What's Inside?
Mass and Density

Larry Lebofsky
Nancy Lebofsky

Background:
We cannot "see" inside a planet, asteroid, or exoplanet. However, we can make an "educated guess" about its interior if we know its density. Is it rocky? Is it icy? Does it have a lot of iron? Is it a rubble pile? By knowing its size (volume) and mass, we can determine its density and try to determine what it is made of. **Note:** ***Mass*** is a measurement of the amount of matter something contains; ***weight*** is the measurement of the pull of gravity on an object. Mass is measured on a balance (as is Figure 1) while weight is measured on a scale. When the astronauts went to the Moon, their mass was the same, but they weighed less in the lower gravity of the Moon.

Procedure:
This activity is intended for setup on a long table so that participants can go from display to display as they learn about mass and density and how we are able to learn about the composition and nature of an object that we cannot see into.

Activity 1: Volume, Mass, and Density

The bag of Cheerios (left) and the rock (right) on the balance are equal in mass, but not in density. It takes more Cheerios (greater volume) to equal the rock in mass, or weight.

Activity 2: A Floater, a Sinker and a "Flinker"

In the clear container are three plastic Easter eggs. The three plastic eggs are the same size, but they have different densities. The Floater stays at the top of the container, the Sinker is at the bottom, and the "Flinker" is about halfway between.

One egg is empty and the other two eggs contain rocks and pebbles. The egg with the lowest density interior floats, the egg with the highest density interior sinks, and the egg with the medium density (fewer pebbles) interior is the "flinker." Below are the weights of each of the eggs. As you can see, a difference of 4 grams is all it takes to make the difference between "flinking" and sinking.

- Floater: 5 grams
- Sinker: 53 grams
- "Flinker": 49 grams

Activity 3: Happy Birthday

Who has not wanted to know what is in the box that contains their birthday present? Pictured above are three boxes. Lift each box and compare their weights.

- Which birthday gift has the highest density (weighs the most)?
- Which birthday gift has the lowest density (weighs the least)?
- Can you guess what the gifts are in the boxes?

Examples of what can be in the boxes:

- Left box: two pairs of socks
- Middle box: a bag of hard candy
- Right box: a book.

Activityy 4: What is in the Potato Chip Can?

Five cans of same volume but different materials inside—different densities

The next display (above) is another example of density. Using the scale provided, try to guess what is inside each can. The five potato chip cans are all the same volume, but different weights.

- Find the potato chip can with the greatest mass (weighs the most; has the highest density)
- Find the potato chip can with the least mass (weighs the least; has the lowest density)
- Can you guess what is in the five cans?

Examples of what can be in the five cans

- Can 1: 50 grams, empty
- Can 2: 54 grams, filled with bubble wrap
- Can 3: 230 grams, filled to the top with potato chips (add a few extra to a standard can so it does not make much noise if shaken)
- Can 4: 665 grams, decorative volcanic rock (also used in gas grills)—vesicular basalt
- Can 5: 1,570 grams, medium-sized rocks such as decorative river wash rocks

It should be noted that filling the can with water gives a total weight of about 980 grams. Deducting the 45 grams of the empty can implies that content of Can 4 has a density 0.6 grams/cc and the density of Can 5 is 1.4 grams/cc. The individual rocks (probably basalt) in can 5 have a density of about 2.8 grams/cc, so there is something like 50% empty space between the rocks in the potato chip can!

Activities 5 and 6: Modeling Asteroid Densities

Three cans, all filled with rocks, with densities the same as water (left), asteroids Ryugu and Bennu (center), and density similar to the carbonaceous chondritic material that the two asteroids are composed of

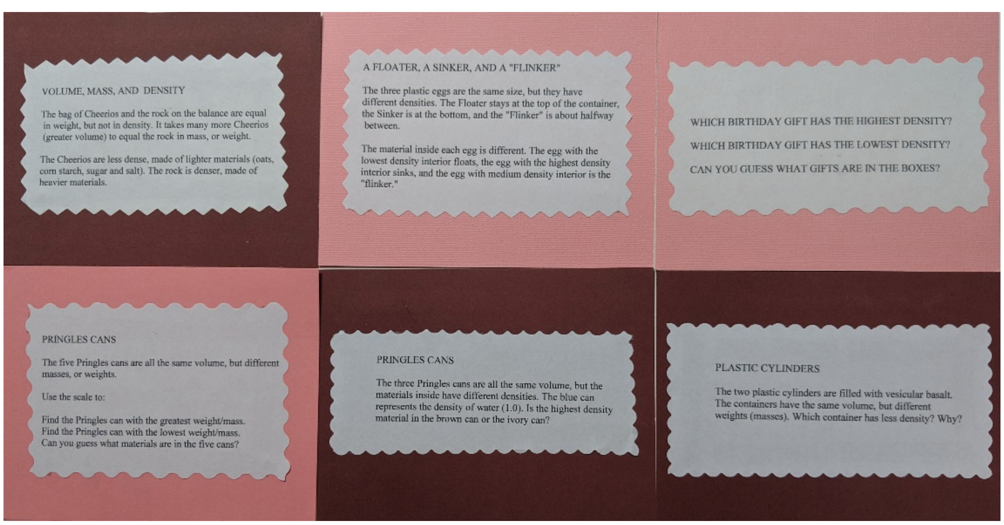
Two clear cylinders demonstrating different densities due to differences in empty space

As mentioned above, the asteroids Ryugu and Bennu both have measured densities that imply that they are rubble piles with about 50% empty space.

Examples of the three cans used to demonstrate a rubble pile

- Can 1 (blue): 980 grams, density of 1.0 grams/cc, the density of water
- Can 2: (ivory) 1,150 grams, density of 1.2 grams/cc, the approximate densities of Ryugu and Bennu
- Can 3 (brown): 1,990 grams, density of 2.1 grams/cc, the average density of a solid carbonaceous chondritic rock

Examples of Display Cards



- **Activity 1:**
  VOLUME, MASS, AND DENSITY

  The bag of Cheerios and the meteorite on the balance are equal in weight, but not in density. It takes many more Cheerios (greater volume) to equal the meteorite in mass, or weight.

  The Cheerios are less dense, made of lighter materials (oats, corn starch, sugar and salt). The meteorite is denser, made of heavier materials (rock and about 10% iron).

- **Activity 2:**
  A FLOATER, A SINKER, AND A "FLINKER"

  The three plastic eggs are the same size, but they have different densities. The Floater stays at the top of the container, the Sinker is at the bottom, and the "Flinker" is about halfway between.

  The material inside each egg is different. The egg with the lowest density interior floats, the egg with the highest density interior sinks, and the egg with medium density interior is the "flinker."

- **Activity 3:**
  WHICH BIRTHDAY GIFT HAS THE HIGHEST DENSITY?

  WHICH BIRTHDAY GIFT HAS THE LOWEST DENSITY?

  CAN YOU GUESS WHAT GIFTS ARE IN THE BOXES?

- **Activity 4:**
  PRINGLES CANS

  The five Pringles cans are all the same volume, but different masses, or weights.

  Use the scale to:

  Find the Pringles can with the greatest weight/mass.
  Find the Pringles can with the lowest weight/mass.
  Can you guess what materials are in the five cans?

- **Activity 5:**
  PRINGLES CANS

  The three Pringles cans are all the same volume, but the materials inside have different densities. The blue can represents the density of water (1.0). Is the highest density material in the brown can or the ivory can?

- **Activity 6:**
  PLASTIC CYLINDERS

  The two plastic cylinders are filled with vesicular basalt. The containers have the same volume, but different weights (masses). Which container has less density? Why?

Real Worlds

- Pluto: density = 1.9 gm/cm^3 (mixture of ice and rock)
- Moon: density = 3.3 gm/cm^3 (rocky with small iron core)
- Mercury: density = 5.4 gm/cm^3 (rocky with large iron core)
- Mars: density = 3.9 gm/cm^3 (rocky with iron/iron sulfide core; iron sulfide less dense than iron)
- Venus: density = 5.2 gm/cm^3 (rocky with iron core; some iron sulfide?)
- Earth: density = 5.5 gm/cm^3 (rocky with iron core)
- Jupiter: density = 1.3 gm/cm^3 (thick gas atmosphere with rocky core)
- TRAPPIST-1 planets (7-planet system): densities = 1.02 to 0.62 times the density of Earth—ranging from rock and iron to rock and ice or water
- Ryugu and Bennu (asteroid sample return missions): about 1.19 gm/cm^3 (rocky rubble piles, lots of empty space?)

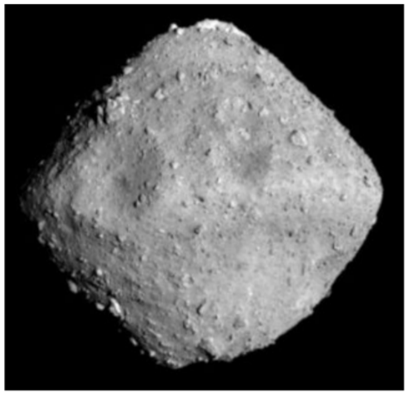
Stars:

- Sun: 1.4 gm/cm^3
- TRAPPIST-1 (red dwarf): 70 gm/cm^3 (90 times the mass of Jupiter but only 1.2 times the diameter of Jupiter)
- Betelgeuse (red giant): 0.00000002 gm /cm^3
- Sirius B (white dwarf): 2,000,000 gm/cm^3
- Neutron star: 100,000,000,000,000 gm/cm^3

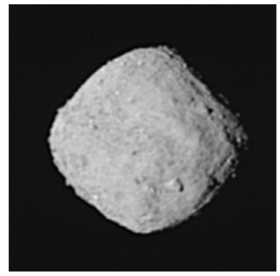
Conclusion—Why is this Important? Two Examples

- Spacecraft are orbiting two asteroids and will be returning surface samples to the Earth. The Japanese Space Agency's spacecraft Hayabusa2 landed three rovers on the surface of 162173 Ryugu, a carbonaceous asteroid. All three rovers were dropped from the main spacecraft. If they landed too hard, they could have bounced off the surface and have been lost in space. NASA spacecraft OSIRIS-Rex will freefall to the surface of 101955 Bennu another carbonaceous asteroid, touch the surface, collect a sample and then bounce back off. Again, the scientists need to know the gravity of the asteroid (related to its size and mass and hence density) in order to accomplish this never-before-done task. In both cases, the densities of these asteroids are about 1.19 grams/cc, much less than 1.6 to 2.4 grams/cc expected for solid bodies of this composition. Thus, it is likely that both of them are "rubble piles," similar to the rocks in several of the potato chip cans and the cylinders! This is something that may be common for small asteroids that have been impacted many times over their lifetimes. Also, it is thought that spinning rubble piles can lead to the unusual shapes that we see for both asteroids with material migrating to their equators as they spin on their axes.

Two Ongoing Sample Return Missions



162173 Ryugu, Japan
equatorial diameter =
1000 meters



101955 Bennu, US
equatorial diameter =
550 meters

- The Juno spacecraft is now orbiting Jupiter, the largest planet in our Solar System. While astronomers have studied the cloud-tops of Jupiter and sent one probe into its atmosphere, there is much to learn about its interior structure. From the Juno website:

  https://www.missionjuno.swri.edu/

  "Juno is equipped with tools that allow us to learn about Jupiter's interior—even if we can't directly see inside the planet. Movement and density variations under the clouds—caused by a thick, churning blob of gas, for example—can subtly alter the gravitational field directly above the surface. By observing these slight effects, Juno can help deduce what's inside."

Appendix: Information Sheets for the six Activities

The following activity sheets are used to assist presenters who may not be totally familiar with the activities. These should be placed behind each activity for the benefit of the presenter.

ACTIVITY ONE

BALANCE

- Balance measures mass; scale measures weight
- The bag of Cheerios and the bag of rocks have equal mass. Their volume and density differ.

ACTIVITY TWO

FLINKERS

- Floaters float on top of the water, sinkers sink to the bottom. "Flinkers" float somewhere between the top and bottom.
- The 3 eggs have the same volume. They are filled with materials of different masses and densities to form the floater (empty), sinker (rocks), and flinker (more rocks).

ACTIVITY THREE

BIRTHDAY BOXES

- This activity is appropriate for kids and adults. The 3 boxes have the same volume, but the "gifts" have different masses and densities. The boxes hold 2 pairs of socks, a bag of candy, and a hard cover book.

ACTIVITY FOUR

PRINGLES CANS (GROUP OF 5)

- There are 5 Pringles cans and a scale to measure weight (mass). The cans have the same volume, but are filled with materials of different densities and weights (mass). Participants should weigh the cans and put them in order, from least mass to greatest.
- Participants may guess what is inside each Pringles can.
- Key: White (empty), yellow (Styrofoam "peanuts"), orange (Pringles chips), red (vesicular basalt/pumice), purple (river rocks).

ACTIVITY FIVE

ASTEROID ANALOGS
PRINGLES CANS (GROUP OF 3)

- Two current asteroids missions are exploring the asteroids Bennu (U of A's OSIRIS-REX mission) and Ryugu (Japanese mission).
- The three Pringles cans have different densities.
- The blue can represents the density of water (1.0).
- The brown can represents the density of the material of which Bennu is composed, the same material as carbonaceous chondritic meteorites (about 2.2).
- Carbonaceous chondritic material is rocky and contains both carbon and water.

- The ivory can represents the actual density of Bennu (about 1.2). Question to participants: What does the difference between the brown and the ivory can tell us about the physical properties of Bennu?
- Answer: The structure of Bennu is closer to a rubble pile than a solid object.

ACTIVITY SIX

PLASTIC CONTAINERS (SET OF 2)

- Both containers are filled with vesicular basalt. They have the same volume, but different weights (masses).
- One container is filled with small pieces, density = .8 (592 grams, rocks only).
- One container is filled with large pieces, density = .58 (436 grams, rocks).
- Question: Asteroids Bennu and Ryugu are made of material whose density, if we had a *whole chunk* of "rock," would be ≥2. The actual density of the *entire asteroid* (i.e., the rubble pile) is <1.2. Why does the container of small rocks have a larger density? Why does the container of large rocks have a smaller density?
- Answer: There are bigger spaces between the larger rocks; therefore, the density is less.

BACKGROUND INFORMATION

- We find an object's density via observations. The density informs us about the composition of the object. A solid object weighs more; pieces weigh less. Big pieces weigh less because there is more empty space between the individual pieces. Small pieces weight more because there is less empty space between the individual pieces.

ACTIVITY SIX, CONTINUED

- The density of plain basalt is $3 g/cm^3$ and the density of vesicular basalt (pumice, "holey" rock) is ≤1.0 (density of water), depending upon the amount of holes in any given specimen of vesicular basalt.
- Our basalt specimen weighs 260 grams; our vesicular basalt specimen weighs 77 grams. They are about the same volume.
- We know the volume of the asteroids from observations and the mass of the asteroids from measuring their gravity. These two measurements give us the density of the objects.
- The spacecraft measure the gravity of the asteroids from orbit (which gives us the mass).
- We know the composition of the asteroids from light measurements (their spectra).