How Much Rock is in an Icy Moon?

Teacher Page

Purpose

To calculate the percentages of rock and ice in the moons of the outer planets.

Background

This activity teaches simple calculations and graphing, and how to use data from a graph. The idea is to figure out the percentages of rock and ice in a number of the satellites (moons) of the outer planets (Jupiter, Saturn, Uranus, Neptune, and Pluto). The students construct a graph of the amount of rock versus the density of the moon, using a simple equation. They then determine the percentage of rock from the densities of several moons and enter the answers in a table. There are some hidden assumptions in the exercise that you may wish to discuss with the students. One is that we know the densities of rock and ice. The activity assumes that rock has a density of 3.5 grams per cubic centimeter. This is reasonable for the rocks that make up the interiors of the planets and most asteroids. However, if the rocks contained significant amounts of water bound in their minerals, a density of 3.5 would be too high. If the rocks averaged 2.5-3.0 grams per centimeter, typical of many water-bearing minerals such as clays, the calculation would underestimate the percentage of rock in each moon. Unfortunately, how much water is contained in the minerals of the icy satellites is not known. Also, in the larger satellites (and in planets), rocky materials are compressed deep inside them, making minerals with higher densities than they have at low pressures. This causes the average density to be higher than 3.5, and would translate to a smaller percentage of rock. We also use the density of water ice, but it is possible that some of the moons contain some other "ices," such as ammonia. Nevertheless, water is certainly the most abundant ice in the satellites. The activity ignores these complications, and to a first approximation, the answers are accurate. Ice and rock could be distributed inside a satellite in a number of ways, such as chunks of rock in a matrix of ice. However, because ice behaves in a plastic way (it flows, like it does in glaciers), the rock will fall through it, accumulating in the centers of the icy satellites. The fact that many of the icy satellites heated up to the melting temperature of water helps smooth the way for the rock to fall to the center. It goes to the center, of course, because it is denser than the ice. So, a drawing of an icy satellite would have a rocky core surrounded by an icy mantle.

In Class

The graph could actually be constructed by calculating the densities of a moon when the percentage of rock is 0 and when it is 100, and connecting the points by a straight line. Some alert students may mention this when they notice they are plotting up a perfectly straight line.

Extensions

As an extension, students could be asked to draw the interior of one of the icy satellites, to scale. This is tricky: the graph gives the percentage by volume, which would need to be converted to percentage of radius. Volume is related to the radius cubed, so the rocky core extends outward much further than you would expect. For example, Earth's metallic core is only 1/8 its volume, but extends from the center of the planet to half its radius (the cube root of 1/8). Thus, if a satellite is half rock and half ice by volume, the decimal fraction of its radius taken up by its rocky core is 0.79 (the cube root of 0.5, or 1/2). That is, 79% of the satellite's radius is rocky core, and the remainder is ice. A satellite that is only 25% rock by volume has a rocky core that occupies well over half its radius, 0.63 (or 63%).

On Earth and the other planets, ice is not a constituent of the interiors. Instead, metallic iron is present in their cores. The percentage of rock can be calculated the same way as for an icy satellite, using the percentage and density of iron instead of ice. However, the density of rock is too low to make accurate predictions because rock compresses quite a bit deep inside the inner planets.

The Fun Extension Using Algebra

Finally, for classes where students have taken some algebra, an interesting extension is to determine the percentage of rock in one satellite. This puts a little algebra into a more interesting context than figuring out the time when a train leaving Chicago going 60 miles an hour will meet up with a train leaving Kansas City traveling 45 miles per hour and how far they will be from Chicago.

The suggestion is to calculate the percentage of rock in Callisto, which has a density of 1.8 grams per cubic centimeter. The students can start with pretty much the same equation used in the exercise:

$$D = (3.5X+0.9Y)/100$$

where **D** is the density of the moon, **X** is the percentage of rock, and **Y** is the percentage of ice. (The 100 is there to convert the percents to fractions.) The constants 3.5 and 0.9 are simply the densities of rock and ice, respectively.

The problem is that we have one equation with two unknowns. This dilemma can be solved by a substitution. Because we have only two components, rock and ice, the percentage of one is 100 minus the percentage of the other:

$$Y = 100-X$$

Substitute this into the equation:

$$\mathbf{D} = [3.5\mathbf{X}+0.9(100-\mathbf{X})]/100$$
$$\mathbf{D} = (3.5\mathbf{X}+90-0.9\mathbf{X})/100$$
$$\mathbf{D} = (2.6\mathbf{X}+90)/100$$

We know that **D**, the density of Callisto, is 1.8, so

$$1.8 = (2.6\mathbf{X}+90)/100$$

Multiplying both sides by 100,

$$180 = 2.6\mathbf{X}+90$$
$$2.6\mathbf{X} = 180-902.6\mathbf{X} = 90\mathbf{X} = 90/2.6\mathbf{X} = 34.6$$

Jupiter's satellite, Callisto, is 34.6% rock.

Students can then check to see if it agrees with their result from the graph. You can also check the result for pure rock (**D**=3.5) and pure ice (**D**=0.9).

How Much Rock is in an Ic

Purpose

To calculate the percentages of rock and ice in the moons of the outer planets.

Background

The outer planets (Jupiter, Saturn, Uranus, Neptune, and Pluto) have icy, rocky sat
the satellites, you can calculate the percentage of rock and ice in the compositions

Procedure

1.
Begin by looking at the density values given for various moons in the "Percent Ro

2.
Are the densities all the same?

3.
Rock has a density of about 3.5 grams per cubic centimeter. Are any of the moons
ones?

4.
Water ice has a density of about 0.9 grams per cubic centimeter. Are any of the mo
which ones?

5.
We can make a graph to help figure out the percentages of rock and ice in the mo
equations shown below to compute the density resulting from different percentage
the table below.

Key Words

satellite
moon
rock
ice
density

Materials

pencil
calculator
"Percent Rock Graph"
"Percent Rock Chart"