Eureka!

Once upon a time there was a Greek wise man called Archimedes who excelled at many STEM subjects. On one occasion he was tasked with determining whether the piece of pure gold that the king had supplied for the forging of a crown had been all used for the making of the crown, or, if by any chance the goldsmith had been dishonest and had mixed the gold with cheaper metals.

Archimedes knew the weight of the crown but this did not help him to discern whether it was made only of gold or a mixed of gold and something else. To be sure of this, he had to know the density of the material the crown was made of. If the crown were made of pure gold, that value would coincide with the density of pure gold. For the calculation of the density though, Archimedes had to work out the volume of the crown - without melting the metal – and this was a very big challenge, as at the time mathematicians only knew how to calculate the volume of simple 3D shapes.

One day, while he was taking a bath, he noticed the water level in the bath rose as he immerse himself into it. He thought that, given that water cannot be compressed (its volume cannot change), the volume of water displaced must be equal to the volume of the object being submerged – in this case himself. He thought that by knowing how much volume of water was displaced when submerging the crown in the water, he would be able to calculate the volume of the crown. Then, knowing the weight of the crown, he would be able to calculate its density, which ultimately would give him the answer he was looking for.

Realising that he had solved the challenge, the legend goes that Archimedes left the bath and, completely naked, went to share his discovery with the world saying "Eureka" (I found it! in Greek).

Experiment 1: Calculation of volume

More than 2,000 years after Archimedes made this sensational discovery, we can use this method for measuring the volume of objects. For this experiment you need:

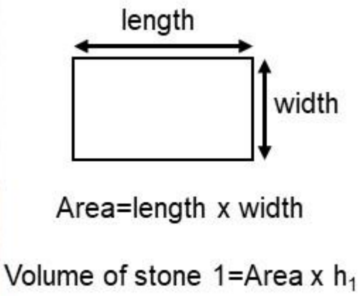
- A measuring jug. Alternatively, a transparent plastic container will do. The container has to be such that its area can be calculated easily – a circular, rectangular or square container would work.
- Water
- A ruler
- Any (waterproof!) object you want to know the volume of

Pour water in the container and mark the water level. Put the object you want to measure the volume of in the container - in this example we have used stones. The object must sink to the bottom of the container, if it floats you won't be able to measure its volume. See how the water level rises when you submerge the object.

Following Archimedes' discovery, we will know the volume of the object by measuring how much water has been displaced. To do this, first calculate the area of the container - in the case of a rectangular/square container this is equal to length multiplied by width. Next, multiply the area by the amount by which the water level rises.

In the example below, the water level without any object in is marked with a red line, and h_1 is the amount by which the water level rises when one stone is in the container. You can use the ruler to measure the dimensions and distances that you need.

$$Volume\ of\ stone\ 1 = Area\ x\ h_1$$



Note for experimentalists!

- *Make sure all the measurements are in the same units.*
- *If they are all in centimetres (cm), the volume will be calculated in cm^3.*
- *Using a smaller container will allow you to measure the volume of smaller objects accurately.*
- *A measuring jug will give you the measure of volume without the need for multiplication. The conversion of millilitres (ml) to cm^3 is $1ml = 1cm^3$.*

If you know the weight of the object, using the kitchen scale for example, you can also calculate the density of the object using:

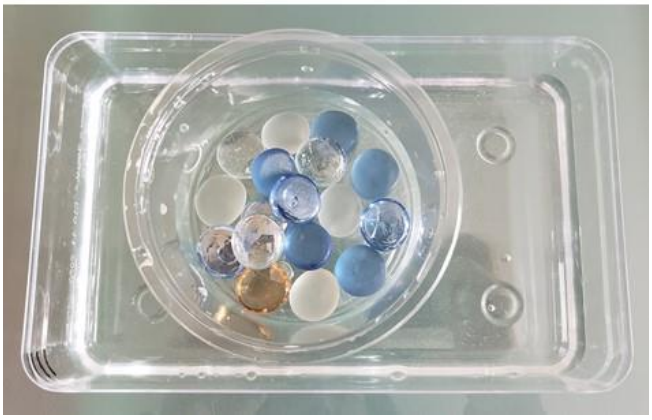
$$Density = \frac{Mass}{Volume}$$

Try submerging three objects at once, for example, and check that the volume of water displaced by the three objects together is equal to the addition of the three volumes calculated separately.

Experiment 2: Calculation of mass

If an object floats on water, the force keeping it afloat balances the weight of the object. For these two forces to be in equilibrium, the weight of a floating object must be equal to the weight of the water displaced. As the density of water is 1 gram per centimetre cubed ($1g/cm^3$), every $1cm^3$ corresponds to 1g of water and hence, as the object floats, to one 1g of the mass of the floating object.

In this example we want to measure the weight of crystals, but the problem is that they normally sink in water! A trick to make objects denser than water float is by placing them in a container that can float in water: we first place the crystals in a small container and next, put that into a bigger container half-filled with water, see the picture below for guidance.



The volume of water displaced can be calculated as in Exercise 1. This volume (in cm^3) will be equal to the mass of the object in grams. You can compare that value with that obtained using the kitchen scale!

In the example shown in the picture the container has the following dimensions:

- Length=17.8cm
- Width=10.8cm

The water level rose by 0.4cm in the big container when the little crystals were added to the circular container. Their weight was then equal to 17.8 x 10.8 x 0.4 = 77g. Using the kitchen scale the weight was 80g - not bad!!