

Name: _____
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16 Building a Comet

During this semester we have explored the surfaces of the Moon, terrestrial planets and other bodies in the solar system, and found that they often are riddled with craters. In Lab 12 there is a discussion on how these impact craters form. Note that every large body in the solar system has been bombarded by smaller bodies throughout all of history. In fact, this is one mechanism by which planets grow in size: they collect smaller bodies that come close enough to be captured by the planet's gravity. If a planet or moon has a rocky surface, the surface can still show the scars of these impact events—even if they occurred many billions of years ago! On planets with atmospheres, like our Earth, weather can erode these impact craters away, making them difficult to identify. On planets that are essentially large balls of gas (the “Jovian” planets), there is no solid surface to record impacts. Many of the smaller bodies in the solar system, such as the Moon, the planet Mercury, or the satellites of the Jovian planets, do not have atmospheres, and hence, faithfully record the impact history of the solar system. Astronomers have found that when the solar system was very young, there were large numbers of small bodies floating around the solar system impacting the young planets and their satellites. Over time, the number of small bodies in the solar system has decreased. Today we will investigate how impact craters form, and examine how they appear under different lighting conditions. During this lab we will discuss both asteroids and comets, and you will create your own impact craters as well as construct a “comet”.

- *Goals:* to discuss asteroids and comets; create impact craters; build a comet and test its strength and reaction to light
- *Materials:* A variety of items supplied by your TA

16.1 Asteroids and Comets

There are two main types of objects in the solar system that represent left over material from its formation: asteroids and comets. In fact, both objects are quite similar, their differences arise from the fact that comets are formed from material located in the most distant parts of our solar system, where it is very cold, and thus they have large quantities of frozen water and other frozen liquids and gases. Asteroids formed closer-in than comets, and are denser, being made-up of the same types of rocks and minerals as the terrestrial planets (Mercury, Venus, Earth, and Mars). Asteroids are generally just large rocks, as shown in Fig. 16.1 shown below.

The first asteroid, Ceres, was discovered in 1801 by the Italian astronomer Piazzi. Ceres is the largest of all asteroids, and has a diameter of 933 km (the Moon has a diameter of 3,476 km). There are now more than 40,000 asteroids that have been discovered, ranging in size from Ceres, all the way down to large rocks that are just a few hundred meters across. It has been estimated that there are at least 1 million asteroids in the solar system with

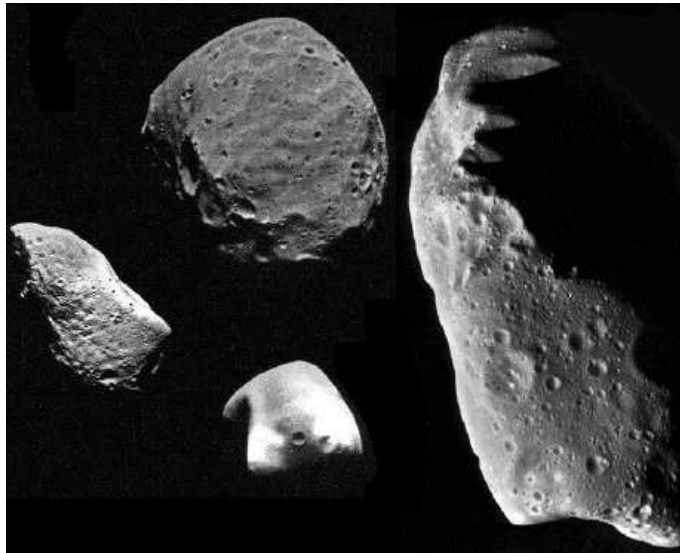


Figure 16.1: Four large asteroids. Note that these asteroids have craters from the impacts of even smaller asteroids!

diameters of 1 km or more. Most asteroids are harmless, and spend all of their time in orbits between those of Mars and Jupiter (the so-called “asteroid belt”, see Figure 16.2). Some asteroids, however, are in orbits that take them inside that of the Earth, and could

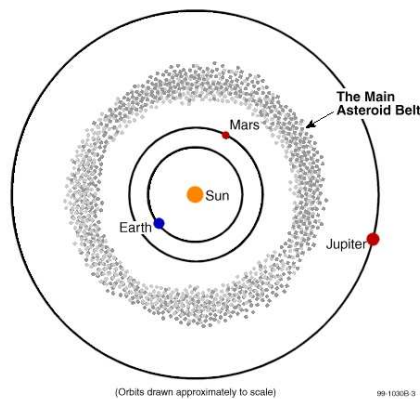


Figure 16.2: The Asteroid Belt.

potentially collide with the Earth, causing a great catastrophe for human life. It is now believed that the impact of a large asteroid might have been the cause for the extinction of the dinosaurs when its collision threw up a large cloud of dust that caused the Earth’s climate to dramatically cool. Several searches are underway to insure that we can identify future “doomsday” asteroids so that we have a chance to prepare for a collision—as the Earth will someday be hit by another large asteroid.

16.2 Comets

Comets represent some of the earliest material left over from the formation of the solar system, and are therefore of great interest to planetary astronomers. They can also be beautiful objects to observe in the night sky, unlike their darker and less spectacular cousins, asteroids. They therefore often capture the attention of the public.

16.3 Composition and Components of a Comet

Comets are composed of ices (water ice and other kinds of ices), gases (carbon dioxide, carbon monoxide, hydrogen, hydroxyl, oxygen, and so on), and dust particles (carbon and silicon). The dust particles are smaller than the particles in cigarette smoke. In general, the model for a comet's composition is that of a “dirty snowball.” 16.3

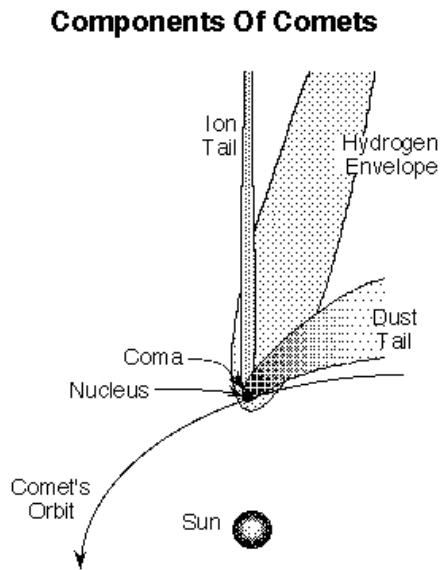


Figure 16.3: The main components of a comet.

Comets have several components that vary greatly in composition, size, and brightness. These components are the following:

- *nucleus*: made of ice and rock, roughly 5-10 km across
- *coma*: the “head” of a comet, a large cloud of gas and dust, roughly 100,000 km in diameter
- *gas tail*: straight and wispy; gas in the coma becomes ionized by sunlight, and gets carried away by the solar wind to form a straight blueish “ion” tail. The shape of the gas tail is influenced by the magnetic field in the solar wind. Gas tails are pointed in the direction directly opposite the sun, and can extend 10^8 km.
- *dust tail*: dust is pushed outward by the pressure of sunlight and forms a long, curving tail that has a much more uniform appearance than the gas tail. The dust tail is

pointed in the direction directly opposite the comet's direction of motion, and can also extend 10^8 km from the nucleus.

These various components of a comet are shown in the diagram, above (Fig. 16.3).

16.4 Types of Comets

Comets originate from two primary locations in the solar system. One class of comets, called the **long-period comets**, have long orbits around the sun with periods of *more* than 200 years. Their orbits are random in shape and inclination, with long-period comets entering the inner solar system from all different directions. These comets are thought to originate in the **Oort cloud**, a spherical cloud of icy bodies that extends from $\sim 20,000$ to $150,000$ AU from the Sun. Some of these objects might experience only one close approach to the Sun and then leave the solar system (and the Sun's gravitational influence) completely.

In contrast, the **short-period comets** have periods less than 200 years, and their orbits are all roughly in the plane of the solar system. Comet Halley has a 76-year period, and therefore is considered a short-period comet. Comets with orbital periods < 100 years do not get much beyond Pluto's orbit at their farthest distance from the Sun. Short-period comets cannot survive many orbits around the Sun before their ices are all melted away. It is thought that these comets originate in the **Kuiper Belt**, a belt of small icy bodies beyond the large gas giant planets and in the plane of the solar system. Quite a few large Kuiper Belt objects have now been discovered, including one (Eris) that is about the same size as Pluto.

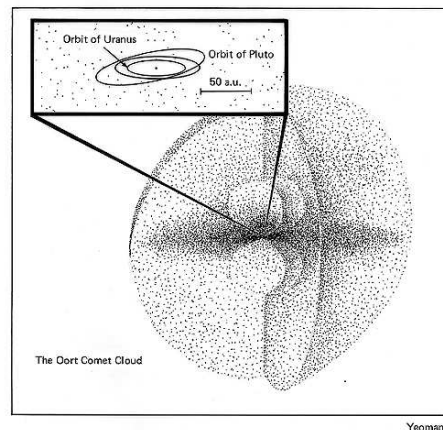


Figure 16.4: The Oort cloud.

16.5 The Impacts of Asteroids and Comets

Objects orbiting the Sun in our solar system do so at a variety of speeds that directly depends on how far they are from the Sun. For example, the Earth's orbital velocity is 30 km/s (65,000 mph!). Objects further from the Sun than the Earth move more slowly, objects closer to the Sun than the Earth move more quickly. Note that asteroids and comets near

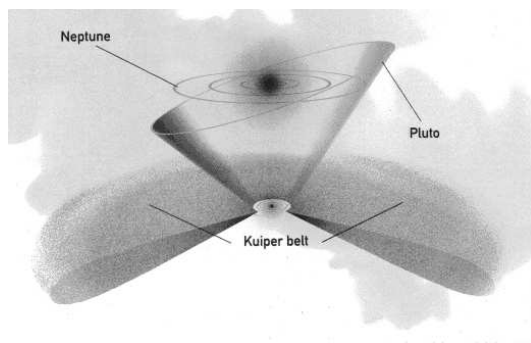


Figure 16.5: The Kuiper belt.

the Earth will have space velocities similar to the Earth, but in (mostly) random directions, thus a collision could occur with a relative speed of impact of nearly 60 km/s! How fast is this? Note that the highest muzzle velocity of any handheld rifle is 1,220 m/s = 1.2 km/s. Thus, the impact of any solar system body with another is a true *high speed collision* that releases a large amount of energy. For example, an asteroid the size of a football field that collides with the Earth with a velocity of 30 km/s releases as much energy as one thousand atomic bombs the size of that dropped on Japan during World War II (the Hiroshima bomb had a “yield” of 13 kilotons of TNT). Since the equation for kinetic energy (the energy of motion) is $K.E. = 1/2(mv^2)$, the energy scales directly as the mass, and mass goes as the cube of the radius (mass = density $\times$ Volume = density $\times R^3$). A moving object with ten times the radius of another traveling at the same velocity has 1,000 times the kinetic energy. It is this kinetic energy that is released during a collision.

16.6 Exercise #1: Creating Impact Craters

To create impact craters, we will be dropping steel ball bearings into a container filled with ordinary baking flour. There are at least two different sizes of balls, there is one that is twice as massive as the other. You will drop both of these balls from three different heights (0.5 meters, 1 meters, and 2 meters), and then measure the size of the impact crater that they produce. Then on graph paper, you will plot the size of the impact crater versus the speed of the impacting ball.

1. Have one member of your lab group take the meter stick, while another takes the smaller ball bearing.
2. Take the plastic tub that is filled with flour, and place it on the floor.
3. Make sure the flour is uniformly level (shake or comb the flour smooth)
4. Carefully hold the meter stick so that it is just touching the top surface of the flour.
5. The person with the ball bearing now holds the ball bearing so that it is located exactly one half meter (50 cm) above the surface of the flour.
6. Drop the ball bearing into the center of the flour-filled tub.

7. Use the magnet to carefully extract the ball bearing from the flour so as to cause the least disturbance.
8. Carefully measure the diameter of the crater caused by this impact, and place it in the data table, below.
9. Repeat the experiment for heights of 1 meter and 2 meters using the smaller ball bearing (note that someone with good balance might have to *carefully* stand on a chair to get to a height of two meters!).
10. Now repeat the entire experiment using the larger ball bearing. Record all of the data in the data table.

Height (meters)	Crater diameter (cm) Ball #1	Crater diameter (cm) Ball #2	Impact velocity (m/s)
0.5			
1.0			
2.0			

Now it is time to fill in that last column: Impact velocity (m/s). How can we determine the impact velocity? The reason the ball falls in the first place is because of the pull of the Earth's gravity. This force pulls objects toward the center of the Earth. In the absence of the Earth's atmosphere, an object dropped from a great height above the Earth's surface continues to accelerate to higher, and higher velocities as it falls. We call this the "acceleration" of gravity. Just like the accelerator on your car makes your car go faster the more you push down on it, the force of gravity accelerates bodies downwards (until they collide with the surface!).

We will not derive the equation here, but we can calculate the velocity of a falling body in the Earth's gravitational field from the equation $v = (2ay)^{1/2}$. In this equation, "y" is the height above the Earth's surface (in the case of this lab, it is 0.5, 1, and 2 meters). The constant "a" is the acceleration of gravity, and equals 9.80 m/s^2 . The exponent of $1/2$ means that you take the square root of the quantity inside the parentheses. For example, if $y = 3$ meters, then $v = (2 \times 9.8 \times 3)^{1/2}$, or $v = (58.8)^{1/2} = 7.7 \text{ m/s}$.

1. Now plot the data you have just collected on graph paper. Put the impact velocity on the x axis, and the crater diameter on the y axis. (**10 points**)

16.6.1 Impact crater questions

1. Describe your graph, can the three points for each ball be *approximated* by a single straight line? How do your results for the larger ball compare to that for the smaller ball? (**3**

points)

2. If you could drop both balls from a height of 4 meters, how big would their craters be? (**2 points**)

3. What is happening here? How does the mass/size of the impacting body effect your results. How does the speed of the impacting body effect your results? What have you just proven? (**5 points**)

16.7 Crater Illumination

Now, after your TA has dimmed the room lights, have someone take the flashlight out and turn it on. If you still have a crater in your tub, great, if not create one (any height more than 1 meter is fine). Extract the ball bearing.

1. Now, shine the flashlight on the crater from straight over top of the crater. Describe what you see. (**2 points**)

2. Now, hold the flashlight so that it is just barely above the lip of the tub, so that the light shines at a very oblique angle (like that of the setting Sun!). Now, what do you see? (**2**

points)

3. When is the best time to see fine surface detail on a cratered body, when it is noon (the Sun is almost straight overhead), or when it is near “sunset”? [Confirm this at the observatory sometime this semester!] **(1 point)**

16.8 Exercise #2: Building a Comet

In this portion of the lab, you will actually build a comet out of household materials. These include water, ammonia, potting soil, and dry ice (CO₂ ice). Be sure to distribute the work evenly among all members of your group. Follow these directions: **(10 points)**

1. Use a freezer bag to line the bottom of your bucket.
2. Place a little less than 1 cup of water (this is a little less than 1/2 of a “Solo” cup!) in the bag/bucket.
3. Add 2 spoonfuls of sand, stirring well. (**NOTE:** Do not stir so hard that you rip the freezer bag lining!!)
4. Add a dash of ammonia.
5. Add a dash of organic material (potting soil). Stir until well-mixed.
6. Your TA will place a block or chunk of dry ice inside a towel and crush the block with the mallet and give you some crushed dry ice.
7. Add about 1 cup of crushed dry ice to the bucket, while stirring vigorously. (**NOTE:** Do not stir so hard that you rip the freezer bag!!)
8. Continue stirring until mixture is almost frozen.
9. Lift the comet out of the bucket using the plastic liner and shape it for a few seconds as if you were building a snowball (use gloves!).
10. Add 1/2 cup water and wait until mixture is frozen.
11. Unwrap the comet once it is frozen enough to hold its shape.

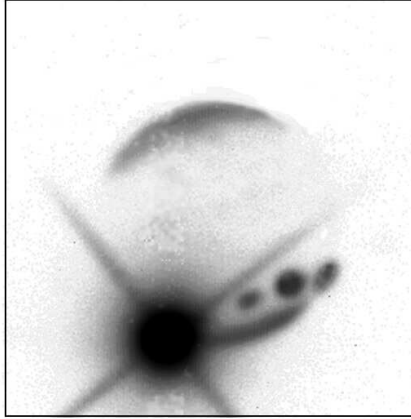
16.8.1 Comets and Light

1. Observe the comet as it is sitting on a desk. Make some notes about its physical characteristics, for example: shape, color, smell (**5 points**):
2. Now bring the comet over to the light source (overhead projector) and place it on top. Observe, and then describe what happens to the comet (**5 points**):

16.8.2 Comet Strength

Comets, like all objects in the solar system, are held together by their internal strength. If they pass too close to a large body, such as Jupiter, their internal strength is not large enough to compete with the powerful gravity of the massive body. In such encounters, a comet can be broken apart into smaller pieces. In 1994, we saw evidence of this when Comet Shoemaker-Levy/9 impacted into Jupiter. In 1992, that comet passed very close to Jupiter and was fragmented into pieces. Two years later, more than 21 cometary fragments crashed into Jupiter's atmosphere, creating spectacular (but temporary) "scars" on Jupiter's cloud deck.

Exercise: After everyone in your group has carefully examined your comet, it is time to say goodbye. Take a sample rock and your comet, go outside, and drop them both on the sidewalk. What happened to each object? (**2 points**)



Impact of Fragment K of Comet Shoemaker-Levy on Jupiter.
The scars of three previous impacts can be seen on the planetary disk.
Image from Peter McGregor and Mark Allen, ANU 2.3m telescope.
Instrument: CASPIR at 2.34 μ m. Colour image Mt Stromlo Observatories.

Figure 16.6: The Impact of “Fragment K” of Comet Shoemaker-Levy/9 with Jupiter. Note the dark spots where earlier impacts occurred.

16.8.3 Comet Questions

1. Draw a comet and label all of its components. Be sure to indicate the direction the Sun is in, and the comet’s direction of motion. (**5 points**)
2. What are some differences between long-period and short-period comets? Does it make

sense that they are two distinct classes of objects? Why or why not? (**5 points**)

3. If a comet is far away from the Sun and then it draws nearer as it orbits the Sun, what would you expect to happen? (**5 points**)

4. Do you think comets have more or less internal strength than asteroids, which are composed primarily of rock? [Hint: If you are playing outside with your friends in a snow storm, would you rather be hit with a snowball or a rock?] (**3 points**)

16.9 Take Home Exercise (35 points total)

Write-up a summary of the important ideas covered in this lab. Questions you may want to consider are:

- How does the mass of an impacting asteroid or comet affect the size of an impact crater?
- How does the speed of an impacting asteroid or comet affect the size of an impact crater?
- Why are comets important to planetary astronomers?
- What can they tell us about the solar system?
- What are some components of comets and how are they affected by the Sun?
- How are comets different from asteroids?

Use complete sentences, and proofread your summary before handing it in.

16.10 Possible Quiz Questions

1. What is the main difference between comets and asteroids, and why are they different?
2. What is the Oort cloud and the Kuiper belt?
3. What happens when a comet or asteroid collides with the Moon?
4. How does weather effect impact features on the Earth?
5. How does the speed of the impacting body effect the energy of the collision?

16.11 Extra Credit (ask your TA for permission before attempting, 5 points)

On the 15th of February, 2013, a huge meteorite exploded in the skies over Chelyabinsk, Russia. Write-up a small report about this event, including what might have happened if instead of a grazing, or “shallow”, entry into our atmosphere, the meteor had plowed straight down to the surface.