1.2 Stable and unstable nuclei

Learning objectives:

- What keeps the protons and neutrons in a nucleus together?
- Why are some nuclei stable and others unstable?
- What happens when an unstable nucleus emits an alpha particle or a beta minus particle?

Specification reference: 3.1.1

How Science Works

Measuring background radiation

Use a Geiger tube and a counter to detect and measure background radiation.

The strong nuclear force

A stable isotope has nuclei that do not disintegrate, so there must be a force holding them together. We call this force the **strong nuclear force** because it overcomes the electrostatic force of repulsion between the protons in the nucleus and (except in unstable nuclei) keeps the protons and neutrons together.

Some further important points about the strong nuclear force are:

- Its range is no more than about 3–4 femtometres (fm), where 1 fm $= 10^{-15}$ m = 0.000 000 000 000 001 m. This range is about the same as the diameter of a small nucleus. In comparison, the electrostatic force between two charged particles has an infinite range (although it decreases as the range increases).
- It has the same effect between two protons as it does between two neutrons or a proton and a neutron.
- It is an attractive force from 3–4 fm down to about 0.5 fm. At separations smaller than this, it is a repulsive force that acts to prevent neutrons and protons being pushed into each other.

Figure 1 shows how the strong nuclear force varies with separation between two protons or neutrons. Notice that the equilibrium separation is where the force curve crosses the *x*-axis.

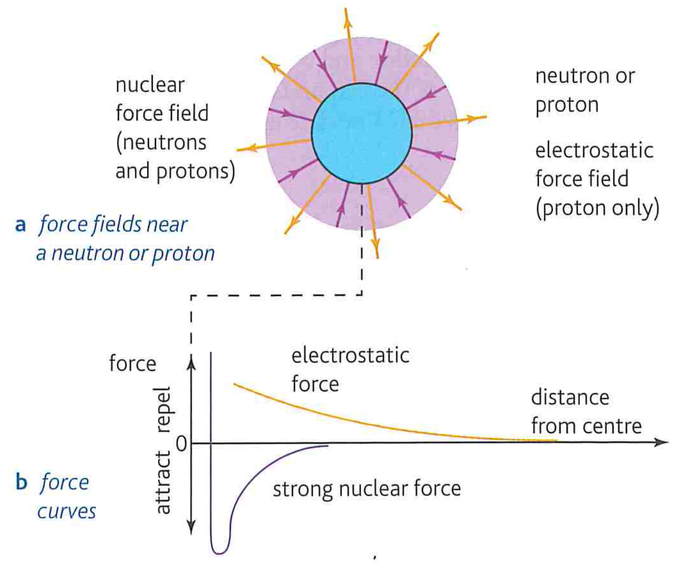

Figure 1 *The strong nuclear force*

Radioactive decay

Naturally-occurring radioactive isotopes release three types of radiation.

1 **Alpha radiation** consists of alpha particles which each comprise two protons and two neutrons. The symbol for an alpha particle is ${}^{4}_{2}\alpha$ because its proton number is 2 and its mass number is 4.

Figure 2 shows what happens to an unstable nucleus of an element X when it emits an alpha particle. Its nucleon number *A* decreases by 4

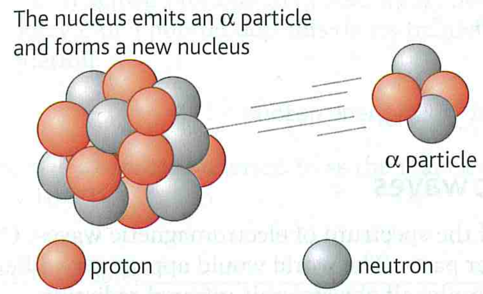

Figure 2 *Alpha particle emission (not to scale)*

and its atomic number *Z* decreases by 2. As a result of the change, the product nucleus belongs to a different element Y.

We can represent this change by means of the equation below:

$${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$$

2 **Beta radiation** consists of fast-moving electrons. The symbol for an electron as a beta particle is ${}^{0}_{-1}\beta$ (or β^-) because its charge is equal and opposite to that of the proton and its mass is much smaller than the proton's mass.

Figure 3 shows what happens to an unstable nucleus of an element X when it emits a β^- particle. This happens as a result of a neutron in the nucleus changing into a proton. The beta particle is created when the change happens and is emitted instantly. In addition, an antiparticle with no charge, called an **antineutrino** (symbol $\bar{\nu}$), is emitted. You will learn more about antiparticles in Topic 1.4. Because a neutron changes into a proton in the nucleus, the atomic number increases by 1 but the nucleon number stays the same. As a result of the change, the product nucleus belongs to a different element Y. This type of change happens to nuclei that have too many neutrons.

We can represent this change by means of the equation below:

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \bar{\nu}$$

3 **Gamma radiation** (symbol γ) is electromagnetic radiation emitted by an unstable nucleus. It can pass through thick metal plates. It has no mass and no charge. It is emitted by a nucleus with too much energy, following an alpha or beta emission.

How Science Works

A very elusive particle!

When the energy spectrum of beta particles was first measured, it was found that beta particles were released with kinetic energies up to a maximum that depended on the isotope. The scientists at the time were puzzled why the energy of the beta particles varied up to a maximum, when each unstable nucleus lost a certain amount of energy in the process. Either energy was not conserved in the change or some of it was carried away by mystery particles, which they called **neutrinos** and **antineutrinos**. This hypothesis was unproven for over 20 years until antineutrinos were detected. Antineutrinos were detected as a result of their interaction with cadmium nuclei in a large tank of water. This was installed next to a nuclear reactor as a controllable source of these very elusive particles. Now we know that billions of these elusive particles from the Sun sweep through our bodies every second without interacting!

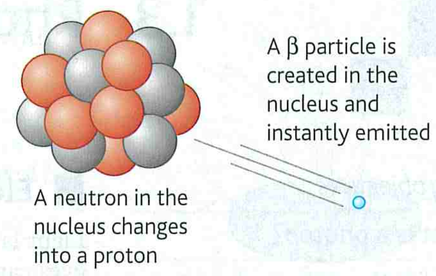

Figure 3 *Beta particle emission (not to scale)*

Study tip

Remember what the numbers stand for in the decay equations on the next page.

Summary questions

1 Which force, the strong nuclear force or the electrostatic force,
  a does not affect a neutron?
  b has a limited range?
  c holds the nucleons in a nucleus?
  d tends to make a nucleus unstable?

2 Complete the following radioactive decay equations:
  a ${}^{229}_{90}Th \longrightarrow Ra + \alpha$
  b ${}^{65}_{28}Ni \longrightarrow Cu + \beta + \bar{\nu}$

3 A nucleus of the radioactive isotope of bismuth ${}^{213}_{83}Bi$ emits a beta particle then an alpha particle then another beta particle before it becomes stable.
  a Show that the stable nucleus that is formed is a bismuth isotope.
  b i Determine the nucleon number of this stable isotope.
  ii How many protons and how many neutrons are in the nucleus immediately after it emits the alpha particle?

4 The neutrino hypothesis was put forward to explain beta decay.
  a Explain what is meant by a hypothesis.
  b i State one property of the neutrino.
  ii Name two objects that produce neutrinos.