

OCR A-LEVEL PHYSICS A • H556

PHYSICS



EXAM QUESTION PACK

6.4 NUCLEAR AND PARTICLE PHYSICS

SCORE

/322

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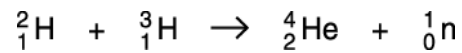
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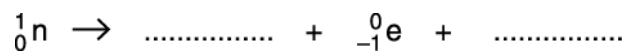
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1(a) A fusion reaction between two nuclei is shown below.



A neutron inside a nucleus is stable. However, a 'free' neutron, when outside the nucleus, undergoes beta decay with a half-life of about 11 minutes.

(i) Complete the decay equation below for a free neutron.



[2]

(ii) Explain what is meant by the *half-life* of a free neutron.

[1]

(b) For the fusion reaction to occur the separation between the deuterium and tritium nuclei must be less than 10^{-14} m. This means that the average kinetic energy of these hydrogen nuclei needs to be about 70 keV. The energy released by the fusion reaction is 18 MeV.

(i) Calculate the repulsive electrical force between the deuterium and tritium nuclei at a separation of 10^{-14} m.

force = _____ N [2]

(ii) Assume that a mixture of these hydrogen nuclei behaves as an ideal gas.

Estimate the temperature of the mixture of nuclei required for this fusion reaction.

temperature = _____ K [3]

(iii) In practice, fusion occurs at a much lower temperature. Suggest a reason why.

_____ [1]

(iv) Calculate the change in mass in a single fusion reaction.

change in mass = _____ kg [2]

- (v) Fig. 3.1 shows the variation of probability of fusion reaction with temperature T for deuterium and tritium and for deuterium and helium.

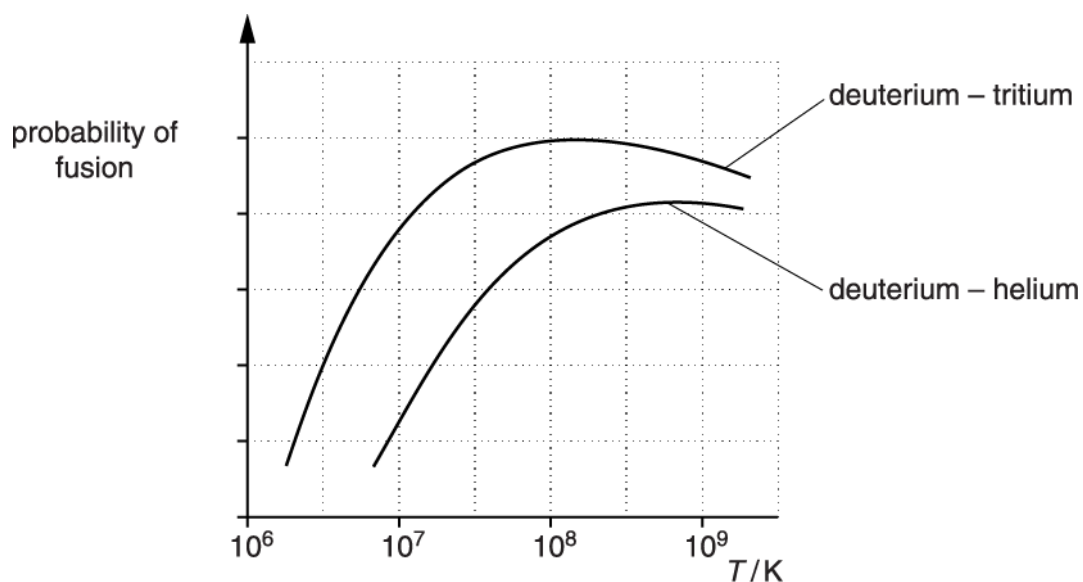


Fig. 3.1

Suggest why the probability of reaction at a given temperature is smaller for deuterium and helium.

[2]

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

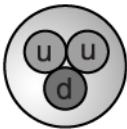
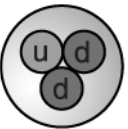
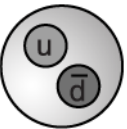
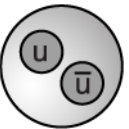
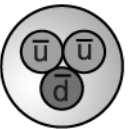
proton	neutron	A	B	C
				

Fig. 6.1

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

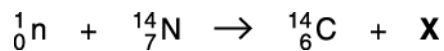
-----[1]

(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.



Identify the particle X.

-----[1]

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

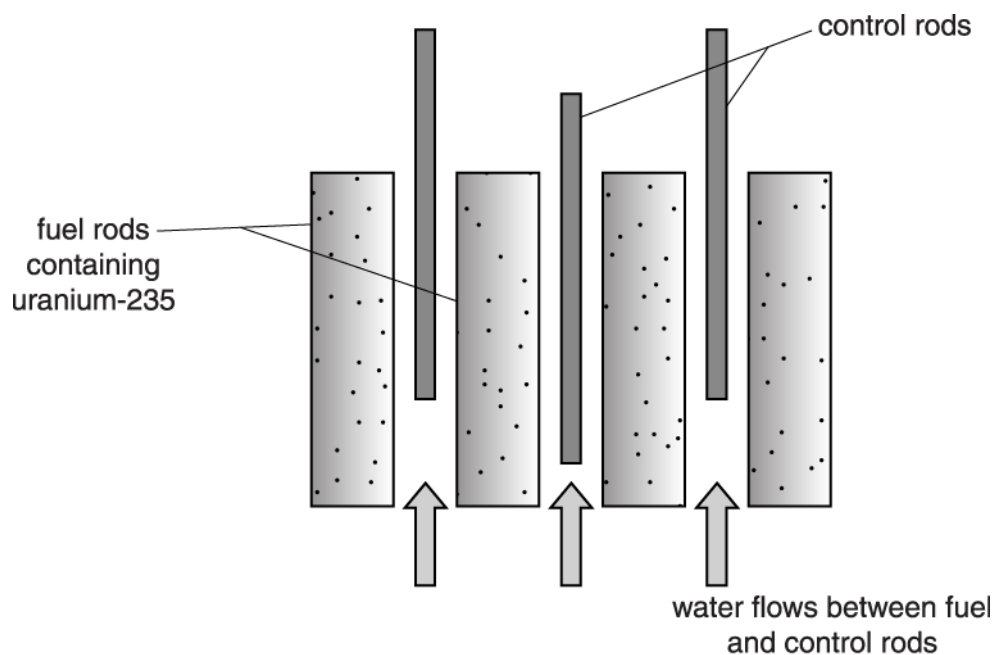


Fig. 6.2

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]

3(a) State, with a reason, whether or not protons and neutrons are fundamental particles.

----- [1]

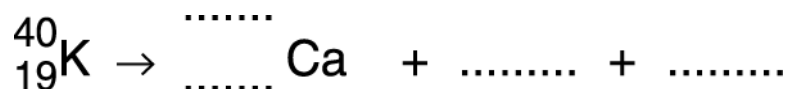
(b) State **two** fundamental particles that can be classified as leptons.

----- [1]

(c) Some fruits, such as bananas, are naturally radioactive because they contain the unstable isotope of potassium-40 ($^{40}_{19}\text{K}$).

(i) The isotope of potassium-40 is a beta-minus emitter.

Complete the following decay equation for $^{40}_{19}\text{K}$.



[2]

(ii) Explain why energy is released when a single nucleus of potassium-40 decays.

----- [2]

(iii) A banana contains 4.5×10^{-4} kg of potassium. About 0.012 % of the mass of potassium in the banana has the unstable isotope of potassium-40. This isotope of potassium-40 has a half-life of 4.2×10^{16} s. The molar mass of potassium-40 is $0.040 \text{ kg mol}^{-1}$.

Calculate the activity from this banana.

activity = _____ Bq [3]

- 4(a) Explain how the experiments on the scattering of alpha-particles by a metal foil provided evidence for the nuclear model of the atom.



In your answer, you should make clear how your conclusions link with the observations.

[3]

- (b) Fig. 5.1 shows an alpha-particle (${}^4_2\text{He}$) of kinetic energy 8.0 MeV moving directly towards a nucleus of aluminium-27 (${}^{27}_{13}\text{Al}$), initially at rest.



Fig. 5.1

- (i) The alpha-particle comes to rest instantaneously a short distance away from the aluminium nucleus. It then reverses its direction of travel. Describe and explain the motion of the aluminium nucleus at the instant the alpha-particle is at rest.

[2]

(ii) Calculate the initial speed of the alpha-particle.

mass of alpha-particle = 6.6×10^{-27} kg

speed = _____ ms^{-1} [2]

(iii) The electric force experienced by the alpha-particle when it is close to the aluminium nucleus is 270 N.
Calculate the separation r between the alpha-particle and the aluminium nucleus when the alpha-particle experiences this force.

r = _____ m [3]

(iv) Consider the situation where the alpha-particle travels much closer to the aluminium nucleus than in (b)(iii).

Discuss how the strong nuclear force may affect the resultant force on the alpha-particle.

_____ [2]

5(a) Explain what is meant by the *binding energy* of a nucleus.

----- [1]

- (b) The fusion of protons occurs in a star when the temperature within the core is greater than about 107 K. It takes the fusion of 4 protons to form a helium-4 (${}^4_2\text{He}$) nucleus. In this process, known as the proton–proton cycle, energy is released.

The net energy released in producing a single helium-4 nucleus is 4.53×10^{-12} J.
Calculate the binding energy per nucleon of the helium-4 nucleus.

binding energy per nucleon = ----- J [1]

- (c) The fusion of helium nuclei to make heavier elements occurs in red giants at temperatures above 10^8 K.

Explain why fusion of helium requires higher temperatures than the fusion of hydrogen (protons).

----- [2]

6(a) An X-ray tube operates using a 150 kV supply. X-ray photons are produced inside the tube when a beam of high-speed electrons accelerated from the cathode collide with the metal anode. About 99% of the total kinetic energy of the electrons at the anode is converted into heat energy which heats the anode. The remaining energy is transformed into the energy of the X-ray photons.

The current in the electron beam between the cathode and the anode is 4.8 mA.

(i) Show that the number of electrons incident at the anode per second is $3.0 \times 10^{16} \text{ s}^{-1}$.

[1]

(ii) The anode is made from metal of specific heat capacity $140 \text{ J kg}^{-1} \text{ K}^{-1}$. It has a mass of 8.6 g. The X-ray tube is switched on. Calculate the initial rate of increase of temperature of the anode.

rate of temperature increase = _____ $^{\circ}\text{C s}^{-1}$ [3]

(iii) A single electron is responsible for producing an X-ray photon. Calculate the shortest wavelength of the X-rays produced from the X-ray tube.

wavelength = _____ m [2]

- (b) An X-ray scan of the heart and its blood vessels shows very poor contrast. Describe and explain a technique that can be used to reveal these blood vessels in an X-ray scan.

----- [2]

7(a) Fig. 8.1 shows an image of a patient from a gamma camera scan.

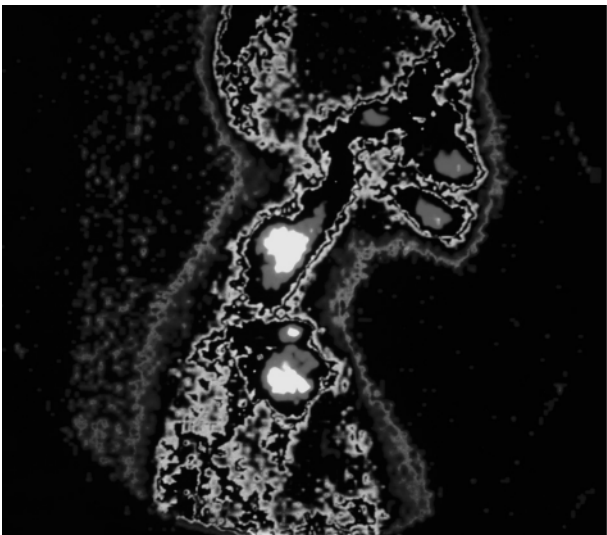


Fig. 8.1

The radioactive gamma-emitting tracer technetium-99m was injected into the patient before the scan. The image shows the distribution and intensity of gamma radiation emitted.

Discuss the advantages of using a gamma-emitting tracer in the patient rather than a beta-emitting tracer.

[2]

8(a) Explain what is meant by *Doppler effect*.

----- [1]

(b) Describe how high-frequency ultrasound can be used to determine the speed of blood through the arteries of a patient.



In your answer you should make it clear how the speed is determined.

----- [3]

- (c) A patient is scanned using ultrasound of frequency 2.4 MHz. The speed of ultrasound in the blood is 1.57 km s^{-1} . The acoustic impedance of blood is $1.66 \times 10^6 \text{ kg m}^{-2} \text{ s}^{-1}$.

Calculate

- (i) the density of blood

density = _____ kg m^{-3} [1]

- (ii) the wavelength of ultrasound in the blood.

wavelength = _____ m [1]

(d) Fig. 9.1 shows a beam of ultrasound incident at right angles to the boundary between muscle and bone.

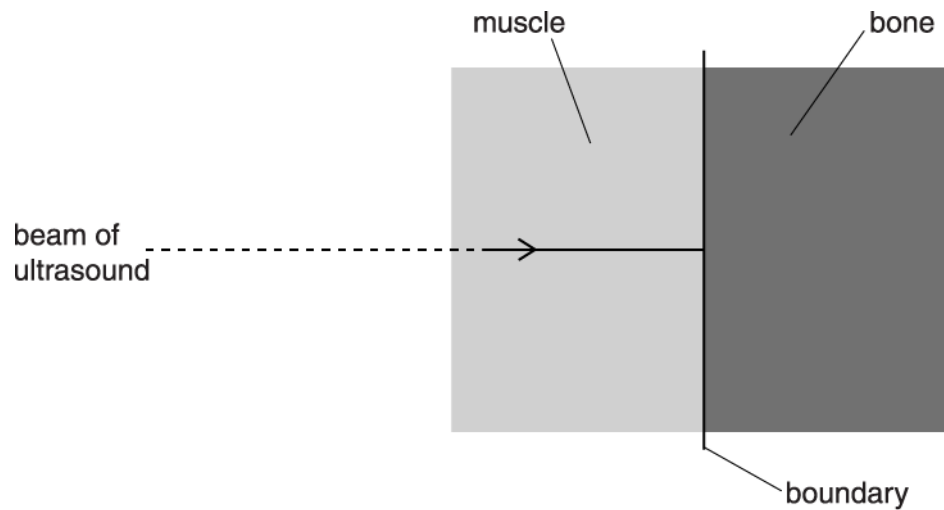


Fig. 9.1

The acoustic impedance of bone is 4 times that of muscle.

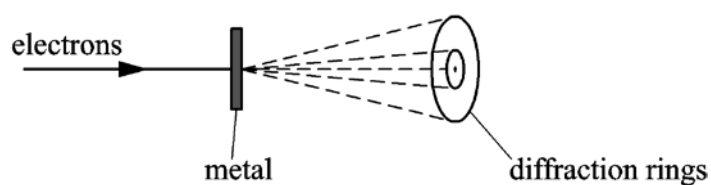
Calculate the percentage of ultrasound intensity transmitted into the bone.

intensity = _____ % [3]

- (e) During an ultrasound scan it is important that most of the ultrasound from the transducer is transmitted into the patient. Describe and explain how this is achieved.

----- [2]

- 9 Electrons travelling through a thin layer of polycrystalline metal are diffracted.



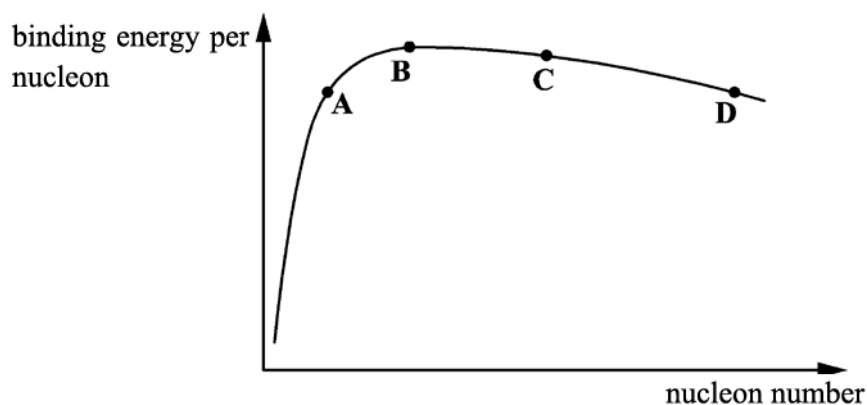
Which statement is correct about these electrons?

- A The electrons travel as photons through the metal.
- B The electrons have a wavelength of about 10^{-10} m.
- C The electrons are diffracted by holes in the metal.
- D The electrons repel each other to produce the diffraction.

Your answer

[1]

- 10 A graph of binding energy per nucleon against nucleon number is shown below.

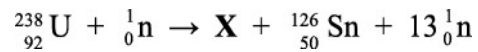


Which nucleus, A, B, C, or D, shown on the graph has the largest magnitude of binding energy?

Your answer

[1]

- 11 When a nucleus of uranium-238 absorbs a neutron, one combination of fission products can be tin-126 and a nucleus of element X. 13 neutrons are also emitted.



How many neutrons are there in the nucleus of element X?

- A 30
- B 42
- C 58
- D 100

Your answer

[1]

- 12 Two leptons are emitted when a down quark decays into an up quark.

Which of the following is correct about this decay?

	force responsible for the decay	leptons emitted
A	strong nuclear	positron and antineutrino
B	weak nuclear	positron and neutrino
C	strong nuclear	electron and neutrino
D	weak nuclear	electron and antineutrino

Your answer

[1]

13 Fig. 22.1 shows the circular track of a positron moving in a uniform magnetic field.

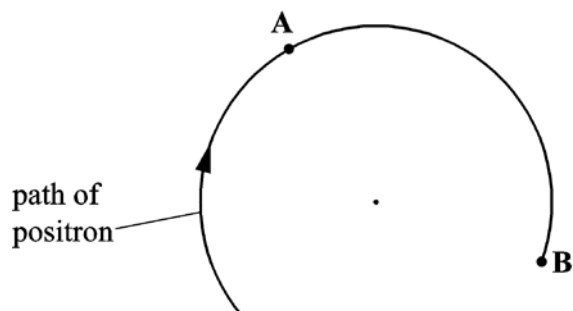


Fig. 22.1

The magnetic field is perpendicular to the plane of Fig. 22.1.

The speed of the positron is $5.0 \times 10^7 \text{ m s}^{-1}$ and the radius of the track is 0.018 m.

At point B the positron interacts with a stationary electron and they annihilate each other. The annihilation process produces two identical gamma photons travelling in opposite directions.

Calculate the wavelength of the gamma photons. Assume the kinetic energy of the positron is negligible.

wavelength = _____ m [3]

14(a) * Lead of different thicknesses can be used to investigate the absorption of gamma photons from a radioactive source.

Fig. 23.1 shows a graph of gamma photon energy against the half-thickness of lead. Half-thickness of lead is the thickness of lead which will reduce the original count-rate by half.

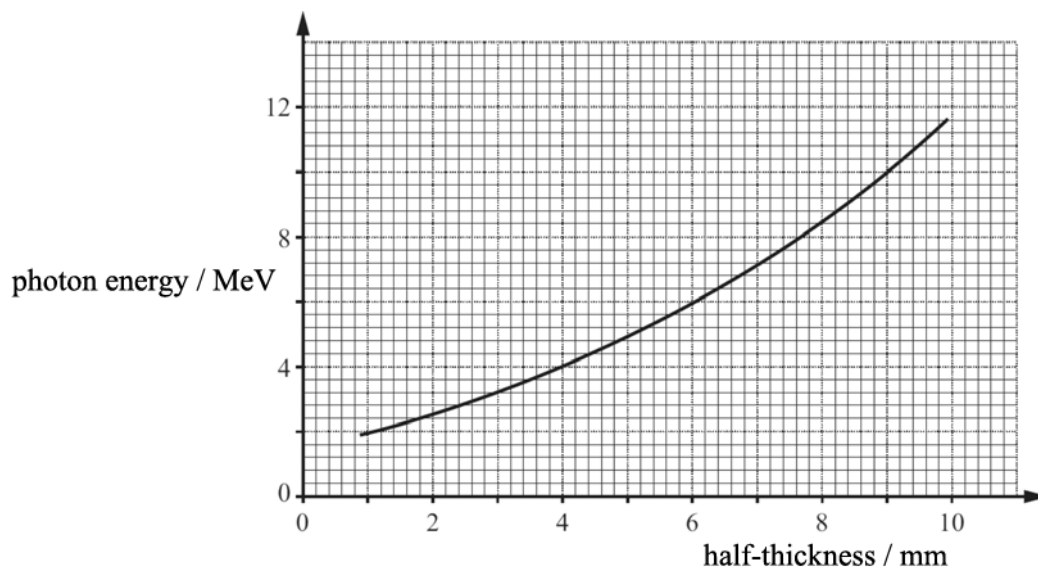


Fig. 23.1

Describe an experiment that can be carried out to determine the half-thickness of lead and how you would use your results with Fig. 23.1 to determine the energy of a gamma photon from a radioactive gamma source in your laboratory.

Include the equipment used, any safety precautions necessary and how the quality of the results may be improved.

[6]

(b) Fluorodeoxyglucose (FDG) is a radioactive tracer often used for PET scans. It contains radioactive fluorine-18, which is a positron-emitter. Some information about FDG and fluorine-18 is given below.

- 9.9% of the mass of FDG is fluorine-18.
- The half-life of fluorine-18 is 6600 s.
- The molar mass of fluorine-18 is $0.018 \text{ kg mol}^{-1}$.

A patient is injected with FDG. The initial activity of FDG is 400 MBq.

Use the information given to calculate the initial mass of FDG given to the patient.

mass = _____ kg [4]

15 Which is the correct decay of a quark?

A $u \rightarrow d + {}_{-1}^0e + \bar{\nu}_e$

B $u \rightarrow d + {}_{-1}^0e + \nu_e$

C $d \rightarrow u + {}_{-1}^0e + \nu_e$

D $d \rightarrow u + {}_{-1}^0e + \bar{\nu}_e$

Your answer

[1]

16(a) State what is meant by the *decay constant* of an isotope.

----- [1]

(b) A radioactive substance has 2000 nuclei. The decay constant of the isotope of the substance is 0.10 s^{-1} .

Use the equation $\frac{\Delta N}{\Delta t} = -\lambda N$ and $\Delta t = 1.0 \text{ s}$ to estimate the number of nuclei left after time $t = 2.0 \text{ s}$.

number of nuclei left = ----- [2]

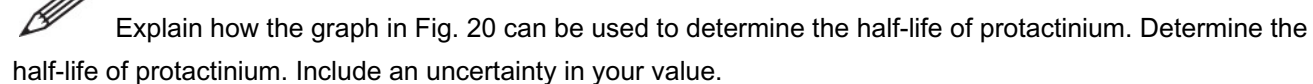
(c) * A group of students are investigating the decay of protactinium.

A fresh sample of protactinium is prepared. The activity of the sample was measured at intervals of 1.0 minutes for 6.0 minutes.

The table shows the activity corrected for background radiation.

time t / min	0	1.0	2.0	3.0	4.0	5.0	6.0
activity A / Bq	943	523	287	161	79	61	20

Fig. 20 shows the variation of $\ln(A)$ with time t .



[6]

17(a) State what is meant by *induced nuclear fission*.

----- [1]

(b) Explain the role of the moderator and the control rods in a nuclear reactor.

----- [4]

(c) A possible fission reaction is



where k is the number of neutrons released in the reaction. The ${}^{236}_{92}\text{U}$ nucleus is very unstable.

(i) State the number k of neutrons released in this reaction.

$k =$ _____ [1]

(ii) State the binding energy of the released neutrons.

_____ [1]

(iii) A nuclear reactor uses uranium-235 as fuel. The output power from the reactor is 1.0 GW. The mass of the ${}^{236}_{92}\text{U}$ nucleus is 236.053 u. The total mass of the fission products is 235.840 u.

Calculate the number of fission reactions per second.

number of reactions per second = _____ s^{-1} [4]

18 Calculate the maximum wavelength of the X-rays for the pair production process.

maximum wavelength = _____ m [3]

[6]

[6]

(b) Uranium-235 is used in many fission reactors as fuel and fusion reactors are still at an experimental stage.

(i) State one major disadvantage of having fission reactors.

----- [1]

(ii) The fission of a uranium-235 nucleus releases about 200 MeV of energy, whereas the fusion of four hydrogen-1 nuclei releases about 28 MeV.

At first sight it would appear that fusion would produce less energy than fission. However the energy released in the fission of one kilogramme of uranium-235 is about eight times less than the energy released in the fusion of one kilogramme of hydrogen-1.

Explain this by considering the initial number of particles in one kilogramme of each.

----- [4]

20(a) The space probe, Curiosity, roaming on the surface of Mars, is powered by a radioisotope thermoelectric generator (RTG). The generator transforms thermal energy into electrical energy. The thermal energy comes from the radioactive decay of plutonium-238.

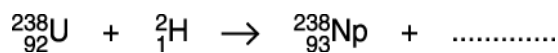
Fig. 5.1 shows an image of Curiosity.



Fig. 5.1

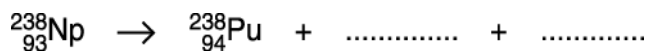
The plutonium-238 ($^{238}_{94}\text{Pu}$) isotope can be artificially produced by bombarding uranium-238 ($^{238}_{92}\text{U}$) with deuterium (^2_1H). This produces an intermediate isotope of neptunium-238 ($^{238}_{93}\text{Np}$) and neutrons. The isotope of $^{238}_{93}\text{Np}$ then decays by beta-minus emission to form plutonium-238.

(i) Complete the following reaction.



[1]

(ii) Complete the following decay equation for $^{238}_{93}\text{Np}$.



[2]

(b) Plutonium-238 is an alpha-emitter with a half-life of 88 years. The kinetic energy produced during each decay is 9.0×10^{-13} J. The RTG on Curiosity produces 120 W of electrical power from 2000 W of thermal power.

(i) Calculate the mass of plutonium-238 on board Curiosity.

molar mass of plutonium-238 = $0.238 \text{ kg mol}^{-1}$

mass = _____ kg [4]

(ii) Calculate the output electrical energy in kW h from the RTG in a day.

energy = _____ kW h [2]

21(a) 0 An electron is an example of a *lepton* and a proton is an example of a *hadron*.

State a property of a hadron.

----- [1]

(b) State the charge, in terms of the elementary charge e , on an up quark and a down quark.

charge on up quark = _____ e charge on down quark = _____ e

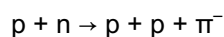
[1]

(c) The quark composition of a neutron is $u d d$.

State the quark composition of a proton.

----- [1]

(d) In large particle accelerators, short-lived particles called pions are created by colliding high-speed protons (p) with stationary neutrons (n). The equation below shows a reaction in which a negative pion (π^-) is produced.



The π^- particle consists of a quark and an anti-quark.

Use the information provided about the neutron and your answer to (c) to write an equation for the reaction in terms of up (u) and down (d) quarks. Hence determine the quark composition of the π^- particle.

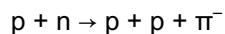
----- [3]

(e)

(i) State Einstein's mass-energy equation and define all the terms.

----- [1]

(ii) In the reaction



the π^- particle is produced when the proton colliding with a stationary neutron has a minimum kinetic energy of 1.4×10^8 eV. The mass of a proton and a neutron may be assumed to be the same.
Calculate the mass of the π^- particle.

mass = ----- kg [2]

22(a) Energy is released in both fission and fusion reactions.

Describe **two** differences between fission and fusion reactions.

1

2

[2]

- [4]

(i) Describe what is meant by an induced fission reaction of a uranium-235 nucleus.

[2]

- Estimate the mean speed of the neutron.

mass of neutron = 1.7×10^{-27} kg

speed = _____ m s^{-1} [3]

- 23 The table shows data on four freshly prepared radioactive samples A, B, C and D.

Sample	Number of active nuclei in the sample	Half-life of the sample
A	N	T
B	N	$3T$
C	$5N$	$0.5T$
D	$8N$	$4T$

Which sample has the **smallest** activity?

Your answer

[1]

- 24 A positive pion (π^+) is an unstable particle produced when high-speed hadrons collide in particle accelerators. The π^+ particle has a charge of $+e$.

What is the quark combination of the π^+ particle?

A $u \bar{u}$

B $u \bar{d}$

C $d \bar{u}$

D $d \bar{d}$

Your answer

[1]

25 The nuclei of uranium-235 ($^{235}_{92}\text{U}$) and carbon-12 ($^{12}_6\text{C}$) have different radii.

What is the ratio

$$\frac{\text{radius of the uranium nucleus}}{\text{radius of the carbon nucleus}} ?$$

- A 2.5
- B 2.7
- C 15
- D 20

Your answer

[1]

- 26(a) The nucleons inside a ${}^3_1\text{H}$ nucleus experience gravitational force and one other type of force.
Name this other type of force and describe its nature.

----- [3]

- (b) Write a decay equation for beta-minus in terms of a quark model.

[2]

(c) The fusion of two ${}^3_1\text{H}$ nuclei produces a stable nucleus of ${}^4_2\text{He}$ and some fast-moving neutrons.

(i) Explain why the fusion of the ${}^3_1\text{H}$ nuclei must produce two neutrons.

----- [2]

(ii) The total energy released in this fusion reaction is 11 MeV. The binding energy per nucleon of the ${}^4_2\text{He}$ nucleus is 7.1 MeV.

Calculate in J the binding energy per nucleon of the ${}^3_1\text{H}$ nucleus.

binding energy per nucleon = _____ J [3]

27 The medical tracer technetium-99m is used in gamma scans. Technetium-99m has a half-life of 6.0 hours and it emits gamma rays.

A fresh sample of a radiopharmaceutical containing technetium-99m is prepared in the radiography department of a hospital. The initial activity of the radiopharmaceutical is 820 MBq. The radiopharmaceutical is injected into the patient some time later when its activity has dropped to 630 MBq.

Calculate the time in hours between the radiopharmaceutical being produced and it being injected into the patient.

time = _____ h [3]

28 This question is about helium in the atmosphere of the Earth.

Experiment shows that most of the Earth's atmosphere is contained within a very thin shell around the surface of the Earth. Less than 0.0001% of this is helium.

The height of the atmosphere is negligible compared with the radius R of the Earth.

- (i) Show that the minimum speed v_E required for an atom or molecule to escape from the top of the Earth's atmosphere is given by the expression

$$v_E = \sqrt{2gR}.$$

[3]

- (ii) The radius R of the Earth is 6.4×10^6 m. Calculate this escape speed v_E .

$$v_E = \text{-----} \text{ m s}^{-1} \text{ [1]}$$

- (iii) Calculate the temperature T in kelvin required at the top of the Earth's atmosphere for the root mean square speed $c_{r.m.s.}$ of the helium atoms there to equal this escape speed.

Molar mass of helium = $0.004 \text{ kg mol}^{-1}$

$T = \dots\dots\dots$ K [3]

(iv) Fig. 1 shows the distribution of the speeds of the atoms of an ideal gas.

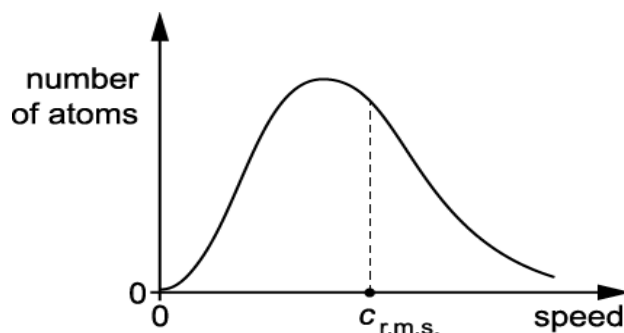


Fig. 1

Use your knowledge of the kinetic theory of gases to describe the shape of this distribution and explain why some helium is able escape from the Earth.

[4]

(v) Over a very long period of time all of the helium should have escaped from the Earth. Suggest why there is still a small amount of helium, about 0.0001%, in the Earth's atmosphere.

[2]

29(a) *Fig. 5 shows a thin slice of rock mounted on the face of a lead holder. The rock contains several different radioactive elements.

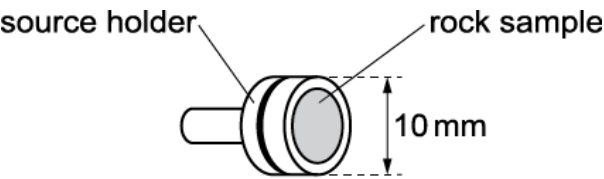


Fig. 5

Plan one or more experiments to determine the **nature** of the emissions from the sample.

A space has been left for you to draw one or more diagrams to show the arrangement of your apparatus

- (b) A grain of a radioactive powder which emits gamma rays accidentally falls onto the workbench.

A sensitive gamma-ray detector is used to look for this grain. The grain can be assumed to be a point source which emits radiation **uniformly in all** directions.

The background count-rate before the accident was negligible.

The detector registers a count-rate of 20 s^{-1} when it is 1.0 m from the grain.

- (i) Explain why the count-rate rises to 320 s^{-1} when the detector is moved to 0.25 m from the grain.

-----[2]

- (ii) A thin lead sheet is now placed on the bench over the grain. This causes the count-rate to halve to 160 s^{-1} . The detector is moved from its position at 0.25 m towards the grain until the count-rate returns to 320 s^{-1} .

1 State the value of the count-rate if the sheet is now removed.

count-rate = _____ s^{-1} [1]

2 Calculate the distance of the detector from the grain.

distance = _____ m [2]

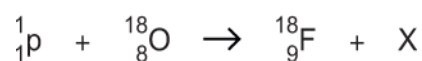
30 Which statement is correct?

- A Hadrons are made up of protons and neutrons.
- B A positron and a proton are examples of leptons.
- C The positron and the electron have the same mass.
- D The weak nuclear force is responsible for alpha-decay.

Your answer

[1]

31 A proton collides with a stationary oxygen-18 nucleus. The collision produces a fluorine-18 nucleus and particle X.



What is particle X?

- A neutron
- B proton
- C electron
- D positron

Your answer

[1]

32(a)

Describe the nature of the *strong nuclear force*.

----- [2]

(b)

(i) Name a hadron found in the nucleus of an atom and state its quark combination.

name of hadron: _____ quark combination: _____ [1]

(ii) Write a decay equation in terms of a quark model for beta-minus decay.

[2]

(c) The radius of a nucleus is directly proportional to $A^{1/3}$, where A is the nucleon number.

The mass of a proton and a neutron are similar.

Explain why the mean density of all nuclei is about the same.

----- [2]

33(a) A stationary uranium-238 nucleus (${}^{238}_{92}\text{U}$) decays into a nucleus of thorium-234 by emitting an alpha-particle.

The chemical symbol for thorium is Th. Write a nuclear equation for this decay.

[2]

- (b) The mass of the uranium nucleus is 4.0×10^{-25} kg. After the decay the thorium nucleus has a speed of $2.4 \times 10^5 \text{ m s}^{-1}$.

Calculate the kinetic energy, in MeV, of the alpha-particle.

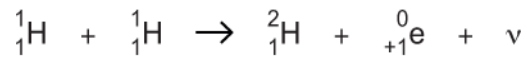
kinetic energy = _____ MeV [4]

- (c) The uranium-238 (${}^{238}_{92}\text{U}$) nucleus starts the decay chain which ends with a nucleus of lead-206 (${}^{206}_{82}\text{Pb}$).
Show that 14 particles are emitted during this decay chain. Explain your reasoning.

[3]

34(a) Stars produce energy by nuclear fusion.

One particular fusion reaction between two protons (${}^1_1\text{H}$) is shown below.



In this reaction 2.2 MeV of energy is released.

Only one of the particles shown in the reaction has binding energy.

Determine the binding energy per nucleon of this particle. Explain your answer.

----- [2]

(b) Explain why high temperatures are necessary for fusion reactions to occur in stars.

----- [2]

(c) In this reaction 2.2 MeV of energy is released.

A gamma photon in a star can spontaneously create an electron-positron pair.
Calculate the **maximum** wavelength of a gamma photon for this creation event.

maximum wavelength = _____ m [3]

Describe how a PET scanner is used to locate an area of increased activity within the patient.

[4]

Calculate the time t in minutes for the activity of the radiopharmaceutical to decrease to 30% of its initial activity.

$t =$ _____ minutes [3]

(c) PET scanners are not available in all hospitals. This is because fluorine-18 requires expensive on-site particle accelerators and fluorine-18 has a very small 'shelf-life'.

Suggest the impact this may have on the treatment and diagnosis of patients in the country.

----- [1]

36 Which lepton is emitted in the decay of an up quark and is affected by a magnetic field?

- A neutrino
- B electron
- C positron
- D antineutrino

Your answer [1]

37 A contrast material is used while taking an X-ray image of a patient.
Which statement is correct?

- A Iodine is a contrast material.
- B Technetium is a contrast material.
- C A contrast material must have a short half-life.
- D A contrast material is used for acoustic matching.

Your answer [1]

The structure of atoms was deduced in the early 1900s by Rutherford and his co-workers from the scattering of alpha-particles by a very thin sheet of gold.

Rutherford assumed that the scattering of the alpha-particles was due to electrostatic forces. Fig. 23 shows a detector used to record the number N of alpha-particles scattered through an angle θ .

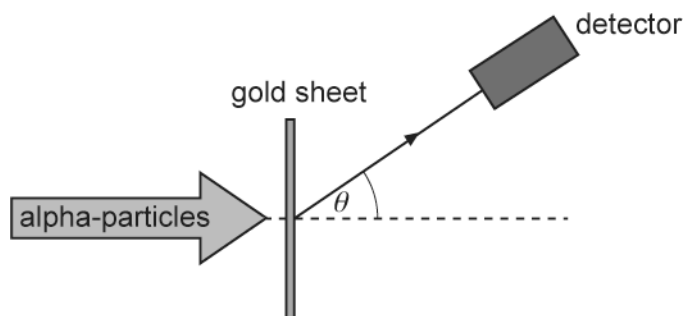


Fig. 23

At $\theta = 0^\circ$, N was too large to be measured. The table below summarises some of the collected data.

$\theta / ^\circ$	$\lg (N)$
150	1.5
75	2.3
60	2.7
30	3.9
15	5.1
0	N too large

- (i) Show that the number of alpha-particles scattered through 15° is about 4000 times more than those scattered through 150° .

[1]

(ii) Use the evidence from the table to explain the structure of the atom.

----- [3]

39(a)

An isotope of polonium-213 ($^{213}_{84}\text{Po}$) first decays into an isotope of lead-209 ($^{209}_{82}\text{Pb}$) and this lead isotope then decays into the stable isotope of bismuth (Bi).

Fig. 24 shows two arrows on a neutron number N against proton number Z chart to illustrate these two decays.

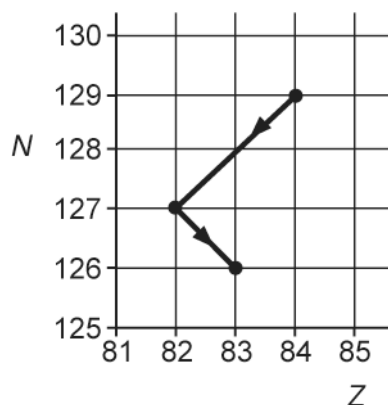
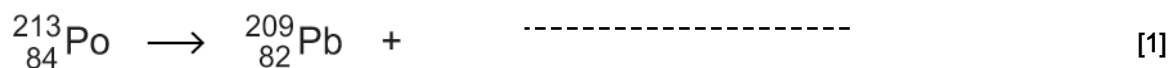


Fig. 24

Complete the nuclear decay equations for

(i) the polonium isotope



(ii) the lead isotope.



- (b) A pure sample of polonium-213 is being produced in a research laboratory.

The half-life of $^{213}_{84}\text{Po}$ is very small compared with the half-life of $^{209}_{82}\text{Pb}$.

After a very short time, the ionising radiation detected from the sample is mainly from the beta-minus decay of the lead-209 nuclei.

- (i) Briefly describe and explain an experiment that can be carried out to confirm the beta-minus radiation emitted from the lead nuclei.

----- [2]

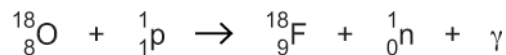
- (ii) The activity of the sample of $^{209}_{82}\text{Pb}$ after 7.0 hours is 12 kBq.

The half-life of $^{209}_{82}\text{Pb}$ is 3.3 hours.

Calculate the initial number of lead-209 nuclei in this sample.

number of nuclei = ----- [4]

The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_9\text{F}$) is made from the isotope of oxygen-18 ($^{18}_8\text{O}$).



The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of $0.25 \times 10^{-11} \text{ J}$.

The binding energy of the $^{18}_8\text{O}$ nucleus is $2.24 \times 10^{-11} \text{ J}$ and the binding energy of the $^{18}_9\text{F}$ nucleus is $2.20 \times 10^{-11} \text{ J}$. The proton and the neutron have zero binding energy.

(i) Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

----- [2]

(ii) Estimate the minimum wavelength λ of the gamma ray photon (γ).

$\lambda = \text{-----} \text{ m}$ [3]

(iii) Fluorine-18 is a positron emitter.

Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

----- [2]

41(a)

${}^{60}_{27}\text{Co}$ is produced by irradiating the stable isotope ${}^{59}_{27}\text{Co}$ with neutrons.

Each nucleus of ${}^{60}_{27}\text{Co}$ then decays into a nucleus of nickel (Ni) by the emission of a low energy beta-minus particle, one other particle and two gamma photons.

Complete the nuclear equations for these two processes.



[3]

(b)

Students want to carry out an investigation into gamma photon absorption using a source of $^{60}_{27}\text{Co}$.

They add sheets of lead between the source S and a radiation detector T, to give a total thickness d of lead. S and T remain in fixed positions, as shown in Fig. 2.1.

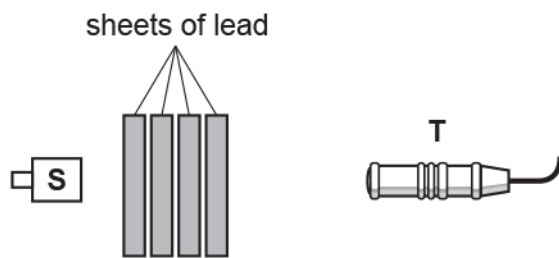


Fig. 2.1

- (i) The $^{60}_{27}\text{Co}$ source emits beta radiation as well as gamma radiation.

Explain why this would not affect the experiment.

[1]

- (ii) The students record the number N of gamma photons detected by T in 10 minutes for each different thickness d of lead. The background count is negligible.

The results are shown in a table. The table includes values of $\ln N$, including the absolute uncertainties.

N	d / mm	$\ln N$
4300 ± 440	0	8.37 ± 0.10
2500 ± 250	0	7.82 ± 0.10
1400 ± 150	20	7.24 ± 0.11
800 ± 90	30	6.68 ± 0.11
500 ± 60	40	6.21 ± 0.12
300 ± 40	50	

N and d are related by the equation $N = N_0 e^{-\mu d}$ where N_0 and μ are constants.

1 The students decide to plot a graph of $\ln N$ against d .

Show that this should give a straight line with gradient $= -\mu$ and y -intercept $= \ln N_0$.

[1]

2 Complete the missing value of $\ln N$ in the table, including the absolute uncertainty.

Show your calculation of the absolute uncertainty in the space below.

[2]

3 In Fig. 2.2, five of the data points have been plotted, including error bars for $\ln N$

- Plot the missing data point and error bar.
- Draw a straight line of best fit and one of worst fit.

[2]

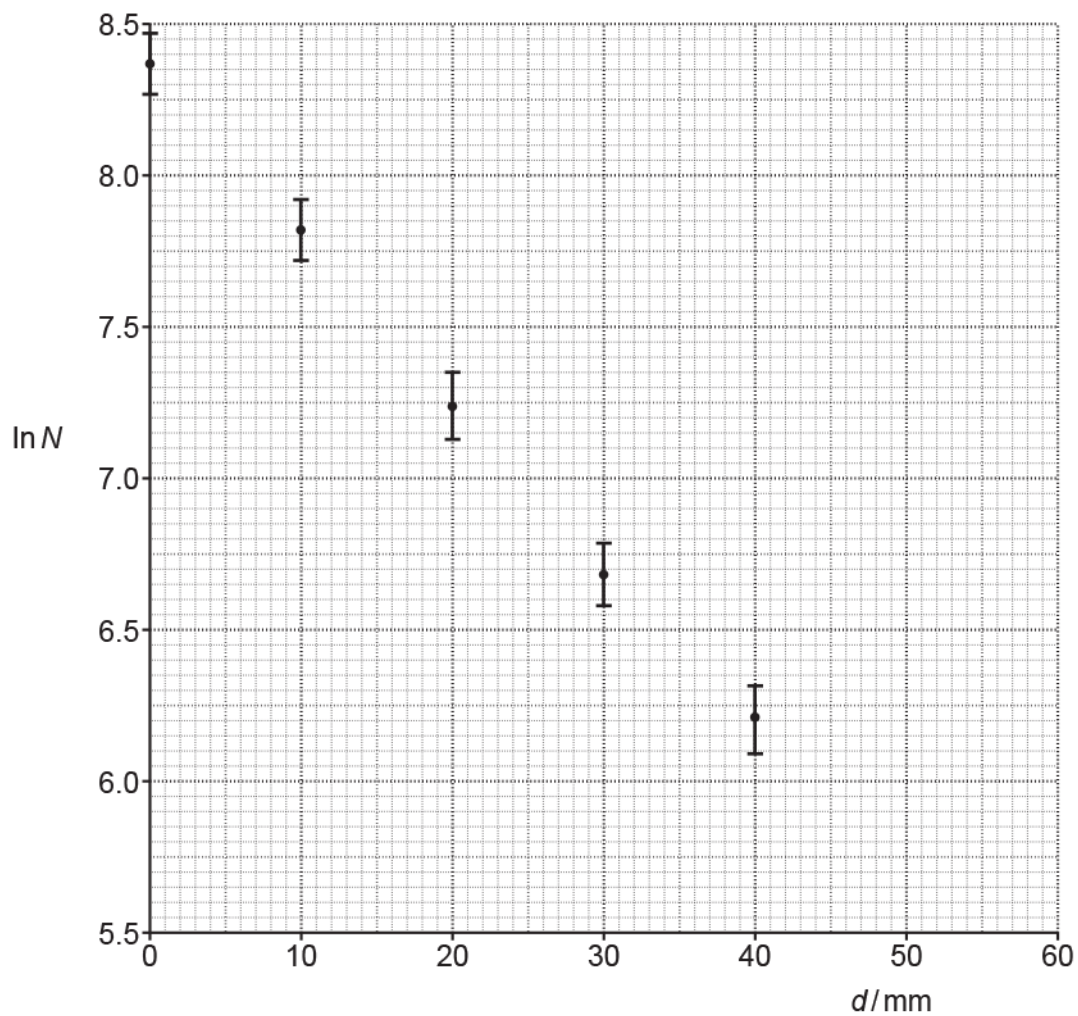


Fig. 2.2

4 Use Fig. 2.2 to determine the value of μ in m^{-1} , including the absolute uncertainty.

$\mu = \dots\dots\dots \pm \dots\dots\dots \text{m}^{-1}$ [4]

5 Determine the thickness, $d_{1/2}$, of lead which halves the number of gamma photons reaching T.

$d_{1/2} = \dots\dots\dots$ m [2]

42 The radius of a gold nucleus with 197 nucleons is 7.3×10^{-15} m.

What is the best estimate for the volume of a uranium nucleus with 235 nucleons?

A $1.6 \times 10^{-42} \text{ m}^3$

B $1.9 \times 10^{-42} \text{ m}^3$

C $2.1 \times 10^{-42} \text{ m}^3$

D $2.8 \times 10^{-42} \text{ m}^3$

Your answer

[1]

- 43 The chemical composition of ancient rocks found on the Earth can be used to estimate the age of the Earth.
Nuclei of rubidium-87 ($^{87}_{37}\text{Rb}$) decay spontaneously into nuclei of strontium-87 ($^{87}_{38}\text{Sr}$).
The half-life of rubidium-87 is 49 billion years.

(i) Name the two leptons emitted in the decay of a rubidium-87 nucleus.

1. _____
2. _____

[1]

(ii) The percentage of rubidium left in a sample of an ancient rock is 95%.

Estimate the age of the Earth in billion years.

age = ... billion years [3]

44(a) Fig. 21 shows stable and unstable nuclei of some light elements plotted on a grid. This grid has number of neutrons N on the vertical axis and number of protons Z on the horizontal axis.

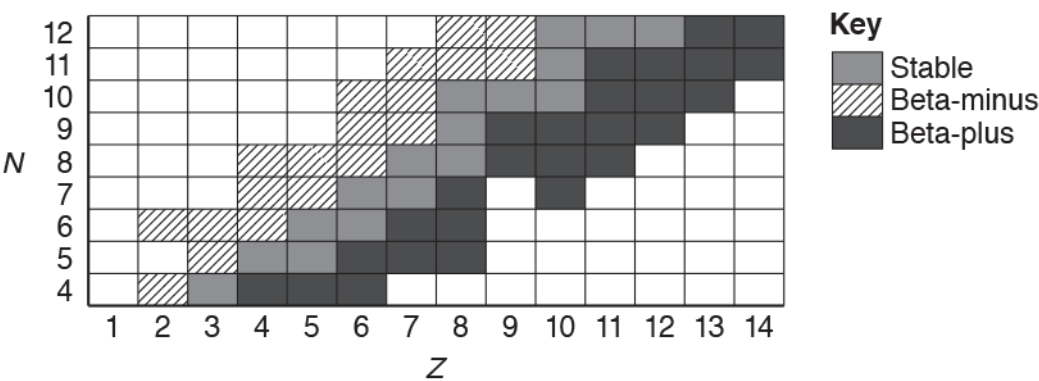


Fig. 21

The key on Fig. 21 shows whether a nucleus is stable, emits a beta-plus particle or emits a beta-minus particle to become stable.

For $Z = 7$, suggest in terms of N why an isotope may emit

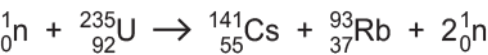
- (i) a beta-minus particle

[1]

- (ii) a beta-plus particle.

[1]

- (b) Inside a nuclear reactor, fission reactions are controlled and **chain reactions** are prevented. A typical fission reaction of the uranium-235 nucleus ($^{235}_{92}\text{U}$) is illustrated below.



The neutron triggering the fission reaction moves slowly. The neutrons produced in the fission reaction move fast.

(i) Describe what is meant by **chain reaction**.

----- [2]

(ii) Explain how chain reactions are prevented inside a nuclear reactor.

----- [2]

(iii) The energy released in each fission reaction is equivalent to a decrease in mass of 0.19 u.
A fuel rod in a nuclear reactor contains 3.0% of uranium-235 by mass.

Estimate the total energy produced from 1.0 kg of fuel rod.

molar mass of uranium-235 = 0.235 kg mol⁻¹

1 u = 1.66 × 10⁻²⁷ kg

energy = ...J [4]

- 45 A student is modelling the decay of a radioactive source using the equation $\Delta N / \Delta t = -0.5 N$.
 The student decides to use $\Delta t = 0.10$ s.
 The number N of radioactive nuclei is 2000 at $t = 0$.

Part of the modelling spreadsheet from the student is shown below.

t / s	Number N of radioactive nuclei remaining at time t	Number of nuclei decaying in the next 0.10 s
0	2000	100
0.10	1900	
0.20		
0.30		

- What is the value of N at $t = 0.30$ s?
- A 1700
 - B 1710
 - C 1715
 - D 1805

Your answer

[1]

46 The half-life of the isotope carbon-14 is 5700 years (y).

- (i) Show that the decay constant λ for this isotope is about $1.2 \times 10^{-4} \text{ y}^{-1}$.

[1]

- (ii) Carbon-dating is a technique used to date an ancient wooden axe.

The ratio of carbon-14 to carbon-12 in the axe material is 78% of the current ratio of carbon-14 to carbon-12 in a living tree.

Calculate the age in years of the wooden axe.

age = ... y [3]

- (iii) State **one** assumption made in the calculation in (ii).

----- [1]

47 The table below shows the quark compositions of four particles A, B, C and D.

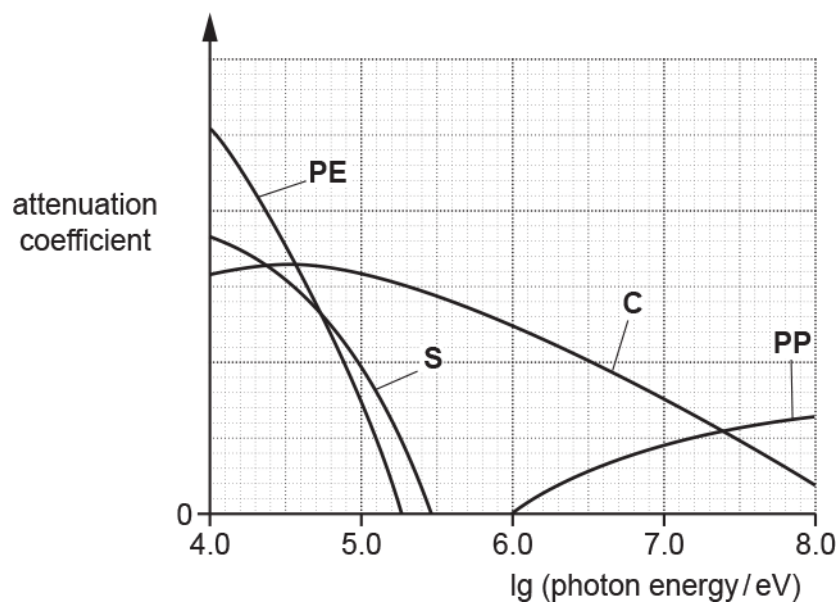
A	B	C	D
u u d	u d d	u d s	s s s

Which particle has a positive charge?

Your answer

[1]

The attenuation coefficient against $\lg(\text{photon energy})$ graphs for simple scattering (S), photoelectric effect (PE), Compton effect (C) and pair production (PP) are shown below.



With the help of a calculation, explain the minimum photon energy for pair production.

[3]

Describe the fundamental particles within an atom of carbon-14 ($^{14}_6\text{C}$). In your answer state the composition of the hadrons.

In your answer state the composition of the hadrons.

[4]

Fig. 21.1 shows the density ρ variation for three different nuclei and Table 21.1 shows the nucleon number A of each nucleus.

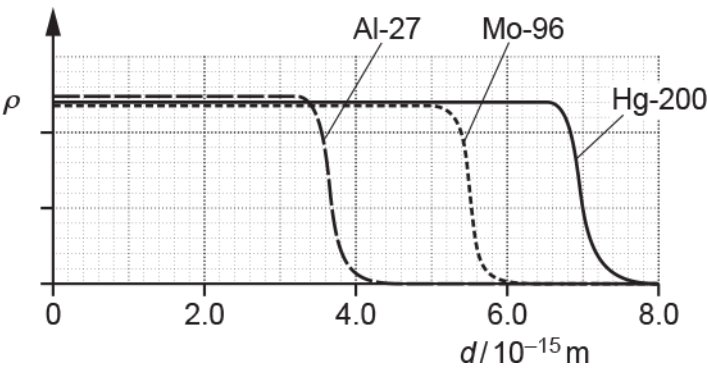


Fig. 21.1

Nucleus	Nucleon number A
Al-27	27
Mo-96	96
Hg-200	200

Table 21.1

Use the information provided opposite to

- describe how the density of a nucleus depends on its nucleon number A
- show numerically that $r \propto A^{1/3}$
- estimate the mean density of the nuclei.

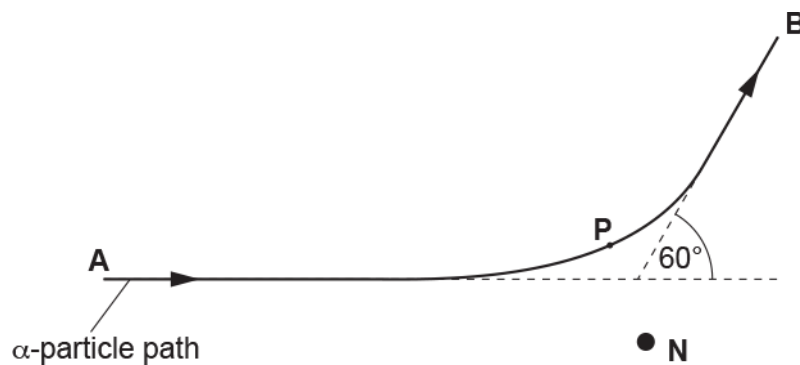
[illegible]

[6]

- 50 A beam of α -particles is incident on a thin gold foil. Most α -particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α -particle which passes close to a gold nucleus **N** in the foil. The α -particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



Another α -particle in the beam is deflected by the same gold nucleus **N** through an angle of 30° .

Sketch its path onto the diagram above.

[2]

* A student attends a lecture about the Sun and makes the following notes.

- 1. The Sun loses more than 4×10^9 kg of its mass every second to maintain its luminosity.
- 2. Treating hydrogen nuclei (protons) as an ideal gas, a temperature of 10^{10} K provides a kinetic energy of about 1 MeV, which is necessary for fusion.
- 3. However, the Sun's core temperature is only 10^7 K, so the chance of protons fusing on collision is very small. This explains why the Sun has such a long lifetime.

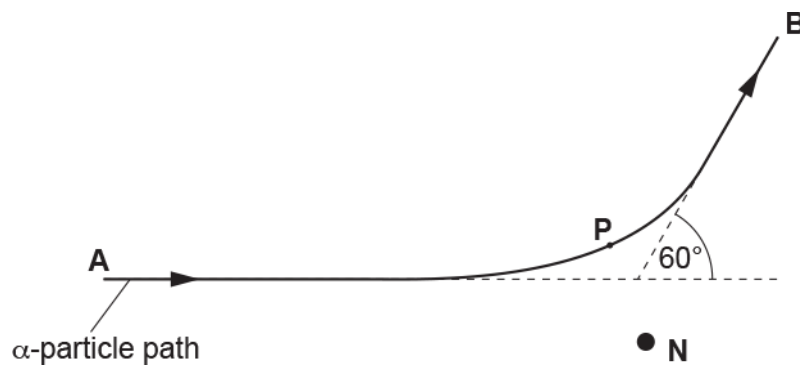
Explain the principles of physics which are involved in each of the three points.
You should include relevant formulae, but no numbers or calculations are required.

Blank lined paper for writing.

- 52 A beam of α -particles is incident on a thin gold foil. Most α -particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α -particle which passes close to a gold nucleus **N** in the foil. The α -particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



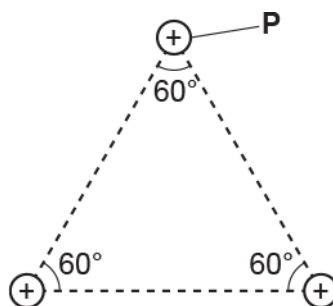
The distance between **P** and **N** is 6.8×10^{-14} m.

Calculate the magnitude of the electrostatic force F between the α -particle (${}^4_2\text{He}$) and the gold nucleus (${}^{197}_{79}\text{Au}$)

when the α -particle is at **P**.

$F = \dots\dots\dots$ N [4]

The diagram below shows the arrangement of the 3 protons inside the nucleus of lithium-6 (${}^6_3\text{Li}$).



The separation between each proton is about 1.0×10^{-15} m.

- (i) Calculate the magnitude of the repulsive electric force F experienced by the proton P.

$F = \dots\dots\dots$ N [4]

- (ii) On the diagram above, draw an arrow to show the direction of the electric force F experienced by P.

[1]

- (iii) Explain how protons stay within the nucleus of lithium-6.

[2]

54 The total energy released in a single fusion reaction is 4.0 MeV.

What is the change in mass in this fusion reaction?

- A 7.1×10^{-36} kg
- B 7.1×10^{-30} kg
- C 2.1×10^{-21} kg
- D 4.4×10^{-17} kg

Your answer

[1]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1	a	i	${}^1_0\text{n} \rightarrow {}^1_1\text{p} + {}^0_{-1}\text{e} + \bar{\nu}_{(\text{e})}$	B1, B1	Allow proton or ${}^1_1\text{H}$ or H^+ or p and (electron) antineutrino. Examiner's Comments Most candidates successfully completed the nuclear decay equation by correctly identifying the missing particles as the proton and the antineutrino. Conventional symbols for these two particles were allowed. About one in five candidates could only identify one of these particles.
		ii	(Average) time taken for half of the neutrons (in a sample) to decay.	B1	Note: Must have reference to 'half' and 'neutrons' Allow 'the time taken for the activity of neutrons to halve'. Examiner's Comments The majority of the candidates struggled to give a clear definition of half life. Definitions were often general and not specific to neutrons. The two most popular incorrect answers were: '<i>it is the time taken for a neutron to half its mass</i>' and '<i>the time taken for a neutron to half its radioactivity</i>'.
	b	i	$F = \frac{1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{4\pi\epsilon_0 \times (10^{-14})^2}$	C1	Not $Q = q = 1$
		i	force = 2.3 (N)	A1	Examiner's Comments Generally, candidates answered the question well and got the correct answer of 2.3 N. The equation for Coulomb's law was familiar to most candidates and the substitution of numbers was clear with fewer calculator errors. A small number of candidates used charges of 2e and 3e and consequently scored no marks.
		ii	$E = 7.0 \times 10^4 \times 1.6 \times 10^{-19} (= 1.12 \times 10^{-14} \text{ J})$	C1	
		ii	$(E = \frac{3}{2}kT); 7.0 \times 10^4 \times 1.6 \times 10^{-19} = \frac{3}{2} \times 1.38 \times 10^{-23} \times T$	C1	Allow any subject. Also, allow $E \approx kT$ since it is an estimate.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	temperature = 5.4×10^8 (K)	A1	Allow 1 sf answer. Examiner's Comments The majority of the candidates scored three marks for this synoptic question requiring knowledge of electronvolts and mean kinetic energy $\frac{3}{2} kT$. The answers were, once again, well-structured and logically presented. A small number of candidates either used 70000 or 18 MeV as the mean kinetic energy; no marks were awarded for such elementary errors.
		iii	Some nuclei will be travelling faster / have greater (kinetic) energy (to overcome electrostatic repulsion and hence cause fusion).	B1	Allow the pressures are high (enough to cause fusion). Not 'nuclei get close enough'. Examiner's Comments This was a good discriminator, with top-end candidates giving perfect answers. Some even mentioned the Maxwell-Boltzmann distribution and how some of the nuclei would have kinetic energies greater than the mean kinetic energy. Descriptions were often far more complex than warranted by this one mark question. Examiners also allowed 'high pressure' as a plausible answer.
		iv	$(\Delta E = \Delta mc^2)$; $18 \times 10^6 \times 1.6 \times 10^{-19} = \Delta m \times (3.0 \times 10^8)^2$	C1	Allow any subject
		iv	change in mass = 3.2×10^{-29} (kg)	A1	Allow a maximum of 1 mark for 18MeV $\pm$ 70 keV. Examiner's Comments This was another high-scoring question. Most candidates used the Einstein massenergy equation and the energy of 18 MeV converted to joules to get the correct answer. Examiners gave no marks if 70 keV was used as the energy. Once again, candidates demonstrated good analytical skills.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		v	Helium (nucleus) has greater charge / more protons.	B1	Do not award this mark if 'helium nuclei are moving slower' is also given as the reason for smaller probability for fusion. Examiner's Comments Most candidates wrote a great deal but the key physics was often omitted. Only a small number of high-scoring candidates realised that the helium nucleus had greater charge. This meant a greater repulsive electrostatic force between the helium nuclei and deuterium nuclei and hence a smaller chance of fusion between helium-deuterium nuclei. The most common misconception was that '<i>the greater mass of helium nuclei means that they are travelling slower and hence less chance of fusion</i>'.
		v	The (electrostatic) repulsive force (between the deuterium and helium nuclei) is greater (hence smaller chance of fusion).	B1	
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
2	a	i	C	B1	Examiner's Comments Almost all candidates correctly identified the anti-proton as particle C from Fig.6.1.
		ii	Zero	B1	Examiner's Comments Most candidates gave the charge of particle B to be zero; many even went as far to show how this came about from the charges of the up and anti-up quarks.
	b	i	proton / ${}^1_1\text{H}$ / ${}^1_1\text{p}$ / p	B1	Examiner's Comments The proton was correctly identified as particle X. However, about a third of the candidates thought it could have been any of these particles too — anti-proton, positron, electron and neutron.
		ii	$\lambda = \frac{0.693}{5700 \times 3.16 \times 10^7} \text{ or } ? = 3.847 \dots$ $\times 10^{-12} (\text{s}^{-1})$	C1	Allow any subject Allow ecf within the calculation for an incorrect λ.
		ii	$(A=\lambda N); N = \frac{1.1 \times 10^{19}}{3.847 \dots \times 10^{-12}} \text{ or } N =$ $2.859 \dots \times 10^{30}$ $\text{mass} = \frac{2.859 \dots \times 10^{30}}{6.02 \times 10^{23}} \times 0.014$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	mass = $6.649... \times 10^4$ (kg) or 6.6×10^4 (kg)	A1	Allow 6.7×10^4 (kg) Examiner's Comments Almost half of the candidates scored full marks for this challenging question. Most answers showed excellent structure and good understanding of radioactive decay and molar mass. A disturbing number of candidates were rounding numbers to 2 significant figures within their calculations. This is a poor practice. It would have been sensible to carry forward the calculator values between stages of this complicated calculation. Examiners were lenient this session, but this poor technique will be penalised in the future.
	c		A (thermal / slow-moving) neutron splits the nucleus into two (smaller) nuclei and (fast-moving) neutron(s).	B1 B1	Allow 'fast neutron'; allow 'decays' instead of 'splits'. Not 'splitting the atom'. Not 'particles' or 'fragments' in place of '(smaller) nuclei'. Examiner's Comments The answers for induced nuclear fission lacked clarity and preciseness. Most candidates scored nothing for their elaborate answers. One mark was being awarded for the idea that a thermal neutron caused the uranium-235 nucleus to split into two smaller nuclei and the other mark was for the emission of one or more fastmoving neutrons. Too many candidates gave unnecessary attention to chain reaction.
	d		Any three from: 1. Fission reactions produce fast neutrons. 2. The moderator / water slows down (the fast-moving) neutrons. 3. Slow-moving neutrons have a greater chance of causing fission (of U-235). (ora) 4. The control rods absorb (some of the) neutrons.	B1 × 3	Allow boron / cadmium instead of control rods in 4.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			5. (On average) one neutron survives between successive (fission) reactions. QWC: The neutrons make collisions with the (moderator) nuclei and transfer (some of) their (kinetic) energy.	B1	Not graphite for 4. Allow atoms / molecules instead of nuclei. Examiner's Comments The descriptive answers demonstrated good understanding of the function of the moderator and the control rods. The QWC mark was reserved for explaining how the neutrons transferred their kinetic energy to the atoms of the moderator material; this was successfully communicated by the top-end candidates. A large number of candidates also realised that slow-moving neutrons had a greater chance of causing fission reactions. The answers to this question were very much Centre-dependent.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
3	a		They are not fundamental particles because they consist of quarks	B1	Not: They can be sub-divided Examiner's Comments The majority of the candidates knew that protons and neutrons were not fundamental particles because they are composed of quarks. A small number of candidates gave incorrect or incomplete answers such as: • Protons and neutrons are hadrons. • Neutrons and protons have other particles inside. • Protons and neutrons can be broken down.
	b		Any two from: electron / positron / neutrino / antineutrino	B1	Allow: muon / tau Examiner's Comments This was a well answered question with a correct pair from the family of leptons. Although not in the specification, it was good to see muon and tau particles mentioned. A very small number of candidates had '<i>electrons and mesons</i>'.
	c	i	${}^{40}_{20}\text{Ca}$ ${}^0_{-1}\text{e} + \bar{\nu}_{(\text{e})}$ or electron + (electron) antineutrino	B1	Allow: ${}^0_{-1}\beta$ but not β^- or e^- for the electron Examiner's Comments This was another success for the candidates with most gaining two marks. Those who made mistakes did so with the proton or nucleon numbers for the calcium nucleus and the incorrect symbol for the electron. Some antineutrino symbols looked deceptively like the Greek gamma.
		ii	There is a decrease in mass	M1	
		ii	Energy (released) given by $(\Delta)E = (\Delta)mc^2$	A1	Ignore Δm being referred to as the 'mass defect'
		ii	or		

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Binding energy increases	M1	Allow: binding energy per nucleon increases Examiner's Comments Many candidates lost marks for being imprecise with their physics. The term mass defect was used by many candidates to mean 'change in mass Δm'. This was overlooked as long as candidates knew that there was a decrease in the mass of the system and this led to energy being released in accordance with Einstein's mass-energy equation. Some candidates decided to answer the question in terms of binding energies. Such answers often led to no marks because the candidates had the binding energy of the calcium nucleus as being less than that of the potassium nucleus. Some of the most frequent incorrect answers were: • Energy is given out because the mass of the particles changes. • Energy is released as kinetic energy of the beta particle. • Energy released is equal to the mass defect.
		ii	Energy (released) is the difference between the binding energies (of Ca and K nuclei)		
		iii	$\lambda = \frac{0.693}{4.2 \times 10^{16}} \quad / \quad N = \frac{0.012}{100} \times \frac{4.5 \times 10^{-4}}{0.040} \times 6.02 \times 10^{23}$	C1	Allow: 1 mark for either $\lambda = 1.65 \times 10^{-17} \text{ s}^{-1}$ or $N = 8.127 \times 10^{17}$
		iii	$A = 1.65 \times 10^{-17} \times 8.127 \times 10^{17}$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	activity = 13 (Bq)	A1	Note: Answer to 3 sf is 13.4 (Bq) Note: 1.3×10^3 (Bq) scores 2 marks; division by 100 omitted Examiner's Comments This question produced a range of marks. Better candidates gave immaculate answers. Many candidates gained a mark for correctly calculating the decay constant for the potassium isotope. Determining the number of potassium nuclei proved to be fairly challenging with many candidates not knowing what to do with the 0.012% or how to use Avogadro constant. A very small number of candidates had the decay constant equal to the half-life. The modal mark for this question was three.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
4	a		Observations: 1. Most of the alpha particles went straight / un-deflected through (the atom(s) / foil) (AW)	M1	Not 'reflected' Allow: The QWC mark even if 'alpha reflected at large angles' is mentioned in 2 Examiner's Comments There was a good spread of marks, with most candidates gaining the QWC mark for clearly linking the observations with the conclusions. The answers showed a good understanding of the scattering experiment. The modal mark for this question was three.
			2. (Some of the) alpha particles were scattered / repelled / deflected through large angles (AW)	M1	
			Conclusions (QWC mark):	A1	
			1 showed that most of the atom is empty space and 2 showed the existence of small / dense / positive nucleus		
	b	i	The aluminium nucleus has velocity / accelerates / moves to the right	B1	Allow: Moves away from the alpha particle Examiner's Comments This was another well answered question with most candidates describing and explaining the motion of the aluminium nucleus in terms of repulsive electrostatic force or conservation of momentum. A small number of candidates tried to explain the fate of the aluminium nucleus in terms of the strong nuclear force.
		ii	There is a repulsive force on the (aluminium) nucleus (to the right) / According to conservation of momentum the (aluminium) nucleus must move (to the right)	B1	
		ii	$8.0 \times 10^6 \times 1.6 \times 10^{-19} = \frac{1}{2} \times 6.6 \times 10^{-27} \times v^2$ (Any subject)	C1	Enter text here.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	speed = $2.0 \times 10^7 \text{ (m s}^{-1}\text{)}$	A1	Note: Answer to 3 sf is $1.97 \times 10^7 \text{ (m s}^{-1}\text{)}$ Allow 1 sf answer $2 \times 10^7 \text{ (m s}^{-1}\text{)}$ Examiner's Comments Most candidates scored full marks for calculating the speed of the alpha-particle. Many candidates knew how to convert the kinetic energy of 8.0 MeV into joules. The most frequent errors were: • Forgetting to square root the final answer. • Using the mass of an electron instead of the alpha-particle. • Using $8.0 \times 10^6 \text{ J}$ as the kinetic energy of the alpha-particle.
		iii	$Q = 13e \text{ or } q = 2e \text{ or } F = \frac{Qq}{4\pi\epsilon_0 r^2}$	C1	Allow: $F = k \frac{Qq}{r^2}$, where $k = 9 \times 10^9$ Note: No credit for using Q and q as 13 and 2 Examiner's Comments This was a well-answered question with the majority of candidates correctly using the equation for Coulomb's law to calculate the distance r. Only a small number of candidates used the incorrect values for the charge of the aluminium nucleus and the alpha-particle. It was good to see many candidates rearranging the equation first, then substituting the values and finally writing the answer to the correct number of significant figures.
		iii	$270 = \frac{13 \times 1.6 \times 10^{-19} \times 2 \times 1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times r^2}$ (Any subject)	C1	
		iii	distance = $4.7 \times 10^{-15} \text{ (m)}$	A1	
		iv	The strong force is attractive	M1	Allow: The strong force is repulsive M1

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	Correct explanation of size / direction of resultant force	A1	Correct explanation of size / direction of resultant force A1 Examiner's Comments The modal mark for this question was one. This mark was scored by candidates for recognising that the strong force was either attractive at long distances or repulsive at very close distances. Only a small number of candidates were successful in discussing the effects of the strong nuclear force and the electrostatic force on the resultant force on the alpha-particle.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
5	a		The (minimum) energy needed to separate / remove all the nucleons / protons and neutrons (to infinity)	B1	Allow: The energy released when (stationary) nucleons combine to form the nucleus Allow: The (minimum) energy required to break the nucleus into its (separate) nucleons Allow: binding energy = mass defect $\times$ speed of light² Allow: 'Work (done)' in place of 'energy' Examiner's Comments Most candidates gave an adequate definition for binding energy of a nucleus. Vague answers such as '<i>it is energy that holds the nucleons together</i>' or '<i>the energy required to break the nuclear bonds</i>' were unacceptable.
	b		BE per nucleon = $4.53 \times 10^{-12}/4$ BE per nucleon = 1.13×10^{-12} (J)	B1	Allow 2 sf answer of 1.1×10^{-12} (J) Examiner's Comments The modal mark for this question was one. The majority of the candidates dividing 4.53×10^{-12} J by the nucleon number of 4. A small number of candidates divided the energy released by the proton number of 2.
	c		The helium nucleus has greater charge / The helium nucleus experience greater repulsive force Helium nuclei need to get close together (for the strong force to initiate fusion)	B1 B1	Examiner's Comments Many candidates struggled to give a decent explanation. The focus was on the higher binding energy or the greater mass of the helium nucleus, rather than the greater charge and greater electrostatic repulsion. Higher temperature was necessary to give the helium nuclei greater kinetic energy and hence a greater chance of getting close enough for the attractive strong nuclear force to trigger fusion.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
6	a	i	number per second = $4.8 \times 10^{-3} / 1.6 \times 10^{-19}$	M1	Note: This must be seen to gain a mark Examiner's Comments Most candidates scored a mark for dividing 4.8×10^{-3} by 1.6×10^{-19}. A small number used a slightly longer route to show that the number of electrons incident at the anode was $3.0 \times 10^{16} \text{ s}^{-1}$. They calculated the total power dissipated using the potential difference and current and then divided the power by the energy gained by each electron ($2.4 \times 10^{-14} \text{ J}$).
		i	number per second = $3.0 \times 10^{16} \text{ s}^{-1}$		
		ii	(incident power =) $150 \times 10^3 \times 4.8 \times 10^{-3}$ or (incident power =) $3.0 \times 10^{16} \times 150 \times 10^3 \times 1.6 \times 10^{-19}$	C1	Note an incident power of 720 (W) scores this C1 mark Note: Answer to 3 sf is 592 ($^{\circ}\text{C s}^{-1}$) Allow: 2 marks for 598 ($^{\circ}\text{C s}^{-1}$) or 600 ($^{\circ}\text{C s}^{-1}$); 99% omitted Allow: 2 marks for $1.97 \times 10^{-14} (^{\circ}\text{C s}^{-1})$; 3.0×10^{16} omitted Examiner's Comments The answers were generally easy to follow. The modal range for this question was two to three marks. The best candidates gave brief and flawless answers. Some candidates lost a mark for - premature rounding of numbers within the calculation; - failing to convert the mass into kg; - subtracting 273 K from the correct answer.
		ii	$(P = mc[\Delta\theta/\Delta t])$ $0.99 \times 720 = 0.0086 \times 140 \times [\Delta\theta/\Delta t]$	C1	
		ii	rate of temperature increase = $590 (^{\circ}\text{C s}^{-1})$	A1	
		iii	(photon energy = maximum KE of electron)	C1	Allow: $E = 720/3.0 \times 10^{16}$
		iii	$E = 150 \times 10^3 \times 1.6 \times 10^{-19}$ or $E = 2.4 \times 10^{-14} \text{ (J)}$		

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$2.4 \times 10^{-14} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{\lambda}$ (Allow any subject)	A1	Allow: 1 mark 8.3×10^{-10} (m); $E = 2.4 \times 10^{-16}$ (J) used Examiner's Comments The more able candidates performed well in this question. The energy of a single photon was equal to the maximum kinetic energy of a single electron. The omission rate was noticeably high for candidates in the lower quartile. The most common errors made were using mc^2 , 1.6×10^{-19} J and 720 J as the energy of the photon. A small number of candidates tried to use the de Broglie equation to determine the shortest wavelength of the X-rays.
		iii	wavelength = 8.3×10^{-12} (m)		
	b		Contrast material / iodine is injected (into the vessels) Any one from: The contrast material • large attenuation / absorption coefficient • has high Z (atoms) (and hence reveal the outline of the blood vessels)	B1	Not: barium for this B1 mark
				B1	Not ‘large μ’ Examiner's Comments Most candidates did manage to score one or two marks for this question. Instead of injecting a contrast material (iodine) into the patient, some candidates opted for using barium and sometimes even boron. Most candidates did know that a contrast material had a greater number of electrons (high Z) or that it had a greater attenuation coefficient compared with the tissues of the heart and blood vessels.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
7	a		Gamma radiation will pass through the patient (and hence can be detected) / beta particles will be absorbed by the patient (and hence cannot be detected)	B1	
			Gamma radiation is not (very) ionising / gamma radiation does little damage to cells / beta particles are (very) ionising / beta particle damage cells	B1	Allow: 'Body' in place of 'cells' Examiner's Comments Most candidates knew about the ionising and penetrating properties of the radiations from the two types of tracers. The answers were generally easy to follow and there were fewer convoluted answers.
	b		X-ray tube rotates around (the patient) / X-ray beam passes through the patient at different angles	B1	Not: Detector rotates around (the patient) Allow: Detectors moves / spirals along (the patient) Examiner's Comments This question produced a range of marks. The principles of a CAT scanner were understood and the answers were generally well-structured. A small number of candidates spoilt their answers by mixing together different types of scanners, which included MRI and PET scanners.
			A thin X-ray beam is used	B1	
			Image(s) of slice(s) / (cross) section(s) through the patient are taken	B1	
			X-ray tube moves / spirals along (the patient)	B1	
			The signals / information / pulses / data (from the detectors) are used by the computer (and its software) to produce a 3D image	B1	
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
8	a		Change in the frequency / wavelength because of source / 'observer' moving	B1	Allow: There is blue / red shift because of relative motion between source and observer Examiner's Comments This question produced a range of marks. The principles of a CAT scanner were understood and the answers were generally well-structured. A small number of candidates spoilt their answers by mixing together different types of scanners, which included MRI and PET scanners.
	b		Any two from: 1. Ultrasound transducer / device / probe emits and detects ultrasound 2. The transducer / device / probe is placed at an angle (to the artery) 3. Ultrasound is reflected by the blood / cells QWC mark - change in frequency / wavelength (of the reflected ultrasound) is related to speed of blood	B1 × 2 B1	Allow: speed of blood ∝ change in frequency Allow: $\Delta f = 2v\cos\theta/c$, where v is the speed of blood, c = speed of ultrasound; no need to define the other labels Note: Do not award this mark if $\Delta f = fv/c$ is used to determine the speed v of the blood Examiner's Comments Most candidates scored two or three marks. There were some excellent answers with the transducer placed at an angle to the artery, ultrasound being reflected off blood cells and the change in the wavelength being proportional to the speed of the blood. It was good to see many candidates quoting the correct equation for the change in frequency of the ultrasound ($\Delta f = 2fv\cos\theta/c$). There was no credit for using the incorrect equation $\Delta f = fv/c$. A small number of candidates thought that the wave equation $v = f\lambda$ could be used to determine the speed of the blood.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	$Z = \rho c$ density = $1.66 \times 10^6 / 1570$ density = $1060 \text{ (kg m}^{-3}\text{)}$	B1	Allow: $1100 \text{ (kg m}^{-3}\text{)}$ Examiner's Comments Generally this was well answered with most candidates correctly using the equation for acoustic impedance. Some candidates incorrectly used the value for the speed of light c in the equation $Z = \rho c$.
		ii	$\lambda = 1570 / 2.4 \times 10^6$ wavelength = $6.5 \times 10^{-4} \text{ (m)}$	B1	Examiner's Comments Most candidates gained a mark for calculating the wavelength of ultrasound. Only a small number of candidates failed to get a mark because of transfer error with the speed (1500 m s^{-1} instead of 1570 m s^{-1}) or omitting the mega prefix.
	d		(fraction of intensity reflected =) $\frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$ (fraction of intensity reflected =) $3^2/5^2$ (= 0.36) intensity = 64%	C1 C1 A1	Note: 2 marks for 36% or 0.36 Examiner's Comments The answers to this question were well-structured and easy to follow. Most candidates wrote the answer as 36%, but this was the percentage of ultrasound intensity reflected at the muscle-bone boundary. A pleasing number of candidates got the correct value of 64%.
	e		Gel is used (between transducer and skin).	B1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			The acoustic impedance / Z of gel is similar to that for skin hence less reflection (at the skin)	B1	Allow: There is acoustic / impedance matching so less reflection Allow: Without the gel, there is large difference between acoustic impedances of air and skin, hence large reflection Note: Must have reference to reflection Examiner's Comments Almost all candidates were familiar with the use a coupling gel. The answers were generally very good and most candidates managed to score full marks. One of the marks was dependent on stating that the acoustic impedance of the gel and skin were similar, so this meant very little reflection of the ultrasound at the gel-skin boundary.
			Total	11	
9			B	1	
			Total	1	
10			D	1	
			Total	1	
11			C	1	
			Total	1	
12			D	1	
			Total	1	
13			energy of <u>two</u> photons = $2 \times mc^2$ or $2 \times \frac{hc}{\lambda} = 2 \times mc^2$ $\lambda = \frac{h}{mc} = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3.0 \times 10^8}$ wavelength = 2.4×10^{-12} (m)	C1 C1 A1	Correct use of $\frac{hc}{\lambda} = mc^2$
			Total	3	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
14	a	* Level 3 (5–6 marks) For equipment expect both E1 and E2 Descriptions has all the points At least two safety precautions mentioned Both Q1 and Q2 mentioned for the quality of results. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Expect at least E1 for equipment For description expect D1 and D2 and an attempt at either D3 or D4 At least one safety point mentioned Expect either Q1 or Q2 for quality of results. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Expect at least E1 for equipment For description expect D1 and D2 At least one safety point mentioned Statements for quality are not relevant. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1	Equipment (E) 1 GM tube, counter or rate-meter and lead plates used 2 Micrometer or vernier calliper (to measure thickness of plates). Description (D) 1 Measure counts for a specific time and hence the count-rate for each thickness of lead 2 Vary the thickness of lead and record the count-rates 3 Plot a graph of count-rate against thickness and determine the half thickness of lead 4 Fig. 23.1 is used to determine the photon energy. Safety (S) 1 Do not point source at person 2 Keep safe distance between you and source 3 Use tongs to handle source. Quality of results (Q) 1 The counts are recorded over a long period of time 2 Background radiation taken into account.
	b	$\lambda = \frac{\ln 2}{6600} = 1.050 \times 10^{-4} \text{ (s}^{-1}\text{)}$ $N = \frac{400 \times 10^6}{1.050 \times 10^{-4}} = 3.809 \times 10^{12}$ mass of FDG = $\frac{3.809 \times 10^{12}}{6.02 \times 10^{23}} \times 0.018 \div 0.099$	C1 C1 C1	Correct use of $A = \lambda N$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			mass of FDG = 1.15×10^{-12} (kg) or 1.2×10^{-12} (kg)	A1	
			Total	10	
15			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16	a		The decay constant is the probability of decay of a nucleus per unit time.	B1	Allow: the decay constant is the fraction of nuclei decaying per unit time. Allow: decay constant = activity ÷ number of nuclei left in a sample.
	b		number decaying in 1st second = $2000 \times 0.10 = 200$ number decaying in the 2nd second = $1800 \times 0.10 = 180$ number left = $1800 - 180 = 1620$	C1 A1	
	c		Level 3 (5–6 marks) Correct explanation Correct determination of λ and half-life Correct determination of uncertainty (Maximum 6 marks) Any point omitted or incorrect (5 marks). <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Mostly correct explanation Mostly correct determination of λ and half-life Some attempt of determining uncertainty (Maximum 4 marks) Any point omitted or incorrect (3 marks). <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Basic explanation Some attempt to determine λ or half-life No attempt at uncertainty. (Maximum 2 marks) <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 x 6	Explanation $A = A_0 e^{-\lambda t}$ $\ln A = \ln A_0 - \lambda t$ - A graph of $\ln A$ against t will be a straight line with gradient $(-)\lambda$ - half-life = $\ln 2 / \lambda$ Determination - Line of best fit drawn - Gradient determined using a large triangle - decay constant in the range 0.5 to 0.7 min^{-1} - half-life in the range 1.0 to 1.4 min Uncertainty - Worst line of fit drawn - Correct attempt to determine uncertainty

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	9	
17	a		The splitting of a (uranium) nucleus as a neutron is absorbed (into two fragment nuclei and neutrons).	B1	
	b		The moderator slows down the fast-moving neutrons. The neutrons lose significant amount of their kinetic energy when colliding with moderator nuclei. or The moderator does not absorb the neutrons. The control rods absorb the neutrons. The rate of fission reactions is less / reduced.	B1 B1 B1 B1	
	c	i	2	B1	
		ii	Zero	B1	
		iii	$\Delta m = 236.053 - 235.840 = 0.213 \text{ u}$	C1	
		iii	$\Delta E = [0.213 \times 1.661 \times 10^{-27}] \times (3.0 \times 10^8)^2 = 3.184 \times 10^{-11} \text{ (J)}$	C1	
		iii	number of reactions per second = $10^9 / 3.184 \times 10^{-11}$	C1	
		iii	number of reactions per second = $3.1 \times 10^{19} \text{ (s}^{-1}\text{)}$	A1	
			Total	11	
18			$\frac{hc}{\lambda} = 2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2}$ $\lambda = 1.2 \times 10^{-12} \text{ (m)}$	C1 C1 A1	Allow 2 marks for $2.4 \times 10^{-12} \text{ (m)}$; factor of 2 omitted in the first line.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
19	a		* Level 3 (5–6 marks) All of B correct. One of S and one of D stated. C fully described. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) B partially given. S and D given but one not clear. C lacks detail. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) B poor and incomplete. Only S or D given. C not mentioned or very inadequate. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1	basic description (B) 1. <i>fission</i>: neutron is absorbed by the nucleus causing it to split into two (major) fragments and several / two / three neutrons 2. <i>fusion</i>: two light nuclei (moving rapidly enough) overcome the Coulomb repulsion between them fuse. similarity (S) 1. release of energy 2. total (rest) mass decrease 3. 'increase' in binding energy 4. conservation of charge / mass-energy. difference (D) 1. cold, hot 2. heavy, light nuclei 3. large (200 MeV), small (30 MeV) energy release per reaction. conditions (C) 1. fission rate can be varied / controlled by absorbing and or slowing released neutrons in reactor where chain reaction is occurring 2. fusion needs a very hot and sufficiently dense and plentiful plasma for random fusion collisions to occur, e.g. inside Sun / star.
	b	i	Fission reactors produce radioactive by-products which affect future generations and the environment in terms of possible contamination / exposure to humans and animals.	B1	
		ii	No of particles in 1000 g U = $1000/235 \times 6.02 \times 10^{23} = 2.56 \times 10^{24}$ No of reactions for U = 2.56×10^{24}	B1	Appreciate that the key to the answer is the difference in numbers of atoms / nuclei or equal number of nucleons involved scores one mark if nothing else achieved.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Energy from U = $2.56 \times 10^{24} \times 200 = 5.12 \times 10^{26}$ MeV	B1	
		ii	No of particles in 1000g H = 6.02×10^{26} No of reactions = $6.02 \times 10^{26}/4$ Energy from H = $6.02 \times 10^{26}/4 \times 28 = 42.14 \times 10^{26}$ MeV	B1	
		ii	Hence energy $42/5 = 8.2$ times higher	B1	
		ii	<i>second method</i> 235 g of U and 4 g of H / He contain 1 mole of atoms	or B1	
		ii	there are 4.26 moles of U and 250 moles of He	B1	
		ii	so at least 58 times as many energy releases in fusion ratio of energies is only 7 fold in favour of U	B1	
		ii	therefore 58/7 times as much energy released by 1 kg of H	B1	
		ii	<i>similar alternative argument, e.g.</i> For U each nucleon 'provides' 0.85 MeV	B1	
		ii	For H each nucleon 'provides' 7 MeV	B1	
		ii	(Approx) same number of nucleons per kg of U or H	B1	
		ii	so 8.2 times as much energy from H	B1	
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a	i	$2\text{}^1_0\text{n}$	B1	Allow answer in words, e.g. 'two neutrons' Allow $2 \times \text{}^1_0\text{n}$ Examiner's Comments More than half of the candidates got the right answer $2\text{}^1_0\text{n}$. The most frequent errors were $\text{}^2_0\text{n}$ and using capital N for the neutron symbol.
		ii	$\text{}^0_{-1}\text{e} / \text{}^0_{-1}\beta^{(-)}$	B1	Not $\text{e} / \text{e}^- / \beta / \beta^-$ Allow electron
		ii	$\text{}^{(0)}_{(0)}\bar{\nu}_{(\text{e})}$	B1	Allow (electron) anti-neutrino Examiner's Comments The majority of the candidates correctly identified the electron $\text{}^0_{-1}\text{e}$ and the antineutrino $\bar{\nu}$ in the decay equation.
	b	i			Allow other correct methods
		i	$(\text{activity} =) \frac{2000}{9.0 \times 10^{-13}}$	C1	Note 2.22×10^{15} scores this C1 mark
		i	$(\lambda =) \frac{0.693}{88 \times 3.16 \times 10^7}$ $(A = \lambda N)$	C1	Note $2.49 \times 10^{-10} \text{ (s}^{-1}\text{)}$ scores this C1 mark
		i	$2.22 \times 10^{15} = 2.49 \times 10^{-10} \times N \text{ (Any subject)}$ $(\text{mass} =) \frac{8.91 \times 10^{24}}{6.02 \times 10^{23}} \times 0.238$	C1	Note $N = 8.91 \times 10^{24}$ scores all three C1 marks Possible ECF for incorrect value(s) of activity and or λ

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	mass = 3.5 (kg)	A1	Allow 3 marks for 0.21 (kg) if 120 W is used <u>Examiner's Comments</u> This was a good discriminating question with most candidates calculating the decay constant in s^{-1} and the activity of the source. Calculation of the mass of plutonium required knowledge of $A = \lambda N$ and molar mass and this is where the top-end candidates showed excellent analytical skills. A small number of candidates used 120 W instead of 200 W and got an answer of 0.21 kg; such an approach was awarded three marks.
		ii	(energy =) 0.120 (kW) $\times$ 24 (h)	C1	Allow 1 mark for 48 (kW h); 2 kW used instead of 0.12 kW Allow 1 mark for 2900; 120 used instead of 0.12 <u>Examiner's Comments</u> The modal mark for this straight-forward question on kW h was zero. Most candidates overcomplicated the question by converting time into seconds and some even tried to link efficiency of the RTG in their answers. Only about 1 in every three candidates got the correct answer of 2.9 kW h.
		ii	energy = 2.9 (kW h)	A1	
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
21	a		Hadrons are made of quarks / they experience the strong (nuclear) force / interaction	B1	Not 'they are baryons' Allow 'held together by gluons' (AW) Ignore the number of quarks mentioned Examiner's Comments Candidates answered this question well. The two most popular answers were '<i>Hadrons contain quarks</i>' and '<i>Hadrons feel the strong (nuclear) force</i>'. Only a small number of candidates gave weak answers such as '<i>Hadrons are heavy particles</i>' and '<i>Hadrons are not fundamental particles</i>'.
	b		$\frac{2}{3}$ (e); $-\frac{1}{3}$ (e)	B1	Allow 0.67 (e) and – 0.33 (e) Examiner's Comments Almost all candidates correctly quoted the charges on the up and the down quarks. A small number of candidates omitted the minus sign for the charge on the down quark.
	c		(proton =) u u d	B1	Allow up up down Examiner's Comments This was a very high scoring question with almost all scripts having the answer uud.
	d		$(p + n \rightarrow p + p + \pi^-)$ $u u d + u d d \rightarrow u u d + u u d + \pi^-$ (left-hand side = d and right-hand side = u + π^-) π^- has one down quark or π^- has d	C1 A1	Allow other correct methods Note: This mark is for <i>substitution</i> Note: Any more than 2 quarks does not score the A1 marks

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			and one anti-up quark or π^- has $\bar{u}$	A1	Allow 3 marks for d $\bar{u}$ Examiner's Comments This was an unfamiliar question and required careful scrutiny of the question. Most candidates arrived at the correct quark combination for the pion. A range of methods were used, including the conservation of charge. Some answers were brief, almost intuitive.
	e	i	$\Delta E = \Delta m c^2$ where ΔE is (change in) energy, Δm is (change in) mass and c is speed of light (in a vacuum)	B1	Allow energy = mass $\times$ speed of light² Not binding energy = mass defect $\times$ speed of light² Not energy = mass defect $\times$ speed of light² Examiner's Comments The Einstein's mass-energy equation was quoted well by most candidates. A small number of candidates spoilt their answers by using mass defect to mean 'change in mass Δm' and binding energy to mean 'change in energy ΔE'.
		ii	(KE =) $1.4 \times 10^8 \times 1.6 \times 10^{-19}$ or 2.24×10^{-11} (J) (mass of π^- =) $\frac{2.24 \times 10^{-11}}{(3.0 \times 10^8)^2}$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	mass = 2.5×10^{-28} (kg)	A1	Examiner's Comments This was another well-answered question with clear conversion of energy from electronvolts to joules and correct application of the mass-energy equation. A very small number of candidates ignored the energy 1.4×10^8 eV and determined the difference in the mass of the neutron and mass of the proton using the Data, Formulae and Relationship Booklet. This gave the incorrect answer of 2.0×10^{-30} kg.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
22	a		Any two from: - A nucleus is split / broken up in a fission reaction OR In a fusion reaction nuclei combine / fuse - High temperatures / pressures / (kinetic) energy required for fusion reaction - More energy per reaction produced in a fission reaction (ORA) - A neutron causes fission reaction - Chain reaction possible in fission 'Larger' nuclei produced in fusion OR 'Smaller' nuclei produced in fission	B1×2	Allow alternative wording (AW) Not 'neutrons are produced in a fission reaction' because neutrons can also be produced in some fusion reactions Examiner's Comments A range of responses were accepted by the examiners. This meant that the majority of the candidates scored one or two marks for describing the difference between fission and fusion reactions.
	b		There is repulsion (between nuclei) (At high temperatures nuclei) move fast / have more KE (At high temperature / pressure the nuclei) have <u>greater</u> chance of fusion / collision / interaction (AW) At high temperatures nuclei get close (enough) to experience the strong force OR At high pressures nuclei are close	B1 B1 B1 B1	Allow reference to 'particles' or protons instead of 'nuclei' Not 'enough / sufficient' KE Allow fuse / collide / interact more frequently Allow At high pressures ... high density / greater number of nuclei per unit volume Examiner's Comments This question produced a range of marks. Most candidates knew about the repulsion between the nuclei (protons). Many also mentioned the high kinetic energy of the nuclei required for fusion but it was difficult to establish whether this was due to the temperature or the pressure. Answers such as '<i>High temperatures and pressures make the protons move faster</i>' were quite common. A significant number of candidates realised that high pressures helped to increase the chance of fusion reactions because of the closeness, or high concentration, of the nuclei.
	c	i	Mention of slow / thermal neutron(s)	B1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	The nucleus splits up into two nuclei / smaller nuclei / daughter nuclei / smaller fragments (and neutrons)	B1	Not 'nucleus undergoes fission / decay / becomes unstable' Examiner's Comments Top-end candidates were familiar with thermal neutrons splitting the uranium nucleus into two smaller nuclei. Some candidates lost a mark for not mentioning the thermal neutrons. A small number of candidates thought that this reaction was triggered by high-speed electrons.
		ii	$\frac{3}{2}kT$ and $\frac{1}{2}mv^2$	C1	Allow 1 mark for $2.7 \times 10^3 \text{ (m s}^{-1}\text{)}$; 300 used instead of 573 Allow 3 marks for $3.8 \times 10^3 \text{ m s}^{-1}$; $1.675 \times 10^{-27} \text{ kg}$ or $1.673 \times 10^{-27} \text{ kg}$ (mass of proton) from Data Booklet used Examiner's Comments The answers to this question were generally well-structured and easy to follow. Most candidates were familiar with the expression $\frac{3}{2}kT = \frac{1}{2}mv^2$ Very few candidates used 300°C instead of 573 K in their calculations.
		ii	$3 \times 1.38 \times 10^{-23} \times 573 = 1.7 \times 10^{-27} \times v^2$ (Any subject)	C1	
		ii	speed = $3.7 \times 10^3 \text{ (m s}^{-1}\text{)}$	A1	
			Total	11	
23			B	1	
			Total	1	
24			B	1	
			Total	1	
25			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
26	a		Strong nuclear (force / interaction)	B1	Allow 'strong' (force / interaction)
			Attractive at short distances and repulsive at short distances	M1	
			Mention of distances of 3 fm and 0.5 fm	A1	
	b		$d \rightarrow u + {}^0_{-1}e$	B1	Allow ${}^0_{-1}\beta^{(-)}$ for the electron
			$+ \bar{\nu}_{(e)}$	B1	
	c	i	total nucleon number after fusion = $3 + 3 - 4 = 2$	M1	Allow other correct methods
		i	total proton number after fusion = $1 + 1 - 2 = 0$	M1	
		i	(Hence it must be 2 neutrons ${}_0^1n$ after the fusion reaction)	A0	
		ii	(BE of neutron(s) = 0 and BE of ${}_2^4He = 28.4$ MeV) BE of ${}_1^3H$ nucleus = $\frac{1}{2} \times (28.4 - 11) = 8.7$ (MeV)	C1	
		ii	BE per nucleon = $8.7/3 = 2.9$ (MeV) BE per nucleon = $2.9 \times 10^6 \times 1.60 \times 10^{-19}$	C1	
		ii	BE per nucleon = 4.6×10^{-13} (J)	A1	
			Total	10	
27			$\lambda = \ln 2/6.0 = 0.116$ (h^{-1}) ($A = A_0 e^{-\lambda t}$)	C1	Allow $\lambda = \ln 2/(6.0 \times 3600) = 3.21 \times 10^{-5}$ (s^{-1}) Allow $\frac{\ln(630/820)}{3.2 \times 10^{-5}}$ (= 8200 s)
			$t = \frac{\ln(630/820)}{0.116}$	C1	
			$t = 2.3$ (h)	A1	
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28		i	$-mV_g = \frac{1}{2}mv^2$ or $\frac{1}{2}mv^2 + mV_g = 0$	B1	Working must be shown
		i	$V_g = -GM/R = -gR$	B1	
		i	$v = \sqrt{(2gR)}$	B1	
		ii	$v = \sqrt{(2 \times 9.81 \times 6.4 \times 10^6)} = 11 \times 10^3 \text{ m s}^{-1}$	B1	allow 11(.2) km s ⁻¹
		iii	$\frac{1}{2}mc^2 = 3/2 \text{ kT}$ where $m = (M/N_A) = 6.6 \times 10^{-27} \text{ kg}$	B1	ecf (ii); allow $m = 4u$ or $4 \times 1.67 \times 10^{-27}$ allow 2 or 2.0
		iii	$T = 6.6 \times 10^{-27} \times 121 \times 10^6 / 3 \times 1.38 \times 10^{-23}$	C1	
		iii	$T = 1.9 \times 10^4 \text{ (K)}$	A1	
		iv	1 random motion and elastic collisions of particles	B1	max 4 out of 5 marking points where answer is a logical progression
		iv	2 lead to distribution of kinetic energies/velocities among particles	B1 B1	
		iv	3 a very few will have very high velocities at top end of distribution 4 a long way from mean /r.m.s. velocity at 300 K 5 hence some able to escape	B1	
		v	helium nucleus is an α -particle	B1	max 2 out of 3 marking points
		v	so helium is generated by radioactive decay helium is found in (natural gas) deposits underground	B1	
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29	a		Level 3 (5–6 marks) Clear set up and description of chosen experiment(s) and clear interpretation of observations <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Limited set up and description of chosen experiment and limited interpretation of observations <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Very basic description of chosen experiment and limited interpretation of observations <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Indicative scientific points may include: 1. range/penetration/absorption/deflection experiment suggested 2. suitable arrangement and choice of apparatus e.g. on diagram; allow GM tube as detector for all particles 3. description of range/penetration/absorption experiment: a. α place detector very close/ 2cm from source; measure count rate, use paper screen or move back to 10 cm or more, measure count rate, interpret result; contrast to background count level and/or other emissions from same source b. β place detector e.g. 10 cm from source measure count rate, add thin sheets of Al until count drops to very low or almost constant value e.g. γ present; interpret result; c. γ place detector e.g. 10 cm from source measure count rate, add thin sheets of Pb until count drops to very low/background level; interpret result 4. deflection experiment: needs vacuum for α experiment; source for radiation passes through region of E- or B-field; deflection or not of particles detected by detector to distinguish emissions; detail of directions; amount of curvature determines energy of emission; and nature of particle
	b	i	$I = I_0/r^2$ or $I = kr^{-2}$	B1	allow inverse square law statement
		i	$(k = 20)$ so $I = 20/(0.25)^2 = 20 \times 16 = 320$	B1	
		ii	640	B1	
		iii	$640 = 20/r^2$	C1	ecf(ii)1
		iii	so $r = \sqrt{(20/640)} = 0.18 \text{ (m)}$	A1	accept 0.177 (m)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	11	
30			C	1	
			Total	1	
31			A	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
32	a		Any <u>two</u> from: It acts between quarks / nucleons / hadrons 'Short-range' force Repulsive below (about) 0.5 fm Attractive up to (about) 3 fm	B1×2	Allow any correctly named particle Allow any value between 0.5 fm and 5 fm Examiner's Comment Most candidates scored two marks and knew a great deal about the strong nuclear force.
	b	i	proton = u u d or neutron = u d d	B1	Examiner's Comment The modal score here was one mark. The answers were brief with either proton as uud or the neutron as udd. The up ↑ and down ↓ arrows were allowed as acceptable notation for the up and down quarks respectively.
		ii	$d \rightarrow u + {}^0_{-1}e$ $+ \bar{\nu}_{(e)}$	M1 A1	Allow the equation expressed in words Allow $udd \rightarrow uud + {}^0_{-1}e$ Allow ${}^0_{-1}\beta$ Not e^- for electron Allow this mark if electron written as e^- or p^- Examiner's Comment A variety of answers for the decay equations were accepted with most candidates picking up marks. No credit could be given for showing the decay of a neutron into a proton because of the absence of the quarks. Some of missed opportunities were: - Representing the electron as e^- rather than ${}^0_{-1}e$. - Confusing the positron and the electron. - Assuming the decay was $u \rightarrow d$ rather than $d \rightarrow u$.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		mass (of nucleus) $\propto A$ volume (of nucleus) $\propto \text{radius}^3 \propto A$ and clears steps using $\rho = m / V$ to show density is (about) the same	B1 B1	Allow mass = Am, mass = Au, etc. Allow r or R for radius Allow any sensible constant in front of the r^3 Examiner's Comment This proved challenging for most candidates with answers lacking clarity. Some candidates secured a mark for suggesting the $\text{mass}_{\text{nucleus}} \propto A$. Only the very top-end candidates managed to show how the density equation and volume $\propto A$ led to the expected conclusion. Too many scripts had vague answers such as '<i>neutrons and protons are the same, so their density is the same</i>' and '<i>protons and neutrons have negligible mass so density is unaffected</i>'.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
33	a		${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + \dots$ ${}^4_2\text{He}$ or ${}^4_2\alpha$	B1 B1	allow proton and / or nucleon number to the right of symbol allow γ-photon; zero for any other extra particle Examiner's Comments Most candidates made a good start to the paper writing a correct equation for the nuclear decay.
	b		$mv = (4.00 - 0.0665) \times 10^{-25} \times 2.40 \times 10^5$ $= 9.44 \times 10^{-20}$ $v = 9.44 \times 10^{-20} / 6.65 \times 10^{-27} = 1.42 \times 10^7$ $\text{k.e.} = \frac{1}{2} \times 6.65 \times 10^{-27} \times (1.42 \times 10^7)^2$ $= 6.70 \times 10^{-13} \text{ (J)}$ $6.70 \times 10^{-13} / 1.60 \times 10^{-13} = 4.19 \text{ (MeV)}$	C1 C1 A1 B1	allow 0.07×10^{-25} for α-particle mass max 3 if use 4.00 instead of 3.93 in momentum eq'n allow ratio of masses 234 and 4 or calculations using 234u and 4u allow $p^2/2m$ calculation for k.e. accept 4.0 to 4.2; ecf (calculated value of k.e. in J)/e N.B. the correct answer automatically gains all 4 marks Examiner's Comments One mark in this question was reserved for converting units from joule into mega electronvolt. This was the only mark awarded to half of the candidates. Few recognised this to be an isolated system, applying the conservation of momentum to solve the problem. Few appeared to realise that the mass of an alpha particle is given in the Data, Formulae, and Relationships Booklet, calculating it instead by summing the masses of neutrons and protons. The most common incorrect approach was to use the formula $E = mc^2$ or to equate the kinetic energies of the thorium nucleus and alpha particle.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$\Delta A = 32 = 4n_{\alpha}$ so $n_{\alpha} = 8$ $\Delta Z = 10 = 2n_{\alpha} - n_{\beta}$ so $n_{\beta} = 6$ argument / reasoning given for both n_{α} and n_{β}	B1 B1 B1	allow 8 (decays), i.e no mention of α particles allow $10 - 16 = -6$; NOT $14 - 8 = 6$; must state $\beta(-)$ particles e.g. change in mass number caused by α decay, change in proton number combination of α and β Examiner's Comments A significant number had no idea where to start and left the page blank. Of the rest most managed to decide on 8 alpha particles. A minority worked initially with the proton number rather than the nucleon number incorrectly choosing 5. The explanations about the choice of 6 beta particles were often just restricted to equating the numbers correctly rather than giving any description of the transformation of neutrons into protons.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
34	a		${}^2_1\text{H}$ has two nucleons binding energy per nucleon = 1.1 <u>MeV</u> (per nucleon)	B1 B1	Allow $1.76 \times 10^{-13} \text{ J}$ (per nucleon) Examiner's Comment About half of the candidates scored one or two marks. Some of the answers were concise with just ' <i>1.1 MeV per nucleon</i> because ${}^2_1\text{H}$ has two nucleons' but some were simply incorrect with an attempt to answer the question using $\Delta E = \Delta mc^2$ and the rest masses of the proton and neutron. Weaker candidates misunderstood the terms 'binding energy' and 'binding energy per nucleon'.
	b		The <u>protons</u> / <u>nuclei</u> repel each other (At high temperature) particles have more <u>KE</u> and hence can get <u>close</u> (enough to fuse)	B1 B1	Not atoms / particles Allow 'enough <u>KE</u> to get close' Not atoms or ions Examiner's Comment Fusion is possible in stars because the higher temperatures ensure that nuclei have large enough kinetic energy for the most energetic ones to get close enough for the attractive strong nuclear force to trigger the reactions. Many candidates did realise that higher temperatures meant greater kinetic energy but some answers were spoilt for either stating that atoms were fusing or mentioning that ' <i>nuclei overcame electrical forces</i> ' without any further explanation. The superficiality of many answers prevented candidates from picking up marks.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$E = hc/\lambda$ and $E = me^2$ or $E = 2 \times mc^2$ $\lambda = \frac{6.63 \times 10^{-34}}{2 \times 9.11 \times 10^{-31} \times 3.0 \times 10^8}$ maximum wavelength = 1.2×10^{-12} (m)	C1 C1 A1	Allow $hc/\lambda = 2mc^2$ with or without the factor of 2 Note: The mass must be $2m_e$ to score this and the next mark Not de Broglie equation $\lambda = h/mv$ with speed of c; which gives 2.4×10^{-12} (m) Allow 2 marks for 6.6×10^{-16} (m); mass of neutron or proton used instead Allow the following marks for 1.02 MeV recalled: $E = 1.63 \times 10^{-13}$ (J) C1 $\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{1.63 \times 10^{-13}}$ C1 maximum wavelength = 1.2×10^{-12} (m) A1 Examiner's Comment This was another question that favoured the top-end candidates. The answers from them showed excellent understanding of pair production. A small number of candidates correctly recalled the 1.02 MeV energy required to produce an electron-positron pair. Full credit was given if this led to the correct answer of 1.2×10^{-12} m for the gamma photon. A disappointing number of candidates used 2.2 MeV from (a) and the equation $\lambda = hc/E$ to calculate the maximum wavelength. There was no credit for this incorrect approach.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
35	a		The patient is surrounded by (gamma) detectors or Increased activity is where F-18 accumulates (AW)	B1	Allow 'diametrically opposite detectors'
			The positrons (from the F-18) <u>annihilate</u> electrons (inside the patient)	B1	
			Each annihilation produces two gamma photons travelling in <u>opposite</u> directions	B1	Not gamma rays / radiation
			The arrival times are used to locate position (of increased activity)	B1	Allow 'delay time'
					Examiner's Comment Most candidates scored two or more marks for their description of the PET scanner. Most candidates knew that the annihilation of positrons and electrons was central to the scanning technique. A small number of candidates either confused the PET scanning with CAT scanning or assumed that the gamma detectors were monitoring the emission of positrons from the patient.
	b		$\lambda = \ln 2 / 110$ or $6.3 \times 10^{-3} \text{ (min}^{-1}\text{)}$ $0.30 = e^{-6.3 \times 10^{-3} t}$ $t = \frac{\ln(0.30)}{-6.3 \times 10^{-3}}$ $t = 190 \text{ (minutes)}$	C1 C1 A1	Allow $1.05 \times 10^{-4} \text{ (s}^{-1}\text{)}$ This is the same as $0.30 = e^{-1.05 \times 10^{-4} t}$ Note: This mark is for a ln expression (any subject) Allow 2 marks for $1.15 \times 10^4 \text{ (s)}$ as the final answer Examiner's Comment This was not an easy question. It required knowledge and understanding of activity, decay constant and natural logs. It is good to report that most of the candidates produced immaculate answers. The common mistakes made were: - Using either $\ln(1/3)$ or $\ln(0.70)$ rather than $\ln(0.30)$ in the calculations. - Assuming the decay was linear rather than exponential.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		Any sensible suggestion, e.g. 'post-code' lottery, some patients may not get the treatment because of where they live, longer waiting lists, etc.	B1	Examiner's Comment Almost all candidates gave a plausible suggestion in this last question in the paper. It is good to report that physicists are mindful of the impact of science on society.
			Total	8	
36			C	1	
			Total	1	
37			A	1	<u>Examiner's Comments</u> The majority of the candidates did get the correct answer A. A significant number of candidates opted for C, confusing contrast material with medical tracers.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
38		i	(N at 15°/N at 150° ⇒) $10^{5.1} \div 10^{1.5}$ or $10^{3.6}$ (≈ 4000)	B1	Enter text here.
		ii	Most of the (alpha) particles went through without (much) deflection, hence the atom is mostly empty / space / vacuum Some of the (alpha) particles were scattered (through large angles / greater than 90°), hence there must be a <u>nucleus</u> (at the centre of the atom). Any <u>one</u> from: • The nucleus is very small compared with the atom • Positive charge at the centre / nucleus is positive • Most of the mass (of the atom) is at centre / dense nucleus	B1 B1 B1	Allow Many / Majority / Lots of the alpha particles Allow Few(er) / Small(er) number of the alpha particles ... Examiner's Comments This question provided good discrimination. It is worth 3-marks, so the examiners were broadly looking for three key disparate points. The exemplar below, from a top-end candidate, illustrates a model answer. There is no ambiguity – full marks scored. Exemplar 12 The majority of the alpha particles pass straight through which suggests that the majority of the atom is empty space. The fact that some were scattered suggested there was a nucleus with a positive charge repelling the positive alpha particles away from it. It would be difficult to provide an improved answer. However, it is worth pointing out that the same ideas can also be presented in bullet-point form – three distinct points for the 3 available marks.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
39	a	i	alpha-particle / ${}^4_2\text{He}$ / ${}^4_2\alpha$	B1	
		ii	nucleon number for Bi = 209 antineutrino / ${}^{(0)}_{(0)}\bar{\nu}_{(e)}$	B1 B1	Note: Do not allow incorrect subscript and superscript
	b	i	Aluminium (sheet placed between source and detector) The count (rate) reduces or Magnetic / electric field used Electrons identified from correct deflection / motion in field	M1 A1 M1 A1	Allow count (rate) drop to background / zero Allow 2 marks for 'the range in air is a few m' <u>Examiner's Comments</u> This turned out to be a low-scoring question from candidates across the ability spectrum. Only a quarter of the candidates gained 2 marks for identifying aluminium as the absorber for the beta-minus radiation (electrons) and providing adequate description in terms of reduction in the count-rate. A small number of candidates opted for charged parallel plates and identified the electrons curving towards the positive plate. There were some baffling descriptions involving pointing the source at ' <i>wires and measuring the current</i> '. Fluorescent screens and cloud chambers were not allowed as acceptable answers because both can be used to detect the presence of gamma-photons and alpha-particles.

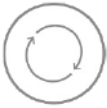
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$(\lambda =) \ln 2 / 3.3 \text{ (h}^{-1}\text{) or } (\lambda =) 0.21 \text{ (h}^{-1}\text{)}$ $(A_0 =) 12 \times 10^3 / e^{-(0.21 \times 7.0)} \text{ or } (A_0 =) 5.219 \times 10^4 \text{ (Bq)}$ $(N_0 =) 5.219 \times 10^4 / 5.835 \times 10^{-5}$ number of nuclei = 8.9×10^8 Or $(\lambda =) \ln 2 / [3.3 \times 3600] \text{ (s}^{-1}\text{) or } (\lambda =) 5.835 \times 10^{-5} \text{ (s}^{-1}\text{)}$ $(N =) 1.2 \times 10^4 / 5.835 \times 10^{-5} \text{ or } 2.057 \times 10^8$ $(N_0 =) 2.057 \times 10^8 / e^{-(0.21 \times 7.0)}$ number of nuclei = 8.9×10^8	C1 C1 C1 A1 C1 C1 C1 A1	Allow credit for alternative methods Note this is the same as $12 \times 10^3 \div (0.5)^{7.0/3.3}$ Note 9.0×10^8 can score full marks if numbers are rounded Possible ECF for incorrect conversion of time Note this is the same as $2.057 \times 10^8 \div (0.5)^{7.0/3.3}$ <u>Examiner's Comments</u> The question was multi-stepped calculation, requiring knowledge of radioactive decay equations, half-time and activity. The final stage of the calculation was dependent on the equation $A = \lambda N$ and working consistently in Bq for the activity and in s^{-1} for the decay constant. The number of nuclei N could not be calculated with the activity in Bq and the decay constant in either h^{-1} or min^{-1} . About half of the candidates scored full marks. Those working with inconsistent units invariably ended up with the incorrect value 2.5×10^5 nuclei, but this still earned them 2 marks for the preceding steps.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
40		i	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	B1 B1	Allow 'proton can experience the strong (nuclear) force' Not 'collide / hit nucleus'
		ii	$E = [0.25 - (2.24 - 2.20)] \times 10^{-11} \text{ (J) or } 0.21 \times 10^{-11} \text{ (J)}$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{0.21 \times 10^{-11}} \text{ (Any subject)}$ $\lambda = 9.5 \times 10^{-14} \text{ (m)}$	C1 C1 A1	Allow 2 marks for 6.9×10^{-14} ; $E = 0.29 \times 10^{-11}$ used Allow 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. $8(.0) \times 10^{-14}$ for $E = 0.25 \times 10^{-11}$ and $5(.0) \times 10^{-13}$ for $E = 0.04 \times 10^{-11}$)
		iii	Used in PET (scans) Any <u>one</u> from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	M1 A1	Enter text here.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
41	a		superscripts 1,60,0 subscripts 0,28,-1 $\bar{\nu}_{(e)}$ (nu-bar)	B1 B1 B1	recognisable correct symbol required If superscripts and subscripts included, both must be 0 Examiner's Comments The correct symbol for the 'one other particle' in this question was $(\bar{\nu})$, $(\bar{\nu}_{e-})$ or $(\bar{\nu}_0)$, all being acceptable. Exemplar 2 ${}^{59}_{27}\text{Co} + {}^1_0\text{n} \rightarrow {}^{60}_{27}\text{Co} \rightarrow {}^{60}_{28}\text{Ni} + {}^0_{-1}\text{e} + \bar{\nu}_{(e)} + 2\gamma \quad [3]$ Exemplar 2 illustrates the two most common problems that were encountered in this response.  AfL Centres should give candidates plenty of practice in balancing equations that involve beta minus decay.
	b	i	Beta radiation would not penetrate/ would be absorbed by the lead	B1	Not gamma radiation would be stopped Ignore reference to alpha radiation Examiner's Comments Most candidates were obviously very familiar with this and gave a clear response. Credit was given for either Gradient of best fit line: - a clear comparison of $\ln N = -\mu d + \ln N_0$ with $y = mx + c$ - using log rules to give $\ln(N_0 e^{-\mu d}) = -\mu d + \ln N_0$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$\ln N = -\mu d + \ln N_0$ compared to $y = mx + c$ (so $m = -\mu$ and $c = \ln N_0$)	B1	or $\ln N = \ln(N_0 e^{-\mu d}) = \ln N_0 - \mu d$ Examiner's Comments Candidates who gained the uncertainty mark mostly used the standard method of finding half the range i.e. $(\ln 340 - \ln 260)/2$. However, a very common response was to calculate the fractional uncertainty in N (i.e. $40/300$) rather than the absolute uncertainty in $\ln N$. This was not given without mathematical justification e.g. $\Delta(\ln N) \approx (\Delta N)/N$.
		iii	5.70 ± 0.14	B1 B1	Both answers must be to 2d.p. Allow ± 0.13 not second B1 mark without correct working shown e.g. $\ln 300 - \ln 260$ or $(5.83 - 5.56)/2$ Allow $\Delta N/N (= 40/300)$ but only if $\Delta(\ln N) \approx \Delta N/N$ is quoted Examiner's Comments The majority of candidates had no difficulty in plotting the point (50, 5.70) correctly. Both best and worst fit lines were usually drawn well enough, although some had very thick pencil lines and a surprising number had not been extended to the $\ln N$ axis. Almost all candidates gained the mark for using a sufficiently large triangle ($\Delta d > 25\text{mm}$) for calculating the gradient of their best fit line.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	Point plotted correctly to within $\frac{1}{2}$ small square Best fit and worst fit line(s) drawn	B1 B1	Ignore accuracy of length of error bar ECF (ii)2 for incorrect value(s) in table ECF (ii)2 for incorrect value(s) in table Best fit line should have an equal scatter of points about the line Worst fit line should be steepest/shallowest possible line that passes through <u>all</u> the error bars (allow $\pm\frac{1}{2}$ small square tolerance vertically) Examiner's Comments Most mathematically able candidates quickly obtained the result $\mu d^{1/2} = \ln 2$ and then used it with their value of μ. Other candidates used a variety of (usually correct) graphical methods with Fig. 2.2.
		v	gradient of best fit line = (-) $\mu = (-) 54 \text{ (m}^{-1}\text{)}$ large triangle used to determine gradient of best fit line calculation of absolute uncertainty using <u>their</u> values in the formula ($\text{wfl gradient} - \text{bfl gradient}$) uncertainty and value of μ to same number of dp	B1 B1 B1 B1	Allow 51 to 56 Allow value of μ up to 4 SF ECF(ii)3 for wrongly plotted point $\Delta d > 25\text{mm}$ (seen from graph or working) ECF (ii)3 for worst fit line Ignore any POT error in gradients Allow value of absolute uncertainty up to 3 SF only e.g. 53.4 ± 5.6 or 54 ± 6

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		vi	$\mu d_{1/2} = \ln 2$ (or 0.693) $d_{1/2} = 0.013$ (m)	C1 A1	ECF (ii)4 for $\frac{1}{2}$ <u>Alternative method:</u> $\ln(N_0/2) = 7.67$ (C1) then use of graph to give $d_{1/2} = 0.013 \pm 0.001$ (m) (A1)
			Total	15	
42			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
43		i	Electron and (electron) antineutrino	B1	Allow beta-minus (particle) / β^-; $\bar{\nu}_{(e)}$ Allow anti electron neutrino Examiner's Comments The majority of the candidates scored a mark for electron and antineutrino as the two leptons. The most common incorrect answers were <i>neutrino</i>, <i>positron</i>, <i>proton</i> and <i>neutron</i>. The pairing of electron and positron also appeared on some scripts.
		ii	$\lambda = \ln 2/49$ or $\lambda = 0.0141$ (billion y^{-1}) $0.95 = e^{-0.0141t}$ or $0.95 = e^{-4.48 \times 10^{-19}t}$ (age = $-\ln(0.95)/0.0141$) age = 3.6 (billion years)	C1 C1 A1	Allow $\frac{\ln 2}{49 \times 10^9 \times 3.16 \times 10^7}$ or $4.48 \times 10^{-19} \text{ (s}^{-1}\text{)}$ Allow both C1 marks for $\ln(0.95) = \ln(0.5) \times t/49$ Allow $0.05/0.0141 \approx t$ (this gives 3.5.. for the final mark) Note age in seconds is $1.15 \times 10^{17} \text{ (s)}$; this will score 2 marks Examiner's Comments Many of the top-half candidates demonstrated how the age of the Earth could be calculated in just a few lines. The use of natural logs (ln) was faultless. Most candidates calculated the decay constant and then used the equation $0.95 = e^{-\lambda t}$, or its equivalent $\ln 0.95 = -\lambda t$, to calculate the age t. Candidates are reminded not to round numbers in long calculations – it is good practice to keep all the digits on your calculator. A significant number of candidates rounded the decay constant to 2 SF (0.014 billion y^{-1}), and this gave an answer of 3.7 billion years. The correct answer, without rounding $\ln 2/49$, was 3.6 billion years. On this occasion, examiners allowed the 3.7 billion years answer. The command term 'estimate' in the question made a small number of candidates to use the equation $\frac{\Delta N}{\Delta t} \approx -\lambda t$. This was allowed, and it gave an estimated age of 3.5 billion years.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					 Misconception These were some common errors being made in this question, these are summarised below. • Incorrect conversion of billion years into seconds. (Most candidates calculated the decay constant in billion year⁻¹, which easily led to the correct answer in billion years.) • Using ln0.05 instead of ln0.95 when calculating the age of the Earth.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
44	a	i	Too many N / neutrons	B1	Allow 'neutron-rich' or (for stability) neutron changes to proton or (for stability) charge increases / Z changes to 8 Allow too few protons / 'proton-poor' <u>Examiner's Comments</u> This question required analysis of the information provided in Fig. 21. Most candidates scored a mark for either recognising that the isotope had too many neutrons or a neutron had to decay into a proton in order to provide stability.
		ii	Too few N / neutrons	B1	Allow 'neutron-poor' or (for stability) proton changes to neutron or (for stability) charge decreases / Z changes to 6 Allow too many protons / 'proton-rich' <u>Examiner's Comments</u> A range of answers were allowed in this question requiring analysis of Fig. 21. Most candidates scored a mark for either recognising that the isotope had too few neutrons or a proton had to decay into a neutron in order to provide stability.
	b	i	More neutrons produced (from each fission reaction) Go on to produce further (fission) reactions / splitting (of nuclei) / energy	B1 B1	<u>Examiner's Comments</u> Most candidates scored 1 mark for the general idea of a chain reaction, but the important role played by the neutrons was often omitted in the descriptions. Only a small number of candidates misunderstood fission as a reaction in which the Cs and Rb nuclei themselves were responsible for triggering subsequent reactions of the uranium nuclei.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Control rod(s) used	B1	Allow boron / cadmium / indium / silver Not moderator
			These absorb the neutrons (without fission)	B1	Not neutrons slowed down and/or stopped <u>Examiner's Comments</u> The mechanism of preventing uncontrolled chain reaction within a nuclear reactor was generally well understood. Having given perfect answers with control rods absorbing the excess neutrons, a significant number of candidates confusing their answers by also mentioning the moderator. It many cases it was impossible for examiners to decide from the candidates response if the control rods, or the moderators, were responsible for preventing chain reactions. Some candidates mentioned 'boron rods', this was an acceptable alternative for the 'control rods'.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$(\Delta m =) 0.190 \times 1.66 \times 10^{-27} \text{ or } 3.15 \times 10^{-28} \text{ (kg)}$ $(\Delta E =) 0.190 \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$ $\text{or } 2.84 \times 10^{-11} \text{ (J)}$ $\frac{1.00}{0.235} \times 6.02 \times 10^{23} \text{ or } 2.56 \times 10^{24}$ $(\text{energy} = 0.03 \times 2.56 \times 10^{24} \times 2.84 \times 10^{-11})$ $\text{energy} = 2.2 \times 10^{12} \text{ (J)}$	C1 C1 C1 A1	Note the 3.0% can be done at any stage, allow other correct methods Allow the use of 1.67×10^{-27} Allow ECF from 1.66×10^{-27} omitted Note 7.69×10^{22} will score this C1 mark; 3.0% included Allow 3 marks for $7.3 \times 10^{13} \text{ (J)}$; 3.0% omitted Allow 3 marks for $1.3 \times 10^{39} \text{ (J)}$; 1.66×10^{-27} omitted Examiner's Comments This proved to be an excellent discriminator with top end candidates showing excellent skills to get to the correct answer of $2.2 \times 10^{12} \text{ J}$. The majority of the candidates correctly converted the 0.19u into kilograms, and then successfully used Einstein's mass-energy equation to calculate the equivalent energy of $2.8 \times 10^{-11} \text{ J}$. The main obstacle in this question was the determination of the number of uranium nuclei in the fuel rods. Avogadro constant, given in the data booklet, was either omitted or the incorrect mass used to determine the number of uranium nuclei.  Misconception There were some missed opportunities, with some candidates making the following mistakes when determining the number of uranium nuclei in the 1.0 kg fuel rod. - Using $0.235 \times N_A$ to calculate the number of uranium nuclei. - Using the rest masses of neutrons and protons. - Omitting the 3.0%.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
45			C	1	
			Total	1	
46		i	(decay constant =) $\frac{\ln 2}{5700}$ decay constant = $1.2(2) \times 10^{-4} \text{ (y}^{-1}\text{)}$	C1 A0	
		ii	$0.78 = e^{-\lambda t}$ $\ln 0.78 = (-) 1.2 \times 10^{-4} \times t$ age = 2100 (y)	C1 C1 A1	Note $1 = 0.78e^{-\lambda t}$ is XP; answer is negative ($- 2100 \text{ y}$) There is no ECF from (b)(i) Note 1.22×10^{-4} gives an answer of 2040 y or 2000 y
		iii	The ratio (of carbon-14 to carbon-12) has remained constant	B1	
			Total	5	
47			A	1	
			Total	1	
48			(energy =) $9.11 \times 10^{-31} \times (3.0 \times 10^8)^2$ (energy =) $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 / 1.60 \times 10^{-19}$ $\lg 1.0(2) \times 10^6 = 6$ (as on graph) OR (energy =) $1.0 \times 10^6 \text{ (eV)}$ or $\lg 1.0 \times 10^6 = 6$ (from graph) (energy =) $1.6 \times 10^{-13} \text{ J}$ and evidence of mc^2 $2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^8)^2 \approx 1.6 \times 10^{-13}$	B1 B1 B1 B1 B1 B1	Note this is $8.2 \times 10^{-14} \text{ (J)}$ Note this is $1.0(2) \times 10^6 \text{ eV}$ Note this can be shown in a variety of ways
			Total	3	

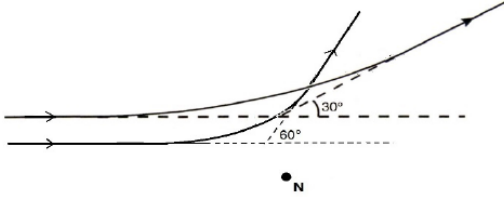
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
49	a		Electrons and quarks identified as fundamental particles There are 6 electrons, 6 protons and 8 neutrons Composition of proton → u u d Composition of neutron → u d d	B1 B1	Allow e for electron, p for proton, and n for neutron throughout Allow 6 electrons, 20 u and 22 d Do not award this mark if electron has quark-composition Allow '2 up and 1 down' Allow '2 down and 1 up'

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	b	Level 3 (5–6 marks) Some description and clear analysis for $r \propto A^{1/3}$ and correct calculation of mean density <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and some analysis for $r \propto A^{1/3}$ or some calculation of mean density OR Some description and clear analysis for $r \propto A^{1/3}$ OR Some description and correct calculation of mean density OR Clear analysis for $r \propto A^{1/3}$ and correct calculation of mean density <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Some description OR Limited analysis for $r \propto A^{1/3}$ OR Limited calculation of mean density <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit	B1×6	Indicative scientific points may include: Description - The density is independent of A - The density is constant for most of d - Nucleus with bigger A is larger (d / volume / mass) Analysis for $r \propto A^{1/3}$ $r \approx 3.6 (\times 10^{-15} \text{ m})$ for Al-27 / $r \approx 5.5 (\times 10^{-15} \text{ m})$ for Mo-96 / $r \approx 7.0 (\times 10^{-15} \text{ m})$ for Hg-200 $r/A^{1/3} = \text{constant}$ (or equivalent) - Evidence for $r \propto A^{1/3}$ with at least 2 nuclei (Note: $3.6 (\times 10^{-15})/27^{1/3} \approx 5.5 (\times 10^{-15})/96^{1/3} \approx 7.0 (\times 10^{-15})/200^{1/3} \approx 1.2 (\times 10^{-15})$) or $r^3/A = \text{constant}$ (or equivalent) - Evidence for $r^3 \propto A$ with at least 2 nuclei (Note: $3.6^3 (\times 10^{-45})/27 \approx 5.5^3 (\times 10^{-45})/96 \approx 7.0^3 (\times 10^{-45})/200 \approx 1.7 (\times 10^{-45})$) Calculation for density $\rho = M/V$ $\rho = Am_n \div \frac{4}{3}\pi r^3$ or $\rho \approx Am_n \div \text{diameter}^3$ $m_n \approx 1.7 \times 10^{-27} \text{ (kg)}$; $\rho \approx 2.3 \times 10^{-17} \text{ (kg m}^{-3}\text{)}$ for at least one of the nuclei given in the figure or table
		Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
50				B1 B1	Path is initially horizontal and further up the page than original Path <u>ends</u> at 30° to horizontal (angle must be labelled) in the direction shown <u>Examiner's Comments</u> The common errors here were: • not realising that, for the particle to be deflected through a smaller angle, it needed to be travelling further away from N • not labelling the final angle of 30° • not adding arrows to show the direction of travel • drawing a path that continued bending beyond the stated 30° (usually ending up parallel to the original path).
			Total	2	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
51	Level 3 (5 – 6 marks) Clear expansion of three statements <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.</i> Level 2 (3 – 4 marks) Clear expansion of two statements or Limited attempt at all three <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Limited attempt at one or two statements <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2⁺ for 3 marks, etc. Indicative scientific points may include: statement 1 • fusion reactions are occurring • which change H into He • and mass is lost which releases energy • energy released = $c^2 \Delta m$ • Δm per second = luminosity / c^2 statement 2 • average k.e. of each proton is $\frac{3}{2}kT$ • high T means protons are travelling at high speed • so fast enough to overcome repulsive forces • and get close enough to fuse • p.e. = $e^2/4\pi\epsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\epsilon_0 r$ • r is approximately 3fm statement 3 • k.e. $\propto T$ so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse • but M-B distribution applies so at the high energy end there will be a few p with enough energy • quantum tunnelling across potential barrier is possible • small probability of many favourable collisions to boost energy of p • 4 p must fuse to produce He; it is complicated process making probability of fusion much less • number of p in Sun is so huge that, even with such a small probability, 4×10^9 kg of p still interact s^{-1} • a larger probability means lifetime of the Sun would be shorter

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Examiner's Comments This was one of the two LoR questions. It required understanding of fusion, mass-energy equivalence, the Maxwell-Boltzmann distribution, and the relationship between mean kinetic energy and temperature for particles in an ideal gas. Responses to the following questions were being sought: 1. Why is the Sun losing mass? 2. Why is an extremely high temperature needed for fusion in stars? 3. Why does fusion occur in the Sun even though its temperature is 1,000 times less than that required by theory? Two dissimilar responses could score comparable marks if the criteria set out in the answer section of the marking scheme were met. Level 3 responses gave a clear answer to all three of the questions, whereas Level 2 responses generally had clear answers to only two. In Level 1, limited answers to only one or two of the above questions were given.
			Total	6	
52			$Q = 79e$ and $q = 2e$ $F = (1/4\pi\epsilon_0)Qq/r^2$ $= 79 \times 2 \times (1.6 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (6.8 \times 10^{-14})^2]$ $= 7.9 \text{ (N)}$	C1 C1 C1 A1	Apply ECF for wrong charge(s), e.g. Q and / or $q = e$, or $Q = 79$ and / or $q = 2$, etc Examiner's Comments The most common error here was to use incorrect values for the charges on the two ions. Even so, most candidates were able to gain most of the marks with ECF.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
53		i	(force =) $\frac{(1.6 \times 10^{-19})^2}{4\pi\epsilon_0 \times (1.0 \times 10^{-15})^2}$ (F =) 230 (N) $F^2 = 230^2 + 230^2 - 2 \times 230 \times 230 \times \cos 120^\circ$ or $F = 2 \times 230 \cos 30^\circ$ F = 400 (N)	C1 C1 C1	Special case: $F = \frac{Qq}{4\pi\epsilon_0 r^2} = \frac{2 \times 1.6 \times 10^{-19}}{4\pi\epsilon_0 \times (1.0 \times 10^{-15})^2}$ loses this C1 mark, then ECF for the rest of the marks Not the first two C1 marks for incorrect charge, then allow ECF for the final C1A1 marks Note force to 4 SF is 230.2 N Allow sine rule / scale drawing Allow this mark for 230cos30° or 200 (N) Allow ± 10 (N) if scale drawing used
		ii	F / arrow vertical up the page	B1	Allow correct arrow direction anywhere on the figure
		iii	Strong (nuclear) force (acts on the protons) The strong (nuclear) force is attractive	B1 B1	Ignore gravitational force Allow pulls / holds (the protons) / binds (the protons) for 'attractive'
			Total	7	
54			B	1	
			Total	1	