ACTIVITY 9

STUDENT SECTION

JUST HOW BIG BIG

MATERIALS

Each group will need
- bag of simulated planetary bedrock
- cup of simulated planetary surface
- container
- sieve or large spoon
- simulated bolides (assorted sizes)
- drop cloth or floor cover
- ruler
- chair
- string, weight on end
- graph paper
- safety goggles for everyone

OBJECTIVE

This activity explores the connection between crater size and the kinetic energy of impacting bolides.

BACKGROUND

In Activity 8, you explored thesconnection between heat and motion. You learned that temperature is affected by mass and velocity shake the sand faster and its temperature rises. Measuring heat in Activity 8 was a way to measure the energy involved in the motion of that system. Kinetics is the study of motion. The kinetic energy of an object is the energy associated with its motion. You may already know that kinetic energy can be calculated as the product of one half the mass of a moving body times its velocity squared:

$$\text{kinetic energy} = 1/2mv^2$$

where m is the mass of the moving body, and v is its velocity. Kinetic energy is expressed in terms of the standard metric unit, joule 0). One joule is the amount of energy needed to move a mass (any mass) a distance of 1 meter using a force of

1 newton. One newton is defined as the force needed to accelerate a 1 kg mass by 1 meter/second^2. Consider the relationship between these variables. Qualitatively, note that

the kinetic energy increases as mass increases or as the velocity increases. Quantitatively, note that if the mass doubles, the energy also doubles. If the velocity doubles, the energy is four times greater. Why? You can see in the formula that kinetic energy is related not to v but to v^2

Think about the kinetic energy involved in dropping water balloons. When you drop a light water balloon and a heavy water balloon, why does the heavy one make such a bigger splash? (Figure 1) Think about how the masses are different and how mass affects kinetic energy.

TABLE 1

Comparison of energy produced during different events

EVENT	ENERGY (KILOJOULES)	COMPARISON
One 1,600 kg (about 3,500 lb) car colliding with wall at 90 kph (55mph)	5×10^5	1
Two 1,600 kg (about 3,500 lb) cars colliding head on at 90 kph (55mph)	1×10^6	2
Explosion of 1 ton TNT	4.2×10^9	8,400
Typical lightning bolt	5×10^9	10,000
Average tornado	7.5×10^{11}	1,500,000
Explosion of 20-megaton fusion bomb	8.4×10^{16}	1,680,000,000,000
Total US electric power production in 1990	1×10^{19}	20,000,000,000,000
Typical 10-day hurricane	2.5×10^{19}	50,000,000,000,000
Earth's daily receipt of solar energy	1.1×10^{22}	22,000,000,000,000,000
Impact of a large bolide (the size that wiped out dinosaurs; 10km diameter, 20km/sec velocity)	7.5×10^{23}	1,500,000,000,000,000,000

— adapted from Ray Newburn, Jr., "The Comet About to Smash into Jupiter," The Universe in the Classroom, 1994, no. 27 (table is on page 5); Arch Johnston, "An Earthquake Strength Scale for the Media and the Public," Earthquakes and Volcanoes, vol. 22 (graph is on page 215).

Now imagine dropping water balloons of the same weight from different heights (Figure 2). If you drop a water balloon from close to the ground, it either won't pop or will create just a minor splash. But drop it from a window or throw it down, and it's sure to scatter water all over. You know the balloon dropped from higher up or thrown will have a higher velocity. Think about how these different velocities affect kinetic energy.

Compared to other events, impacts of large bolides involve an enormous amount of energy (see Table 1). Bolides move at high velocities (kilometers per second) and can be enormous in size. These features give the rarest, largest bolides huge kinetic energies. Look at the craters they form!

FIGURE 2

OBSERVATION BOX 1

MASS (G)	CRATER DIAMETER (MM)			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE
____	____	____	____	____
____	____	____	____	____
____	____	____	____	____
____	____	____	____	____
____	____	____	____	____
____	____	____	____	____
____	____	____	____	____

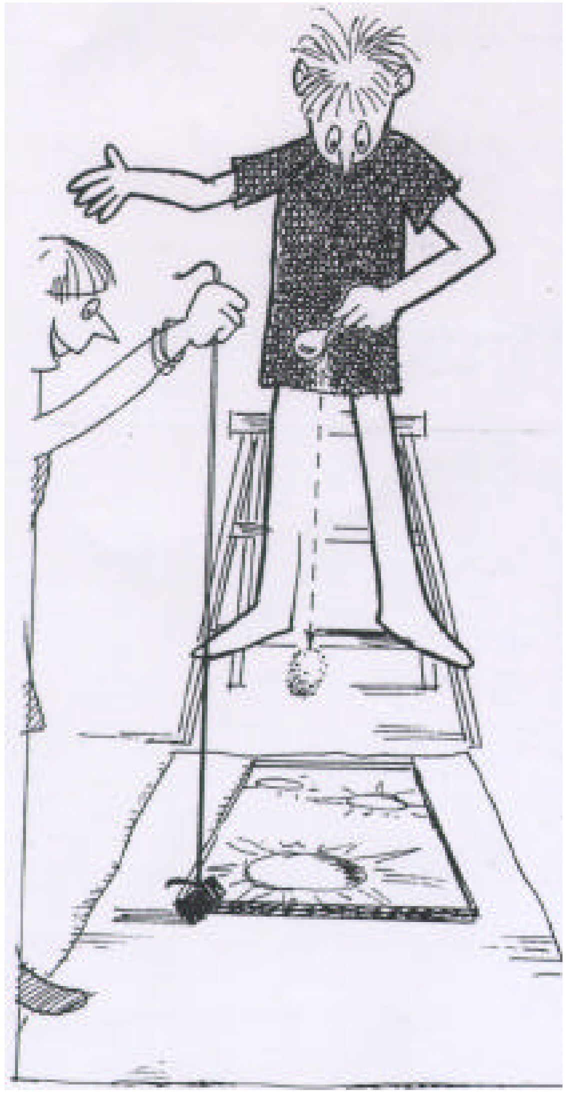
In this activity, you will explore the connection between the energy bolides carry and the craters that form during impacts. Through experiments and calculations, you vill be able to build quantitative estimates about the energy bolides carry just from measuring crater sizes. You also will be able to predict the size of craters formed during particular bolide impacts.

Part I: Experimental Trials

PROCEDURE

1. Clear a working area by moving desks, chairs, and other objects. Open your drop cloth and lay it down smoothly on the ground. Put the container in the center of your workspace. Fill this container with simulated planetary bedrock (light-colored material) up to several millimeters below the rim. Lightly pack the bedrock and smooth the surface with your ruler so *it* is flat. Cover the bedrock with a thin layer of simulated planetary surface (dark-colored material).

2. Move a chair or stepladder next to your test surface. You'll want to be able to look down over your test surface. Have one member of your group climb on the chair—*be careful to keep balanced!* This will be the bolide dropper. A second member of your group should hold the measuring string vertically next to the test surface and position the bolide dropper's hand exactly at the desired height above the test surface. The standard height is important, as you'll see in the analysis.



Part II: Predictions Based on Calculations

PROCEDURE

Graphing the mass against the cube of crater diameter, D^3, produces roughly a straight line. Why? You know that a bolide's mass affects its kinetic energy. (If everything else is constant, higher mass means higher kinetic energy.) You also know that kinetic energy influences crater size (increasing the energy increases the crater size.) In Part I, you experimented with these connections. In Part II, you will extend that work to build quantitative predictions about the relation bet veen mass and crater size. Begin with this chain of reasoning:

a. When a crater is formed, the total amount of energy used is proportional to the volume of material excavated.

b. Because a crater is roughly a hemisphere, its volume is determined by the cube of the diameter (D), or D^3. (The volume for hemisphere is $2/3\ \pi (D/2)^3$.)

c. As a result, energy needed is proportional to D^3

d. In an impact, the energy involved is kinetic energy, which is defined as $1/2\ mv^2$

e. If kinetic energy is proportional to D^3, then for an impact, you can predict

$$D^3 \text{ will be proportional to } mv^2$$

(In proportions like this, constants—such as the 1/2—can be dropped out.)

This prediction (D^3 will be proportional to mv^2) matches the results of Part I: increasing bolide mass causes a proportional increase in the volume of the crater. This explains the roughly straight line. Knowing this relationship, you can make quantitative predictions about a bolide's mass once you've measured its crater size.

The lunar farside photographed by Apollo 11 astronauts.
The large crater is I.A. U. crater no. 308 (approximately 80 km in diameter).
Think about the differences in mass required to create
these different sized craters.

PREDICTION BOX 1

Quantitative predictions

INCREASE IN CRATER DIAMETER (D)		REQUIRED INCREASE IN MASS
2X		_____ times
5X		_____ times
10X		_____ times
20X	REQUIRES	_____ times
50X		_____ times
100X		_____ times
200X		_____ times

QUESTIONS / CONCLUSIONS

1. Use the formula in (e.) to answer the following question: In order to produce a crater twice (two times) as large as another, how much larger must a bolide be?

   ______ times as large
   (Hint: the answer is not two times.)

Check the result you obtain with your teacher before proceeding.

2. Once you learn the basic rule for solving problems like Question 1, complete Prediction Box 1.

3. In applying the formula (D^3 will be proportional to mv^2) to Prediction Box 1, what are you assuming is constant for all impacts?

4. What additional factors could produce variations in the results compared to the predictions?

5. Compare your predictions to the results obtained in Part I. Does the prediction — D^3 will be proportional to mv^2 — accurately estimate your results? Explain any variation you find.