From clay balls to the structure of the Earth
A discussion of how physics can be used to probe Earth's structure

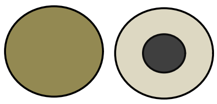
Using clay balls to ask key questions
Prepare two clay balls of the same size for each group, one with a ball bearing in the centre. Then ask this series of questions.

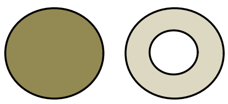
1. Two clay balls – what is the difference?
Give each group of pupils a pair of balls and ask them to use their senses to detect the difference between them, ***without destroying the balls***. Most will soon realise that one ball is heavier than the other.

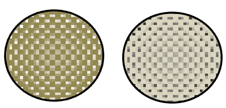
2. What could explain the difference?
Confirm that one ball is heavier than the other. Then ask each group the reason for this. Challenge them to suggest at least three different ideas.

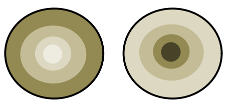
The different hypotheses they suggest should include:
- one has something heavy in the middle (eg. a piece of metal);
- one has something light in the middle (eg. a hole or a piece of polystyrene);
- one is made of heavier clay than the other.

They might even suggest:
- one ball becomes steadily heavier towards the middle (with layers like some gobstopper sweets); or
- one ball become steadily lighter towards the middle.


Something heavy in the middle


Something light in the middle


'Heavy' and 'light' clay


Steadily heavier or lighter

3. How could we find out which idea is right?
Now challenge each group to suggest how the balls could be tested ***without destroying them***, to find out which of the suggested ideas is right. They can use any of the apparatus in the school or in the town.

Ideas usually suggested include using:
- something to stick into each ball;
- a small amount of clay from each ball for weighing;
- a magnet (or a magnetic sensor);
- ultrasound (as used to detect babies before birth);
- electromagnetic resonance (many hospitals have an EMR machine; metal detectors use EMR too);
- X-rays;
- radiation (correctly called ionising radiation – alpha, beta or gamma radiation).

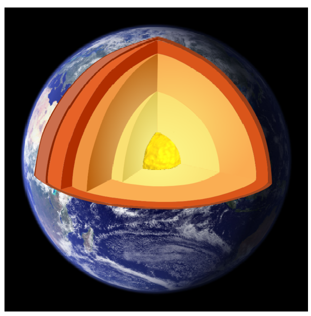
Some may also suggest testing differences in how the balls roll or spin.

Incorrect suggestions include, that you could test whether the balls float or sink, or you could weigh them. These would only confirm what we already know – that one ball is heavier than the other.

The responses to the other ideas are:
- something to stick into each ball – *if you stick a matchstick into each ball, one will go through and the other will be stopped by the ball bearing*;
- a small amount of clay from each ball to be weighed – *if this were done, the density of the clay would be the same*;
- a magnet (or a magnetic sensor); ultrasound; electromagnetic resonance and X-rays – *these should all detect the metal ball bearing*;
- radiation – *alpha and beta radiation would not penetrate the clay, but the ball bearing would be detected by gamma radiation*;
- even though the ball with the bearing should roll and spin better, this is usually not detectable.

4. Which of these ideas could be used to find out if the Earth has a core?
Ask the groups to discuss and then suggest which of the ideas listed could be used to probe the Earth to find out if it has a core. The answers are:
- something to stick into the Earth – *this is not possible, as the deepest hole ever drilled into the Earth is 12 km deep, yet the outer edge of the core is about 3000 km below the surface*;
- a small amount of clay from each ball to be weighed – *we can weigh the Earth, and so find it has a relative density of about 5.5, meanwhile crustal rocks have a relative density of around 3, indicating that there is something of high density deep in the Earth*;
- a magnet (or a magnetic sensor) – *these will detect the Earth's magnetic field, so there must be something deep in the Earth causing it*;
- ultrasound – *this has too high a frequency to penetrate the Earth, but low frequency sound (possibly called 'infra-sound'), or seismic waves do penetrate the Earth, and provide the best evidence for the position and character of the core*;
- electromagnetic resonance and X-rays - *cannot penetrate the Earth*;
- ionising radiation – *even gamma radiation can only penetrate a few metres into concrete, and so cannot penetrate the Earth*;
- how the Earth spins (its rotational inertia) – *this does suggest that the Earth has a dense core.*

Summarise the findings – the best evidence we have for the core is seismic waves, but density-measurements, inertia and magnetism all play their part.


The Earth's core - shown in yellow.

The back up

Title: From clay balls to the structure of the Earth.

Subtitle: A discussion of how physics can be used to probe Earth's structure.

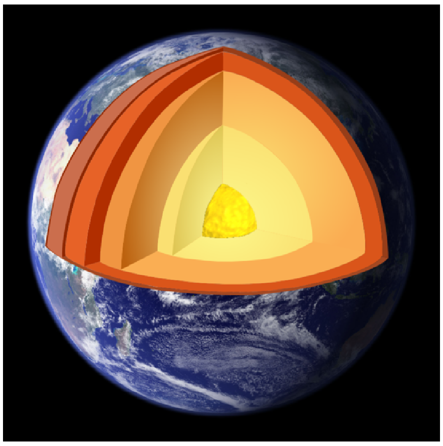
Topic: A series of questions is given to provoke discussion in groups of pupils that will develop their understanding of the structure of the Earth, how some geophysical methods are used, and their thinking skills as well.

Age range of pupils: 14 – 18 years

Time needed to complete activity: 20 mins

Pupil learning outcomes: Pupils can:
- develop hypotheses through discussion;
- suggest methods of testing hypotheses;
- suggest which physical methods could be used to probe the Earth;
- describe the methods that are used to provide evidence for the Earth's core.

Context:
You could teach pupils that the Earth has a core in a quick and simple way by giving them a diagram showing the core and asking them to copy and learn it. Or … you could develop a deeper understanding of the evidence for the Earth having a core by following the question scheme above.



A cutaway view of the Earth, showing the core in yellow.

Even though the ball-based discussion takes a lot longer to run in class than asking pupils just to draw diagrams, it does develop much better understanding of the evidence for the core whilst covering many aspects of physics and developing thinking skills.

Following up the activity:
Pupils can be asked to find the density of the ball bearing in a way similar to the method that we use to estimate the density of the Earth's core, by:
- weighing the ball that has no ball bearing to find its mass;
- finding the volume of this ball by measuring its radius and using the formula:
  volume of a sphere = $^4/_3 \pi r^3$
- calculating the density of the ball and thus the density of the clay using the formula:
  density = mass/volume
- weighing the ball with the ball bearing to find its mass;
- subtracting the weights of the two balls, to find the extra mass of the ball bearing;
- finding the radius of the ball bearing by sticking a matchstick into the clay ball with the ball bearing and subtracting that measurement from the radius of the ball;
- calculating the volume of the ball bearing;
- calculating the extra density of the ball bearing by dividing the extra mass of the ball bearing by its volume;
- adding this to the density of clay to give the density of the ball bearing.

These principles have been used to calculate the densities of the different shells of the Earth. From these calculations, we estimate that the relative density of the core ranges from around 9.9 at the margin of the outer core to around 13 at the centre. Meanwhile, the crust has a relative density of around 3, whilst the relative density of the whole Earth is around 5.5.

Underlying principles:
- This consolidates understanding of many physical processes and characteristics including, density, inertia, magnetism, electromagnetism, sound (ultrasound and seismic) and radiation (X-rays and ionising).
- The best evidence we have for the core's position and character is seismic waves, but density-measurements, inertia and magnetism each contribute useful information too.

Thinking skill development:
The development of hypotheses involves construction, and the group discussions are sure to develop cognitive conflict and probably metacognition, as some pupils are asked to describe their reasoning. The transition from the clay balls to the Earth involves bridging.

Resource list:
- a pair of clay (or Plasticine™) balls per group of students – each ball should be 2 cm to 3 cm in diameter, and one with a ball bearing (or other small piece of metal) at the centre, occupying about half the diameter of the ball; for ease of sorting out the balls after the activity, use a different colour of clay for the balls with bearings
- one used matchstick (or a cocktail stick or needle)
- a strong magnet
- optional, for the extension work: a balance and a ruler (or preferably callipers for accuracy)

Useful links:
The US Geological Survey has published a useful downloadable book about the structure of the Earth and plate tectonics on its website, called '*This dynamic Earth: the story of plate tectonics'* available at: http://pubs.usgs.gov/gip/dynamic/dynamic.html

Source: Based on the account in 'King, C. (2002) The secrets of Plasticine balls and the structure of the Earth: investigation through discussion. *Physics Education,* 37 (6), 485 – 491', based in turn on an idea by John Reynolds and Maggie Williams, described in 'King, C. & York, P. (1996) *Investigating the science of the Earth, SoE2: geological changes – Earth's structure and plate tectonics.* Sheffield: Earth Science Teachers' Association.'