■ ★ 2.0 hours

Impact Cratering

Instructor Notes

Suggested Correlation of Topics

Craters on planets and satellites, gradation, impact mechanics, physics

Purpose

This exercise demonstrates the mechanics of impact cratering and will show the student impact crater morphologies. Upon completion of this exercise the student should understand the relationship between the velocity and mass of the projectile and the size of the resultant crater. The student should also be able to identify the morphologic zones of an impact crater and, in certain cases, be able to deduce the direction of the incoming projectile.

Materials

Suggested: If performed as an instructor demonstration: one set of the following:

- sand (very fine and dry), tray (e.g., kitty litter box), dyed sand, slingshot, scale, ruler, lamp, calculator, safety goggles, drop cloth, fine screen or flour sifter
- projectiles: 4 different sizes of steel ball bearings; 4 identical ball bearings of one of the intermediate sizes, one each of the three other sizes (sizes should range from 4mm to 25 mm)
- 3 identical sized objects with different densities (e.g., large ball bearing, marble, balsawood or foam ball, rubber superball)

If performed by students: enough sets of the above list for all students/groups.

Substitutions: dry tempera paint can be dry-mixed with sand to make dyed sand (but do not get this mixture wet!), a thick rubber band can be substituted for a slingshot.

Background

This exercise demonstrates the mechanics of impact cratering and introduces the concept of kinetic energy (energy of motion): $KE = 1/2\ (mv^2)$, where m = mass and v = velocity. The effects of the velocity, mass, and size of the impacting projectile on the size of the resultant crater are explored. By the conclusion of the exercise, the student should understand the concept of kinetic energy, and know that the velocity of the impactor has the greatest effect on crater size [$KE = 1/2\ (mv^2)$].

Use of a slingshot to fire projectiles is required in this exercise. It is the instructor's decision whether this exercise should be done as a demonstration or by the student. Students should be supervised carefully at all times during the firing of the projectiles and everyone should wear protective goggles. Place the tray on a sheet of plastic or drop cloth; this will make cleanup easier. Fill the tray completely with sand, then scrape the top with the ruler to produce a smooth surface. The dyed sand is best sprinkled on the surface through a fine screen, or a flour sifter.

This exercise requires the calculation of kinetic energies. All of the velocities necessary for these calculations have been provided in the student's charts. Calculation of velocity for dropped objects is simple using the formula:

$v = (2ay)^{.5}$ where v is the velocity, a is the acceleration due to gravity ($9.8\ m/s^2$), and y is the distance dropped

Calculation of the velocity for objects launched by a slingshot is a time consuming procedure for values used in only two entries in the exercise; however, it is an excellent introduction to the physics of motion and can be done in a class period before performing this exercise. The procedure for calibrating the slingshot and for calculating velocities of objects launched by the slingshot follows the answer key (where it may be copied for student use).

Advanced students and upper classes can answer the optional starred (*) questions, which apply their observations to more complex situations.

Science Standards

- Earth and Space Science
  - Origin and evolution of the Earth system

Mathematics Standards

- Geometry
- Computation and Estimation
- Measurement

Answer Key

1. **a.** The crater.

   b. Undisturbed surface layer of sand.

   c. No.

   d. Thick and continuous near the crater, thin and discontinuous far from the crater.

2. Not much, although the ejecta of the 65° impact may be slightly oblong.

Part B

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1	1.4	~0.002	0.00196	~2
Shot 2	6.3	~0.002	0.03969	~4
Shot 3	14*	~0.002	0.196	~5
Shot 4	69*	~0.002	4.761	~11

* velocities are approximate; NM = Newton x meter

Part C

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1 (4 mm)	6.3	~0.00034	0.0067473	~2.5
Shot 2 (8 mm)	6.3	~0.002	0.03969	~3.5
Shot 3 (18 mm)	6.3	~0.028	0.55566	~7
Shot 4 (25 mm)	6.3	~0.067	1.329615	~7

Part D

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1 (steel)	6.3	~0.028	0.55566	~7
Shot 2 (glass)	6.3	~0.008	0.15876	~6
Shot 3 (wood)	6.3	~0.002	0.03969	~3.5

3. As impact angle decreases toward 10°, ejecta becomes more oblong pointing downrange. Ejecta is absent on the uprange side of the crater.

4. **a**. Low angle.

   b. Entered from the east and bounced off the surface leaving two craters with an oblong ejecta pattern.

5. **a.** The higher the kinetic energy, the larger the crater.

   b. Higher velocities produce larger craters.

   c. Larger masses produce larger craters.

   d. Larger sizes (of the same density material) produce larger craters. Mass (density) is the controlling factor. Size (radius) is not a factor in the equation for kinetic energy.

   Instructor's note: Impacting objects in space have different densities. For example, meteorites occur as high density objects (iron meteorites) or as lower density objects (stony meteorites). Comets are composed mostly of water ice and have relatively low density. Like the foam ball, impacting comets might not form a crater at all.

   e. Velocity of the projectile is most important, as shown by the kinetic energy equation.

*6. Craters are better preserved on flat terrain. In rugged areas, craters can be modified by landslides (mass wasting).

Calibrating the Slingshot

Objective

To determine the initial velocity of a mass that is propelled by a slingshot.

Background

This procedure applies two physical laws, Hooke's Law and the Law of Conservation of Energy. Hooke's Law (F=kx) states that the force (F) applied to an elastic material depends upon how stiff the material is (k) and how far you pull the elastic material (x). The stiffness of the elastic material (k) is small if the elastic material is soft, and large if the elastic material is stiff. The Law of Conservation of Energy (W = PE = KE) states that there is a relationship between work (W) performed on a system (the force applied to an object to move it a certain displacement in the same direction as the force is acting) and the potential energy (PE, stored energy) of a system and the kinetic energy (KE, energy of motion) of the system. The equations for Hooke's Law, work, and potential energy are derived from a graph of force versus elongation.

The velocity term that we want to solve for is found in the kinetic energy portion of the Law of Conservation of Energy.

KE = $1/2\ mv^2$, where m is the mass of the object being launched and v is the velocity.

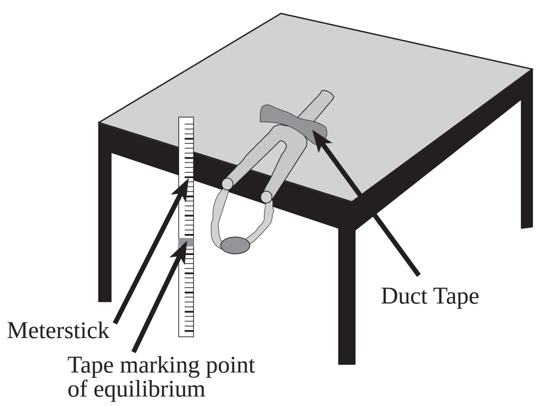
The potential energy of elasticity is a combination of Hooke's Law and work.

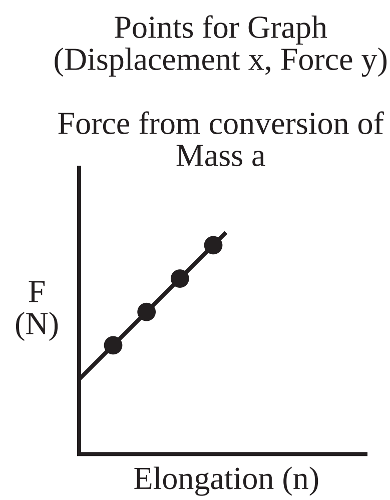
PE = $1/2kx^2$ where k is the spring constant and x is the elongation distance of the slingshot—how far back it is pulled.

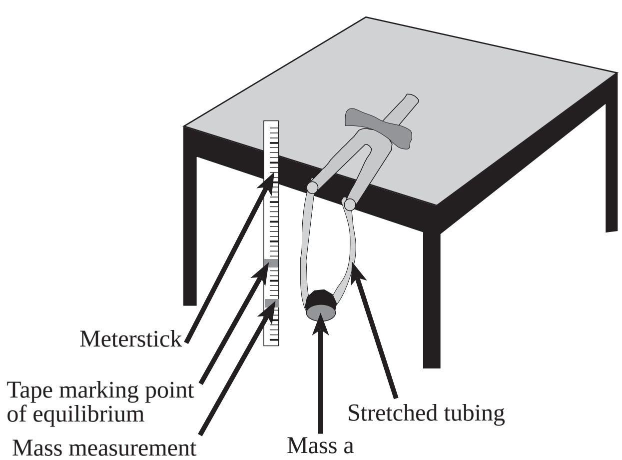
Because the Law of Conservation of Energy states that the potential and kinetic energies of a system are equal, we can set these equations equal to each other.

$1/2mv^2 = 1/2kx^2$; solving for v gives: $v = (kx^2/m)^{.5}$

We will control x (the distance pulled back) and will measure m (the mass of the object being launched). But to solve for v (the velocity) we must first calibrate the slingshot by experimentally solving for the spring constant, k.







How to Solve For k

1. Place the slingshot on the edge of a table or counter so that the elastic band hangs free. Immobilize the slingshot by placing a large weight on it or by duct-taping it to the counter. Rest a meter stick on the floor and tape it along side the slingshot. Pull down on the elastic tubing of the slingshot until all the slack is taken out, but do not stretch the tubing. Mark this point on the meter stick. This is the point of equilibrium.

2. Place slotted masses in increments of 100, 150 or 500 grams (depending on the stiffness of the slingshot) in the pocket of the slingshot until it begins to elongate or stretch past the point of equilibrium. This initial mass is called the "preload force" and is not counted as a recordable force in the data table. (On the graph of force versus elongation, the preload force will appear as a y-intercept.) Once the slingshot starts to elongate or stretch, begin recording the amount of mass you are adding to the pocket and how far from the point of equilibrium the pocket is displaced. Maximize your range of data! Keep taking measurements until you have 7 or 8 data points.

3. Convert the mass from grams into kilograms and multiply by 9.8 m/s^2 to get force in the unit of Newtons.

   example: 150 g (1 kg/1000g) = .150 kg; .150kg(9.8 m/s^2) = 1.47 N

   Convert the elongation measurements from centimeters to meters. Now you are ready to graph force (in Newtons) versus elongation (in meters).

4. Graph force (on the y-axis) versus elongation (on the x-axis). The graph will be a linear function with the slope representing the spring constant, k (in N/m). If you are using a computer graphing program it will automatically calculate the slope and y-intercept of the graph. If you are graphing on graph paper, calculate the slope of the graph using two data points and the equation: slope = $(y_2-y_1)/(x_2-x_1)$

   example: (3,5) (4, 6) slope = (6-5)/(4-3) = 1/1 = 1 N/m, in this case k = 1 N/m

   If the graph has a y-intercept, disregard it (it is simply part of the preload force).

   The slope of the line is the value of the spring constant, k, and can now be used in the velocity equation above.

Name ______________________________

Impact Cratering

Purpose

To learn about the mechanics of **impact cratering** and the concept of **kinetic energy;** and to recognize the **landforms** associated with impact cratering.

Materials

For each student group: Sand, tray, colored sand, drop cloth, screen or flour sifter, slingshot, safety goggles(one for each student), triple beam balance, ruler, lamp, calculator

Projectiles: 4 different sizes of steel ball bearings: 4 identical ball bearings of one of the intermediate sizes, one each of the three other sizes; 3 identical sized objects with different densities (large ball bearing, marble, wood or foam ball, rubber superball)

Introduction

Impact craters are found on nearly all solid surface planets and satellites. Although this exercise simulates the impact process, it must be noted that the physical variables do not scale in a simple way to compare with full-size crater formation. In other words, this exercise is a good approximation but not the real thing.

Impact craters form when objects from space, such as asteroids, impact the surface of a planet or moon. The size of the crater formed depends on the amount of kinetic energy possessed by the impacting object. Kinetic energy (energy in motion) is defined as: $KE = 1/2\ (mv^2)$, in which m = mass and v = velocity.

Weight is related to the mass of an object. During impact the kinetic energy of the object is transferred to the target surface.

Safety goggles must be worn whenever the slingshot is in use!

Procedure and Questions

Part A

Place the tray on the drop cloth. Fill the tray with sand, then smooth the surface by scraping the ruler across the sand. Sprinkle a very thin layer of the colored sand over the surface (just enough to hide the sand below) using the flour sifter. Divide the tray (target area) into four square shaped sections, using the ruler to mark shallow lines in the sand.

In one section produce a crater using the slingshot to launch an intermediate size steel ball bearing straight down (at 90°, vertical) into the target surface. The slingshot should be held at arms length from sand surface (70 to 90 cm) facing straight down into the tray. Do not remove the projectiles after launch. ***Use the space on the following page to make a sketch of the plan (map) view and of the cross section view of the crater.*** Be sure to sketch the pattern of the light-colored sand around the crater. This material is called **ejecta**. Label the crater floor, crater wall, crater rim, and ejecta on the sketch.

1. **a.** Where did the ejecta come from?

   b. What would you expect to find beneath the ejecta?

Sketch area

c. Would you expect the ejecta to be of equal thickness everywhere?

d. What is the ejecta distribution and thickness in relation to the crater?

In the next section of the target tray, produce a crater using the slingshot to launch a steel ball bearing (the same size as above) at 65° to the surface. The angle can simply be estimated. The end of the slingshot should still be 70 to 90 cm from tray. Be certain no one is "down range" in case the projectile ricochets. ***Sketch the crater and ejecta in plan view on the space provided below.***

Sketch area

2. Is there an *obvious* difference between the two craters or ejecta patterns?

In the third section of the target tray, produce a crater using the slingshot to launch a steel ball bearing (the same size as above) at 45° to the surface. Again, estimate the angle. The end of the slingshot should still be 70 to 90 cm from the tray. Be certain no one is "down range" in case the projectile ricochets. ***Sketch the crater in plan view on the space provided on the following page.*** As above, label the parts of the crater.

Sketch area

In the fourth section of the target tray, produce a crater using the slingshot to launch a steel ball bearing (the same size as the previous exercise) at about 5 to 10° to the surface. Again, estimate the angle, and make sure not to hit the rim of the tray. The end of the slingshot should still be 70 to 90 cm from tray. Be sure no one is "down range" in case the projectile ricochets. ***Sketch the crater in plan view and cross section on the space provided below.***

Sketch area

Examine the sand craters and your sketches.

3. How does ejecta distribution change with impact angle?

Examine Figure 4.1, a photograph of the lunar crater Messier.

4. **a.** Was this a high angle or low angle impact?

b. Did the meteoroid which formed Messier impact from the east or west?

Part B

Remove the four steel ball bearings from the sand tray and thoroughly mix the sand and colored sand to produce a uniform mixture. Smooth the target surface with the ruler. The remaining experiments will be performed without a colored upper layer of sand. Divide the target area into four sections as before.

Produce four craters on the smooth target surface, using the same four identical steel ball bearing as in *Part A*. Find the mass of one of the projectiles before launching it and enter the value in the table below.

- Make the first crater by dropping the projectile from a height of 10 cm above the surface. Measure the diameter of the crater formed and enter the value in the table.
- For the second crater, drop the projectile from a height of 2 meters. Measure the crater diameter and enter it in the table.
- The third projectile should be launched with the slingshot 70 to 90 cm above the tray and with the rubber tubing pulled back slightly (extended ~3 cm). Measure the crater diameter and enter it in the table.
- For the last crater, extend the slingshot ~15 cm. The slingshot should still be 70 to 90 cm above tray. Measure the crater diameter and enter it in the table.
- Calculate the kinetic energy of each projectile and enter the values in the table.

Part B

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1	**1.4**			
Shot 2	**6.3**			
Shot 3	**14***			
Shot 4	**69***			

** velocities are approximate*

Part C

Remove the projectiles and smooth the target surface with the ruler. Divide the target into four sections. Find the mass of each projectile and enter the values in the table below. Produce four craters by dropping 4 different sized steel ball bearings from a height of 2 meters above the target surface. Measure the crater diameter produced by each impact. Enter the projectile mass and resultant crater diameters in the table below. Calculate the kinetic energy of each projectile and enter the values in the table on the next page.

Part C

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1 (smallest)	**6.3**			
Shot 2 (next larger)	**6.3**			
Shot 3 (next larger)	**6.3**			
Shot 4 (largest)	**6.3**			

Part D

Remove the projectiles and smooth the target surface with the ruler. Divide the target into three sections. Find the mass of each projectile and enter the values in the table below. Produce three craters by dropping 3 identical size, but different mass, projectiles from a height of 2 meters above the target surface. Measure the crater diameter produced by each impact. Enter the projectile mass and resultant crater diameters in the table below. Calculate the kinetic energy of each projectile and enter the values in the table below.

Part D

	Velocity (m/sec)	Mass (kg)	KE (Nm = kg m2/sec2)	Crater Diameter (cm)
Shot 1 (steel)	**6.3**			
Shot 2 (glass)	**6.3**			
Shot 3 (wood)	**6.3**			

Examine the results of parts B, C, and D. Use the completed tables to answer the following questions.

5. **a.** How does kinetic energy of the projectile relate to crater diameter?

   b. How does velocity relate to crater size?

   c. How does mass relate to crater size?

d. How does the size of the projectile relate to crater size?

e. Which is the most important factor controlling the crater size; the size, mass, or velocity of the projectile?

*****Part E*

Remove all projectiles from the sand tray and smooth the target surface. Divide the sand into two equal halves. In one half form a ridge of sand about 10 cm high and 15 cm wide, and leave the other half smooth. Use intermediate size steel ball bearings and form one crater on the side of the ridge. Form another crater on the flat section, launching it with the slingshot from 70 to 90 cm above the tray. Compare the two craters.

*6. What can you say about crater preservation on rugged terrain versus smooth terrain?

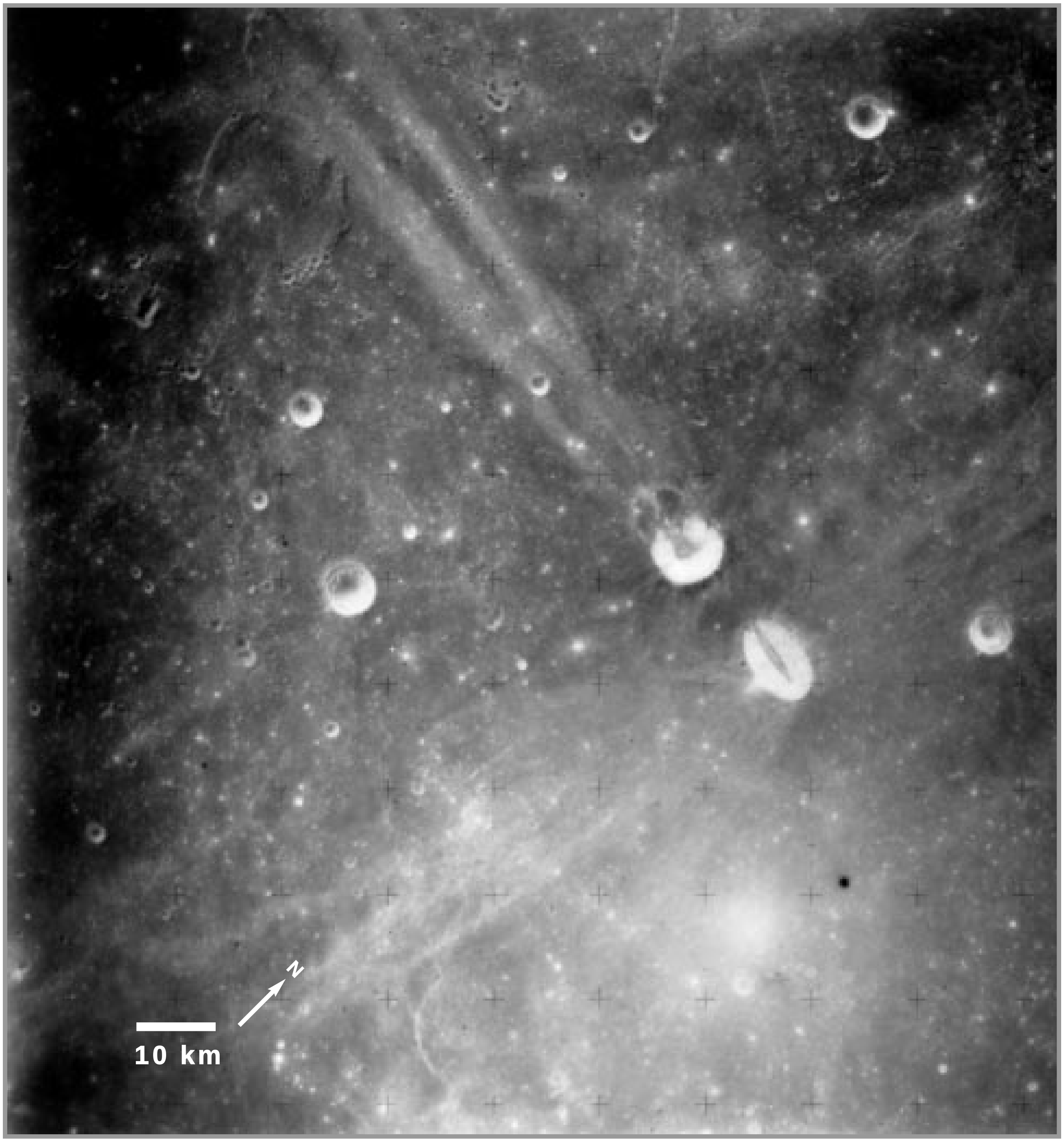


Figure 4.1. *Apollo 15 photograph of lunar craters Messier A and B. The small crosses are camera registration marks. North is to the upper right corner of the photo. The oblong crater (Messier A) is 11 kilometers in diameter. (Apollo Metric frame AS152674).*