Particle physics

The alpha-scattering experiment, the nuclear atom, nuclide notation and isotopes, alpha, beta and gamma radiation, antiparticles and neutrinos, decay equations, quarks, hadrons and leptons.

11.1 Atoms, nuclei and radiation

Alpha-particle scattering

Alpha particles were fired at a very thin gold foil in a vacuum.

Observation	What it shows
Most went straight through	the atom is mostly empty space
A few were deflected through small angles	there is a concentrated positive charge
A very few (about 1 in 8000) bounced back through more than 90°	that charge and nearly all the mass are in a very small nucleus

Nuclei have diameters of about 10^{-15} m, while atoms are about 10^{-10} m across.

The nuclear atom and nuclides

The nucleus contains **protons** and **neutrons** (together called nucleons), and electrons orbit it. A nuclide is written ${}^{A}_{Z}\mathrm{X}$:

- A is the **nucleon number**, which is protons plus neutrons.
- Z is the **proton number**.

Isotopes are forms of the same element, with the same number of protons but different numbers of neutrons. For example, ${}^{235}_{92}\mathrm{U}$ and ${}^{238}_{92}\mathrm{U}$.

The **unified atomic mass unit** is $1\ \mathrm{u} = 1.66 \times 10^{-27}$ kg, about the mass of one nucleon.

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Radiation

Radiation	Composition	Mass	Charge
α	helium nucleus, two protons and two neutrons	4 u	$+2e$
β^-	electron	about $\frac{1}{1800}$ u	$-e$
β^+	positron	about $\frac{1}{1800}$ u	$+e$
γ	electromagnetic radiation	0	0

Antiparticles and neutrinos

An **antiparticle** has the same mass as its particle but the opposite charge. The positron is the antiparticle of the electron.

- β^- decay also emits an **electron antineutrino**, $\bar{\nu}$.
- β^+ decay also emits an **electron neutrino**, ν.

Alpha particles from a given decay have **discrete energies**. Beta particles have a **continuous range** of energies, because the energy released is shared between the beta particle and the (anti)neutrino in varying proportions.

Decay equations

Nucleon number and charge are conserved in nuclear processes.

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$$

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta + \bar{\nu}$$

$$^{11}_{6}\mathrm{C} \rightarrow {}^{11}_{5}\mathrm{B} + {}^{0}_{+1}\beta + \nu$$

> **TRY IT**
>
> **A nuclide $^{226}_{88}\mathrm{Ra}$ emits an alpha particle. What are the new numbers?** $A = 226 - 4 = 222$ and $Z = 88 - 2 = 86$.

11.2 Fundamental particles

Quarks

A **quark** is a fundamental particle. There are six flavours. Each has an antiquark with the opposite charge.

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Quark	Charge	Antiquark charge
up (u), charm (c), top (t)	$+\frac{2}{3}e$	$-\frac{2}{3}e$
down (d), strange (s), bottom (b)	$-\frac{1}{3}e$	$+\frac{1}{3}e$

Hadrons

Protons and neutrons are **not** fundamental. They are made of quarks.

- A **hadron** is any particle made of quarks.
- A **baryon** has three quarks. Proton = uud (charge $+\frac{2}{3}+\frac{2}{3}-\frac{1}{3}=+1$). Neutron = udd (charge $+\frac{2}{3}-\frac{1}{3}-\frac{1}{3}=0$).
- A **meson** has one quark and one antiquark.

Quark changes in beta decay

β^- : $\mathrm{d} \rightarrow \mathrm{u} + e^- + \bar{\nu}$ (a neutron becomes a proton)

β^+ : $\mathrm{u} \rightarrow \mathrm{d} + e^+ + \nu$ (a proton becomes a neutron)

Leptons

Electrons and neutrinos are fundamental particles called leptons. They are not made of quarks, and they do not count as hadrons.

TRY IT

What is the charge of a meson made of an up quark and an anti-down quark? $+\frac{2}{3}e+\frac{1}{3}e=+1e.$

NOTE

Exam tip: the antiparticle of a neutrino is an antineutrino, and the particle paired with an emitted positive beta is the neutrino. If you are asked to complete a decay equation, check that A and Z balance on each side.

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