Density

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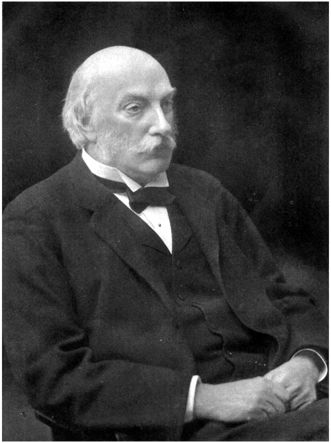
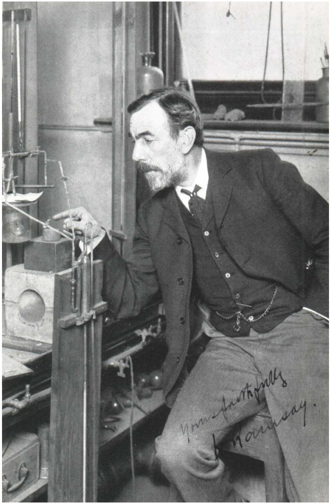
The discovery of Argon



Lord Rayleigh



Sir William Ramsay

The discovery of Argon

In the early nineteenth century, air was known to be made up of oxygen and nitrogen.
Lord Rayleigh removed the oxygen from the air, and measured the density of the remaining nitrogen. He obtained:

$$\rho_{\mathrm{N}} = 1.2572\,\mathrm{kg\,m^{-3}}.$$

He then measured the density of nitrogen prepared from chemicals, and found:

$$\rho_{\mathrm{N}} = 1.2505\,\mathrm{kg\,m^{-3}}.$$

This is a small discrepancy, representing an error of about 0.5%.
However, Rayleigh was confident that his errors were less than this.

The discovery of Argon

Lord Rayleigh presented his findings in *Nature* in 1892, and gave a talk in 1894 which Ramsay attended. After this, the pair teamed up to find out whether the nitrogen from the air might contain a small quantity of a heavier gas, causing the difference in density. Ramsay, a chemist, succeeded in isolating a new gas, which he named 'Argon'

Lord Rayleigh won the Nobel Prize in physics 1904 for the discovery of Argon, and Sir William Ramsay won the Nobel prize in Chemistry that same year.

Lesson Objectives

1. To understand the notes on density.
2. To measure the density of solids experimentally.
3. To learn how to answer questions on density.

Textbook pp. 162–163

REMINDER: Office hours are week 2 Tuesdays 3.45–5.0 p.m. in room 19.
Next office hours: Tuesday 22 January 2013

Bulk properties of solids

Density $\rho = \frac{m}{V}$

[AQA GCE AS and A Level Specification Physics A, 2009/10 onwards]

Reading memos

Density

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'What weighs more: a pound (lb) of feathers or a pound of lead?' Of course, we all know that they both weigh the same (because they have the same mass), but we often hear the expressions 'as light as a feather' or 'as heavy as lead', and it is true that equal volumes of different substances vary considerably in mass. In physics, we use the property of *density* to compare the 'lightness' or 'heaviness' of different materials.

Definition

The density of a material is its mass per unit volume.

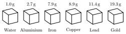
$$\text{density} = \frac{\text{mass}}{\text{volume}}$$
$$\rho = \frac{m}{V}$$

The SI unit of density is the kilogram per cubic metre, $\mathrm{kg\,m^{-3}}$, for which we must use kilograms to measure the mass and cubic metres to measure the volume. Sometimes it is more convenient to measure the density in different units, most commonly g for mass and $\mathrm{cm^3}$ for volume. It is very easy to convert between the two, and it is worth remembering that water has a density of $1\,\mathrm{g\,cm^{-3}}$:

$$\text{density of water} = 1\frac{\mathrm{g}}{\mathrm{cm^3}} = \frac{1/1000\,\mathrm{kg}}{(1/100\,\mathrm{m})^3} = 1000\,\mathrm{kg\,m^{-3}}.$$

Typical densities

We have already seen that a cubic centimeter of water will have a mass of 1 g. Let us see what mass a $\mathrm{cm^3}$ of various metals will have:



The density tells us how well the matter is packed together in a material. It depends on the mass of the particles that make up the material, and how efficiently they are packed together. A perfect vacuum has a density of zero[1], gases have low densities since their particles are far apart, and solids have much higher densities. The densities of most solids lie in the range 500 to $1000\,\mathrm{kg\,m^{-3}}$, and gases in general are about 10^3 times less dense than this.

substance	density / $\mathrm{kg\,m^{-3}}$
lead	11 300
aluminium	2700
water	1000
air	1.2
hydrogen	0.08

Even in a solid, though, the atoms are almost entirely empty space, with almost all of the mass contained in the protons and neutrons at the centre of the atom (the electrons have a vanishingly small mass in comparison). Nuclear material therefore has incredibly high density. If we could somehow collapse everyday objects by removing the empty space in their atoms, they would still have the same mass, but would occupy a tiny fraction of their former volumes. Careful observations of certain white dwarf stars (such as Sirius B) have led astronomers to calculate that such a 'superdense' state[2] can exist; a teaspoon of Sirius B would weigh not grams but tonnes!

Measuring density

The densities of many substances have been carefully measured, and compiled in tables of physical constants, and an unknown substance can often be identified by measuring its density and comparing it with known substances. In order to determine the density, usually the mass and the volume must be measured first. The mass can be very accurately measured in the laboratory using a balance.

The volume can be more of a challenge. If the material is a solid in a regular shape, these can be accurately measured, e.g. with a vernier caliper, and the volume worked out. Otherwise the solid could be put into a measuring cylinder partly filled with water and the rise in water could be noted. For a liquid, a burette of known volume could be filled with the liquid, and then that volume could be weighed.

[1] At least classically: quantum theory tells us that there is some 'vacuum energy density' due to *ground state fluctuations*, as shown by the Casimir effect.

[2] The protons and neutrons of many atoms are packed close together, surrounded by an electron gas. This is known as *electron-degenerate matter*. More massive stars can enter a denser state still, where the protons become bonded to the electrons, forming a *neutron star* (observationally confirmed as pulsars).

History

The most famous and oldest story of identification by density is that of Archimedes and the King of Sicily's crown. Archimedes was a great scientist of ancient times, who lived in Syracuse in about 300 B.C. The King of Sicily commissioned his royal goldsmith to make him a gold crown from a lump of gold. When the crown had been made, though its mass was correct, the King suspected the goldsmith of cheating him by including some silver, a much cheaper metal, in the crown and stealing some of the gold. Archimedes had to find out whether this had indeed happened, without damaging the crown.

He was unable to solve this problem until one day, on getting into his bath, he noticed that the water rose. Whereupon, he realized how to solve the problem—presumably by obtaining lumps of gold and silver of the same mass as the crown, measuring their volumes by seeing how much the water rose in a container, and comparing these with the volume of the crown, thus comparing the density of the three objects, allowing him to calculate the crown's composition and tell the King whether he had been robbed—and he celebrated by rushing naked through the streets of Syracuse shouting '*ευρηκα* / eureka!' (which means 'I have found it!')

Some uses of density

An engineer can work out the weight of a bridge from its dimensions, using the density of the materials used in its construction. Aircraft are made from aluminium alloys, which are as strong as steel, but which, volume for volume, weight less than half as much.

A *hydrometer* can be used to accurately measure the density of a liquid within a narrow range, and this can be used to determine its alcohol content, e.g. in beer and wine making. This method is also used by revenue officers to work out how much tax must be paid on spirits.

A ship often has a scale near its waterline which works on the same principle, allowing it to be loaded in freshwater ($\rho = 1000\,\mathrm{kg\,m^{-3}}$, and then float at the correct draft to maintain a safe bouyancy in sea water ($\rho = 1025\,\mathrm{kg\,m^{-3}}$).

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Reading memos

The NB system seems not to be working properly at the moment (I've emailed the MIT people) so we'll have to do reading memos on paper until that is sorted...

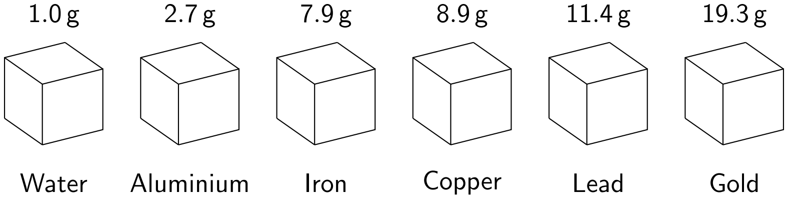
1 person had emailed me the reading memo last night by 9.30. Hopefully at the start of the lesson I now have the other 14 memos!

Remember:

- You **must** make at least 1 comment (1 is not really enough).
- Make sure you write down any difficulties you had in understanding (even if you puzzle it out later).

Questions arising from reading memos. . .

Masses of centimetre cubes



Densities of various substances

substance	$\rho/\mathrm{kg\,m^{-3}}$
lead	11 300
aluminium	2700
water	1000
air	1.2
hydrogen	0.08

Copy this table

Material	m/g	x/cm	y/cm	z/cm	V/cm^3	$\rho/\text{g cm}^{-3}$
A:						
B:						
C:						
D:						
E:						
F:						

Practical: measuring density

1. Have a guess what each material is, and put this in the first column (material)
2. Fill in the mass m, length x, width y and height z for each material **to an appropriate degree of accuracy**
3. Work out the volume V and write it in the table **to an appropriate degree of accuracy**
4. Calculate the density ρ, and note down the value in the table **and think about the error $\Delta\rho$ on this value, and write down what you think it is**

Discussion of results

ACN's results

Material	m/g	x/cm	y/cm	z/cm	V/cm^3	$\rho/\mathrm{g\,cm}^{-3}$
A:	160.7	5.0	3.9	2.9	57	2.8
B:	168.1	5.0	1.9	2.0	19	8.9
C:	56.4	5.0	4.0	3.1	62	0.91
D:	0.3	4.8	2.0	1.8	17	0.02
E:	29.6	5.0	3.9	2.9	57	0.52
F:	466.3	5.0	3.9	3.0	59	8.0

Do we have a good 'sense' of density?

Density is defined as
mass per unit volume
Density = mass/Volume
$\rho = m/V$

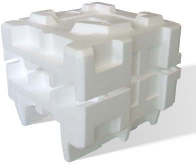
Gold

(Image: W.J.Pilsak)

Water

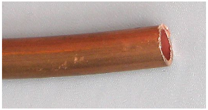
(Image: Alex Ex)

Oil



(Image: Acdx)

Expanded polystyrene



(Image: Saperaud)

Copper

Do we have a good ‘sense’ of density?

Density is defined as
mass per unit volume
Density = mass/Volume
$\rho = m/V$

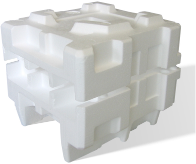
Gold:
19 300 kg m^{-3}

(Image: W.J.Pilsak)

Water:
1000 kg m^{-3} or 1 kg/l

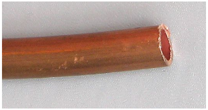
(Image: Alex Ex)

Olive Oil:
800 – 920 kg m^{-3}



(Image: Acdx)

Expanded polystyrene:
30 – 100 kg m^{-3}



(Image: Saperaud)

Copper:
11 300 kg m^{-3}

1. The mass of a cork is 10 g, and its volume is 40 cm^3. What is its density?
2. A gold ring has a mass of 9.65 g. If the density of gold is 19 300 $kg\,m^{-3}$, what is the volume of the ring?
3. The density of glass is 2.6 $g\,cm^{-3}$. A sheet of glass is square, having a side of length 40 cm, and is 0.25 cm thick. Find the mass of the sheet.
4. A piece of tin foil is rectangular in shape, being 10 cm long and 8 cm wide. If it has a mass of 29.2 g and the density of the tin is 7.3 $g\,cm^{-3}$, find its thickness.

Density Calculations II

Adapted from *General physics*, A.E.E. McKenzie, Cambridge University Press, 1965

5 A thread of mercury 12 cm long has a mass of 8.16 g. If the density of mercury if 13 600 $kg\,m^{-3}$, find the cross sectional area of the thread.

6 A full-size wooden model of an iron object has a mass of 100 kg. What is the mass of the iron object? Densities of wood and iron are 0.70 and 7.7 $g\,cm^{-3}$ respectively.

7 25 cm^3 of salt solution of density 1200 $kg\,m^3$ are mixed with 35 cm^3 of pure water. What is the density of the mixture?

Samuel Plimsoll was born in 1824 in Bristol. He was a politician and social reformer, who fought against "coffin ships" which were unseaworthy and overloaded vessels. In 1876 the Merchant Shipping Act made the load line compulsory on ships.

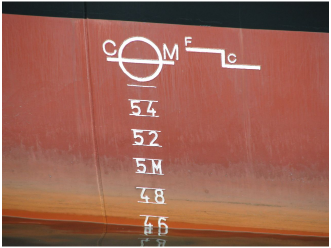


Image: Brinki

The plimsoll line on a ship's hull indicates the safe limit to which a ship may be loaded. Different ships have different load limits, and there are different lines for different waters.