1 **(a)** Fig. 6.1 shows the quark composition of some particles.

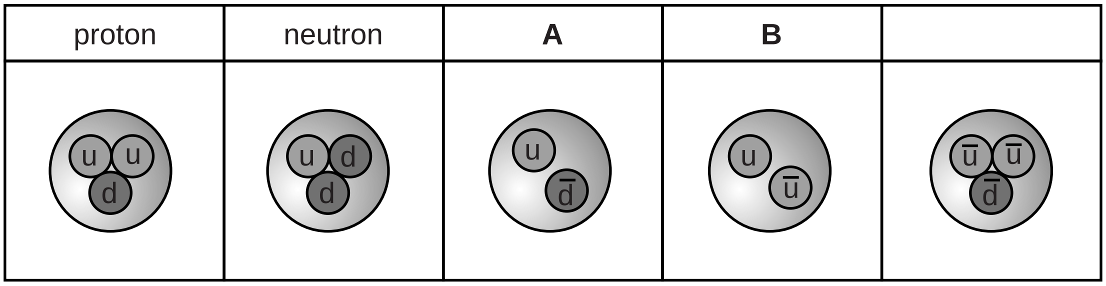


Fig. 6.1

(i) Identify the anti-proton from the table of particles shown in Fig. 6.1.

.... **[1]**

(ii) State the value of the charge of particle **B**.

.... **[1]**

(b) The nuclei of carbon-14 are produced naturally in the upper atmosphere from the reactions of slow-moving neutrons with nitrogen nuclei.

(i) The reaction below shows a nuclear reaction between a neutron and a nitrogen nucleus.

$$^{1}_{0}\text{n} \; + \; ^{14}_{7}\text{N} \; \rightarrow \; ^{14}_{6}\text{C} \; + \; \mathbf{X}$$

Identify the particle **X**.

.... **[1]**

(ii) Carbon-14 has a half-life of 5700 years. The molar mass of carbon-14 is 0.014 kg mol^{-1}. The total activity from all the carbon-14 nuclei found on the Earth is estimated to be 1.1×10^{19} Bq. Estimate the total mass of carbon-14 on the Earth.

mass = ... kg **[3]**

(c) Energy in the core of a nuclear reactor is produced by induced nuclear fission of uranium-235 nuclei. Explain what is meant by *induced nuclear fission*.

....

....

.... **[2]**

(d) Many nuclear reactors use uranium-235 as fuel. Some of these reactors use water as both coolant and moderator. The control rods contain boron-10. Fig. 6.2 shows part of the inside of the core of a nuclear reactor.

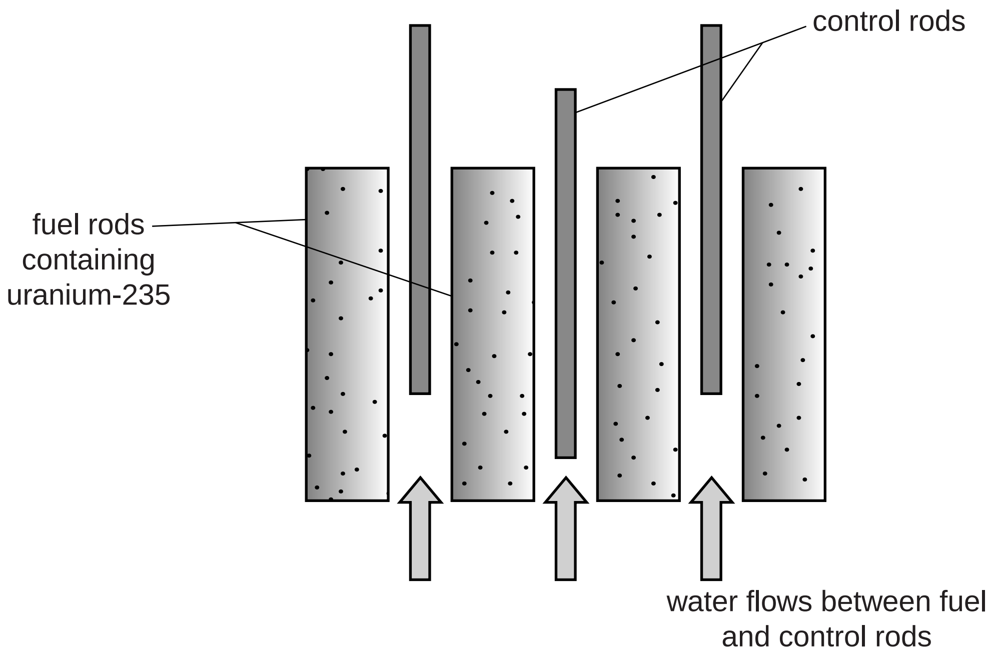


Fig. 6.2

Explain the purpose of using a moderator and control rods in the core of a nuclear reactor.

In your answer you should make clear how a moderator works at a microscopic level.

....

....

....

....

....

....

....

.... **[4]**

[Total: 12]

2 **(a)** The diameter of a nucleus is about 10^{-14} m.

(i) Complete the sentence below.

The diameter of a nucleus is .... times smaller than the diameter of an atom. **[1]**

(ii) Very high-energy electrons are diffracted by the nucleus when they have a wavelength similar to the nuclear diameter.

1 Estimate the momentum of an electron with a de Broglie wavelength equal to the diameter of a nucleus.

momentum = ...kg m s^{-1} **[2]**

2 Suggest why the speed of these electrons cannot be calculated by dividing the answer to **(ii)1** by the mass 9.11×10^{-31} kg.

....

....

....

.... **[1]**

(b) The table of Fig. 5.1 shows some of the isotopes of phosphorus and, where they are unstable, the type of decay.

Isotope	$^{29}_{15}P$	$^{30}_{15}P$	$^{31}_{15}P$	$^{32}_{15}P$	$^{33}_{15}P$
Type of decay	β^+	β^+	stable	β^-	β^-

Fig. 5.1

(i) State the difference between each of the isotopes shown in the table.

....

.... **[1]**

(ii) Describe the structure of the proton in terms of up (u) and down (d) quarks.

.... **[1]**

(iii) Describe what happens in a beta-plus (β^+) decay using a quark model.

....

....

.... **[2]**

(iv) State **two** quantities conserved in a beta decay.

....

.... **[1]**

(v) Examine the table of isotopes in Fig. 5.1 and suggest what determines whether an isotope emits β^+ or β^-.

....

....

.... **[1]**

[Total: 10]

3 **(a)** Explain what is meant by the statement

below.

Radioactivity is a random process.

....

.... **[1]**

(b) Uranium-235 was present during the formation of the Solar System, including the Earth. The percentage of the original quantity of $^{235}_{92}U$ found in rocks today is 1.1%. The half-life of $^{235}_{92}U$ is 7.1×10^8 years. Calculate the age, in years, of the Earth.

age = ... y **[3]**

(c) Fig. 6.1 shows the variation of binding energy per nucleon against nucleon number *A*.

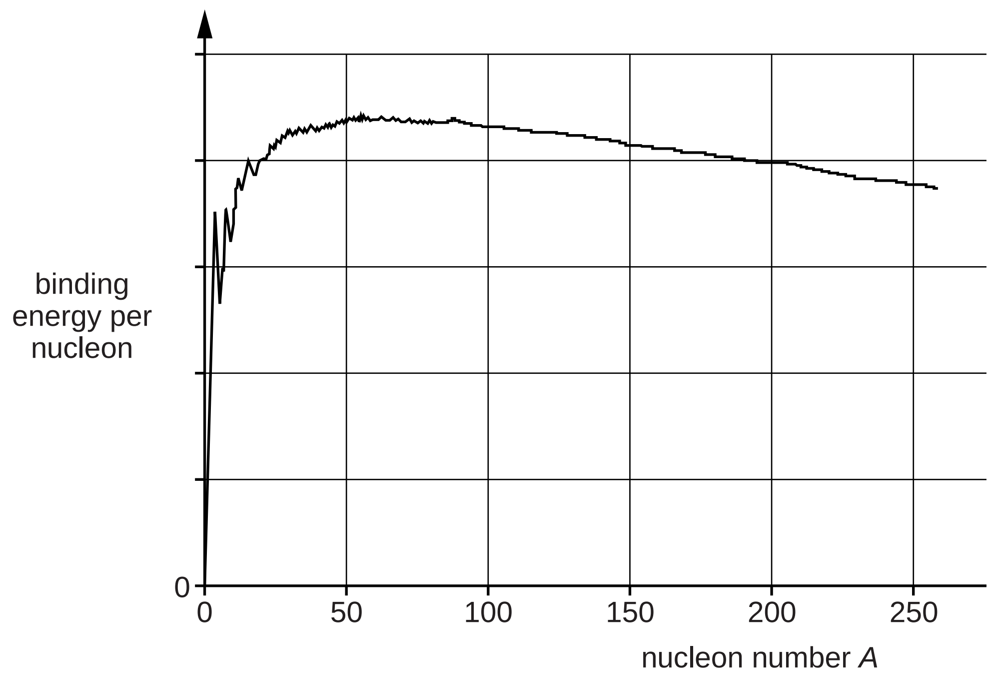


Fig. 6.1

(i) Use Fig. 6.1 to estimate the value of the nucleon number of the most stable isotope.

.... **[1]**

(ii) Use Fig. 6.1 to explain why nuclei of $^{100}_{42}Mo$ cannot produce energy by **fusion**.

....

....

.... **[1]**

(iii) The mass of a $^{8}_{4}Be$ nucleus is 1.329×10^{-26} kg. Use data provided on the second page of the Data, Formulae and Relationships Booklet to determine the binding energy per nucleon for this nucleus.

binding energy per nucleon = ... J **[4]**

[Total: 10]

4 An alpha particle is fired at high speed directly towards a stationary nucleus of a gold atom. At its distance of closest approach to the gold nucleus, the alpha particle stops and the gold nucleus has a small velocity, see Fig. 4.1. The alpha particle and the gold nucleus both have positive charges.

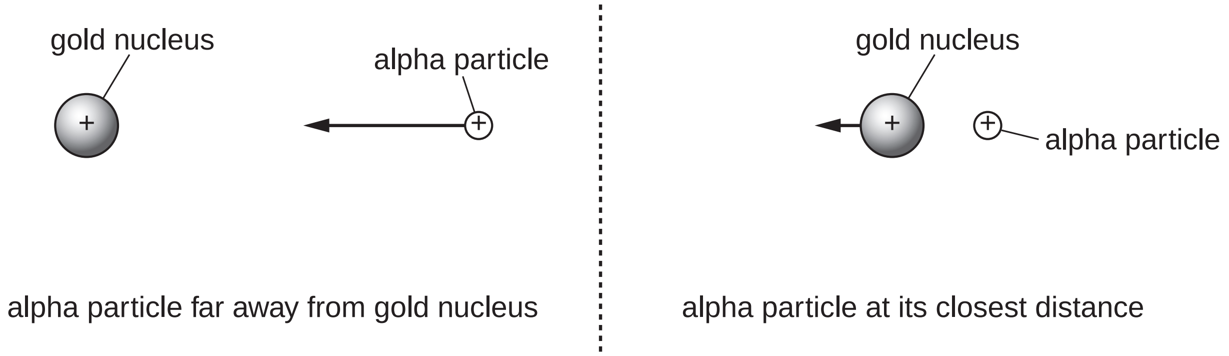


Fig. 4.1

(a) Explain why, at this distance of closest approach, the gold nucleus has a velocity and the alpha particle does not.

....

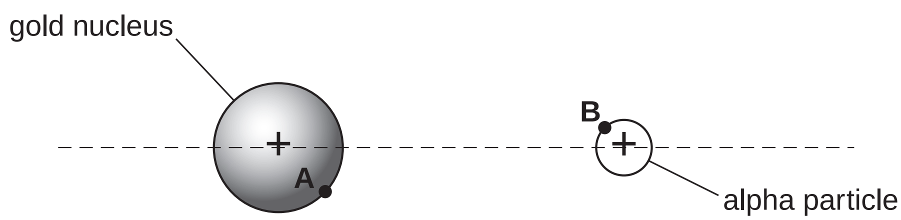
....

....

....

.... **[2]**

(b) Fig. 4.2, shows the alpha particle at its closest distance to the gold nucleus. Draw one electric field line from point **A** and one from point **B**. For each field line, show the direction of the field.



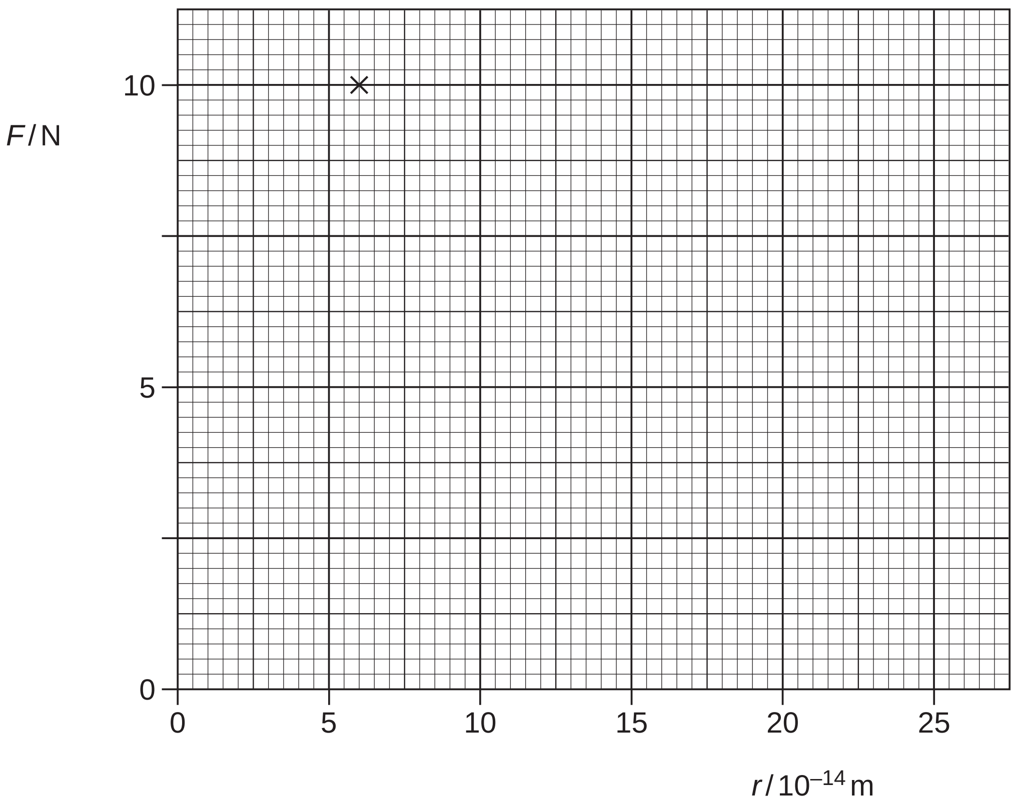
[2]

Fig. 4.2

(c) Show that the electrical force experienced by the alpha particle at its closest distance of 6.0×10^{-14} m to the gold nucleus is about 10 N. The gold nucleus has 79 protons and the alpha particle has 2 protons.

[3]

(d) On Fig. 4.3, sketch a graph to show the variation of the electrical force *F* on the alpha particle with distance *r* from the centre of the gold nucleus. The value of *F* at the distance of closest approach has been marked on the graph.



[2]

Fig. 4.3

[Total: 9]

5 The radioactive nucleus of plutonium ($^{238}_{94}Pu$) decays by emitting an alpha particle ($^{4}_{2}He$) of kinetic energy 5.6 MeV with a half-life of 88 years. The plutonium nucleus decays into an isotope of uranium.

(a) State the number of neutrons in the **uranium** isotope.

.... **[1]**

(b) The mass of an alpha particle is 6.65×10^{-27} kg.

(i) Show that the kinetic energy of the alpha particle is about 9×10^{-13} J.

[1]

(ii) Calculate the speed of the alpha particle.

speed = ... m s^{-1} **[2]**

(c) In a space probe, a source containing plutonium-238 nuclei is used to generate 62 W for the onboard electronics.

(i) Use your answer to **(b)(i)** to show that the initial activity of the sample of plutonium-238 is about 7×10^{13} Bq.

[1]

(ii) Calculate the decay constant of the plutonium-238 nucleus.

1 year = 3.16×10^7 s

decay constant = ... s^{-1} **[2]**

(iii) The molar mass of plutonium-238 is 0.24 kg. Calculate

1 the number of plutonium-238 nuclei in the source

number of nuclei = ... **[2]**

2 the mass of plutonium in the source.

mass = ... kg **[1]**

[Total: 10]