Eureka! – detecting ore the Archimedes way
Measuring density using a stick, string, a ruler, a bucket and a bottle of water

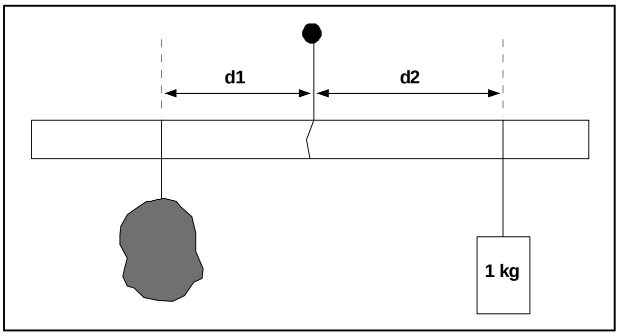
A rock that feels heavy may contain mineral ores. But how can we find out if rocks that feel heavy for their size really are more dense than ordinary rocks?

'Rocks', one with ore. *Photos: Peter Kennett*

The simple way to find out is to use the method discovered by the famous scientist Archimedes more than 2000 years ago. To investigate if something is heavy for its size (has a high density) or light for its size (low density) we need to measure how heavy it is (its mass) and what size it is (its volume).

Finding the mass

Tie string to the centre of the stick or rod and hang it so it can swing freely. Move the string until the stick hangs as close to horizontal as possible. Tie the litre bottle of water (weighing one kilogram or 1000 grams) near one end, and the rock to the other end and then balance them – as in the diagram:



Since the turning effect is the same on one side of the stick as the other then:

Turning effect on the left = Turning effect on the right

Mass of rock x distance d1 = Mass of water bottle x distance d2

i.e. Mass of rock (g) x d1 (cm) = 1000 (g) x d2 (cm)

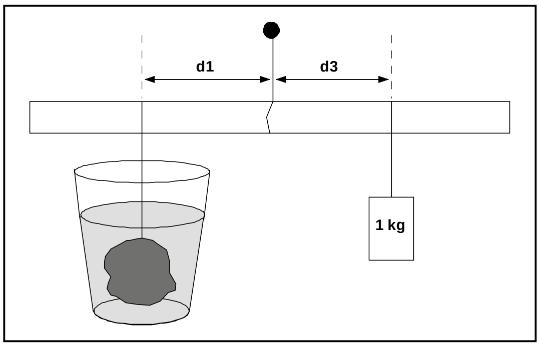
So measure d1 and d2 and find the mass from:

$$\text{Mass of rock (g)} = \frac{1000 \times d2}{d1}$$

Finding the volume

This is the clever bit – Archimedes' Principle. If the rock is hung in water it will appear lighter. The apparent loss of mass is the mass of water displaced. Since water has a density of 1g cm^{-3}, this is the same number as the volume of the water displaced, and the volume of the rock too!

So, hang the rock in the bucket of water, keeping d1 the same, i.e. without moving it along the stick. Then move the1000g bottle of water along the stick until it balances again, at d3 – as in this diagram:



Then:
Turning effect on the left = Turning effect on the right

So with d1 the same, measure d3.

Mass of rock in water x d1 = 1000g x d3

$$\text{So mass of rock in water} = \frac{1000\text{g} \times d3}{d1}$$

$$\text{Mass of rock in air – mass of rock in water} = \frac{1000d2}{d1} - \frac{1000d3}{d1}$$

$$\text{Volume of rock} = \frac{1000d2}{d1} - \frac{1000d3}{d1}\ \text{cm}^3$$

$$\text{Density} = \frac{\text{mass of rock}}{\text{Volume}} = \frac{1000d2}{d1} \div \left(\frac{1000d2}{d1} - \frac{1000d3}{d1} \right)$$

This cancels down to:

$$\text{Density of rock} = \frac{d2}{(d2 - d3)}\ \text{g cm}^{-3}$$

So by measuring just d2 (in experiment 1) and d3 (in experiment 2) you can calculate the density directly.

The apparatus in action *Photo by Peter Kennett*

Which rock is the most dense?

Now you have a method to find the density of any rock, or anything else of a similar size. You can use this to find which are the most dense rocks – the ones that are most likely to contain valuable minerals.

The back up:

Title: Eureka! – detecting ore the Archimedes way.

Subtitle: Measuring density using a stick, string, a ruler, a bucket and a bottle of water.

Topic: Using very simple apparatus to measure density.

Age range of pupils: 11 - 18 years

Time needed to complete activity: 20 mins

Pupil learning outcomes: Pupils can:
- manipulate simple apparatus;
- take accurate distance measurements;
- do simple calculations;
- describe density as a measure of mass related to volume.

Context:
This activity shows that fairly sophisticated measurements can sometimes be made with very simple apparatus.

Following up the activity:
You could tell the Archimedes story to your pupils. *Archimedes had been asked by the King to find out if his crown was made of pure gold or if some lighter metals had been mixed with the gold. To do this he realised that he needed to measure the density of the crown. If the density was too low, then a lighter metal must have been mixed with the gold. It was easy to measure the mass of the crown, but difficult to measure the volume of this odd-shaped object. This was when Archimedes took a bath – it was so full that it overflowed, and he realised that he had discovered a method of measuring volume. Fill a container with water, drop the object in, and the amount of water that overflows has the same volume as the object – the Archimedes Principle. It is said that Archimedes was so excited about his discovery that he ran from his bath, naked through the streets, shouting, 'Eureka'! – Greek for 'I have found it!' According to the story, he found that some of the gold was missing from the crown and so the King had the goldsmith beheaded.*

Underlying principles:
- This activity depends on Archimedes' Principle – that a body immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid.
- The apparatus uses the Principle of Moments, that the turning effect on one side of a pivot (force x distance) is the same as that on the other side. This is based on another of Archimedes' discoveries – the lever.

Thinking skill development:
The appreciation that density is the result of two factors, mass and volume, and that patterns of density can be found, involves construction.

Resource list:
- a straight stick, rod or beam around a metre long
- a known mass, e.g. a litre bottle full of water (1 litre of water = 1 kilogram = 1000 grams)
- string
- a ruler or tape measure
- a bucket of water
- something to hang the apparatus from
- rocks to be measured – these can be large mineral specimens, as shown in the photos

Useful links:
To find more detail of Archimedes' story and his many other achievements, type his name into a search engine like Google.

Source: Idea and diagrams from John Perry of Keele University Education Department (after Archimedes).