11. Particle Physics

11.1 Atoms, nuclei and radiation

Paper 2

Question Paper

1 Nuclei of an isotope of copper (Cu) each have 29 protons and 37 neutrons. This isotope is a β^- emitter.

(a) State the nuclide notation in the form ${}^{A}_{Z}X$ for this nucleus of copper.

[1]

(b) The energy spectrum of the β^- radiation emitted by a sample of this isotope is shown in Fig. 7.1.

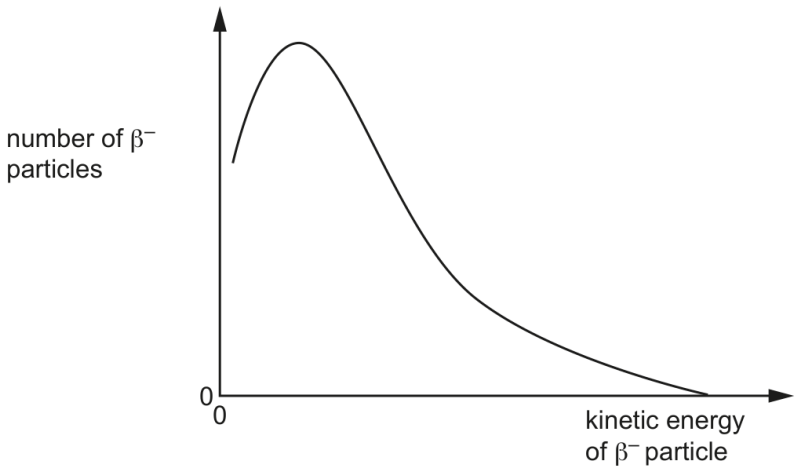


Fig. 7.1

(i) Use Fig. 7.1 to explain why other particles apart from the β^- particles must be emitted during this decay.

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.....

..... [3]

(ii) State the name of the other particle emitted during the decay of this isotope.

..... [1]

(iii) The copper isotope decays to an isotope of zinc (Zn).

Give the radioactive decay equation for this decay. Include the nucleon and proton numbers of **all** the particles involved.

[3]

2 **(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.

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

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

P = ... *R* = ...

Q = ... *S* = ...

[2]

(ii) State the name of particle Z.

..... [1]

3 **(a)** Compare an α-particle with a β^+ particle in terms of their masses and charges.

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..... [3]

(b) Nucleus P undergoes α-decay to form nucleus Q. Nucleus Q then undergoes a further decay to form nucleus R. The proton and nucleon numbers of P and R are shown in Fig. 6.1.

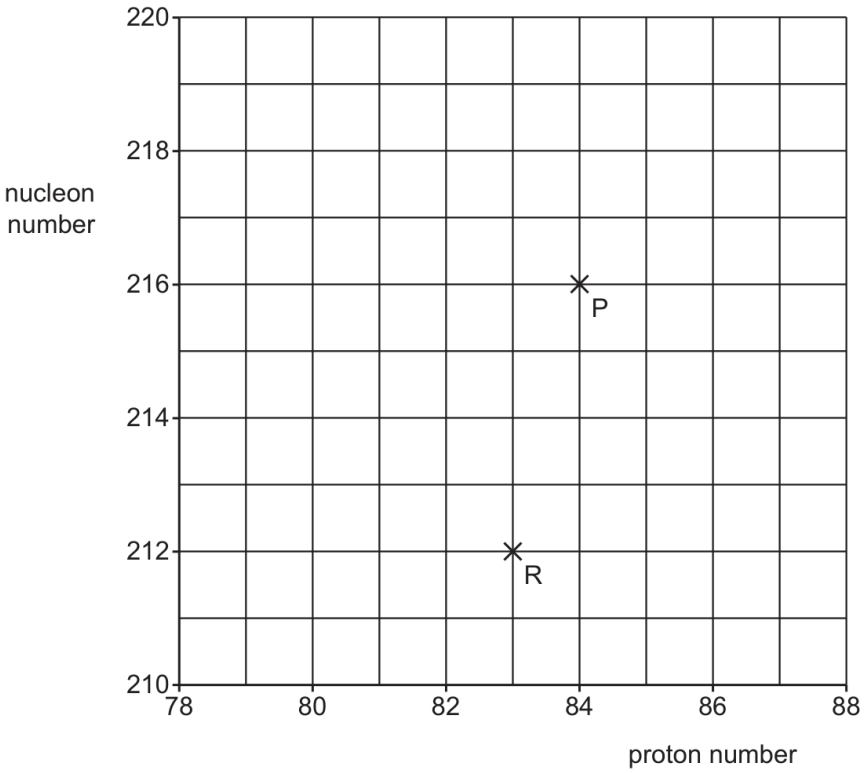


Fig. 6.1

(i) On Fig. 6.1, draw a cross (×) to show the proton number and nucleon number of Q. Label your cross Q. [1]

(ii) State the names of the particles emitted as Q decays to form R.

.....

..... [2]

4 An isolated stationary nucleus X decays by emitting an α-particle to form a nucleus Y.

Nucleus Y and nucleus Z are isotopes of the same element.

(a) By comparing the number of protons in each nucleus, state and explain whether the charge of nucleus Y is less than, greater than or the same as the charge of:

(i) nucleus Z

.....

..... [1]

(ii) nucleus X.

.....

.....

..... [2]

5 **(a)** Nucleus P and nucleus Q are isotopes of the same element.

Nucleus Q is unstable and emits a β^- particle to form nucleus R.

(i) For nuclei P and Q, compare:

- the number of protons

.....

- the number of neutrons.

.....
[2]

(iii) State the name of another particle that must be emitted from nucleus Q in addition to the β^- particle.

..... [1]

6 **(a)** The results of the α-particle scattering experiment led to the development of the nuclear model for the atom.

State the results that suggested that most of the mass of the atom is concentrated in a very small region and most of the atom is empty space.

.....

.....

.....

..... [2]

(b) State the composition of γ-radiation.

..... [1]

(d) The discovery of a particle with an unusual charge was an important step in the development of the theory of quarks. The particle is a hadron with a mass of 2.19×10^{-27} kg and a charge of $+2e$, where e is the elementary charge.

(i) Calculate the mass, in u, of the particle. Give your answer to three significant figures.

mass = ... u [1]

7 **(b)** A nucleus of thorium-230 ($^{230}_{90}$Th) decays in stages, by emitting α-particles and β^- particles, to form a nucleus of lead-206 ($^{206}_{82}$Pb).

Determine the total number of α-particles and the total number of β^- particles that are emitted during the sequence of decays that form the nucleus of lead-206 from the nucleus of thorium-230.

number of α-particles = ...

number of β^- particles = ...
[2]

8 **(a)** An unstable nucleus $^{A}_{Z}$X decays by emitting a β^- particle.

(i) Determine quantitatively the changes, if any, in *A* and *Z* when X decays.

change in *A* = ...

change in *Z* = ...
[2]

(ii) In addition to the β^- particle, another lepton is emitted during the decay.

State the name of the other lepton that is emitted.

..... [1]

9 **(a)** A nucleus of caesium-137 ($^{137}_{55}Cs$) decays by emitting a β^- particle to produce a nucleus of an element X and an antineutrino. The decay is represented by

$$^{137}_{55}Cs \rightarrow {}^{Q}_{S}X + {}^{P}_{R}\beta^- + {}^{0}_{0}\overline{\nu}.$$

(i) State the number represented by each of the following letters.

P .....

Q .....

R .....

S .....

[2]

10 **(a)** Describe the structure of an **atom** of uranium-238, $^{238}_{92}U$.

.....

.....

..... [2]

(b) The decay of uranium-238 is shown by the equation

$$^{238}_{92}U \rightarrow {}^{234}_{90}Th + X.$$

For nucleus X, calculate the ratio, in $C\,kg^{-1}$, of

$$\frac{\text{charge}}{\text{mass}}.$$

ratio = ... $C\,kg^{-1}$ [3]

11 (a) A proton in a nucleus decays to form a neutron and a β^+ particle.

(i) State the name of another lepton that is produced in the decay.

..... [1]

(iii) State which of the three particles (proton, neutron or β^+ particle) has the largest ratio of charge to mass.

..... [1]

12 (a) One of the results of the α-particle scattering experiment is that a very small minority of the α-particles are scattered through angles greater than 90°.

State what may be inferred about the structure of the atom from this result.

.....

.....

.....

..... [2]

13 **(a)** Complete Table 6.1 to show the masses (in terms of the unified atomic mass unit u) and charges (in terms of the elementary charge *e*) of α, β^+ and β^- particles.

Table 6.1

	mass / u	charge / *e*
α-particle		
β^+ particle		
β^- particle		

[4]

(b) Carbon-14 is radioactive and decays by emission of β^- particles.

(iii) Suggest why the β^- particles are emitted with a range of different energies.

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.....

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..... [2]

14 A stationary nucleus P of mass 243 u decays by emitting an α-particle of mass 4 u to form a different nucleus Q, as illustrated in Fig. 7.1.

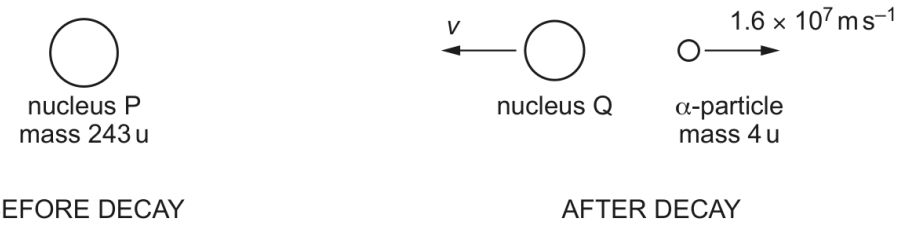


Fig. 7.1

The initial speed of the α-particle is $1.6 \times 10^7\,\text{m s}^{-1}$.

(d) A graph of number of neutrons N against proton number Z is shown in Fig. 7.2.

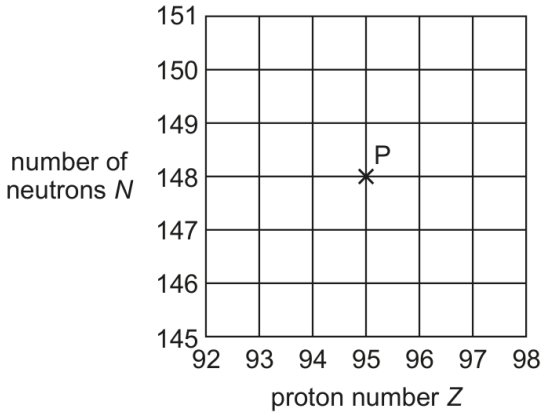


Fig. 7.2

The graph shows a cross that represents nucleus P.

A nucleus R has a nucleon number of 242 and is an isotope of nucleus P.

Nucleus R decays by emitting a β^- particle to form a different nucleus S.

(i) On Fig. 7.2, draw a cross to represent:

1. nucleus R (label this cross R)

2. nucleus S (label this cross S).

[2]

(ii) State the name of the other lepton, in addition to the β^- particle, that is emitted during the decay of nucleus R.

..... [1]

15 (b) An uncharged atom of uranium-238 ($^{238}_{92}$U) has a change made to its number of orbital electrons. This causes the atom to change into a new particle (ion) X that has an overall charge of +2*e*, where *e* is the elementary charge.

(i) Determine the number of protons, neutrons and electrons in the particle (ion) X.

number of protons = ...

number of neutrons = ...

number of electrons = ...

[3]

(iii) The nucleus of uranium-238 ($^{238}_{92}$U) decays in stages, by emitting α-particles and β^- particles, to form a nucleus of thorium-230 ($^{230}_{90}$Th).

Calculate the total number of α-particles and the total number of β^- particles that are emitted during the decay of uranium-238 to thorium-230.

number of α-particles = ...

number of β^- particles = ...

[2]

16 **(a)** A nucleus of an element X decays by emitting a β^+ particle to produce a nucleus of potassium-39 ($^{39}_{19}K$) and a neutrino. The decay is represented by

$$^{Q}_{S}X \rightarrow {}^{39}_{19}K + {}^{P}_{R}\beta^{+} + {}^{0}_{0}\nu.$$

(i) State the number represented by each of the following letters.

P .....

Q .....

R .....

S .....

[2]

17 **(b)** For a nucleus of aluminium-25 ($^{25}_{13}Al$):

(i) state the number of protons and the number of neutrons

number of protons = ...

number of neutrons = ...

[1]

(ii) show that the charge is 2.1×10^{-18} C.

[1]

18 (a) The decay of a nucleus $^{35}_{18}Ar$ by β^+ emission is represented by

$$^{35}_{18}Ar \longrightarrow X + \beta^+ + Y.$$

A nucleus X and two particles, β^+ and Y, are produced by the decay.

State:

(i) the proton number and the nucleon number of nucleus X

proton number = ...

nucleon number = ...
[1]

(ii) the name of the particle represented by the symbol Y.

..... [1]

19 A nucleus of plutonium-238 ($^{238}_{94}$Pu) decays by emitting an α-particle to produce a new nucleus X and 5.6 MeV of energy. The decay is represented by

$$^{238}_{94}\text{Pu} \rightarrow \text{X} + \alpha + 5.6\,\text{MeV}.$$

(a) Determine the number of protons and the number of neutrons in nucleus X.

number of protons = ...

number of neutrons = ...
[2]

20 A β^- particle from a radioactive source is travelling in a vacuum with kinetic energy 460 eV. The particle enters a uniform electric field at a right-angle and follows the path shown in Fig. 7.1.

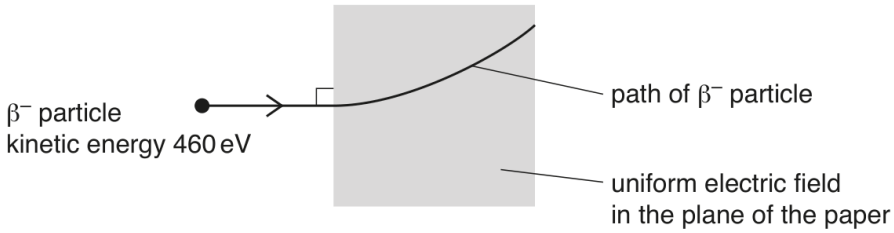


Fig. 7.1

(c) Other β^- particles from the same radioactive source travel outside the electric field along the same incident path as that shown in Fig. 7.1.

State and briefly explain whether those β^- particles will all follow the same path inside the electric field.

.....

.....

.....

.....[2]

21 A stationary nucleus X decays to form nucleus Y, as shown by the equation

$$X \longrightarrow Y + \beta^- + \bar{\nu}.$$

(b) State the name of the particle represented by the symbol $\bar{\nu}$.

.....[1]

(c) Energy is released during the decay process. State the form of the energy that is gained by nucleus Y.

.....[1]

(d) By comparing the compositions of X and Y, state and explain whether they are isotopes.

.....

.....

.....[2]

22 **(c)** A stationary nucleus X decays by emitting an α-particle to form a nucleus of plutonium, $^{240}_{94}Pu$, as shown.

$$X \longrightarrow {}^{240}_{94}Pu + \alpha$$

(i) Determine the number of protons and the number of neutrons in nucleus X.

number of protons = ...

number of neutrons = ...

[2]

23 **(b)** A stationary nucleus of magnesium-27, $^{27}_{12}Mg$, decays by emitting a β^- particle and γ radiation. An incomplete equation to represent this decay is

$$^{27}_{12}Mg \rightarrow X + \beta^- + \gamma.$$

(i) State the nucleon number and the proton number of nucleus X.

nucleon number = ...

proton number = ...
[2]

(iii) State **two** possible reasons why the sum of the kinetic energy of the β^- particle and the energy of the γ radiation is less than the total energy released during the decay of the magnesium nucleus.

1. .....

.....

2. .....

.....
[2]