PLANET DENSITY

Students use iron and sand to model the composition of the Earth and estimate what fraction of the Earth is occupied by its iron core.

Apparatus and Materials

(per group of 2 to 4 students)

- Balance
- Measuring cylinder
- Steal ball bearing or steel block approx.. 2 or 3 cm across
- Sand

Each student will also require a photocopy of the instructions and worksheet (pages 16 and 17 respectively).

Health & Safety and Technical Notes

If using ball bearings, remind students that if any fall on the floor they must be picked up promptly so that so no-one slips on them. Give each group a dish to keep them in. A little bit of tissue paper on the balance will stop them rolling off.

Learning objectives

After completing this activity, students should be able to:

- measure mass and volume.
- calculate density from mass and volume.
- understand that planets can be classified according to their densities.

Introducing the activity

Introduce the idea of an exoplanet and explain why they are difficult to observe. (They are very distant and much smaller than stars, and they are not sources of light.)

Explain that astronomers can determine the radius and mass of an exoplanet, and hence deduce its density. By comparing an exoplanet's size and density with that of the Earth and other planets, they hope to find Earth-like planets orbiting other stars.

Explain that the Earth is made of two materials: the dense iron core and the less dense outer rocky region (mantle and crust). Its average density is between the densities of iron and rock. They are going to use a simplified model to estimate what fraction of the Earth is iron (by volume).

The practical activity

You could introduce the activity by showing a steel ball (to represent the Earth's core) and some Plasticine. Discuss their different densities. Explain how to calculate density and introduce units. (For ease of calculation g/cm^3 rather than kg/m^3 are used throughout this activity).

Wrap a layer of Plasticine around the ball to represent the mantle and crust. What can be said about the average density? (It must be between that of steel – 7.9 g/cm^3 and that of Plasticine – 1.9 g/cm^3.)

(You could measure mass and volume of the ball + Plasticine by immersing the ball in water in a measuring cylinder on a balance and then add increasing amounts of Plasticine. However, sand is a better material to represent rock as its density is closer to that of the rock found on the Earth's surface.)

A blank table for tabulating results and calculations is provided on the worksheet. Alternatively students can use a Microsoft Excel spreadsheet for processing data. Remind them that before taking readings for the sand-steel mixture they should place the measuring cylinder on the balance and zero it.

They should find that the average density decreases from that of steel as more sand is added. Typical results are shown in figure 4a. The equation for calculating the steel-percentage by volume is provided on the worksheet and a graph of density against percentage provides a straight line from which the percentage that gives a density of 5.5 g/cm^3 can be read (see figure 4b). They should get an answer of between 50-60%.

After the activity you may want to discuss the composition of the Earth (figure 4c). Explain that although the crust is of a similar density to sand, the rock in the mantle has a higher density (between 3 and 6 g/cm^3). What does this imply about the size of the core? Will it be bigger or smaller than their estimate? (They should conclude that their estimate provides a maximum size for the core; the actual volume will be lower). There is also the additional complication that the iron in the core is denser than the steel they have used in their model.

About planetary densities

For the Solar System, the masses of planets can be deduced from the orbital speeds of their moons – a moon orbiting a massive planet has to orbit quickly to avoid being pulled in by its strong gravity. Their radii can be measured from photographs taken using telescopes, or by observing them transiting across distant stars.

The chart on the student instructions shows how we can divide them into the higher density rocky planets and the lower density gas giants. (The gases are, of course, frozen.) Astronomers would like to find examples of Earth-like exoplanets. They can then concentrate their efforts on trying to discover whether they may have signs of life such as atmospheres containing oxygen and methane.

It is harder to find the mass and radius of an exoplanet. The radius can be found from the transit light curve – the initial dip takes longer for a bigger exoplanet (see teacher notes for activity 1). The mass can be found from the wobble of the parent star as the exoplanet orbits it – the star moves in a small circle and this can be detected from the Doppler shift in its light.

Taking it further

Students can research the densities of some known exoplanets and identify ones that have similar densities to Earth.

Figure 4a – Typical results

	A	B	C	D	E	F
1	**Volume of steel (cm^3)**	**Total mass (g)** (sand + steel)	**Volume of sand (cm^3)**	**Total volume (cm^3)** (sand + steel)	**Steel percentage by Volume**	**Average density (g/cm^3)**
2	*7.6*	*60.1*	*0*	*7.6*	*100 %*	*7.9*
3		*87.6*	*11*	*18.6*	*41 %*	*4.7*
4		*110.1*	*20*	*28.6*	*27 %*	*3.9*
5		*130.1*	*28*	*35.6*	*21 %*	*3.7*
6		*160.1*	*40*	*47.6*	*16 %*	*3.4*
7		*182.6*	*49*	*56.6*	*13 %*	*3.2*

Figure 4b – Average density against steel percentage. The percentage that gives a density equal to that of the Earth (5.5 g/cm^3) can be read from the graph.

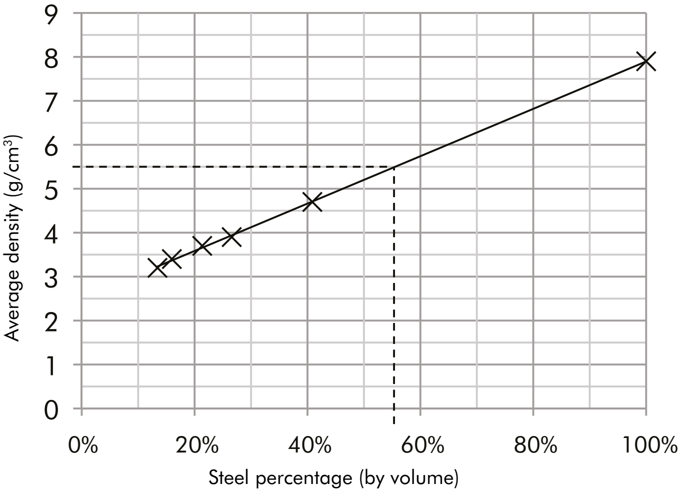
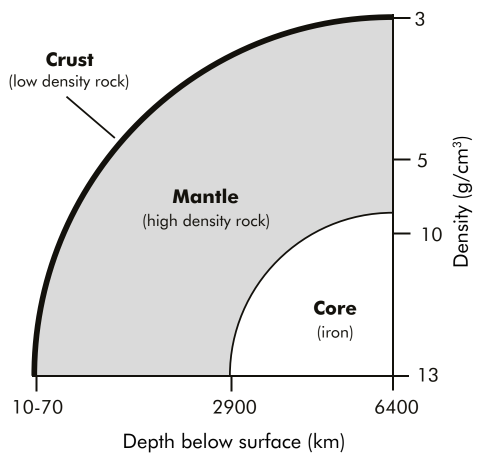


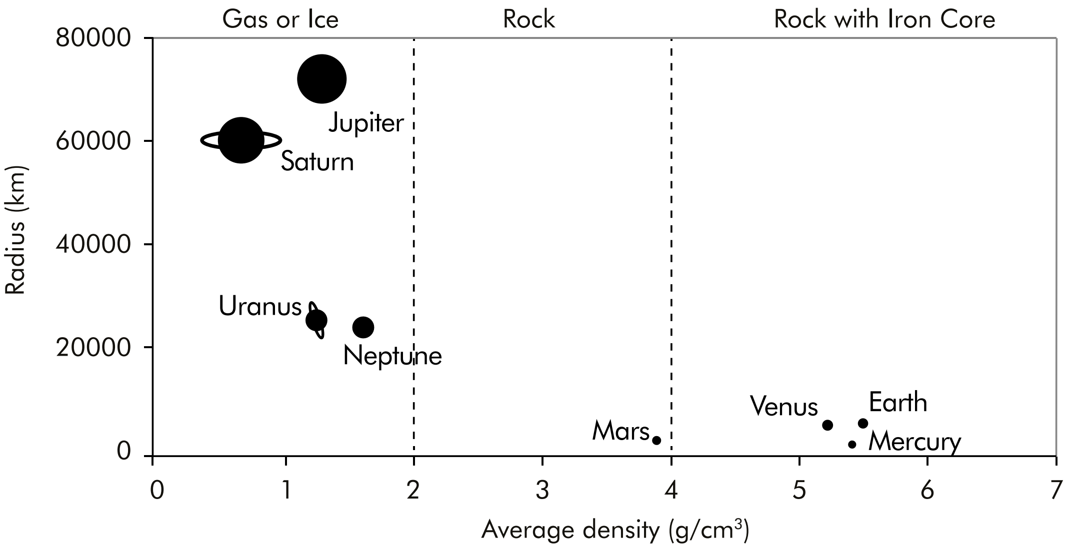
Figure 4c – Layers of the Earth, their approximate densities and composition. Density depends on depth as well as composition. For example, the iron core's density increases from around 10 g/cm^3 (at its outer edge) to around 13 g/cm^3 (at its centre).



EXOPLANET PHYSICS

FINDING AN EARTH-LIKE EXOPLANET: PLANET DENSITY

To find out what an exoplanet is made of, astronomers look at its size and mass. From this they can calculate its density. This will help them to decide whether it is likely to be a rocky planet like the Earth or a gas giant.



Note: Planets are not to scale

The biggest planets of the Solar System (Jupiter and Saturn) have the lowest densities. They are gas giants, made of frozen gas or ice. We couldn't live there. The Earth is more dense. It is a rocky planet with an iron core.

The Earth's average density is about 5.5 g/cm^3. That is in between the density of rock (about 2.5 g/cm^3) and the density of iron (7.9 g/cm^3).

In this activity you will find out how much of the Earth is rock and how much is iron.

What you'll need:

- Balance
- Measuring cylinder
- Steel ball bearing or steel block approx. 2 or 3 cm across
- Sand

What you need to do:

The steel represents the core of a planet.
The sand represents the rocky exterior.

1. Measure or calculate the volume of the steel. (Decide on your own method for this.)
2. Zero the balance. Measure the mass of the steel.
3. Work out the density of steel using

$$\textit{Density of steel} = \frac{\textit{mass of steel}}{\textit{volume of steel}}$$

4. Remove the steel from the balance.
5. Follow the instructions on the student worksheet to work out the density of a steel-sand mixture and the percentage of the Earth made of iron.

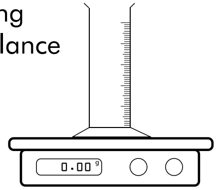
ACTIVITY 4
WORKSHEET

EXOPLANET PHYSICS

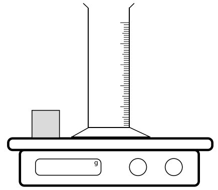
PLANET DENSITY: MODELLING THE EARTH

Record the volume of the steel in cell A2 of the table

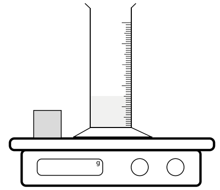
Place the measuring cylinder on the balance and **zero it.**



Place the steel on the balance and record the **mass** in cell B2 of the table



Add some sand and record the total mass and volume of sand in cells B3 and C3 of the table



	A	B	C	D	E	F
1	Volume of steel (cm^3)	Total mass (g) (sand + steel)	Volume of sand (cm^3)	Total volume (cm^3) (sand + steel)	Steel percentage by Volume	Average density (g/cm^3)
2			*0*		*100 %*	
3						
4						
5						
6						
7						

Gradually increase the amount of sand, recording the total mass in column B and volume of sand in column C of the table

For each of your values calculate the total volume (steel + sand). Record your answers in column D

For each of your values calculate the percentage of the total volume that is steel using

$$Steel\ \% = \frac{Volume\ of\ steel}{Total\ volume} \times 100\%$$

Record your answers in column E

For each of your values calculate the average density using

$$Average\ density = \frac{Total\ mass}{Total\ volume}$$

Record your answer in column F

Plot a **graph** of average density against steel percentage. Use the graph to work out the percentage of the Earth occupied by the core

Taking it further Use the internet to find out about the densities of some exoplanets. Which are likely to be gas giants? Which might be Earth-like?