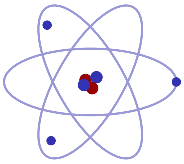
Particle Physics

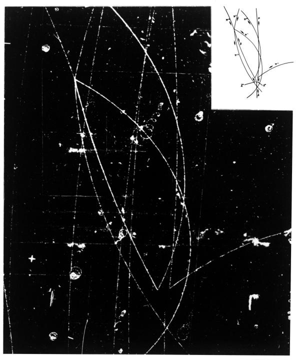
AS Physics ▪ Topic 11

A-Level Physics



What we will cover

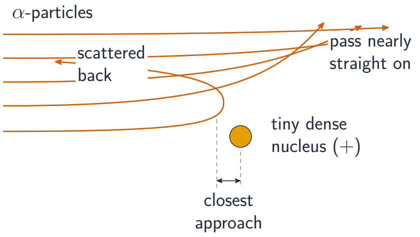
1. α-scattering & the nucleus
2. Nuclide notation & isotopes
3. Radioactive emissions
4. Decay equations
5. Quarks & fundamental particles
6. Recap



Production and decay of neutral lambda and anti−lambda hyperons

1 The nuclear atom

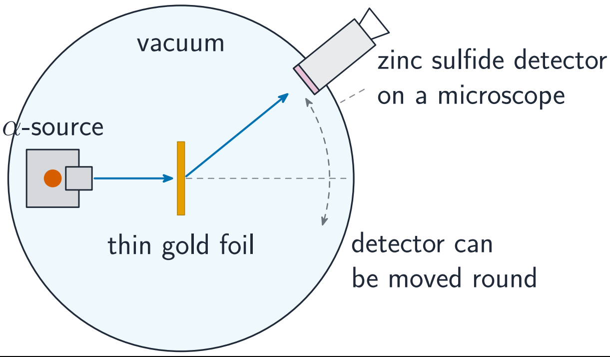
α-particle scattering



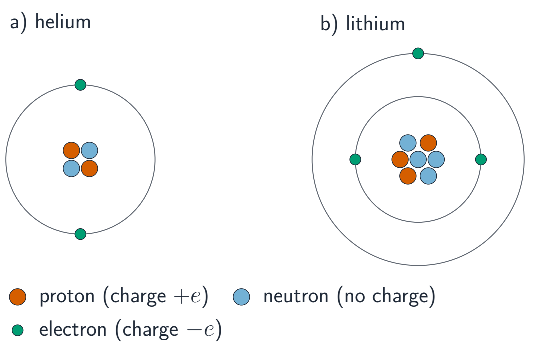
- mostly pass straight through, with very little **deflection** 偏转,
- sometimes deflect through small angles,
- rarely (about 1 in 8000) deflect through angles greater than $90°$.
- the atom is **mostly empty space** (most -particles pass straight through),

The experiment itself

Almost every α went straight through; a very few came straight back. That is only possible if the positive charge sits in a tiny, massive core.



The nuclear model



- **protons** 质子 ($+e$) and **neutrons** 中子 (0) in the nucleus, $\approx 1\,\mathrm{u}$ each
- **electrons** 电子 ($-e$) around it, $\frac{1}{1836}$ of the mass

Nuclide notation and isotopes

$$^{A}_{Z}\mathrm{X}$$

- A nucleon number
- Z proton number

- neutrons $N = A - Z$
- **isotopes** 同位素: same Z, different A (e.g. $^{12}_{6}\mathrm{C}$, $^{14}_{6}\mathrm{C}$)

> In every nuclear process, A and charge are conserved.

Reading the notation

$$^{A}_{Z}\mathrm{X}$$

A = nucleon number (protons + neutrons)

Z = proton number

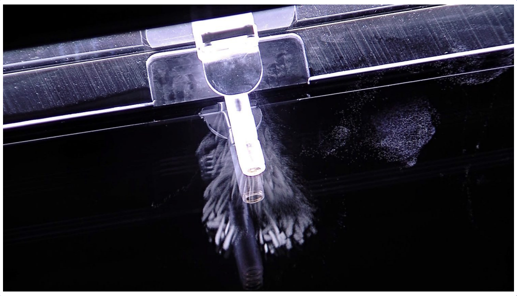
Top is the **nucleon number** 核子数 A, bottom the **proton number** 质子数 Z.
Isotopes 同位素 share Z and differ in A.

2 Radioactive emissions

Three kinds of radiation

α	β	γ
He nucleus	fast electron/positron	**photon** 光子
$+2e$, $\approx$ 4 u	$\pm e$, tiny mass	0 charge, 0 mass
stopped by paper	stopped by Al	attenuated by lead
discrete energy	continuous energy	discrete energy

Tracks in a cloud chamber

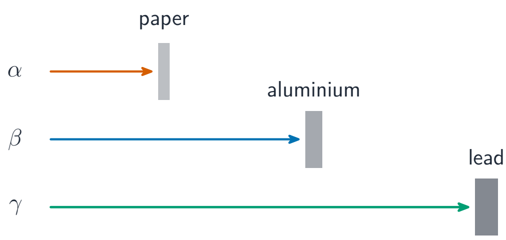


α tracks are short, straight and thick — heavily ionising, quickly stopped.

Penetrating power

- α – paper
- β – a few mm of aluminium
- γ – only attenuated by lead

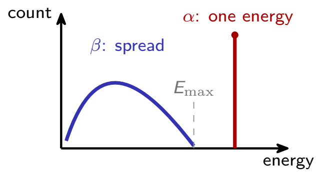
Ionising power is the reverse order: α strongest.



Antiparticles and the neutrino

Every particle has an **antiparticle** 反粒子: same mass, opposite charge (positron = anti-electron). β-decay always emits a third particle:

- β^-: an **antineutrino** 反中微子 $\bar{\nu}_e$
- β^+: a **neutrino** 中微子 ν_e



> α: energy shared by 2 bodies $\rightarrow$ discrete. β: shared by 3 $\rightarrow$ continuous – the neutrino takes a varying share.

Writing decay equations

$${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\alpha$$
$${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A}_{Z+1}\mathrm{Y} + {}^{0}_{-1}\beta + \bar{\nu}_e$$

Balance A (top) and Z (bottom) on both sides.

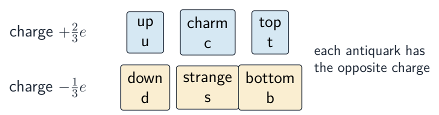
U-238 (α) and C-14 (β^-)

$${}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$$
$${}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta + \bar{\nu}_e$$

check: $A\ 238 = 234 + 4$ ✓ $Z\ 92 = 90 + 2$ ✓

3 Fundamental particles

Quarks



Six **quark** 夸克 flavours:

- u, c, t carry $+\frac{2}{3}e$
- d, s, b carry $-\frac{1}{3}e$

Each **antiquark** 反夸克 has the opposite charge.

Hadrons: baryons and mesons

Particles built from quarks are **hadrons** 强子:

baryons 重子

three quarks
proton (u u d), neutron (u d d)

mesons 介子

one quark + one antiquark
e.g. $\pi^+ = \mathrm{u}\bar{\mathrm{d}}$

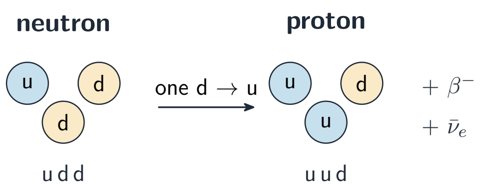
Protons and neutrons are not fundamental – they are baryons.

β-decay at the quark level

A neutron → proton: one down quark becomes an up quark.

$$\mathrm{d} \to \mathrm{u} + \beta^- + \bar{\nu}_e$$

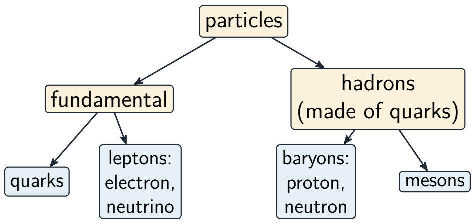
$$(\beta^+\!: \mathrm{u} \to \mathrm{d} + \beta^+ + \nu_e.)$$



Beta-minus decay: one down quark becomes an up quark, turning a neutron into a proton

Some particles are **fundamental** 基本粒子 (point-like, with no smaller parts as far as we know); others are built from fundamental ones.

Classifying particles



Fundamental: **quarks** 夸克 and **leptons** 轻子 (electron, neutrino).

Built from quarks: protons, neutrons, baryons, mesons.

4 Recap

Topic 11 – key takeaways

1 Nuclear atom

tiny dense + nucleus; $^{A}_{Z}$X, A & charge conserved

2 Radiation

α (paper), β (Al), γ (lead)

3 β & neutrinos

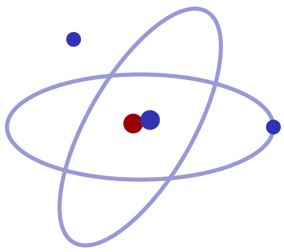
3 bodies $\rightarrow$ continuous spectrum

4 Quarks

hadrons from quarks; quarks & leptons fundamental

Check yourself

1. What did the rare large α deflections show?
2. $^{226}_{88}$Ra decays by α – the daughter's A and Z?
3. Which radiation is a photon?
4. Quark content of a neutron?



Answers **1.** a tiny dense nucleus **2.** $A = 222$, $Z = 86$ **3.** γ **4.** u d d