe the plot)

10. If velocity is increased by a factor of 5 (from, say 100 cm/s to 500 cm/s), by what factor does the crater diameter increase?

11. What size crater would be made by the same ball with an impact velocity of 900 cm/s?

12. Which has a stronger affect on crater size: mass or velocity of the projectile?

#### OTHER PROPERTIES

13. Are there any properties you suggested in number 2 that we haven't tested? If the answer is no, think of one now.

14. How would you test this property for an effect on impact craters? Carry out this test and describe

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what you are doing and what your results are. Does this property affect crater size? Note: you will be graded on how scientifically valid your test is.

### KINETIC ENERGY

You might have noticed that the exponent from the fit for impactor velocity is approximately twice as large as the exponent from the fit for impactor mass. That means that if the diameter is proportional to the mass then it is also proportional to the velocity squared. Mass times velocity squared (actually, one half of that) is already a quantity commonly used in physics. This property is called kinetic energy and is given by the following equation:

$$\mathbf{KE = \frac{1}{2} mv^2}$$

Where  $m$  is the mass and  $v$  is the velocity.

Kinetic energy is a useful quantity that plays a major role in classical physics. It is used in designing roller coasters, cars, basically anything that moves. It makes sense that the crater diameter depends upon kinetic energy as that quantity is one of the deciding factors in any sort of collision (including car crashes). During an impact, the energy is transferred to the target surface, breaking up rock and moving the particles around.

You can calculate the kinetic energy in the craters you've already made by plugging the velocity and mass into the formula above. As long as your mass is in grams and your velocity in centimeters per second then your energy is in a unit called ERGS. The spreadsheet has already done this for you in table 3. It has also plotted these data (see "graph 3") and fitted a power law,  $y = cx^p$ . Basically, the program found values for  $c$  and  $p$  that best fit your data. Again, the fit line should go near all of your points, but may not go through all of them.

15. Reading from the fit on your graph, what is the numerical value of  $p$ ? Type this value into the spreadsheet in sheet 1.

16. What is the numerical value of  $c$ ? Type this value into the spreadsheet in sheet 1.

Choose any ball and any height. Record the properties of your choice in Table 4 in the spreadsheet. We can use the relationship you have already determined (ie, the values for  $c$  and  $p$ ) to predict the diameter of the impact crater formed by dropping this ball from this height. The spreadsheet will do this calculation for you. As before, drop the ball from that height three times and record your measurements in the spreadsheet. It will calculate the average of your three trials and the percent difference between your predictions and your measurements. Try it with at least 1-2 more combinations of height and mass.

17. How do the predictions compare to your measurements? As the Mythbusters might say, is the mathematical formula Confirmed, Plausible, or Busted?

### BARRINGER CRATER



The Barringer Crater (also called Meteor Crater) is a large impact crater in northern Arizona. The crater's diameter is 1.2 km. The crater resulted from what was probably the most recent large meteorite to hit the Earth, some 25,000 years ago. Based on the analysis of your experiments in this lab and on the extremely bold assumption that the mathematical relationship you found can be extrapolated to very large sizes into solid rock, we will now predict the size of Barringer Crater.

18. It has been determined that the impactor was metal approximately 40 m in diameter with a mass of about  $3 \times 10^{11}$  g. It likely impacted the earth at a velocity of  $1.3 \times 10^6$  cm/s giving a kinetic energy of about  $2.5 \times 10^{23}$  ergs. Plug this energy into your relationship to determine the predicted diameter of the crater. (Hint: the spreadsheet does this for you.)
19. How does the predicted diameter compare to the actual diameter of 1.2 km ( $1.2 \times 10^5$  cm)?
20. Taking into consideration that you extrapolated this relationship pretty far (note that the kinetic energies in the lab varied from  $10^5$  to  $10^7$  and for Barringer crater is a whopping  $10^{23}$ ), do you consider your prediction Confirmed, Plausible, or Busted? Explain. Save your spreadsheet or e-mail to the instructor.



<b>Composition</b>	<b>Size</b>	<b>Mass (g)</b>
Steel	3/8"	3.54
Steel	13/32"	4.50
Steel	7/16"	5.63
Steel	1/2"	8.40
Steel	5/8"	16.4
Steel	3/4"	28.3
Steel	1"	67.2
Wood	1/2"	0.8
Wood	3/4"	2.3
Wood	1"	6.4
Wood spool	3/4" x 1"	4.0
Wood spool	3/4" x 5/8"	1.8
Glass	1/2"	3.7