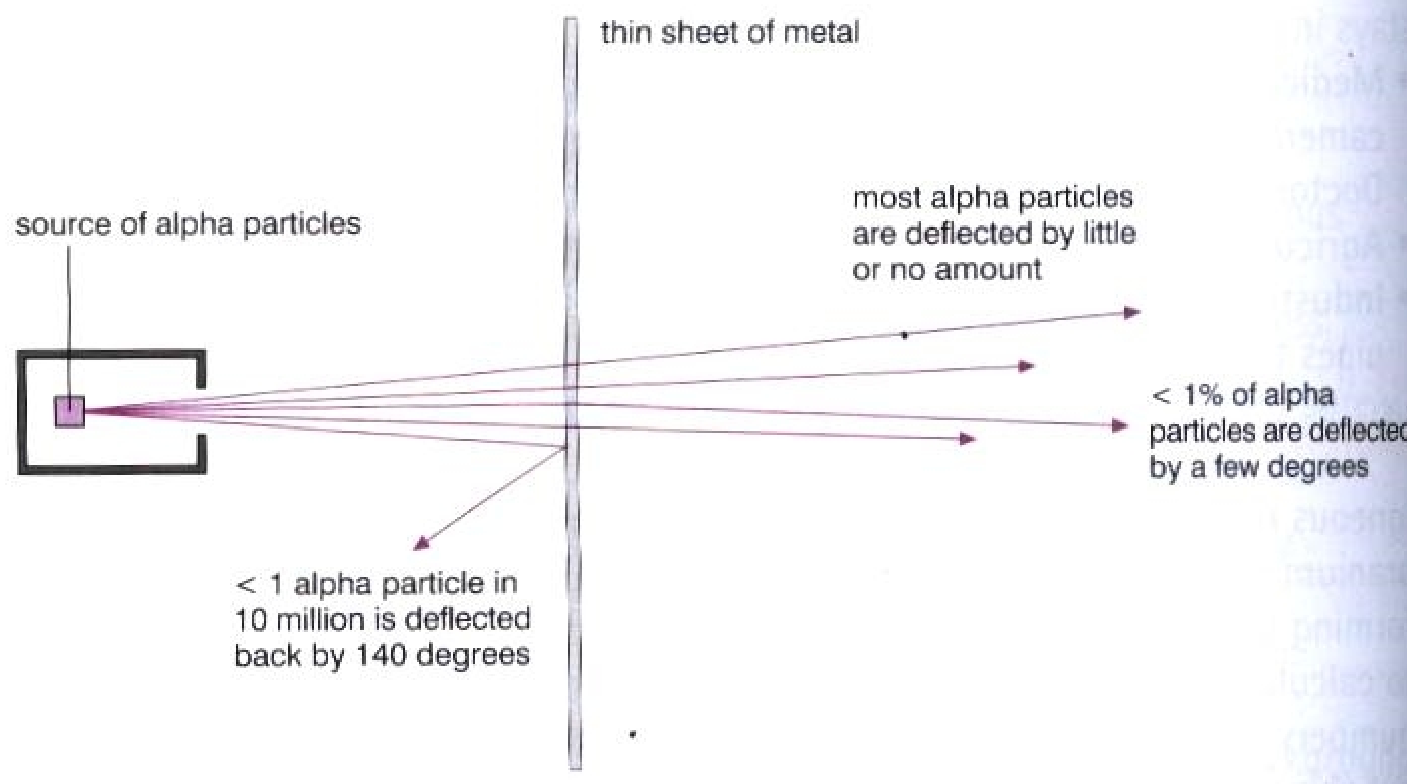
# 2 The Nuclear Atom

## Atomic model

At the beginning of the 20th century, scientists knew that the atom contained positive and negative charges, but the structure was a great mystery. An experiment by Rutherford discovered what is now called Rutherford scattering. This effect was a surprising discovery, but one that greatly advanced our understanding of the atom.

(The actual work was done by two students of his, Geiger and Marsden. We were to hear more of Geiger later in his career.)




What they discovered was that almost all of the alpha particles got through the thin metal sheet with no difficulty, but that perhaps one particle in a million was scattered by a relatively massive object that sent it off at a wide angle, and perhaps even back the way it had come. This told them that the atom consists of a nucleus that contains almost all of the mass of the atom. Because so few alpha particles were scattered by the nucleus, it had to be extremely small, surrounded by a cloud of extremely light electrons.

We are left with the slightly disturbing thought that almost all of a solid object is actually empty space, loosely filled with electrons, with a tiny nucleus at the centre of each atom. If all of the space were taken out of an atom (and this can happen in a neutron star) then matter would have a density of 300 *million* tonnes per cubic centimetre.

The nucleus is made of protons and neutrons, bound together by an extremely strong force, far stronger than gravity, magnetism or electricity, and completely different from any of them.

There are several hundred different **nuclides** (types of nucleus), each with a different number of protons and neutrons. Nuclides tend to have rather more neutrons than protons. The majority of nuclides are radioactive. Most atoms on earth are not radioactive, of course, but these atoms are chosen from the limited number of nuclides that are stable.

## Nucleus

You can write down nuclear changes as **nuclear equations**. Each nucleus is represented by its chemical symbol with two extra numbers written before it. Here is the symbol for Radium-226:

the top number is the **mass number** (the total number of protons and neutrons)

the bottom number is the **atomic number** (the number of protons)

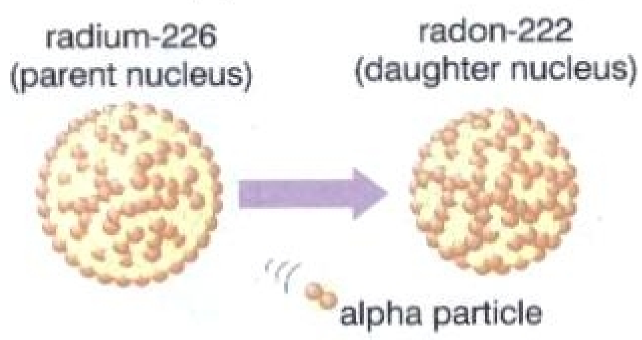
$$^{226}_{88}\mathrm{Ra}$$

The mass numbers and atomic numbers must balance on both sides of a nuclear equation.

### A* EXTRA

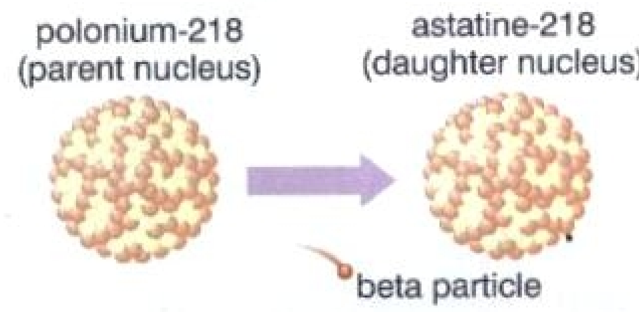
- In a nuclear equation an $\alpha$ particle is written as $^{4}_{2}\mathrm{He}$ or $^{4}_{2}\alpha$. This is because it is the same as a helium nucleus.
- A $\beta$ particle is written $^{0}_{-1}e$ or $^{0}_{-1}\beta$ to show that it has negligible mass and is of exactly opposite charge to a proton.

Alpha decay – the nucleus emits an $\alpha$-particle (2 protons and 2 neutrons)




$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha$$

Beta decay – a neutron changes into a proton in the the nucleus



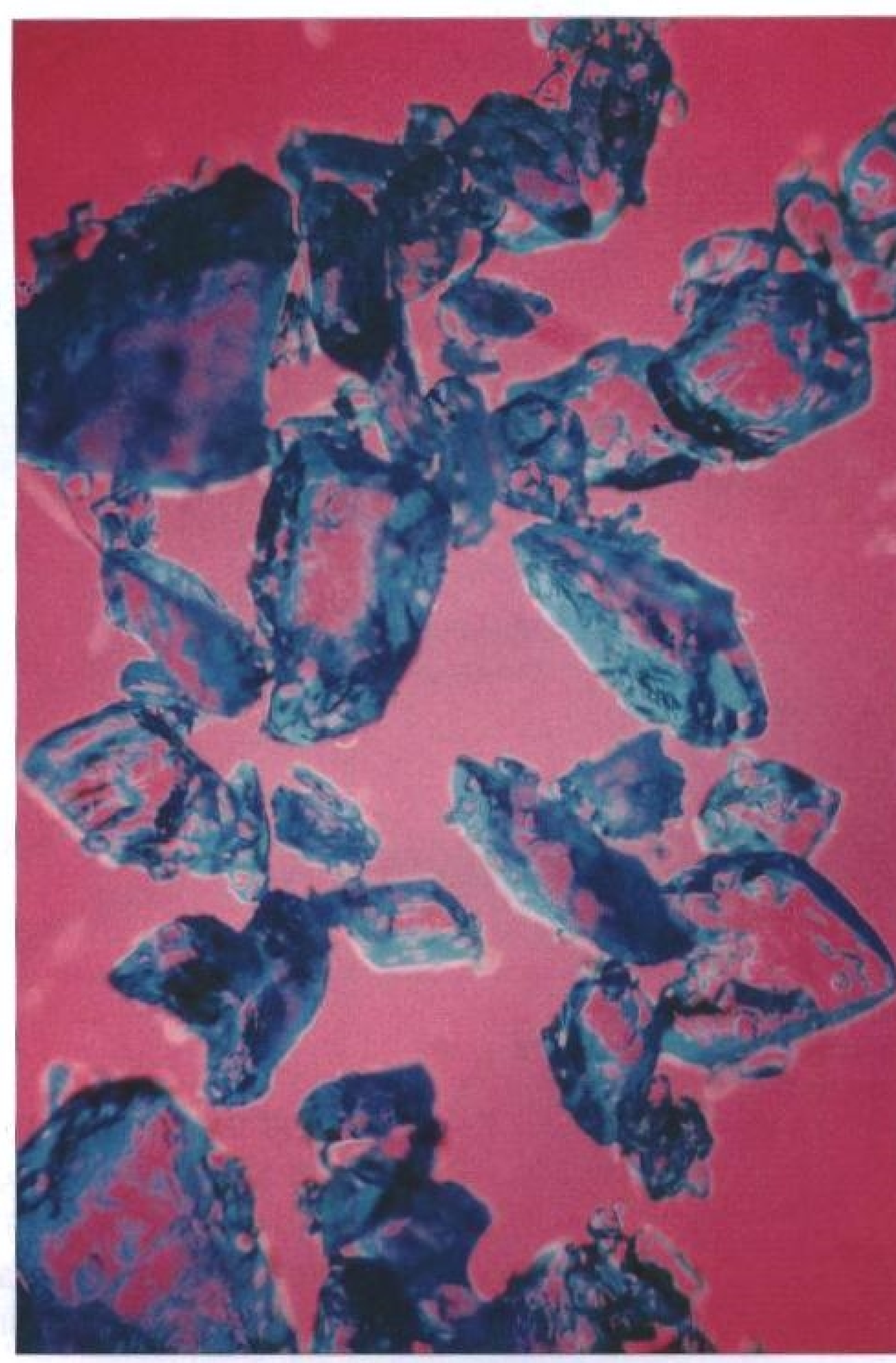

$$^{218}_{84}\mathrm{Po} \rightarrow {}^{218}_{85}\mathrm{At} + {}^{0}_{-1}\beta$$

## Isotopes

There are two non-radioactive types of copper nuclei, $^{63}_{29}\mathrm{Cu}$ and $^{65}_{29}\mathrm{Cu}$. The first type contains 29 protons and 63 nucleons, hence (63 – 29) = 34 neutrons. The second type contains 29 protons and 36 neutrons. These two types of copper are known as isotopes of copper.

Isotopes contain the same number of protons but a different number of neutrons.

In naturally occurring copper, just under 70 per cent of the nuclei are $^{63}_{29}\mathrm{Cu}$, and just over 30 per cent are $^{65}_{29}\mathrm{Cu}$. Because they both contain 29 protons, they are surrounded by 29 electrons in the same pattern. It is the structure of the electrons around the nucleus that fix how the chemistry will work, so these two isotopes have the same chemistry, forming blue crystals of copper II sulfate, etc.



Tiny crystals of copper II sulfate under a microscope.

In addition there are various radioactive isotopes of copper. Because these do not have the ideal number of neutrons the nucleus is unstable. There are nine radioactive isotopes, with mass numbers that vary from $^{59}_{29}Cu$ to $^{69}_{29}Cu$. These two extremes are very unstable with half-lives of a few minutes. $^{64}_{29}Cu$ has a half-life of 12 hours. So all of the radioactive isotopes of copper are extremely radioactive. Some radioactive isotopes of other elements are much less radioactive, and have half-lives measured in years, if not thousands of years.

This copper statue contains 69 per cent $^{63}_{29}Cu$ nuclei and 31 per cent $^{65}_{29}Cu$ nuclei.

Radioactive iodine is injected in the treatment of cancer.

## USES OF ISOTOPES

Radioisotopes have the same chemistry as non-radioactive isotopes of the same element. This can be very valuable in research as well as medicine. A famous example is the use of radioactive iodine in treatment of diseases of the thyroid.

The thyroid gland in the neck can grow dangerously large. Because the cells of the thyroid absorb far more iodine than other parts of the body, the thyroid can be targeted by injecting the body with radioactive iodine. Iodine-131 with a half-life of 8 days is used. This iodine is absorbed by some of the cells of the thyroid, and kills them as it decays and gives off beta particles.

There are many other uses of isotopes, such as:

- smoke detectors: they allow the smoke from a fire to be detected at an early stage and this early warning saves lives;
- food irradiation: a method of treating food in order to make it safer to eat and have a longer shelf life;
- agricultural applications: they are used to help understand chemical and biological processes in plants;
- archaeological dating of bones and artefacts.

## REVIEW QUESTIONS

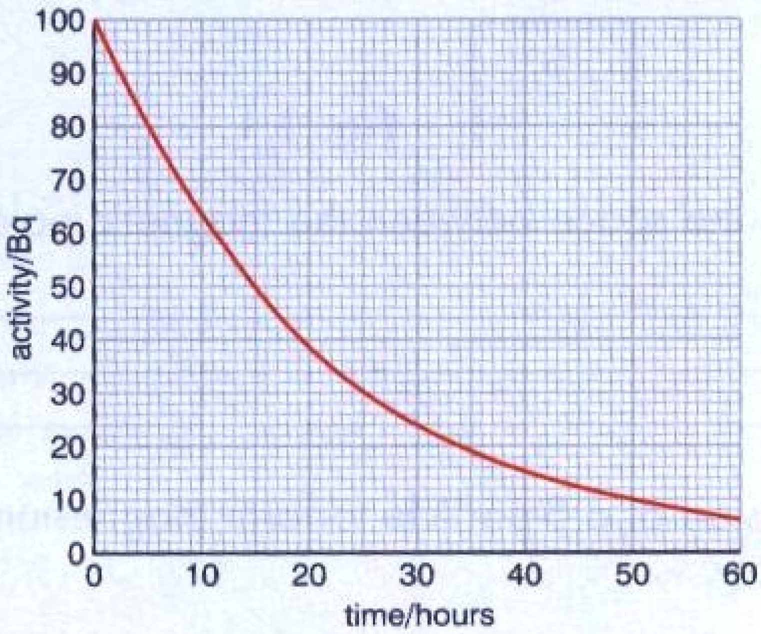
**Q1** Copy and complete this table to show the particles in these atoms.

| Atom | Symbol | Number of protons | Number of neutrons | Number of electrons |
|---|---|---|---|---|
| Hydrogen | $^{1}_{1}H$ | | | |
| Carbon | $^{12}_{6}C$ | | | |
| Calcium | $^{40}_{20}Ca$ | | | |
| Uranium | $^{238}_{92}U$ | | | |

**Q2** The graph shows how the activity of a sample of sodium-24 changes with time. Activity is measured in becquerels (Bq).

**a** Sodium-24 has an atomic number of 11 and a mass number of 24. What is the composition of the nucleus of a sodium-24 atom?

**b** Use the graph to work out the half-life of the sodium-24.




**Q3** The following equation shows what happens when a nucleus of sodium-24 decays.

$^{24}_{11}Na \rightarrow ^{x}_{y}Mg + ^{0}_{-1}\beta$

**a** What type of nuclear radiation is produced?

**b** What are the numerical values of *x* and *y*?

Examination questions are on page 170.

More questions on the CD ROM