SMAP
Saturday Morning Astrophysics at Purdue

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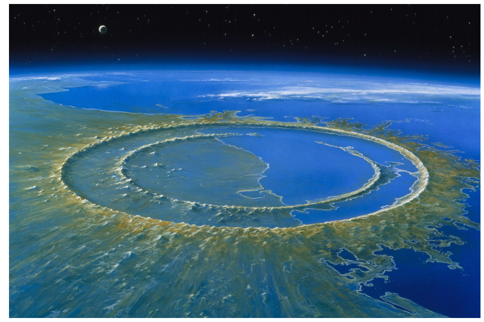
Impact Cratering



The formation of impact craters is process that is much more involved than an object simply smashing into a surface. In this experiment, however, you will be able to explore how a meteor's **energy** might affect the **size** of a crater. You will do this by modeling a meteor with a ball bearing, and using a slingshot to fire the crater into a sandbox. In order to determine how the energy affects the size of the crater, we will use the Law of Conservation of energy.

What is Energy?

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

1 Joule = kg m^2 / s^2.

- 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 how high it is. In this experiment you will calculate the potential energy of your "meteor" from two sources, the Earth's gravity and a slingshot:

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

   Gravitational $$PE = m \times g \times h$$

2. **Spring potential energy** comes from the slingshot (a spring) and will depend on the **mass** (***m***) of the meteor, the **distance** (***s***) you stretch the spring, and the spring's stiffness, called the **spring constant** (***k***).

   Spring (slingshot) $$PE = \frac{1}{2} \times k \times s^2$$

The constant (***k***) measures how springy or stiff a material is. Stiffer materials have higher k values than more stretchy materials.

Conservation of Energy

Physicists often rely on a very important principle, called the **conservation of energy**. In this experiment, potential energy (from gravity and the slingshot) will converted to kinetic energy in the meteor (steel marble). But, the total energy throughout the process remains the same – **energy is conserved**, in other words, no energy is lost.

$$\boldsymbol{KE\ (final) = PE(initial)}$$

Copy the correct parts (red text) from equations on page 1, to complete the equation below:

Kinetic Energy (meteor) = ____________________ + ____________________

Potential Energy (gravity) Potential Energy (slingshot)

Materials for each group

- Steel marble
- Slingshot
- Clamp
- Sandbox
- Spoon (for meteor retrieval)
- Pencil
- Small metric ruler
- Safety glasses
- Scientific calculator
- Electronic balance
- Weighing dish or small cup
- Flashlight or mobile phone light (optional)

Safety

1. You must wear safety glasses at all times.
2. Aim well! Be careful to launch your meteor into the middle of the sandbox.
3. The sand you will use is mixed with powdered paint. It is messy and will stain your fingers and clothes. Use the large spoon to retrieve your meteor after each drop.

Before you begin: Give your team a name: ____________________________________

Assign jobs. Write the name(s) of the team member(s) who will:

1. Drop or launch the meteor ____________________________
2. Make measurements (length, height, diameter) ____________________________
3. Record the data ____________________________
4. Supervise aim ____________________________

Part 1: Dropping the Meteor

In this experiment, you will be dropping a meteor into sand from different heights.

1. Write the equation will you use to calculate the potential energy of the meteor at the height from which you drop it?

2. Write the value you will use for g, the gravitational constant (include units). ______________
3. Record the mass of your meteor in **kilograms (kg):** ______________________ **kg**.
4. Sprinkle a very thin layer of paint powder over the sand to just cover the surface.
5. Place the tray on the floor next to your table.
6. Make 5 drops from different heights; record the drop height and crater diameter of each trial.
   - Between drops, you may want to smooth the surface of the sand with a small ruler.
   - Remember 100 cm = 1 m

Table 1. Kinetic Energy and Diameter from Dropping

Trial	**Drop height (*h*)**	**Crater diameter**	**Potential Energy** $PE = mgh$	**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

Do the calculation using your data for trial 1 and have your teacher check your work before you proceed.

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

Now, what do you think?

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

2. What energy conversions take place *during* the time it was falling?

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

Part 2: Firing the Meteor with Slingshot

In this part of the experiment, you will be using a slingshot to accelerate your meteor into the sand. Write the (*two*) equations you will use to calculate the combined potential energy for your steel meteor.

Remember, the stiffness or "strength" of a spring is described by its **spring constant** (***k***).

Copy down the spring constant (***k***) for the material used in your slingshot **k =** _____________ **kg/s²**.

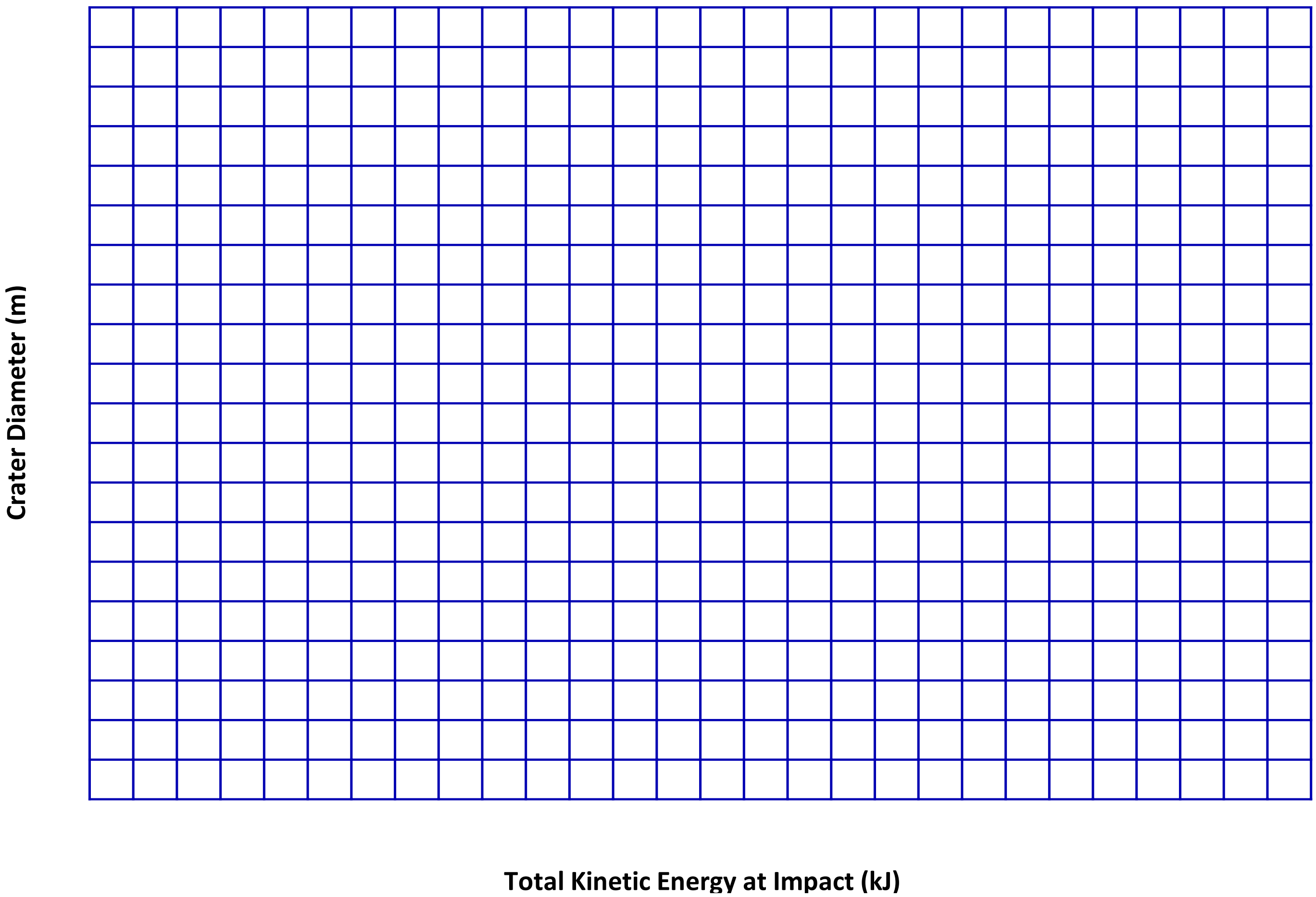
1. Try to make as many impacts as you can, from different heights. Enter your data and calculation results for Part 2 in the separate page, **Data Table 2**.
2. Prepare your slingshot by <u>firmly</u> clamping it in place so that the jaw projects about 6 inches from the edge of the table.
3. Place your tray of sand directly below the elastic band of the slingshot and, if necessary, sprinkle a little more paint powder over your sand.
4. To begin, measure and record in Table 2:
   - The length of the relaxed (unstretched) elastic band on the slingshot (l), and
   - The distance of the board above the sand (d).
5. For <u>each trial</u>, measure and record in Table 2:
   - The distance (p) you pull the elastic band above the slingshot board, and
   - Then calculate and record the stretch distance).
6. Do the calculation using your data for trial 1 and have your teacher check your work before you proceed):

$PE\ (gravity) = m \times g \times h$	$PE\ (slingshot)\ \frac{1}{2} \times k \times s^2$

Part 3: Data Analysis

Make a graph, showing the relationship between kinetic energy (***KE***) and crater diameter. Decide on for scale to each axis that fits your data. Draw a best-fit 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. Besides diameter, what characteristics of real-world craters did you see in your experiment? Were there any characteristics of real craters that you didn't see?

3. For real meteor impacts, what do you think happens at the moment of impact when the meteor strikes the Earth's surface?

Part 4: 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 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.

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!

Impact Craters - Teacher Notes:

Useful demos:

- KE/PE/heat conversions with Therabands (material used for the slingshots). Hold to lip or forehead, pull away, rapidly stretch and touch again to feel generated heat (work).

Clarifying concepts

- Springs (or materials) with different spring constants
  - Define what k represents
  - Everything in life is a spring
  - Consider the slingshot board itself
- Discuss the concepts of work and energy transformations; give/show examples
- Conservation (bouncing ball or Newton's Cradle as demos).
  Energy conversions, to heat, sound, light, work, mechanical energy, friction, etc.

Pedagogy:

- Intro PowerPoint; limit to no more than 10 minutes, just wo wet the apetite and set the stage. The remainder of the presentation (15 minutes) will come at the end and summarize these experiments, relative to real impact events.
- Demo how to retrieve the steel marble; the paint is dirty; don't get sand all over the floor.
- Only provide materials for **Part 1** and review results before going to **Part 2**.
- Work through algebra as a group to derive equations; talk about and give examples of the variables to reduce the fear from seeing all the symbols.
- Have students do trial 1 and work through all of the table data entry and calculations to be clear on purpose.
- Review results and discuss ideas and answers from Part 1; start Part 2 all together as a group.
- Before students get the slingshots, demo the procedure; refer to the instructions, step by step, as necessary, in particular,
  - How to position the clamp
  - Measuring the unstretched elastic band (will be the same for all trials)
  - Measuring the stretch
  - Aiming the projectile

- **Time**- students will need 1:35-1:45 to do all of the trials in both parts 1 and 2. For upper level classes, Part 1 may be skipped; it is intended to give younger students an opportunity to become familiar with the types of calculations they will make.
- **Technique** – Data from both parts 1 and 2 can be combined for the class on one spreadsheet and graphed. To do this, however, consider the differences students may have in their techniques – measuring the crater diameters, for example. Some may measure from inside or the rim, some, outside. This can be brought out in discussion, as to variations across groups that may increase the scatter of the data, or consider discussing standard techniques beforehand.
- **Typical values** – the range of potential energies using the Theraband slingshots is typically about 2 to 50 joules.

Safety:

- The slingshots develop a lot of force. Warn students, and watch closely about staying clear when the slingshots are pulled back. They must wear safety glasses.
- When clamping the slingshots to the table top, position the clamp such that protruding parts are pointed downward instead of upward where a student could easily poke themselves.
- Teachers should double check to assure that the clamps holding the slingshots are **tight**.
- When pouring the sand to and from the trays, particularly sand that has been previously used, avoid breathing the dust generated; wear a mask or do it outside, it can be a dirty procedure.

Clarifications as necessary

- Demonstrate how to calculate stretch (s), using pull and the length of the unstretched elastic band.
- Starting Part 2, remind students of the variables (i.e., "what is **s, l, h**", etc.) are.

Wrapping up / Making sense:

- Wrap up with some images of assorted craters (both on Earth and other planets and moons) and compare the features of these with images from our own experiments (rim, rays, etc.).
- Discuss relevant comparisons between our experiments and real impact events:
    - Consider that the Earth and our moon have experienced essentially the same number of impact events.
    - At impact KE is transformed to heat, sound, light, work…
    - How can we tell relative ages of impact craters?
- Provide examples of artifacts from real impact events, that students can handle; shatter cone fragments; meteor remains, with explanations.
- As time permits, and just for fun, demonstrate the web simulation, **Impact Earth**. Students can also do this at home.

Therabands

We use therapeutic Therabands of different resistance in making the slingshots. By color, the calculated spring constants are:

Color of Band	Spring Constant (k, kg/s^2)
Yellow	129
Blue	174
Red	182
Green	200
Grey	333

Material preparations

We use fine silica sand for a substrate, covered with Tempura powdered paint "topsoil" to provide a contrast between layers for easier measurement of crater diameter. An alternative could be powdered cocoa.