Saturday Morning Astrophysics at Purdue

Impact Cratering

Forty-nine thousand years ago, an asteroid smashed into into a smooth, peaceful plateau in northern Arizona. In the following seconds, The massive explosion from the event expelled 175 tons of rock in a matter of seconds, creating a crater nearly a mile wide and almost 600 feet deep.

The formation of impact craters, however, is a process that is much more complicated than an impactor like a meteor or asteroid simply smashing into a surface. The impactor, as well as the bedrock, plants and animals at the site of impact are instantly vaporized, similar to the effects of a nuclear blast.

The Barringer Crater in northern Arizona

In this experiment, you will try to create **models** of impact craters to explore how the **energy** resulting from an impact affects the physical features of a resulting crater.

What is Energy?

Energy is defined as the "capacity for doing work" (like making objects move), and can exist in many forms (kinetic, potential, chemical, nuclear, heat, light, and others). The transformation of one form of energy to another or exchange of energy between objects is "work".

- Kinetic Energy (*KE*) is energy related to motion. It depends on the **mass** (***m***) of an object, and **how fast** it is moving (v).

$$KE = \frac{1}{2} \times m \times v^2$$

- Potential Energy (*PE*) is energy related to **state** or **position** of an object, for example, how much something is bent or stretched, or (in the case of an object beginning to fall to Earth) **how high** it is.

In this experiment you will calculate the potential energy of your "meteor" from the effects of Earth's gravity:

Gravitational potential energy depends on the mass (***m***) of the meteor, Earth's gravitational constant (***g***), and the height (***h***) of the meteor above the ground. The gravitational constant (***g***) for Earth = **9.8 m/s^2**.

$$\text{Gravitational } PE = m \times g \times h$$

Physicists rely on a very important principle, called the **Law of Conservation of Energy**. In this experiment, potential energy from gravity will converted to kinetic energy of the meteor (the stone). But, the total energy throughout the process remains the same – **energy is conserved**, in other words, no energy is lost. Written as a mathematical equation,

$$KE\ (final) = PE(initial)$$

Materials you will need (Check out the video, https://bit.ly/3e6GpvZ)

- 5 lb baking flour (whole wheat flour seems to work well)
- Metal roasting pan or wide metal or plastic mixing bowl or storage container (3-4 in deep)
- 2 lb corn meal, dyes with food coloring(1)
- Disposable plastic drop cloth, old sheet or newspapers
- Masking tape (to hold the drop cloth or newspapers in place) if necessary
- 4 or 5 smooth stones (often called river rock) of different sizes (2 cm to 6 cm across)
- Ruler with metric scale (to measure crater diameter)
- Meter stick (yard stick or contractor measuring tape is fine)(2)
- Calculator
- Flashlight (mobile phone light works well; gives dramatic cross lighting of craters)
- Scale capable of measuring up to 200 g (food scale is fine)(3)

(1) Dyed cornmeal will cover the surface of the terrain. Chocolate pudding mix, chocolate milk powder, or powdered paint are alternatives, as well as dry ground coffee. Additional items are for dying and drying the cornmeal (see Part 1 below) include food coloring, cookie sheet, aluminum foil, measuring cup.

(2) Measurements in inches can be converted to metric; 1 inch = 2.54 cm.

(3) If you do not have a scale available, no problem; you can approximate the mass of small (river rock) stones. (See Part 1, step 4.)

Safety

1. Please perform these activities with responsible/adult supervision.
2. If you have safety glasses, wear them.
3. The flour substrate and top soil layer will splatter and find its way to all surrounding areas.
4. Flour on the drop cloth or floor can be slippery; be careful.
5. Use caution if you dry the colored corn meal in the kitchen oven; cookie sheets will be hot!

Part 1: Preparing the impact materials

The terrain into which you will drop your meteors will consist of two layers spread into large bowl or roasting pan. The flour will be topped with a dark colored powdery material. Options include:

- Powdered paint (Tempura or other water based paint powder; at art/hobby stores)
- Chocolate pudding mix
- Ground coffee
- Dyed cornmeal

If you want to dye the cornmeal:

1. Add the equivalent of a small bottle of food coloring to half a cup of water. Dump the corn meal into a large mixing bowl, pour in the colored water and stir until the color is uniform (a whisk works well).
2. Line a cookie sheet with aluminum foil and spread half of the damp cornmeal around the foil. The foil will make it easier to pour the corn meal back into the container after it is dry.
3. Dry the first half of the cornmeal in a low (200 ^{o}F) oven. After about an hour, take a spoon to re-distribute the meal and then return to the oven until dry. Pour the dyed and dried cornmeal back into the container and dry the remaining half. (You can also let the cornmeal air dry; it will just take longer.)

You need to know the mass of the stones you will be using. If you do not have a scale handy, you can find an approximate mass of river rocks from their estimated volume and the average density of that kind of stone (most commonly granite).

Finding the mass of your stones (if you have a scale to measure grams, skip this part!):

1. Measure the length, width and height (x, y and z axes) of the stone (in cm) and take the average. We will use this average as the diameter of an approximate "sphere" (the stone).

$$\frac{length + width + height}{3} = \ average\ \text{"}diameter\text{"}\,\text{of the stone}$$

2. Using that average as an average diameter of the stone, first divide by 2 to find the radius, then calculate the volume of the stone.

$$Radius\ (r) = \ \frac{diameter}{2} = \ \_\_\_\_\_\_\_\_\_\_\_\_\_\ cm$$

$$Volume\ of\ a\ sphere = \frac{4\,\pi\, r^3}{3} = \ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\ cm^3$$

3. Once you estimate the volume of the rock, you can find the mass from the average density of granite rock (2.65 g/cm3:

$$Mass\ = \ density\ x\ volume\ = \ \frac{2.65\ g}{cm^3}\ x\ volume\ = \ \_\_\_\_\_\_\_\_\_\_\_\_\_\ g$$

   *Or…, you can use the graph, Mass of River Rock Stones vs Estimated Volume at the end of this handout. Locate the estimated volume on the x axis, go up to the red line, and then to the corresponding mass on the y axis.

4. Record the mass of your stone in Part 2 #4 below.

Part 2: Setting up

In the experiments that follow, you will be dropping your model meteor into sand from different heights, to compare the relationship between the kinetic energy of the impactor and characteristics of the crater formed.

1. Write the general equation (from **What is Energy**, above) that will you use to calculate the **potential energy** of the meteor at the height from which you drop it. Label each of the terms. What are the units for energy?
2. What is the quantity you will use for g, the gravitational constant in the above equation?

   (include units.) ______________________
3. Select a medium size stone from those you have with a mass of between 50-60 grams (a stone 4-5 cm across.
4. Record the mass of your meteor in **kilograms (kg):** ______________________ **kg**.

Part 3: Dropping the Meteor

1. Work on covered a surface. The floor is good, but use a drop cloth, newspapers or old sheet.
2. In the middle of your working area, pour flour into the roasting pan or bowl to a depth of about 8 - 10 cm.
3. Sprinkle a very thin layer of colored “soil” over the flour to dust the surface.
4. Make 8 drops from different heights, ranging from 20 cm to 200 cm (2 m) above the surface of the flour; record the drop height and crater diameter of each trial in Table 1, on the next page.
   - Measure the height from the top of the flour, not the floor or bottom of the pan.
   - Between drops, you may want to smooth the surface with a small ruler or index card.
   - Remember 100 cm = 1 m

Table 1. Drop height versus kinetic energy

Trial	**Drop height (*h*)**	**Crater diameter**	**Initial Potential Energy** $(\boldsymbol{PE = mgh})$	**Kinetic Energy (at impact)**
1	_________ cm = _________ m	_________ cm = _________ m	___________ J	___________ J
2	_________ cm = _________ m	_________ cm = _________ m	___________ J	___________ J
3	_________ cm = _________ m	_________ cm = _________ m	___________ J	___________ J
4	_________ cm = _________ m	_________ cm = _________ m	___________ J	___________ J
5	_________ cm _________ m	_________ cm _________ m	___________ J	___________ J
6	_________ cm _________ m	_________ cm _________ m	___________ J	___________ J
7	_________ cm _________ m	_________ cm _________ m	___________ J	___________ J
8	_________ cm _________ m	_________ cm _________ m	___________ J	___________ J

Use your data for trial 1 to calculate the potential energy, and have someone check your work before you proceed. Be sure to include the units in your answer.

$$\boldsymbol{PE}\ (\boldsymbol{gravity}) = \boldsymbol{mass}\ (in\ kg) \times \boldsymbol{g} \times \boldsymbol{h}\ (in\ meters)$$

Think about it…

1. What is the kinetic energy of the meteor at the instant before you released it.

2. What happens to the kinetic energy *during* the time the rock was falling?

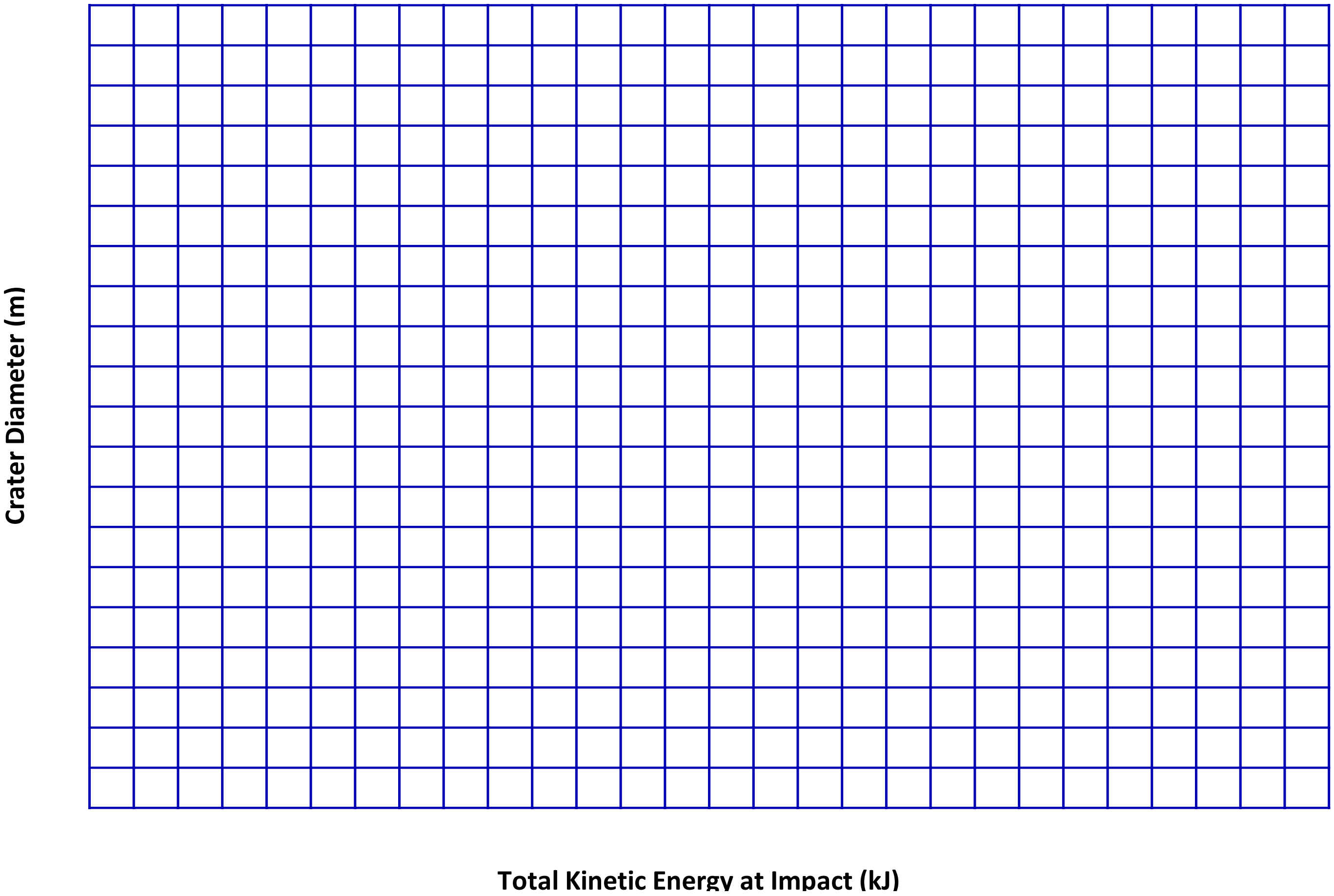
3. What would the kinetic energy of the meteor be the instant *after* impact?

4. What would the potential energy be the instant after impact?

5. In what form do you think the energy is the instant after impact? In other words, what happened to the kinetic energy at impact?

Part 4: Data Analysis

Plot your data on a graph using the template on the next page, showing the relationship between kinetic energy (***KE***) and crater **diameter**. Figure out a scale to each axis that fits your data. Draw a best-fit straight line through your data points.



Kinetic Energy versus Crater Diameter

1. Write a sentence to describe the relationship between kinetic energy and crater diameter.

2. Select two convenient points on the straight line of your graph and show how you would calculate the **slope** of the line. (You will use this later for The Santa Problem, below.)

3. Besides diameter, what characteristics of real impact craters did you see in your experiment? Were there any characteristics of real craters that you didn't see?

4. In real impacts events, the crater formed is 10-20 times larger in diameter than the diameter of the impactor. What do you think you could explain this

Part 5: Mass versus Energy (Optional)

If you are up for a little more adventure, you can try dropping meteors of **different mass** from the **same height**. What do you think you will find?

Part 6: The Santa Problem – Oh no!

Santa's delivery of a new Tesla Model S unfortunately drops from the sleigh at a height of 35,000 m. The mass of the Tesla is 4969 lb. Based on your graph from Part 3 (your calculate slope), and assuming that the Tesla drops into a powdery landscape of flour, show the steps you would follow and calculate the diameter (in m) of the crater the Tesla might make upon impact. (1 kg = 2.2 lb)

Part 7: Understanding Real Impacts

One way with which we can better understand things that are difficult to measure or observe is to create simulation models. ***Impact Craters!*** is a simulation created by researchers at Purdue that will let you observe the effects of some known impacts and also let you create your own.

Go to the link, https://www.purdue.edu/impactearth/, or just search Impact Earth. This is what you'll find. The variables highlighted are the ones you will most likely want to vary.

PARAMETERS
Projectile Diameter: 0 m
Projectile Density: 0 kg/m^3
Angle of Impact: 45 degrees
Velocity: 11 km/s
Target Type: Sedimentary Rock
Distance from Impact: 0 km

* All fields are required

Start by selecting **FAMOUS IMPACTS** at the top of the screen. Select and run the simulations for several well-known impacts. And look at the variables (e.g., diameter, angle, velocity).

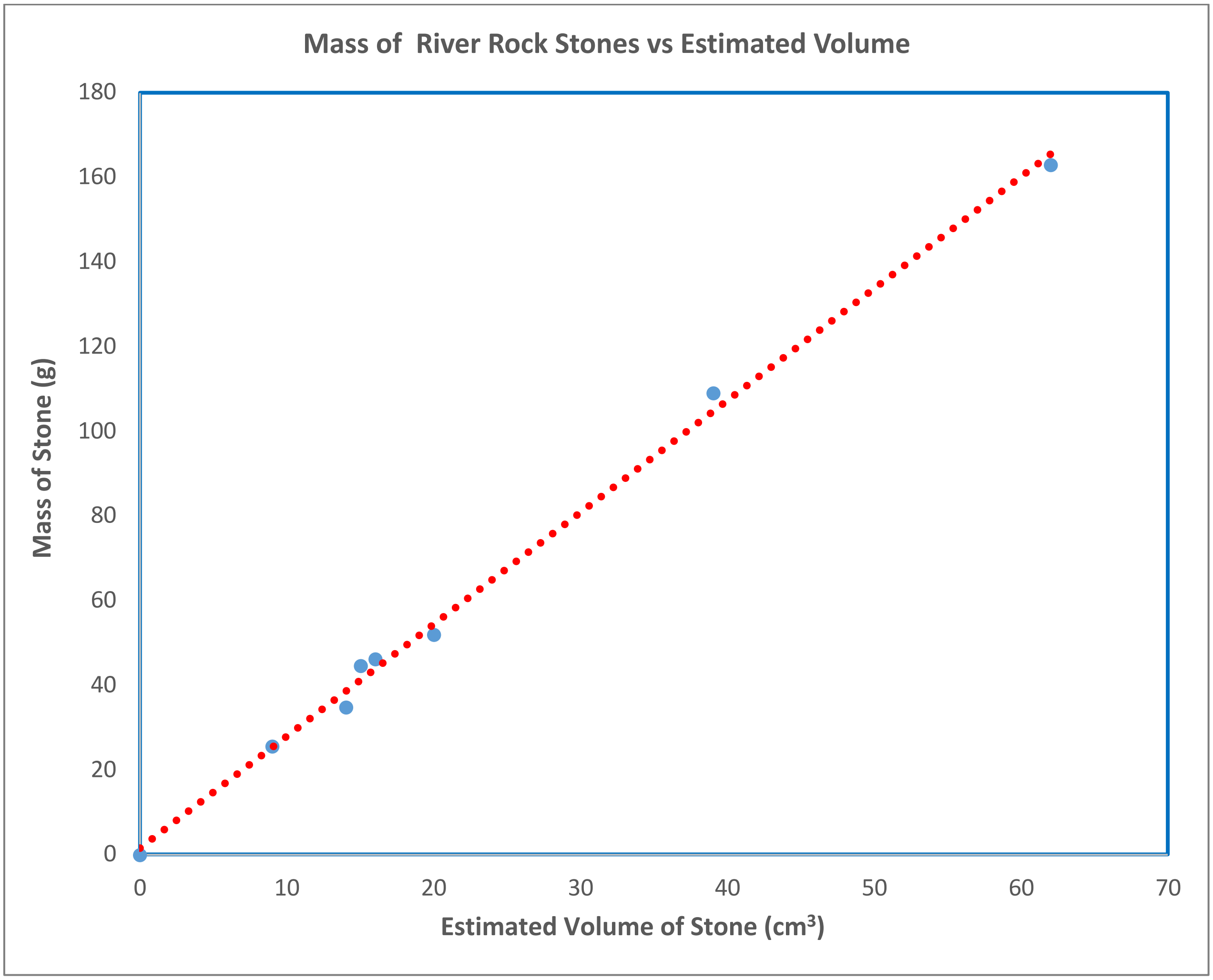
- In what ways (which variables) are these actual impacts similar?

- In what ways are they different?

Choose a distance from impact for any of the above examples and compare zones of relative destruction.

Now, try your hand at creating your own destruction, and have some fun!

More Resources
https://www.lpi.usra.edu/science/kring/epo_web/impact_cratering/enviropages/Barringer/barringerstartpage.html#:~:text=Forty%2Dnine%20thousand%20years%20ago,wide%20and%20570%20feet%20deep.


Mass of River Rock Stones vs Estimated Volume
Mass of Stone (g)
Estimated Volume of Stone (cm³)
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60
70