MIKE FOLLOWS

Snooker balls, plum and solar systems

GCSE key words
Atomic structure
Atomic particles

People have long wondered about what matter is made of. Snooker balls, plum puddings and solar systems have all featured in descriptive models of atoms. This article describes how people's ideas about atomic structure have changed over the years.

Before anyone knew what they were, electrons were called cathode rays because they came out of the negative terminal, the cathode.

Most ancient civilisations tried to explain the nature of matter, or substance. One explanation offered by the Greek Democritus, who lived four centuries before Christ, was that everything was made of solid particles like snooker balls, called **atoms**. Atoms are too small to see so his ideas were theoretical and not based on experimental evidence. For example, he believed that food tasted sweet because it was made of 'large' round atoms but that small, sharp atoms made things taste sour.

The word 'atom' comes from the Greek word for 'cannot be divided' and this idea was echoed by the British chemist John Dalton in 1808. Dalton proposed that matter could not be subdivided indefinitely. Each element was made up of indivisible particles — atoms — that could not be made or destroyed. All atoms of an element were exactly alike — with the same mass, volume and chemical properties.

It is almost impossible to imagine how small an atom is. Millions of carbon atoms would fit side by side on the full stop at the end of this sentence. Atoms are impossible to see with visible light but a picture of them can be built up using electrons in place of light. The photograph above right is a scanning electron micrograph of some gold and carbon atoms and they certainly look a bit like hard snooker balls.

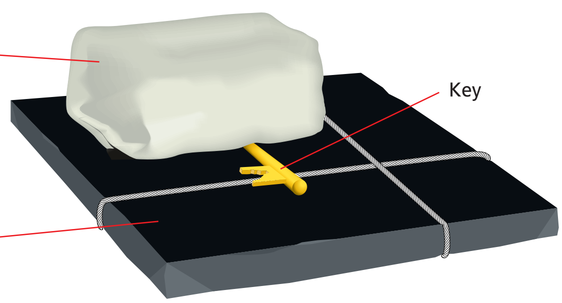
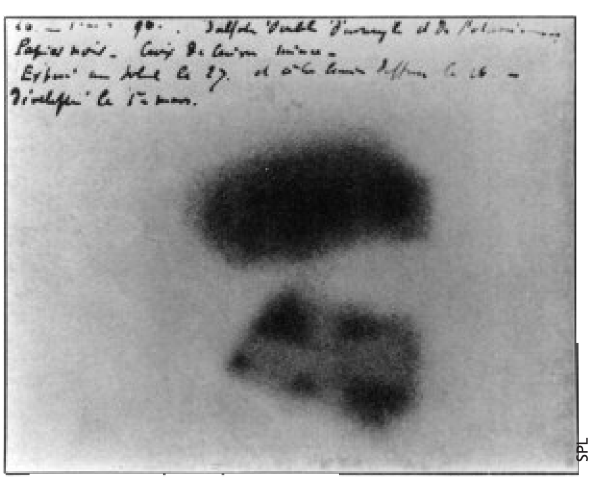


Figure 1 *Becquerel's experiment with uranium salts*

Fluorescent and phosphorescent materials both glow when they absorb radiation. A fluorescent material instantly re-emits the absorbed energy as light while phosphorescent materials glow for several hours.



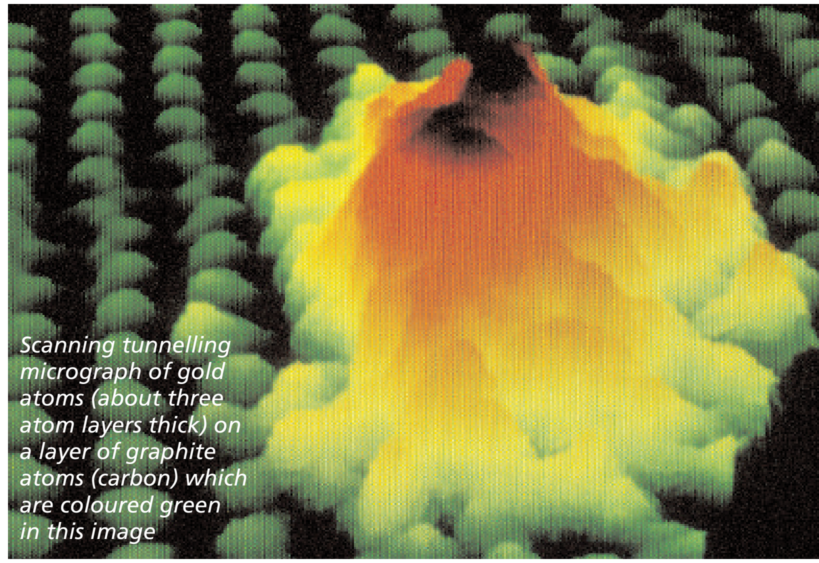
The photograph produced by Becquerel's experiment with uranium salts

BECQUEREL TURNED THE KEY

Wilhelm Röntgen discovered X-rays in 1895 (see the September 2003 issue of CATALYST). They appeared to be produced by fluorescence. Henri Becquerel wanted to know whether **phosphorescence** would also produce X-rays. He had some potassium uranium sulphate crystals. These crystals phosphoresce (glow) after they have been exposed to sunlight. He sandwiched some coins and other metal shapes between these crystals and a photographic plate that had been double wrapped in black paper to prevent it being exposed to light (see Figure 1). As he expected, when he developed the plate, he saw the shadow made by the metal shapes just in the same way that bones cast a shadow in X-rays.

He tried repeating the experiment but the sun did not come out for several days which meant that his crystals did not phosphoresce. He decided to develop the plates anyway. To his surprise the metal shapes showed up just as well as before. He deduced that uranium was a source of invisible radiation.

puddings



Scanning tunnelling micrograph of gold atoms (about three atom layers thick) on a layer of graphite atoms (carbon) which are coloured green in this image

Philippe Plailly/SPL

THOMPSON'S PLUM PUDDING

In 1897 the British scientist J. J. Thompson discovered the **electron**, confirming that the atom was not the hard snooker ball that everyone had previously thought. Electrons could leak out of atoms.

Atoms are usually electrically neutral. This means they contain the same number of positive and negative charges. To reflect this, Thompson believed that the negatively charged electrons were contained inside a 'sphere of positive charge' — like the plums in plum pudding, which was popular at the time (see Figure 2).

In the meantime Becquerel had shown that his radiation from uranium salts was charged, and so could not be X-rays. Ernest Rutherford went on to label this radiation alpha, beta and gamma. Apparently atoms could fall apart or decay in the process called **radioactivity**.

When atoms decay, they also give off energy that ends up as heat. Radioactivity deep inside the Earth provides half the heat energy that drives the convection currents moving the tectonic plates around the Earth's surface.

FIRING ALPHA PARTICLES

Along with a couple of assistants, Ernest Rutherford decided to use alpha particles as 'bullets' and fired them at a thin gold foil 'target' (see Box 1). Why did Rutherford do this experiment? He was the world expert on alpha particles and this was a good way of providing more evidence to support the 'plum pudding' model. An alpha particle is deflected when repelled by another positive charge. If the atom was

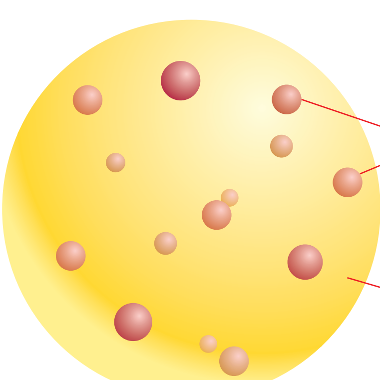


Figure 2 *J. J. Thompson's 'plum pudding' model of the atom. The electrons are like the fruit spread through a Christmas pudding*

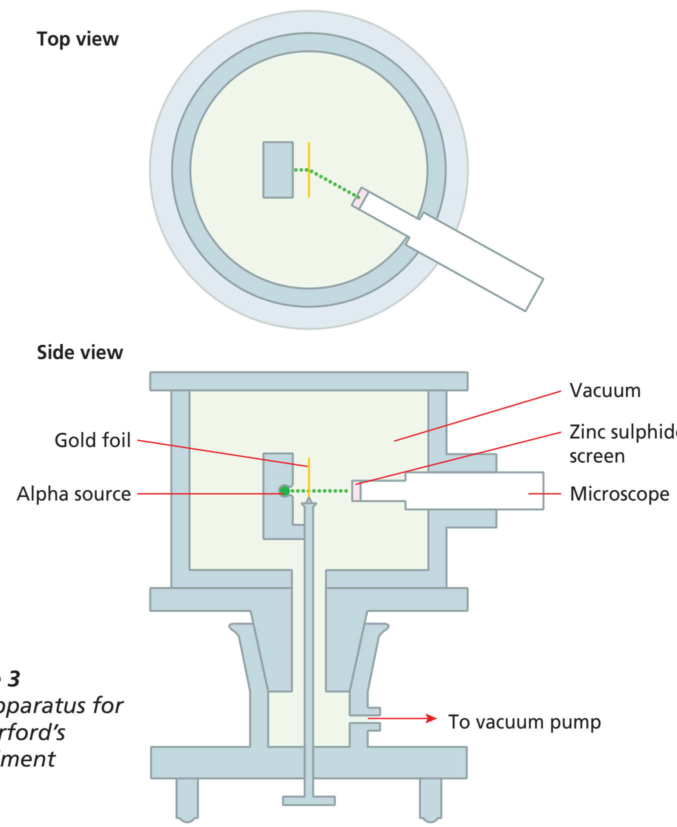


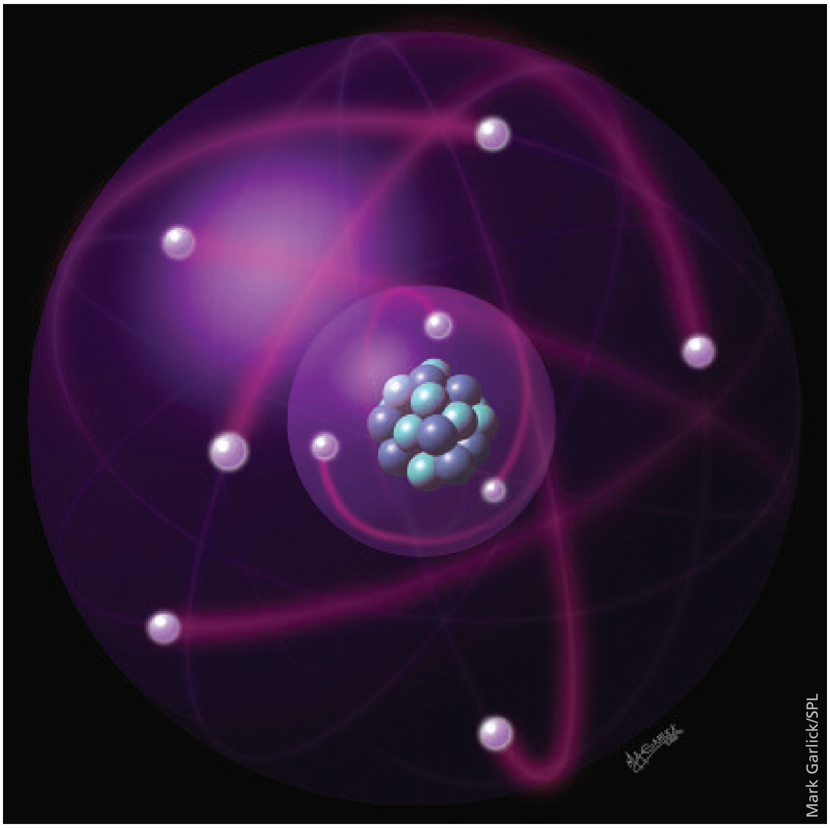
Figure 3
The apparatus for Rutherford's experiment

BOX 1 TARGET PRACTICE

The apparatus for Rutherford's experiment is shown in Figure 3. Gold was chosen because it could be beaten into a very thin leaf about 400 atoms thick. This would ensure that the alpha particles would be scattered by a single gold atom.

Had the air not been pumped out of the apparatus, the alpha particles would not have reached the foil. Their kinetic energy would have been used up ionising the air, knocking electrons out of the air molecules. It is because they are so ionising that alpha particles only travel a few centimetres in air.

A microscope was fitted to a pivoted arm in order to measure the angle through which the alpha particles were deflected. The microscope was focused on a zinc sulphide screen that would fluoresce when struck by an alpha particle.



Artist's impression of atomic structure. The central nucleus is orbited by electrons — three in an inner shell and six in an outer shell. The sizes of the particles are not to scale — they would be much smaller in an actual atom

If the electrons really did orbit the nucleus in the same way that planets orbit the Sun then they would rapidly lose energy and spiral into the nucleus. The atom would collapse in a ten billionth of a second.

really like a 'plum pudding' then the alpha particles should not have been deflected by more than 4° (see Figure 4). However, about 1 in 8000 alpha particles was deflected by more than 90°. This shocked Rutherford, 'It was quite the most incredible event that ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you.'

A 'SOLAR SYSTEM' IN THE ATOM

Rutherford developed a theory and predicted what would happen if gold was replaced by a different metal, or if the thickness of the foil was changed.

The nucleons themselves are believed to be made of even smaller particles called quarks.

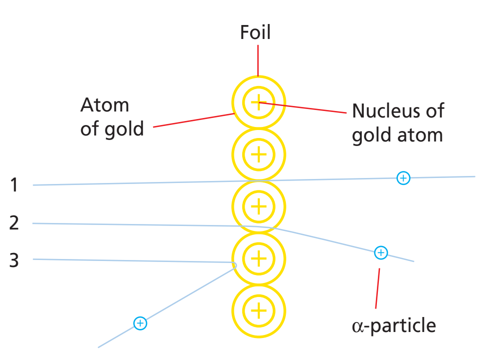


Figure 4 *What happened in Rutherford's experiment*

Table 1 *The properties of the particles inside the atom*

Sub-atomic particle	Relative mass	Relative charge
Proton	1	+1
Neutron	1	0
Electron	$\frac{1}{1840}$	–1

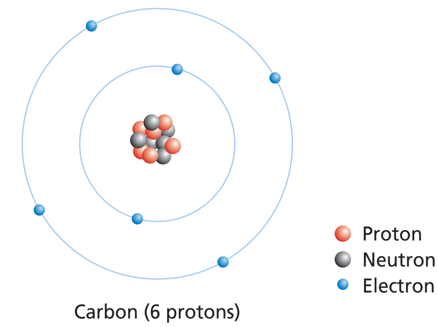


Figure 5 *The 'solar system' model for the atom*

The experiments performed by his assistants confirmed his theory that most of the atom is empty space. A new model of the atom was born, with negatively charged electrons orbiting a positive **nucleus**. The nucleus contains positive **protons** and neutral **neutrons**. If an atom were the size of a football stadium then the nucleus would be roughly the size of a pea placed in the centre circle and electrons would be like crisp packets being blown by the wind around the stands.

Table 1 summarises the properties of the particles inside the atom. It shows that the protons and neutrons carry all the mass. These particles, known collectively as nucleons, live inside the nucleus. Figure 5 shows Rutherford's model of a carbon atom.

Models of the atom are useful because they help us visualise something that is too small to see. Thompson's 'plum pudding' model explained how atoms could remain neutral even though they contained negatively-charged electrons. This model is rarely used now because Rutherford's 'solar system' model explains this and much more. It also shows that the atom is mostly empty space, with electrons orbiting the tiny nucleus in shells. Because all the positive charges are concentrated in the nucleus, where they are desperately repelling each other, it also hints at why nuclei fall apart or decay.

Bohr, a Danish physicist, modified Rutherford's model of the atom to explain how atoms absorb and emit light. In order to do this he treated electrons as waves instead of particles…but that is another story.

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