Past-paper walk-through

Atoms, nuclei and radiation ▪ 11.1

eXercise

Questions in this set

- 9702/11 N25 Q38 ▪ 1 mark
- 9702/11 N25 Q39 ▪ 1 mark
- 9702/12 N25 Q39 ▪ 1 mark
- 9702/12 N25 Q40 ▪ 1 mark
- 9702/14 N25 Q38 ▪ 1 mark
- 9702/14 N25 Q39 ▪ 1 mark
- 9702/21 N25 Q6 ▪ 9 marks
- 9702/24 N25 Q6 ▪ 10 marks
- 9702/11 J25 Q39 ▪ 1 mark
- 9702/12 J25 Q38 ▪ 1 mark

Questions in this set

- 9702/21 J25 Q7 ▪ 8 marks
- 9702/21 N24 Q5 ▪ 7 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 38

9702/11 N25 ▪ Q38 ▪ 1 mark

The diagram shows a sequence of radioactive decays involving three α-particles and a β^- particle.

$$^{237}_{93}\text{Np} \xrightarrow{\alpha} \text{Q} \xrightarrow{\beta^-} \text{R} \xrightarrow{\alpha} \text{S} \xrightarrow{\alpha} \text{T}$$

What is nuclide T? **[1]**

A $^{225}_{88}\text{Ra}$

B $^{231}_{88}\text{Ra}$

C $^{225}_{90}\text{Th}$

D $^{229}_{90}\text{Th}$

Solution 38

A $^{225}_{88}\text{Ra}$ ✓

B $^{231}_{88}\text{Ra}$

C $^{225}_{90}\text{Th}$

D $^{229}_{90}\text{Th}$

Why

- Each α removes 4 from the nucleon number and 2 from the proton number, so three remove 12 and 6.
- A β^- leaves the nucleon number alone and *adds* 1 to the proton number.
- $237 - 12 = 225$ and $93 - 6 + 1 = 88$, giving $^{225}_{88}\text{Ra}$.

Question 39

9702/11 N25 ▪ Q39 ▪ 1 mark

The number of electrons in a neutral atom of an isotope of plutonium, $^{239}_{94}$Pu, is changed to produce a charged atom (ion) W.

W has an overall charge of $+1.6 \times 10^{-19}$ C.

How many protons, neutrons and electrons are in W? **[1]**

A protons: 94, neutrons: 145, electrons: 93

B protons: 94, neutrons: 145, electrons: 95

C protons: 238, neutrons: 94, electrons: 239

D protons: 239, neutrons: 94, electrons: 238

Question 39

	protons	neutrons	electrons
A	94	145	93
B	94	145	95
C	238	94	239
D	239	94	238

Solution 39

- **A** protons: 94, neutrons: 145, electrons: 93 ✓
- **B** protons: 94, neutrons: 145, electrons: 95
- **C** protons: 238, neutrons: 94, electrons: 239
- **D** protons: 239, neutrons: 94, electrons: 238

Why

- The charge is $+e$, so the atom has lost exactly one electron: $94 - 1 = 93$.
- The proton number stays at 94 – removing an electron does not touch the nucleus.
- Neutrons $= 239 - 94 = 145$.

Question 39

9702/12 N25 ▪ Q39 ▪ 1 mark

A nucleus of magnesium-23 decays to form a nucleus of sodium-23, emitting a β^+ particle and particle X.

What is particle X? **[1]**

A an antineutrino

B an electron

C a neutron

D a neutrino

Solution 39

A an antineutrino

B an electron

C a neutron

D a neutrino ✓

Why

- This is β^+ decay: a proton inside the nucleus becomes a neutron.
- Lepton number must balance, and the emitted positron carries -1.
- So the third particle is a neutrino, with lepton number $+1$ – not an antineutrino.

Question 40

9702/12 N25 ▪ Q40 ▪ 1 mark

A nucleus of ${}^{238}_{92}$U decays in stages by emitting α-particles and β^- particles, eventually forming a nucleus of ${}^{206}_{82}$Pb.

How many α-particles and how many β^- particles are emitted during the decay chain? **[1]**

A 8 α-particles and 6 β^- particles

B 8 α-particles and 10 β^- particles

C 16 α-particles and 6 β^- particles

D 16 α-particles and 22 β^- particles

Question 40

	α-particles	β^- particles
A	8	6
B	8	10
C	16	6
D	16	22

Solution 40

A 8 α-particles and 6 β^- particles ✓

B 8 α-particles and 10 β^- particles

C 16 α-particles and 6 β^- particles

D 16 α-particles and 22 β^- particles

Why

- The nucleon number falls by $238 - 206 = 32$, and only α decay changes it, by 4 each: $32/4 = 8$ alphas.
- Those 8 alphas alone would take the proton number from 92 to $92 - 16 = 76$.
- The product actually has 82, so $82 - 76 = 6$ β^- decays each added a proton.

Question 38

9702/14 N25 ▪ Q38 ▪ 1 mark

What is the correct equation for β^+ decay? **[1]**

A neutron $\rightarrow$ proton $+$ electron $+$ electron antineutrino

B neutron $\rightarrow$ proton $+$ electron $+$ electron neutrino

C proton $\rightarrow$ neutron $+$ positron $+$ electron antineutrino

D proton $\rightarrow$ neutron $+$ positron $+$ electron neutrino

Solution 38

A neutron $\rightarrow$ proton $+$ electron $+$ electron antineutrino

B neutron $\rightarrow$ proton $+$ electron $+$ electron neutrino

C proton $\rightarrow$ neutron $+$ positron $+$ electron antineutrino

D proton $\rightarrow$ neutron $+$ positron $+$ electron neutrino ✓

Why

- In β^+ decay a proton turns into a neutron, so the left-hand side must be a proton.
- The emitted lepton is a positron.
- Lepton number balance then demands a *neutrino*, not an antineutrino.

Question 39

9702/14 N25 ▪ Q39 ▪ 1 mark

A nucleus of polonium, $^{214}_{84}\text{Po}$, decays by emitting an α-particle to become a nucleus of lead.

The nucleus of lead is also unstable and decays by emitting a β^- particle to form a nucleus of bismuth which then decays by emitting a β^- particle to produce a nucleus X.

What is the number of neutrons in nucleus X? **[1]**

A 126

B 128

C 130

D 210

Solution 39

- **A** 126 ✓
- **B** 128
- **C** 130
- **D** 210

Why

- The α gives ${}^{210}_{82}\mathrm{Pb}$; each β^- then adds a proton without changing the nucleon number.
- After the two betas X has $A = 210$ and $Z = 84$.
- Neutrons $= 210 - 84 = 126$; D is the nucleon number, not the neutron count.

Question 6

9702/21 N25 ▪ Q6 ▪ 9 marks

The nuclide ${}^{3}_{1}\text{H}$ is an isotope of hydrogen that is called tritium.

(a)(i) Determine the numbers of protons, neutrons and electrons in a neutral atom of tritium. **[2]**

(a)(ii) Draw a labelled diagram to represent a simple model of the arrangement of the protons, neutrons and electrons in a tritium atom. **[2]**

(b)(i) Complete the equation to represent the radioactive decay of tritium.

$${}^{3}_{1}\text{H} \rightarrow \frac{\quad}{\quad}\text{He} + \frac{\quad}{\quad}\beta + {}^{0}_{0}\,\text{X}$$

[2]

(b)(ii) State the name of particle X. **[1]**

(c) Determine the quark composition of a tritium nucleus. **[2]**

Solution 6

(a)(i)

Worked steps

Read the two numbers off the nuclide symbol: the bottom one is the proton number, the top one is the nucleon number.

- Protons $= 1$ (the bottom number, Z).
- Neutrons $= A - Z = 3 - 1 = 2$.
- Electrons $= 1$: the atom is **neutral**, so electrons balance protons.

Mark scheme

- numbers of protons and electrons both $= 1$ **A1**
- number of neutrons $= 2$ **A1**

Solution 6

(a)(ii)

Worked steps

- Draw a small nucleus containing **one proton and two neutrons**, and label them.
- Draw **one electron** clearly separated from the nucleus, on an orbit around it, labelled.
- Keep the electron well away from the nucleus — a diagram where it touches the protons loses the second mark.

Mark scheme

- diagram shows 2 neutrons and 1 proton labelled and forming a nucleus **B1**
- diagram shows 1 electron labelled and separated from the nucleus (not touching the proton and neutrons) **B1**

Solution 6

(b)(i)

Mark scheme

- helium nucleus: top line $= 3$ and bottom line $= 2$ **A1**
- beta particle:
- top line $= 0$ and bottom line $= -1$ **A1**

(b)(ii)

Mark scheme

- (electron) antineutrino **B1**

Solution 6

(c) Worked steps

Build the nucleus out of its nucleons, then count.

- A proton is **up up down**; a neutron is **up down down**.
- Tritium's nucleus is 1 proton + 2 neutrons.
- Ups: $2 + (2 \times 1) = 4$. Downs: $1 + (2 \times 2) = 5$.
- So the nucleus is **4 up quarks and 5 down quarks**.

Solution 6

Check it: total charge $= 4(+\frac{2}{3}) + 5(-\frac{1}{3}) = +1$, which is one proton's worth — correct for tritium.

Mark scheme

- proton: up up down or neutron: up down down **C1**
- (tritium:) 4 up, 5 down **A1**

Question 6

9702/24 N25 ▪ Q6 ▪ 10 marks

Fig. 6.1 shows four alpha particles W, X, Y and Z moving towards a gold nucleus that is in thin gold foil.

(a)(i) The paths of particles X and Z are shown.

Complete Fig. 6.1 to show possible paths for particles W and Y. **[3]**

(a)(ii) Describe what may be inferred about the structure of an atom from the path of particle X. **[1]**

(a)(iii) When a beam containing many alpha particles is incident on thin gold foil, nearly all of the alpha particles follow paths that are similar to the path of particle Z.

Describe what may be inferred from this about the structure of an atom. **[1]**

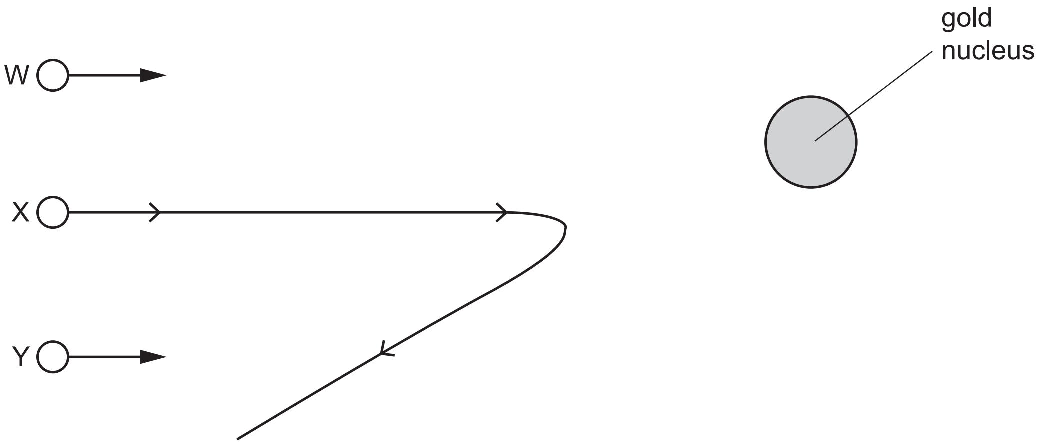
(b) State the mass and the charge, in terms of the atomic mass unit *u* and the elementary charge *e*, of an alpha particle. **[2]**

(c)(i) State the name of this type of hadron. **[1]**

Question 6

(c)(ii) Show, by reference to their constituent quarks, that the hadrons in an alpha particle have charges of either zero or $+1e$. **[2]**

Question 6



Solution 6

(a)(i)

Mark scheme

- W deflects upwards B1
- W has deflection that is the mirror image of X B1
- Y deflects downwards less than X or path of Y is parallel to particle Z B1

(a)(ii)

Mark scheme

- nucleus has most of the mass of the atom or nucleus is charged B1

Solution 6

(a)(iii)

Mark scheme

- atom is mostly empty space or nucleus occupies a very small proportion of the space in the atom **B1**

Solution 6

(b)

Mark scheme

- mass $= 4$ u **A1**
- charge $= (+)2$e **A1**

Solution 6

(c)(i)

Mark scheme

- baryon **B1**

Solution 6

(c)(ii) Mark scheme

- charge on up quark $= (+)\ 2$
- 3 (e) and charge on down quark $=$
- 1
- 3
- –
- (e) C1
- (proton is up up down and neutron is up down down)
- 2

Solution 6

- 1
- 2
- 1
- 1
- 3
- 3 e e
- (
-)
- (
-)

Solution 6

- $\times$
- $-$
- $\times$
- $=$
- $($
- $)$
- $($
- $)$
- $($
- $)$

Solution 6

- (
-) and
- 2
- 1
- 1
- 2
- 0
- 3
- 3 e e
- (

Solution 6

- $)$
- $($
- $)$
- $\times$
- $-$
- $\times$
- $=$
- $($
- $)$
- $($

Solution 6

-)
- (
-)
- (
-) **A1**

Question 39

9702/11 J25 ▪ Q39 ▪ 1 mark

Which statement explains why alpha-particles have discrete energies, but beta-particles have a continuous range of energies? **[1]**

A Beta-particles have a much smaller mass than alpha-particles which means beta-particles can be emitted with a larger range of velocities.

B Only alpha-particles experience repulsion from the nucleus which is dependent on the number of protons in the nucleus.

C Only beta-particles are emitted with another lepton and some energy is transferred to the other lepton.

D Only the energy of alpha-particles is discrete because the composition of alpha-particles is always the same.

Solution 39

A Beta-particles have a much smaller mass than alpha-particles which means beta-particles can be emitted with a larger range of velocities.

B Only alpha-particles experience repulsion from the nucleus which is dependent on the number of protons in the nucleus.

C Only beta-particles are emitted with another lepton and some energy is transferred to the other lepton. ✓

D Only the energy of alpha-particles is discrete because the composition of alpha-particles is always the same.

Why

- Alpha decay is a two-body split, so the energy is shared one fixed way – giving discrete energies.
- Beta decay releases a third particle, a neutrino or antineutrino, alongside the beta particle.
- The available energy is divided between them in any proportion, so the beta energy varies

Question 38

9702/12 J25 ▪ Q38 ▪ 1 mark

Two neutral atoms are isotopes of the same element.

Which statement about the atoms is correct? **[1]**

A They have a different number of neutrons and a different number of electrons.

B They have a different number of neutrons and the same number of protons.

C They have the same number of neutrons and a different number of electrons.

D They have the same number of neutrons and the same number of protons.

Solution 38

A They have a different number of neutrons and a different number of electrons.

B They have a different number of neutrons and the same number of protons. ✓

C They have the same number of neutrons and a different number of electrons.

D They have the same number of neutrons and the same number of protons.

Why

- Isotopes of an element share the same number of protons – that is what makes them the same element.
- They differ in their number of neutrons, which is what changes the nucleon number.
- Both atoms are neutral, so each has as many electrons as protons; the electron counts match too.

Question 7

9702/21 J25 ▪ Q7 ▪ 8 marks

(a) Nitrogen-12 ($^{12}_{7}$N) is an unstable isotope of nitrogen that decays by the emission of radiation to carbon-12 ($^{12}_{6}$C).
Complete the full nuclear equation for the decay, including all the particles involved.

$$^{12}_{7}\mathrm{N} \rightarrow$$

[3]

Question 7

flavour	charge / e

Question 7

9702/21 J25 ▪ Q7 ▪ 8 marks

(b)(i) State the charge on the positron in terms of the elementary charge *e*. **[1]**

(b)(ii) State the group (class) of fundamental particle to which the positron belongs. **[1]**

(b)(iii) In Table 7.1, state the flavour and charge of the three antiquarks that comprise the antiproton.

Table 7.1

flavour	charge/e

Question 7

[3]

Solution 7

(a) Mark scheme

- ( )
- ( )
- 0
- 12
- 12
- 0
- 7
- 6

Solution 7

- 1
- 0
- N
- C n
- $+$
- $\rightarrow$
- $+$ $\beta +$ beta-plus shown **B1**
- neutrino shown **B1**
- symbols, nucleon numbers and proton numbers all correct **B1**

Solution 7

(b)(i)

Mark scheme

- $+1$ **B1**

(b)(ii)

Mark scheme

- Lepton(s) **B1**

Solution 7

(b)(iii) Mark scheme

- flavour charge / e up / u
- 2
- – 3 up / u
- 2
- – 3 down / d
- ( )
- $+1$
- 3

Solution 7

- 3 correct quark flavours **B1**
- Charge on anti-up quark – (e) **B1**
- Charge on anti-down quark (+) (e) **B1**

Question 5

9702/21 N24 ▪ Q5 ▪ 7 marks

5 **(a)** Potassium-40 ($^{40}_{19}$K) undergoes β^- decay to form a nuclide of element X. Particle Z is emitted during the decay. The equation for the decay is shown.

$$^{40}_{19}\mathrm{K} \rightarrow {}^{P}_{Q}\mathrm{X} + {}^{R}_{S}\beta^- + \mathrm{Z}$$

(i) State the values of *P*, *Q*, *R* and *S*.

Question 5

[2]

(ii) State the name of particle Z.

Question 5

(iii) State the name of the class of fundamental particle to which both the β^- particle and particle Z belong.

Question 5

(b) Determine the quark composition of an alpha-particle.

Question 5

[Total: 7]

Solution 5

(a)(i)

Worked steps

Balance the two numbers separately across the arrow: nucleon number on top, proton number below.

- Nucleon numbers must be equal: this fixes $P = 40$ and $R = 0$ — a β^- particle has nucleon number 0.
- Proton numbers must be equal: this fixes $Q = 20$ and $S = -1$ — a β^- particle has charge -1.

Mark scheme

- P = 40 and R = 0
- Q = 20 and S = –1

Solution 5

(a)(ii)

Mark scheme

- (electron) antineutrino

(a)(iii)

Mark scheme

- leptons

Solution 5

(b) Worked steps

Build the particle from its nucleons and count the quarks.

- An α-particle is 2 protons and 2 neutrons.
- A proton is **up up down**; a neutron is **up down down**.
- Ups: $(2 \times 2) + (2 \times 1) = 6$. Downs: $(2 \times 1) + (2 \times 2) = 6$.
- So an α-particle is **6 up and 6 down** quarks.

Check the charge: $6(+\frac{2}{3}) + 6(-\frac{1}{3}) = +2$, which is right for an α-particle. **Mark scheme**

- (alpha particle consists of) 2 protons and 2 neutrons

Solution 5

- quark composition of proton = up up down
- or
- quark composition of neutron = up down down
- quark composition (of alpha particle) = 6 up, 6 down
- 9702/21
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