

Exercise walk-through

11.1.1

Decay equations, antiparticles and neutrinos

A-Level Physics

Sheet 11.2.1 – what you need to know

You must be able to:

- describe the quark change in β^- and β^+ decay
- write each change with its two **leptons**, and check the charge
- recall that electrons and neutrinos are fundamental leptons
- classify a particle as a lepton, a baryon or a meson

What the exam asks

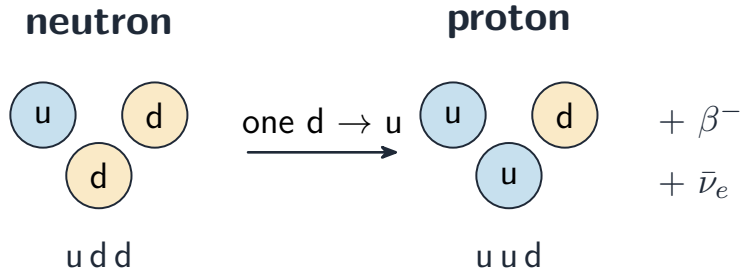
“Describe the change to the quark composition of the nucleon.” **[1]**

“State the equation for β^- decay in terms of the fundamental particles involved.” **[1]**

“State the name of the group (class) of fundamental particles to which the positron and neutrino belong.” **[1]**

Practise on exercise sheet 11.2.1, then try the real exam questions on past-paper sheet 11.2.1.

β -decay at the quark level



decay	quark	leptons emitted
β^-	$d \rightarrow u$	electron, antineutrino
β^+	$u \rightarrow d$	positron, neutrino

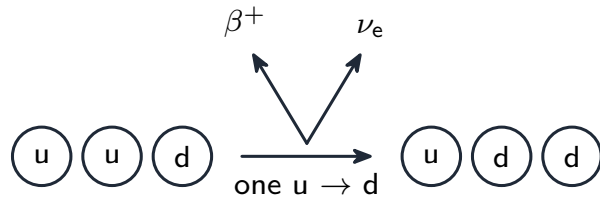
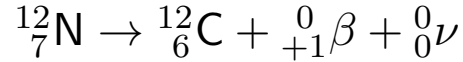
Charge is conserved in the change

$$q_d = q_u + q_{e^-} + q_{\bar{\nu}}: -\frac{1}{3}e = +\frac{2}{3}e - e + 0$$

$$q_u = q_d + q_{e^+} + q_{\nu}: +\frac{2}{3}e = -\frac{1}{3}e + e + 0$$

The other two quarks are spectators: the nucleon is still there, so the **nucleon number** does not change.

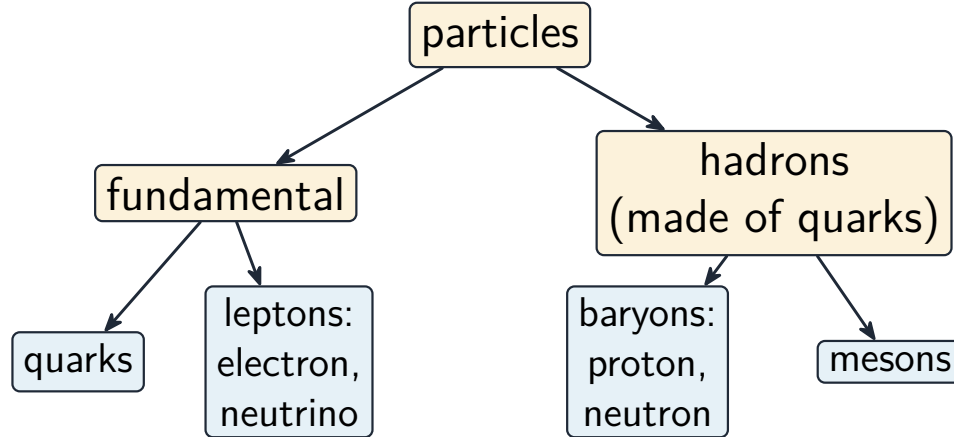
From the nucleus down to the quark



proton (u u d), charge $+e$ neutron (u d d), charge 0

- 1 nucleus:** Z falls from 7 to 6, A stays 12, so a proton has become a neutron
- 2 nucleon:** uud has become udd
- 3 quark:** $u \rightarrow d + e^+ + \nu_e$

Classifying particles



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

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

Exercises 2.1·2.2

2.1 State the **two** quantities that must balance on each side of a nuclear decay equation.[2]



2.2 State what is meant by an **antiparticle**, and name the antiparticle of the electron.[2]

antiparticle

Exercises 2.1·2.2

2.1 State the **two** quantities that must balance on each side of a nuclear decay equation.[2]



2.1

- the **nucleon number** (the top numbers)
- the **charge**, which is the proton number (the bottom numbers)

2.2 State what is meant by an **antiparticle**, and name the antiparticle of the electron.[2]

antiparticle

2.2

- an antiparticle has the **same mass** as its particle but the **opposite charge**
- the antiparticle of the electron is the **positron**

Exercise 2.3

2.3 Radium-226, $^{226}_{88}\text{Ra}$, decays by α emission to radon (Rn). Write the decay equation.[2]



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

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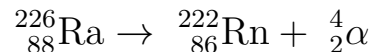
2.3

- the α -particle carries off 4 nucleons and 2 protons

$$A_{\text{Rn}} = A_{\text{Ra}} - 4 = 226 - 4 = 222$$

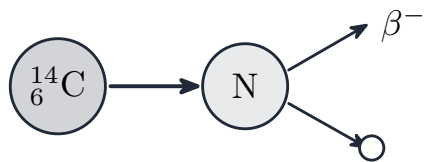
$$Z_{\text{Rn}} = Z_{\text{Ra}} - 2 = 88 - 2 = 86$$

- the equation



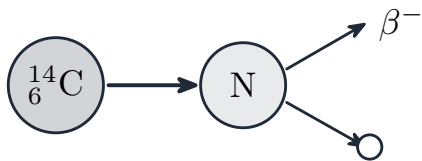
Exercise 2.4

2.4 Complete the β^- decay equation, and name the third particle emitted: ${}^{14}_6\text{C} \rightarrow \text{N} + {}^0_{-1}\beta + ?$ [2]



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2.4

- the nucleon number is unchanged and the proton number rises by one



- the third particle is an (electron) **antineutrino**

Exercise 2.5

2.5 Write the complete decay equation for the β^+ decay of ${}^{11}_6\text{C}$ to boron (B), including the third particle. [2]



${}^{11}_6\text{C}$

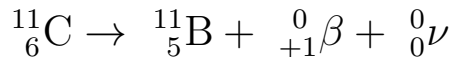
Exercise 2.5

2.5 Write the complete decay equation for the β^+ decay of $^{11}_6\text{C}$ to boron (B), including the third particle. [2]


 $^{11}_6\text{C}$

2.5

- the nucleon number is unchanged and the proton number falls by one



- the third particle is an (electron) **neutrino**, because this is β^+ decay

Exercise 2.6

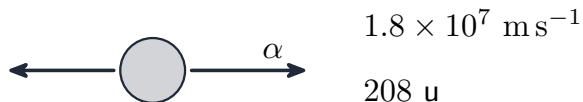
2.6 A stationary nucleus emits an α -particle at $1.8 \times 10^7 \frac{\text{m}}{\text{s}}$. The daughter nucleus has a mass of 208 u. Calculate the recoil speed of the daughter nucleus. [2]



$1.8 \times 10^7 \text{ m s}^{-1}$
208 u

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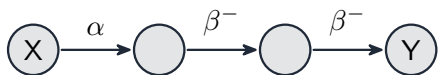
- the total momentum is zero before and after, so $m_{\alpha}v_{\alpha} = m_{\text{D}}v_{\text{D}}$

$$v_{\text{D}} = \frac{m_{\alpha}v_{\alpha}}{m_{\text{D}}} = \frac{(4 \text{ u})(1.8 \times 10^7 \frac{\text{m}}{\text{s}})}{208 \text{ u}} = \mathbf{3.5 \times 10^5 \frac{\text{m}}{\text{s}}}$$

Exercise 3.1

3.1 A nucleus emits an α -particle and then two β^- -particles. What is the overall change to the nucleus? [1]

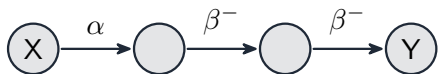
	nucleon number	proton number
A	falls by 4	unchanged
B	falls by 4	falls by 2
C	falls by 4	rises by 2
D	unchanged	falls by 2



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	nucleon number	proton number
A	falls by 4	unchanged
B	falls by 4	falls by 2
C	falls by 4	rises by 2
D	unchanged	falls by 2



3.1 A

- the α -particle lowers the nucleon number by 4 and the proton number by 2; each β^- raises the proton number by 1

$$\Delta Z = \Delta Z_{\alpha} + 2 \Delta Z_{\beta} = -2 + 2 \times (+1) = 0$$

- B** forgets the two β^- decays; **C** counts them twice

Exercise 3.2

3.2 Which particle is emitted together with a positron in β^+ decay?

[1]

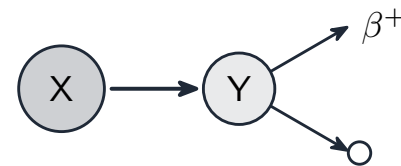
☐

A an electron

B an electron antineutrino

C an electron neutrino

D an α -particle



Exercise 3.2

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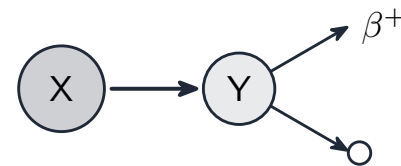
☐

A an electron

B an electron antineutrino

C an electron neutrino

D an α -particle



3.2 C

- β^+ decay emits a positron and an electron **neutrino**
- **B**, the antineutrino, goes with β^- decay

Exercise 3.3

3.3 A nuclide X decays by β^- emission to a nuclide Y. Nuclide Y then decays by β^+ emission to a nuclide Z.

State how the proton number of Z compares with that of X, and name the particle emitted alongside the β -particle in **each** of the two decays. [3]



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State how the proton number of Z compares with that of X, and name the particle emitted alongside the β -particle in **each** of the two decays. [3]



3.3

- β^- decay raises the proton number by one and β^+ decay lowers it by one, so Z has the **same proton number as X**
- the β^- decay also emits an (electron) **antineutrino**
- the β^+ decay also emits an (electron) **neutrino**

Exercise 3.4

3.4 A nucleus of radium-228, $^{228}_{88}\text{Ra}$, decays in a series of steps to a nucleus X, emitting 5 α -particles and 4 β^- -particles in total. Determine the number of protons and the number of neutrons in X. [3]



Exercise 3.4

3.4 A nucleus of radium-228, $^{228}_{88}\text{Ra}$, decays in a series of steps to a nucleus X, emitting 5 α -particles and 4 β^- -particles in total. Determine the number of protons and the number of neutrons in X. [3]



3.4

- each α takes away 2 protons and 2 neutrons; each β^- turns a neutron into a proton

$$Z_{\text{X}} = Z_{\text{Ra}} - 2n_{\alpha} + n_{\beta} = 88 - 2 \times 5 + 4 = \mathbf{82}$$

- radium-228 has $N = A - Z = 228 - 88 = 140$ neutrons

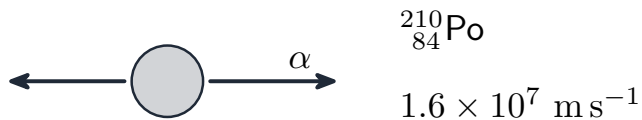
$$N_{\text{X}} = N_{\text{Ra}} - 2n_{\alpha} - n_{\beta} = 140 - 2 \times 5 - 4 = \mathbf{126}$$

Exercise 3.5 (a)

3.5 A stationary nucleus of polonium-210, $^{210}_{84}\text{Po}$, decays by α emission to an isotope of lead (Pb).

(a) Write the decay equation.

[2]

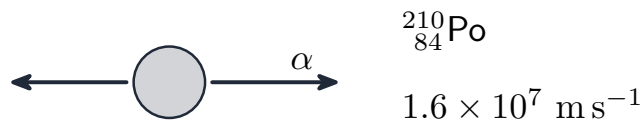


Exercise 3.5 (a)

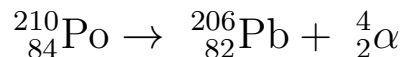
3.5 A stationary nucleus of polonium-210, $^{210}_{84}\text{Po}$, decays by α emission to an isotope of lead (Pb).

(a) Write the decay equation.

[2]



(a) the nucleon number falls by 4 and the proton number by 2



Exercise 3.5 (b)

3.5 A stationary nucleus of polonium-210, $^{210}_{84}\text{Po}$, decays by α emission to an isotope of lead (Pb).

(b) State **three** quantities that are conserved in the decay.

[2]

Exercise 3.5 (b)

3.5 A stationary nucleus of polonium-210, $^{210}_{84}\text{Po}$, decays by α emission to an isotope of lead (Pb).

(b) State **three** quantities that are conserved in the decay. [2]

(b) any three of: **nucleon number**, **charge** (proton number), **momentum**, **mass-energy**

Exercise 3.5 (c)

3.5 A stationary nucleus of polonium-210, $^{210}_{84}\text{Po}$, decays by α emission to an isotope of lead (Pb).

(c) The α -particle leaves with a speed of $1.6 \times 10^7 \frac{\text{m}}{\text{s}}$. Calculate the speed of the lead nucleus. [3]

Exercise 3.5 (c)

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(c) The α -particle leaves with a speed of $1.6 \times 10^7 \frac{\text{m}}{\text{s}}$. Calculate the speed of the lead nucleus. [3]

(c) the momentum is zero before the decay, so it is zero after

$$m_{\alpha}v_{\alpha} = m_{\text{Pb}}v_{\text{Pb}}$$

- rearrange, with the masses in u

$$v_{\text{Pb}} = \frac{m_{\alpha}v_{\alpha}}{m_{\text{Pb}}} = \frac{(4 \text{ u})(1.6 \times 10^7 \frac{\text{m}}{\text{s}})}{206 \text{ u}} = \mathbf{3.1 \times 10^5 \frac{\text{m}}{\text{s}}}$$

Exercise 3.5 (d)

3.5 A stationary nucleus of polonium-210, $^{210}_{84}\text{Po}$, decays by α emission to an isotope of lead (Pb).

(d) Explain why the lead nucleus moves in the opposite direction to the α -particle. [1]

Exercise 3.5 (d)

3.5 A stationary nucleus of polonium-210, $^{210}_{84}\text{Po}$, decays by α emission to an isotope of lead (Pb).

(d) Explain why the lead nucleus moves in the opposite direction to the α -particle. [1]

(d) the total momentum stays zero, so the two momenta must be equal in size and **opposite in direction**