

Exercise walk-through

11.1

Atoms, nuclei and radiation

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

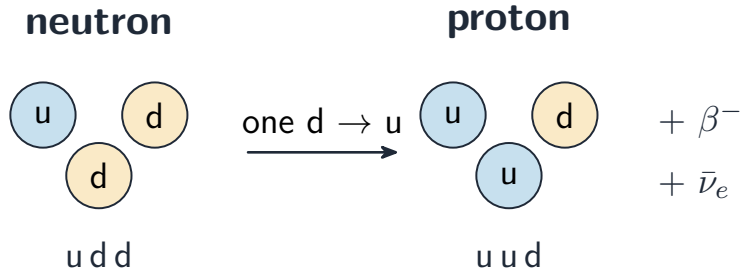
“Describe the change to the quark composition of the nucleon.” **[1]**

“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

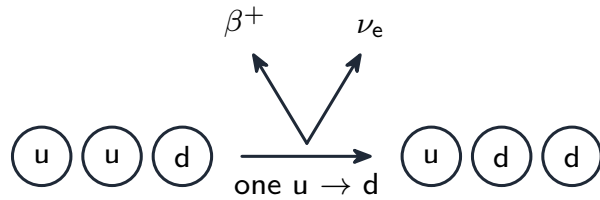
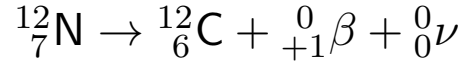
Charge is conserved in the change

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

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

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

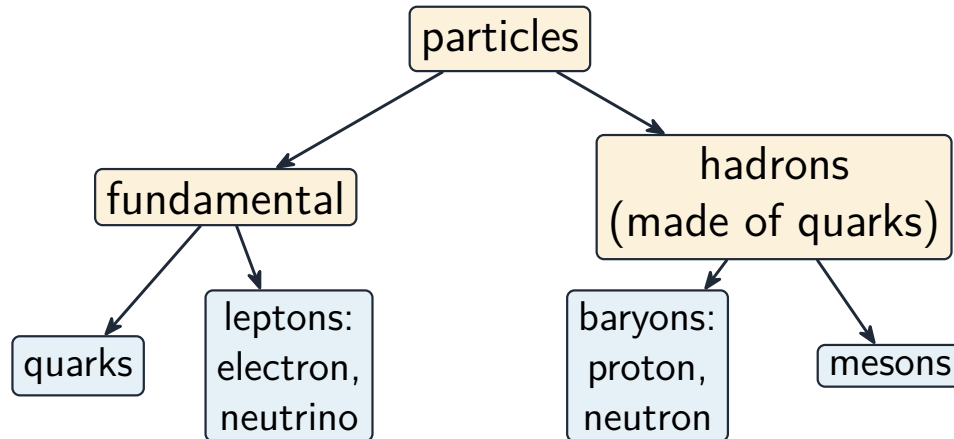
From the nucleus down to the quark



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

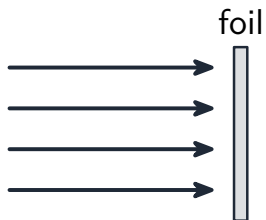


Fundamental: **quarks**
and **leptons** (electron,
neutrino).

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

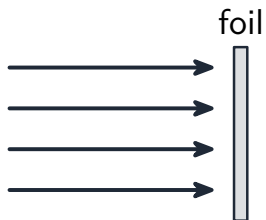
Exercise 2.1

2.1 State **two** conclusions about the atom that were drawn from the α -particle scattering experiment. [2]



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2.1

- any two: the atom is **mostly empty space**; it has a **tiny nucleus**; the nucleus is **positively charged**; most of the atom's **mass** is in the nucleus

Exercises 2.2-2.3

2.2 For a neutral atom of $^{14}_6\text{C}$, state the numbers of protons, neutrons and electrons. [2]



$^{14}_6\text{C}$

2.3 Define **isotopes**.

[1]

isotopes

Exercises 2.2·2.3

2.2 For a neutral atom of ${}^{14}_6\text{C}$, state the numbers of protons, neutrons and electrons. [2]



${}^{14}_6\text{C}$

2.2

- protons = $Z = 6$, and a neutral atom has as many electrons, 6
- the neutron number is the nucleon number minus the proton number

$$N = A - Z = 14 - 6 = 8$$

2.3 Define **isotopes**.

[1]

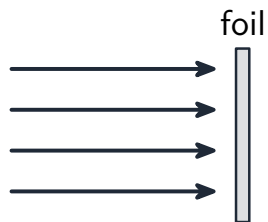
isotopes

2.3

- nuclides of the **same element**, with the same number of protons but **different numbers of neutrons**

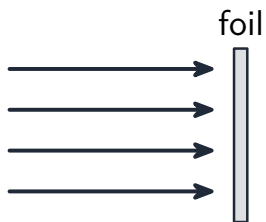
Exercise 2.4

2.4 In the α -scattering experiment, explain why the gold foil must be **thin** and why the apparatus must be in a **vacuum**. [2]



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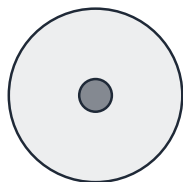


2.4

- thin: so that each α -particle is scattered by **one nucleus at most** and is not absorbed in the foil
- vacuum: so that the α -particles are not **absorbed or scattered by air**, in which they travel only a few centimetres

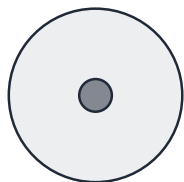
Exercise 2.5

2.5 State the numbers of protons, neutrons and electrons in the ion $^{35}_{17}\text{Cl}^-$. [3]

 $^{35}_{17}\text{Cl}^-$

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 ${}^{35}_{17}\text{Cl}^-$

2.5

- protons = $Z = 17$
- neutrons

$$N = A - Z = 35 - 17 = 18$$

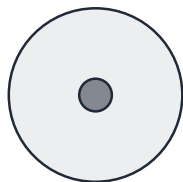
- a charge of $-e$ means one electron has been gained

$$n_e = Z + 1 = 17 + 1 = 18$$

Exercise 2.6

2.6 Calculate the mass, in kg, of a nucleus of ${}^{40}_{20}\text{Ca}$.

[2]

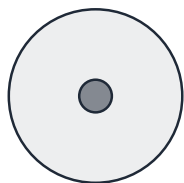


${}^{40}_{20}\text{Ca}$

Exercise 2.6

2.6 Calculate the mass, in kg, of a nucleus of ${}^{40}_{20}\text{Ca}$.

[2]



${}^{40}_{20}\text{Ca}$

2.6

- the mass of a nucleus is about A u

$$m = A \times 1 \text{ u} = 40 \times 1.66 \times 10^{-27} \text{ kg} = \mathbf{6.64 \times 10^{-26} \text{ kg}}$$

Exercise 3.1

3.1 Which statement about two isotopes of the same element is correct?

[1]

☐

A They have the same nucleon number but different proton numbers.

B They have the same proton number but different numbers of neutrons.

C They have the same number of neutrons but different numbers of protons.

D Their neutral atoms have different numbers of electrons.

isotopes

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isotopes

3.1 B

- isotopes have the same proton number, so they are the same element, and different numbers of neutrons
- **A** describes two different elements; **D** is wrong because a neutral atom has Z electrons, the same for every isotope

Exercise 3.2

3.2 The mass of a certain nucleus is 3.99×10^{-26} kg. What is its nucleon number? [1]

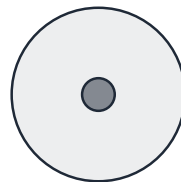
☐

A 12

B 16

C 24

D 40



3.99×10^{-26} kg

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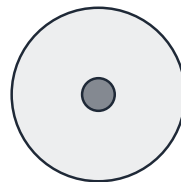
☐

A 12

B 16

C 24

D 40



3.99×10^{-26} kg

3.2 C

- the mass of a nucleus is about A u, so

$$A = \frac{m}{1 \text{ u}} = \frac{3.99 \times 10^{-26} \text{ kg}}{1.66 \times 10^{-27} \text{ kg}} = 24$$

Exercise 3.3 (a)

3.3 In the α -particle scattering experiment, a beam of α -particles is directed at a thin gold foil.

(a) Describe what is observed for most of the α -particles, and state what this shows about the atom.

[2]

Exercise 3.3 (a)

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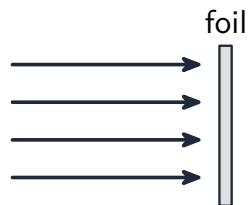
(a) almost all of the α -particles pass **straight through** the foil, undeflected

- so the atom is **mostly empty space**

Exercise 3.3 (b)

3.3 In the α -particle scattering experiment, a beam of α -particles is directed at a thin gold foil.

(b) A very small fraction of the α -particles are deflected through more than 90° . Explain what this shows about the charge, the mass and the size of the nucleus. [3]

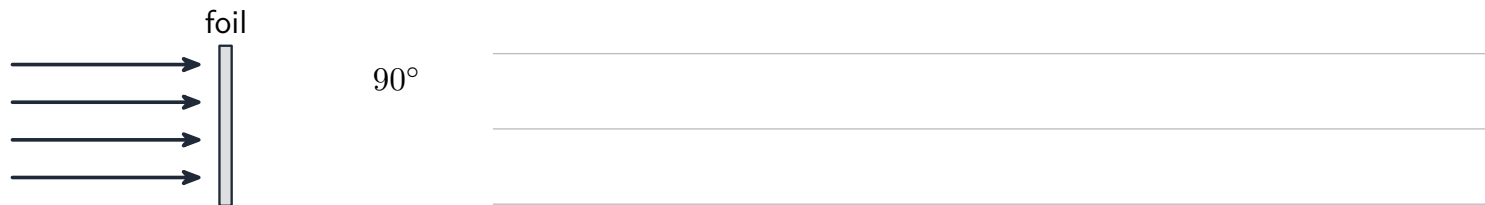


90°

Exercise 3.3 (b)

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(b) such a large deflection needs a strong repulsion, so the nucleus carries a concentrated **positive charge**

- the α -particle is turned back, so the nucleus is **much more massive** than the α -particle
- it happens very rarely, so the nucleus is **very small** compared with the atom

Exercise 3.4 (a)

3.4 The unified atomic mass unit is 1.66×10^{-27} kg and the elementary charge is 1.60×10^{-19} C.

(a) State what is meant by the **unified atomic mass unit**.

[1]

Exercise 3.4 (a)

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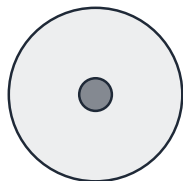
(a) State what is meant by the **unified atomic mass unit**. [1]

(a) one twelfth of the mass of an atom of **carbon-12**

Exercise 3.4 (b)

3.4 The unified atomic mass unit is 1.66×10^{-27} kg and the elementary charge is 1.60×10^{-19} C.

(b) Calculate the mass, in kg, of a nucleus of ${}^7_3\text{Li}$. [2]



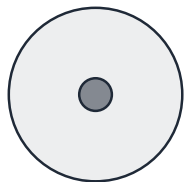
$$1.66 \times 10^{-27} \text{ kg}$$

$$1.60 \times 10^{-19} \text{ C}$$

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(b) Calculate the mass, in kg, of a nucleus of ${}^7_3\text{Li}$. [2]



$$1.66 \times 10^{-27} \text{ kg}$$

$$1.60 \times 10^{-19} \text{ C}$$

(b) the mass of a nucleus is about $A \text{ u}$

$$m = A \times 1 \text{ u} = 7 \times 1.66 \times 10^{-27} \text{ kg} = \mathbf{1.16 \times 10^{-26} \text{ kg}}$$

Exercise 3.4 (c)

3.4 The unified atomic mass unit is 1.66×10^{-27} kg and the elementary charge is 1.60×10^{-19} C.

(c) A different nucleus has 27 nucleons and a charge-to-mass ratio of 4.6×10^7 C kg⁻¹. Determine its number of protons and its number of neutrons. [3]

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(c) the mass of the nucleus

$$m = A \times 1 \text{ u} = 27 \times 1.66 \times 10^{-27} \text{ kg} = 4.48 \times 10^{-26} \text{ kg}$$

- its charge is Ze , so

$$Z = \frac{(Q/m) \times m}{e} = \frac{(4.6 \times 10^7 \text{ C kg}^{-1})(4.48 \times 10^{-26} \text{ kg})}{1.60 \times 10^{-19} \text{ C}} = 12.9$$

- a whole number of protons, $Z = \mathbf{13}$, and then

$$N = A - Z = 27 - 13 = \mathbf{14}$$

Exercise 3.4 (d)

3.4 The unified atomic mass unit is 1.66×10^{-27} kg and the elementary charge is 1.60×10^{-19} C.

(d) The charge-to-mass ratio of a ${}^4_2\text{He}$ nucleus is 4.8×10^7 C kg⁻¹. Explain why the nucleus in (c) has a slightly smaller ratio. [2]

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(d) the ratio depends only on the number of protons per nucleon

- helium has 2 protons in 4 nucleons, exactly a half; this nucleus has 13 in 27, less than a half, because heavier nuclei have more neutrons than protons