DETERMINING THE SIZE AND ENERGY OF THE K-T ASTEROID

INTRODUCTION

The Howard Hughes Medical Institute short film *The Day the Mesozoic Died* tells the story of how geologist Dr. Walter Alvarez and colleagues came to propose that an enormous **asteroid** collided with Earth and precipitated an environmental disaster that led to the extinction of the dinosaurs. The team had been studying a 1-cm-thick layer of clay that separated the **Cretaceous** from the **Tertiary** period—known as the **K-T boundary**—in a section of **sedimentary rocks** located in Italy. Their original purpose had been to measure the amount of iridium in this thin clay layer to determine how long it took for it to be deposited. When they analyzed their samples, however, the team was surprised to find enormous quantities of iridium that they could not readily explain. Based on this initial finding, Dr. Alvarez and colleagues developed the hypothesis that the iridium in the layer had been carried to Earth in a mountain-sized asteroid. At the same time, Dr. Jan Smit in Spain independently made similar observations and came to the same conclusion as Alvarez.

In this activity, you will use the total amount of iridium found in the K-T layer worldwide to estimate the mass and size of the asteroid that caused the K-T mass extinction. The calculations you will perform are similar to the ones that Dr. Alvarez and Dr. Smit and colleagues conducted in 1980, when they published their discovery.

(Note: words that are in bold in the introduction and throughout the document are defined in a glossary on the last page.)

MATERIALS

You will need:

- scientific calculator

PROCEDURE

1. Watch the HHMI short film *The Day the Mesozoic Died*. As you watch, pay special attention to the case presented by the Alvarez team for using the abundance of the element iridium as evidence of an asteroid impact.

2. Calculate the size and energy of the K-T asteroid by following the steps below. You will need information included in Table 1 to complete some of the calculations.

Table 1: Selected Data	
Description	Value
Diameter of Earth	12,756 km
Average iridium abundance in C1 chondrites	500 ppb
Average density of a C1 chondrite	2200 kg/m^3

QUESTIONS

1. In this activity, we will use the iridium concentration Dr. Smit found in the Spain clay layer (about 3×10^{-8} g/cm^2). Dr. Smit assumed that a similar amount of iridium would be found in the K-T boundary worldwide. Based on this estimate and the data in Table 1, calculate the *total mass of iridium* deposited on Earth in this layer.

2. In step 1 above, you calculated how much iridium was required to produce a global layer with an average abundance of iridium of 3×10^{-8} g/cm^2. We will assume that when the asteroid hit Earth it vaporized, blasting fine particles high into the atmosphere. All of the asteroid material, including iridium, was transported around the planet and settled on Earth's surface within a few years following impact. The asteroid that caused the K-T extinction is thought to have the chemical composition of a **carbonaceous chondrite** of the C1 group (a **C1 chondrite**). Based on the information presented, determine the *mass of the asteroid* needed to supply that amount of iridium. Be sure to convert your answer into kilograms.

3. In step 2, you calculated a reasonable estimate of the mass of the asteroid that caused the extinction of the dinosaurs. You can now calculate the volume of the asteroid using the average density of a C1 chondrite listed in Table 1. Once you determine the volume, find the average diameter for an asteroid of this size that was roughly spherical in shape.

4. Asteroids of this size that impact Earth are called Earth-crossing asteroids. The term simply means that the orbit of the asteroid intersects the orbit of our planet on a regular basis and collision is only a matter of time. If the asteroid crosses Earth's orbit at the same time that Earth crosses the asteroid's orbit, they will collide. Scientists have identified thousands of Earth-crossing asteroids, and NASA has classified 1027 of them as *potentially hazardous asteroids*. This classification means that their orbits bring them to within at least 7.5 million kilometers of Earth's orbit and they are at least 150 m in diameter. Studies have determined that asteroids of this group would typically impact Earth at an average of 25,000 m/s. Using your results from step 4 and this new information, determine the kinetic energy that the K-T asteroid would have had.

5. Using the Internet or another resource, find the amount of energy released by the largest atomic bomb ever exploded. How does this compare to the energy released by the asteroid that caused the K-T extinction? How many times bigger was the K-T event?

6. Find some other benchmarks of energy to compare the K-T event to. Examples might include the amount of the sun's energy that strikes Earth in a single minute or the amount of energy released by a hurricane. Feel free to make up your own comparisons too. (Example: This is equivalent to all the food energy needed by the world's 7 billion people over the next 58.6 million years!)

QUESTIONS WITH GUIDED CALCULATIONS

1. In this activity, we will use the iridium concentration Dr. Smit found in the Spain clay layer (about 3×10^{-8} g/cm^2). Dr. Smit assumed that a similar amount of iridium would be found in the K-T boundary worldwide. Based on this estimate and the data in Table 1, calculate the *total mass of iridium* deposited on Earth in this layer.

- First, figure out the Earth's surface area:
  - o What is the diameter of the Earth? _______________ What is the radius? ________________
  - o Notice the units in the final answer. Convert the radius to centimeters. _______________
  - o Calculate the Earth's Surface Area. Surface Area = $4 \times \prod \times r^2$ _____________________

- Now use the surface area and the concentration of Iridium the Spanish clay to estimate the total mass of Ir in the KT layer worldwide.
  - o Calculate the mass of iridium. Mass iridium (Ir) = Surface Area x Concentration of Ir _________________

2. In step 1 above, you calculated how much iridium was required to produce a global layer with an average abundance of iridium of 3×10^{-8} g/cm^2. We will assume that when the asteroid hit Earth it vaporized, blasting fine particles high into the atmosphere. All of the asteroid material, including iridium, was transported around the planet and settled on Earth's surface within a few years following impact. The asteroid that caused the K-T extinction is thought to have the chemical composition of a **carbonaceous chondrite** of the C1 group (a **C1 chondrite**). Based on the information presented, determine the *mass of the asteroid* needed to supply that amount of iridium. Be sure to convert your answer into kilograms.

- Convert the Average iridium abundance in C1 chondrites from ppb to scientific notation. ____________________
  - o Remember that ppb is the same as $1 \text{x} 10^{-9}$.
- Calculate the mass of the asteroid. Mass of asteroid = Mass Ir (from step 1) ÷ fraction of Ir in C1 chondrites

- Your answer should be in grams. Convert your answer to kg. ___________________________

3. In step 2, you calculated a reasonable estimate of the mass of the asteroid that caused the extinction of the dinosaurs. You can now calculate the volume of the asteroid using the average density of a C1 chondrite listed in Table 1. Once you determine the volume, find the average diameter for an asteroid of this size that was roughly spherical in shape.

- Calculate the volume of the asteroid. Volume (V) = Mass of asteroid ÷ Density of asteroid (C1 chondrite)
- Now use the other formula for volume to determine the radius of the asteroid. $V_{sphere} = 4/3 \times \prod \times r^3$

- Double the radius to calculate the diameter: _____________. Convert the diameter to km: _______________

4. Asteroids of this size that impact Earth are called Earth-crossing asteroids. The term simply means that the orbit of the asteroid intersects the orbit of our planet on a regular basis and collision is only a matter of time. If the asteroid crosses Earth's orbit at the same time that Earth crosses the asteroid's orbit, they will collide. Scientists have identified thousands of Earth-crossing asteroids, and NASA has classified 1027 of them as *potentially hazardous asteroids*. This classification means that their orbits bring them to within at least 7.5 million kilometers of Earth's orbit and they are at least 150 m in diameter. Studies have determined that asteroids of this group would typically impact Earth at an average of 25,000 m/s. Using your results from step 4 and this new information, determine the kinetic energy that the K-T asteroid would have had.

- Calculate the Kinetic Energy of the asteroid. Kinetic energy (KE) = ½ $m_{(a)} \times v^2$.
  - m = mass in kg and v = velocity of asteroid
  - A unit of energy is a Joule (J).

5. Using the Internet or another resource, find the amount of energy released by the largest atomic bomb ever exploded. How does this compare to the energy released by the asteroid that caused the K-T extinction? How many times bigger was the K-T event?

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6. Find some other benchmarks of energy to compare the K-T event to. Examples might include the amount of the sun's energy that strikes Earth in a single minute or the amount of energy released by a hurricane. Feel free to make up your own comparisons too. (Example: This is equivalent to all the food energy needed by the world's 7 billion people over the next 58.6 million years!)

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GLOSSARY

Asteroid: a large, rocky body in orbit around the sun.

C1 chondrite or chondrite: a type of stony **meteorite** that formed without melting of the source material. C1 chondrites are a group of **carbonaceous chondrites**, which are thought to be some of the oldest materials in the solar system.

Cretaceous: a geologic time period lasting from 145.5 million years ago to 65.5 million years ago. The Cretaceous was the last period of the age of the dinosaurs.

K-T boundary: the boundary between the Cretaceous (K) and Tertiary (T) periods. It is characterized by a thin layer of clay found all over the world. The Tertiary has been recently reclassified as the Paleogene and Neogene. The K-T boundary is now known as the K-Pg boundary.

Meteorite: an asteroid or body from space that does not burn up in Earth's atmosphere and lands on Earth's surface.

Sedimentary rock: a kind of rock formed from the deposition of sediment at Earth's surface, which subsequently becomes consolidated and cemented together. It can form in both terrestrial and aquatic environments.

Tertiary: a geologic period lasting from 65.5 million years ago to 2.6 million years ago. The Tertiary period was the beginning of the age of the mammals.

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