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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Nuclear and particle physics (6.4)

A Level Physics A (H556) · Module 6: Particles and medical physics

54 questions · 280 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions run from the lowest mark tariff to the highest, so similar questions sit together.

Click any row below to jump straight to that question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTION	SOURCE	MARKS	PAGE
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QUESTIONS

54 questions · 280 marks · lowest tariff first



MULTIPLE-CHOICE QUESTIONS

29 questions in this booklet



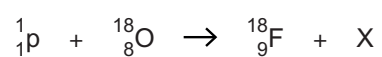
10 Which statement is correct?

- 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]

- 12 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]

14 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]

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15 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]

SECTION B

Answer **all** the questions.



- 10 A coil with 500 turns is placed in a uniform magnetic field.
The average cross-sectional area of the coil is $3.0 \times 10^{-4} \text{ m}^2$.
The magnetic flux through the plane of the coil is reduced from $1.8 \times 10^{-4} \text{ Wb}$ to zero in a time t .
The average electromotive force (e.m.f.) induced across the ends of the coil is 0.75 V .

What is the value of t ?

- A $3.6 \times 10^{-5} \text{ s}$
B $2.4 \times 10^{-4} \text{ s}$
C 0.12 s
D 8.3 s

Your answer

[1]

11 The magnetic flux through the plane of a coil of 100 turns is reduced from $1.8 \times 10^{-4} \text{ Wb}$ to zero in a time t . The average electromotive force (e.m.f.) induced across the ends of the coil is 0.75 V .

11 The radius of a gold nucleus with 197 nucleons is $7.3 \times 10^{-15} \text{ m}$.

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]

- 9 A student is modelling the decay of a radioactive source using the equation $\Delta N/\Delta t = -0.5N$. 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]



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

What is the change in mass in this fusion reaction?

A $7.1 \times 10^{-36} \text{ kg}$

B $7.1 \times 10^{-30} \text{ kg}$

C $2.1 \times 10^{-21} \text{ kg}$

D $4.4 \times 10^{-17} \text{ kg}$

Your answer

[1]

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12 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]

- 13 The nucleus of thorium-232 (${}^{232}_{90}\text{Th}$) emits two alpha particles and two beta-minus particles to become a nucleus of an isotope of radium.

What is the nucleon number A and the proton number Z for the nucleus of this radium isotope?

A $A = 224, Z = 88$

B $A = 228, Z = 86$

C $A = 224, Z = 84$

D $A = 228, Z = 88$

Your answer

[1]

- 15** A radiation detector is placed in front of a beta-emitting source. The count-rate is measured and recorded every 10 minutes. The results are shown below.

 311 s^{-1} 309 s^{-1} 299 s^{-1} 307 s^{-1} 321 s^{-1}

What term can be used to describe the data shown?

- A** exponential
- B** linear
- C** random
- D** spontaneous

Your answer

[1]

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Turn over

SECTION B

Answer **all** the questions.



- 2 The half-life of fluorine-18 isotope is T .
After time $t = 4T$ the number of fluorine-18 nuclei in a source is N .

How many fluorine-18 nuclei have decayed in the time interval from $t = 0$ to $t = 4T$?

- A** $3N$
B $4N$
C $15N$
D $16N$

Your answer

[1]

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- 3 The activity of an alpha-emitting source is 120 kBq. The kinetic energy of each alpha-particle is 4.0 MeV.

What is the rate of energy released by the source?

A $6.4 \times 10^{-13} \text{ W}$

B $4.8 \times 10^{-8} \text{ W}$

C $7.7 \times 10^{-8} \text{ W}$

D $1.2 \times 10^5 \text{ W}$

Your answer

[1]



4 Which of the following statement(s) correctly describe radioactive decay?

- 1 Radioactive decay can be modelled using dice.
- 2 Radioactive decay of nuclei is random.
- 3 Radioactive decay of nuclei is spontaneous.

A Only 1

B Only 2

C 2 and 3

D 1, 2 and 3

Your answer

[1]

- 5 A gamma-ray photon of frequency $6.76 \times 10^{22} \text{ Hz}$ creates a particle-antiparticle pair. The particle-antiparticle pair have zero kinetic energy.

What is the mass of the particle?

A $2.49 \times 10^{-28} \text{ kg}$

B $4.98 \times 10^{-28} \text{ kg}$

C $7.47 \times 10^{-20} \text{ kg}$

D $4.48 \times 10^{-11} \text{ kg}$

Your answer

[1]

- 13 The mass of a proton is m_p , the mass of a neutron is m_n , and the mass of a hydrogen-3 (${}^3_1\text{H}$) nucleus is M . The speed of light in a vacuum is c .

Which expression is correct for the binding energy (B.E.) of the hydrogen-3 nucleus?

- A B.E. = $M \times c^2$
- B B.E. = $(m_n + m_p - M) \times c^2$
- C B.E. = $(m_n + 2m_p - M) \times c^2$
- D B.E. = $(2m_n + m_p - M) \times c^2$

Your answer

[1]

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Turn over



3 Which of these statements is/are true?

- 1 Antiprotons are hadrons so are subject to the strong nuclear and weak nuclear forces.
- 2 Neutrons are subject to the weak nuclear force only.
- 3 The weak nuclear force is the only force that causes a change of quark type.

- A** 1, 2 and 3
- B** Only 1 and 2
- C** Only 1 and 3
- D** Only 3

Your answer

[1]

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6 Technetium-99m (Tc-99m) is a metastable isotope used in medical diagnosis.

Which ionising radiation does Tc-99m emit?

- A alpha
- B beta-minus
- C beta-plus
- D gamma

Your answer

[1]

- 9 The centres of a positron and a helium nucleus are separated by 2 mm.

What is the electrostatic force between them?

- A** $1.15 \times 10^{-28} \text{ N}$
- B** $2.30 \times 10^{-25} \text{ N}$
- C** $5.75 \times 10^{-23} \text{ N}$
- D** $1.15 \times 10^{-22} \text{ N}$

Your answer

[1]

13 In the Rutherford scattering experiment alpha particles are directed at a gold foil.

Gold nuclei have 79 protons. The distance of closest approach is 47.0 fm.

Which is the best estimate of the work done on an alpha particle as it moves from 53.0 fm to the point of closest approach?

A 10^{-18} J

B 10^{-16} J

C 10^{-15} J

D 10^{-13} J

Your answer

[1]

2 A neutrino is a fundamental particle.

Which row of the table correctly describes a neutrino?

	Classification	Force felt
A	hadron	strong nuclear
B	hadron	weak nuclear
C	lepton	strong nuclear
D	lepton	weak nuclear

Your answer

[1]



7 This question is about the rate of decay of a radioactive source.

Which of the following statements is/are true?

The rate of decay is

- 1 dependent on the decay constant.
- 2 independent of the mass of the source.
- 3 dependent on time.

A 1 only

B 1 and 3

C 2 only

D 2 and 3

Your answer

[1]

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12 What is the radius of a carbon nucleus that has 6 protons and 7 neutrons?

Assume that the average radius of a nucleon r_0 is 1.2 fm.

A 2.2 fm

B 2.3 fm

C 2.8 fm

D 1.6 fm

Your answer

[1]

13 A sub-atomic particle has a positive charge.

Which type of particle is it?

- A** anti-proton
- B** down quark
- C** neutrino
- D** positron

Your answer

[1]

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Turn over



2 What is a reasonable estimate for the diameter of an atom?

A 10^{-15}m

B 10^{-12}m

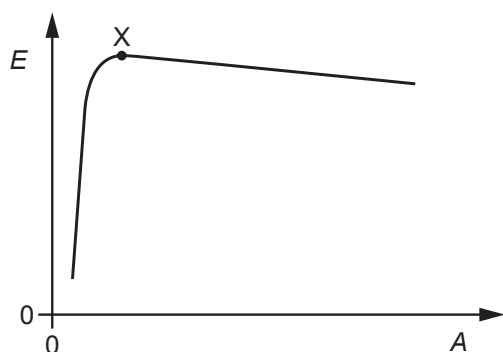
C 10^{-10}m

D 10^{-7}m

Your answer

[1]

- 3 The graph below shows the binding energy per nucleon, E , for nuclei of different nucleon number, A .



Which of the following statement(s) correctly describe nuclear processes?

- 1 Fission of nuclei to the right of X releases energy
- 2 Fusion of nuclei to the left of X releases energy
- 3 Fission of nuclei to the right of X can happen spontaneously

A Only 1

B Only 2

C Only 2 and 3

D 1, 2 and 3

Your answer

☐

[1]

- 5 An isotope has a half-life of 243 years.

One sample of this isotope has activity A_1 .

A second sample of the same isotope has activity A_2 .

What is the ratio: $\frac{\text{mass of isotope in first sample}}{\text{mass of isotope in second sample}}$?

A $243 \frac{A_1}{A_2}$

B $\frac{A_1}{243}$

C $\frac{A_1}{A_2}$

D $\frac{A_2}{243}$

Your answer

[1]



6 A student wants to determine the count-rate from a **beta-emitting** source in the laboratory.

Which procedure would be the best to determine the count-rate?

- A Measure the counts over a long period of time
- B Place the radiation detector (Geiger tube) about 1 metre away from the source
- C Place the source close to a very strong magnet
- D Place the source inside a lead box when measuring the counts

Your answer

[1]

- 9 The radius R of the nucleus of an unknown isotope with nucleon number is calculated using the formula

$$R = r_0 A^{1/3}, \text{ where } r_0 \text{ is a constant.}$$

The percentage uncertainty in r_0 is $\pm 5\%$.

The percentage uncertainty in A is $\pm 3\%$.

What is the percentage uncertainty in R ?

A $\pm 2\%$

B $\pm 4\%$

C $\pm 6\%$

D $\pm 8\%$

Your answer

[1]



4-MARK QUESTIONS

1 question in this booklet



- 22** The medical tracer fluorine-18 is used in positron emission tomography (PET). Fluorine-18 is a beta-plus emitter with a short half-life.

Describe how the fluorine-18 nuclei are located in a patient using a PET scanner.

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..... [4]

7-MARK QUESTIONS

4 questions in this booklet



23 (a) Describe the nature of the *strong nuclear force*.

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..... [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.

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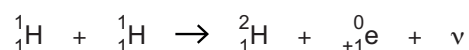
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..... [2]

24 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.

- (a)** 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)** 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]

20 Fig. 20 illustrates a device used to determine the relative abundance of charged rubidium ions.

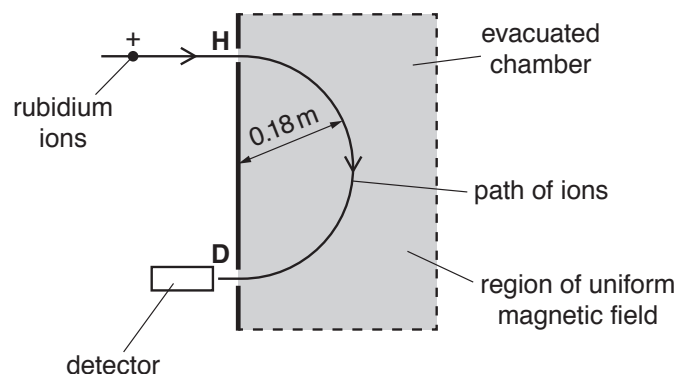


Fig. 20

A uniform magnetic field is applied to an evacuated chamber. The direction of the magnetic field is perpendicular to the plane of the paper.

A beam of positive rubidium ions enters the chamber through a hole at **H**. The ions travel in a semi-circular path in the magnetic field. The ions are detected at point **D**.

- (a) Each rubidium ion has charge $+1.6 \times 10^{-19} \text{ C}$ and speed $4.8 \times 10^4 \text{ ms}^{-1}$.
 The radius of the semi-circular path of the ions is 0.18 m.
 The mass of a rubidium ion is $1.4 \times 10^{-25} \text{ kg}$.

Calculate the magnitude of the magnetic flux density B of the magnetic field.

$B = \dots\dots\dots \text{ T [3]}$

- (b) 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]

- 25 (a)** A researcher is doing an experiment on a radioactive solution in a thin **glass** tube. The solution has two radioactive materials **X** and **Y**. The table below shows some data on these two materials.

	Material X	Material Y
Half-life	10 minutes	10 hours
Particles emitted	Alpha	Beta-minus
Daughter nuclei	Stable	Stable

The solution has the same number of nuclei of **X** and **Y** at the start.

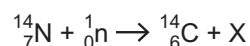
- (i)** State and explain which material has the greatest activity at the start.

.....
 **[1]**

- (ii)** State why it is dangerous for the researcher to handle the test tube with bare hands.

.....
 **[1]**

- (b)** Carbon-14 ($^{14}_6\text{C}$) is produced in the upper atmosphere of the Earth by collisions between nitrogen nuclei and fast-moving neutrons. The nuclear transformation equation below shows the formation of a single carbon-14 nucleus.



- (i)** State the proton number of particle X.

proton number = ... **[1]**

(ii) Use the data below to determine the binding energy per nucleon of the $^{14}_6\text{C}$ nucleus. Write your answer to **3** significant figures.

- mass of neutron = $1.675 \times 10^{-27} \text{ kg}$
- mass of proton = $1.673 \times 10^{-27} \text{ kg}$
- mass of $^{14}_6\text{C}$ nucleus = 14.000 u
- $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$

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



8-MARK QUESTIONS

4 questions in this booklet



- 23 (a)** 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 .

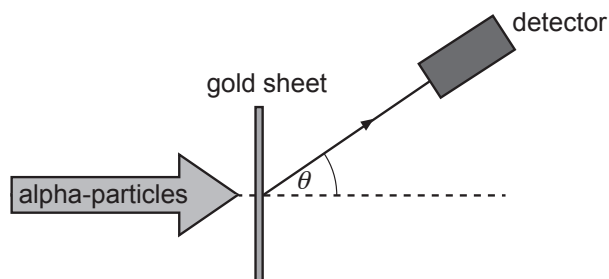


Fig. 23

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.

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..... [3]

- (b) A proton with kinetic energy 0.52 MeV is travelling directly towards a stationary nucleus of cobalt-59 ($^{59}_{27}\text{Co}$) in a head-on collision.

- (i) Explain what happens to the electric potential energy of the proton-nucleus system.

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..... [1]

- (ii) Calculate the **minimum** distance R between the proton and cobalt nucleus.

$$R = \text{..... m [3]}$$

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Additional answer space if required

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- 3 (a) In beta-plus decay, a proton decays into three other particles.

Write a nuclear equation for this process.

[2]

- (b)* A student, supervised by their teacher, carries out an experiment with three unlabelled radioactive sources.

The student is told that each source emits only one type of radiation. One emits gamma rays, one emits beta-minus particles and one emits beta-plus particles.

The student has the following equipment:

- a selection of materials with different thicknesses
- a strong magnet
- a radiation counter (GM tube and counter).

Explain how the student can use this equipment to determine safely which radiation each source emits.

You may use the space below to draw a diagram.

[6]

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Additional answer space if required

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9-MARK QUESTIONS

3 questions in this booklet



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

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

[2]

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

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]

- 24** 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.

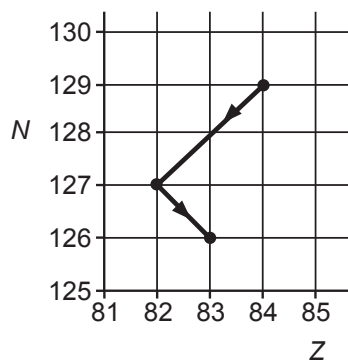
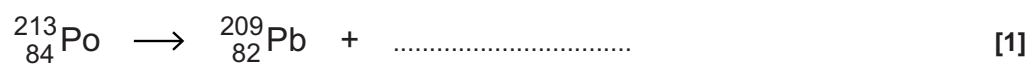


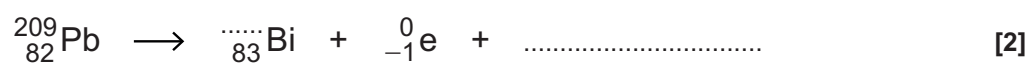
Fig. 24

- (a)** 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]

- 5 Large power stations generate an electrical power of about 1 GW.

Current methods of energy production that use nuclear fusion are unable to produce enough energy for large-scale energy production. A proposed method of controlling nuclear fusion is inertial confinement fusion (ICF). ICF uses a large number of powerful lasers to create the high temperatures required for nuclear fusion to occur.

One ICF experiment uses a network of capacitors to store the energy needed to power the lasers. When the network is fully charged:

- potential difference across the network = 24 kV
- total energy stored in the network = 400 MJ

- (a) (i) Calculate the total capacitance, C , of the network.

$C = \dots\dots\dots$ F [2]

- (ii) Explain why the individual capacitors in the network should be connected in parallel in order to produce this total capacitance.

.....
 [1]

- (b) The total stored energy must be released in a time of less than 1 millisecond.

Explain, using a calculation, why the lasers are powered by the network of capacitors instead of being connected directly to the mains electricity supply.

.....

 [2]

(c) The fusion reaction in the ICF experiment is

deuterium + tritium $\rightarrow$ alpha particle + neutron

Calculate the number of fusion reactions that must occur for the energy released by fusion to be equal to the electrical energy stored in the network of capacitors.

- mass of deuterium = 2.014102 u
- mass of tritium = 3.016049 u
- mass of alpha particle = 4.002603 u
- mass of neutron = 1.008665 u

number of fusion reactions = ... [4]

10-MARK QUESTIONS

4 questions in this booklet



- 21 (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.

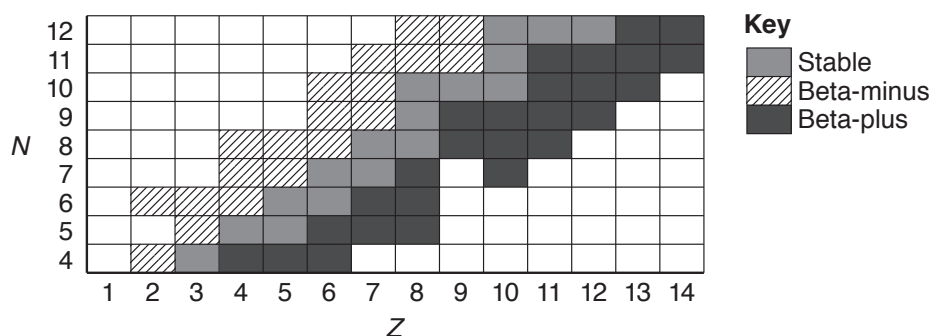


Fig. 21

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

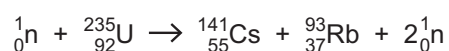
- (i) a beta-minus particle

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 [1]

- (ii) a beta-plus particle.

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 [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.

.....
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..... [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 = $0.235 \text{ kg mol}^{-1}$

$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$

energy = ... J [4]



- 20 (a) Deuterium is an isotope of hydrogen.
A nucleus of deuterium has a proton and a neutron.

Describe the nature and range of the **two** forces acting between these two hadrons.

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[4]

- (b)* Here is some data for a nucleus of carbon-14 ($^{14}_6\text{C}$) and a nucleus of uranium-235 ($^{235}_{92}\text{U}$).

	Carbon-14 nucleus	Uranium-235 nucleus
Decay mode	Beta-minus decay	Alpha decay
Mass of nucleus / u	14.0	235.0
Radius of nucleus / 10^{-15}m	2.9	7.4

Use the data to:

- describe the composition of the nuclei before and after the decay in terms of hadrons and quarks
- show that both nuclei have the same density.

[6]

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Additional answer space if required

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- 22** Radiographers commonly use molecules containing fluorine F-18 as tracers in positron emission tomography (PET) scanning.

Fluorine has a proton number of 9.

F-18 decays to oxygen (O) by β^+ decay.

- (a)** Write the equation for the decay of a nucleus of F-18 using nuclear notation.

[2]

- (b)** The β^+ particle (positron) produced travels only a short distance in the patient before it meets an electron and is annihilated.

Calculate the wavelength λ of gamma photons produced.

$\lambda = \dots\dots\dots$ m [3]

- (c)** X-rays and gamma-rays are produced by different physical processes.

Briefly describe both processes.

.....

 [2]

- (d)** F-18 has a half-life of 109.7 minutes.

Explain the advantage that this has for the patient but the disadvantage that this has for the radiographers.

.....

 [3]

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19

(a) Describe the difference between hadrons and leptons.

.....

.....

..... [2]

(b) An 'up' quark decays according to the equation below.

$$u \rightarrow d + {}^0_{+1}\text{e} + \nu$$

Give the name(s) of the lepton(s) in this equation.

..... [1]

(c) The above decay takes place within a nucleus of carbon-11. The half-life of this isotope of carbon is 1220 s.

A sample of carbon-11 has an activity of 800 Bq.

Calculate the activity, A , of this sample of carbon-11 after 5.0 minutes.

$A = \dots\dots\dots$ Bq [3]

(d) The particle with symbol ${}^0_{+1}\text{e}$ can annihilate with its anti-particle.

Describe a practical use of this process in medical imaging.

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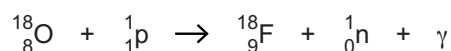
..... [4]

11-MARK QUESTIONS

2 questions in this booklet



- 25 (a) 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).

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

- (iii) Fluorine-18 is a positron emitter.
 Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

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 [2]

(b) Describe how the components of a computerised axial tomography (CAT) scanner can produce high-quality images of the internal structures of a patient.

[4]

24 (a) Fig. 24 shows two horizontal metal plates in a vacuum.

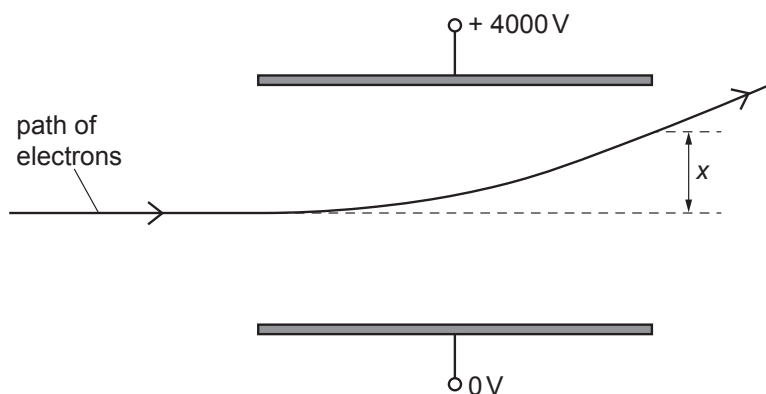


Fig. 24

The diagram is **not** drawn to scale.

Electrons travelling horizontally enter the space between the charged plates and are deflected vertically.

The potential difference between the plates is 4000 V.

The distance between the plates is 0.08 m.

The initial speed of the electrons is $6.0 \times 10^7 \text{ m s}^{-1}$.

The vertical deflection of the electrons at the far end of the plates is x .

(i) Show that the vertical acceleration a of an electron between the plates is $8.8 \times 10^{15} \text{ m s}^{-2}$.

[3]

(ii) The length of each plate is 0.12 m.

Show that the time t taken by the electron to travel this length is $2.0 \times 10^{-9} \text{ s}$.

[1]

(iii) Calculate the vertical deflection x of the electron.

$x = \dots\dots\dots$ m [2]

(b) The arrangement shown in **Fig. 24** is now used to investigate positrons emitted from a radioactive source.

The speed of the positrons is also $6.0 \times 10^7 \text{ ms}^{-1}$.

The initial path of the positrons is the same as that of the electrons in **Fig. 24**.

On **Fig. 24**, sketch the path of the positrons between the plates. [2]

(c) Beta-minus particles (electrons) emitted from a radioactive source have a range of speeds.

Describe and explain how a uniform magnetic field can be applied in the space between the charged plates to select beta-minus particles with a specific speed. No calculations are required.

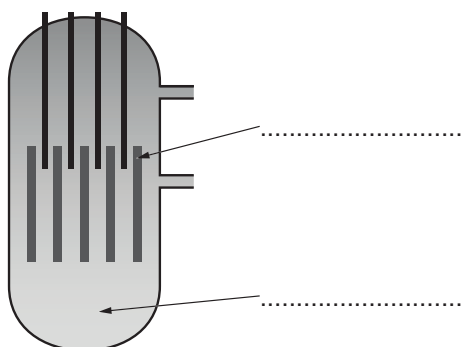
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..... [3]

12-MARK QUESTIONS

1 question in this booklet



- 21 The diagram shows a simplified layout of a nuclear fission reactor used in a nuclear power station.



- (a) Complete the labels on the diagram [2]

- (b)* Describe how fission of nuclei is induced and controlled in the nuclear reactor.

Show how fission leads to the release of large amounts of energy.

The following masses may be useful.

Particle	Mass / u
U-235 nucleus	235.04395
Ba-141 nucleus	140.91440
Kr-92 nucleus	91.92617
${}_0^1\text{n}$ neutron	1.00867

[6]

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Additional answer space if required

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- (c) The energy released from the fusion of 1 kg of hydrogen is more than seven times the energy released by the fission of 1 kg of uranium.

Compare the practicalities of using nuclear fusion of hydrogen with using nuclear fission of uranium to meet our energy needs.

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..... [4]

13-MARK QUESTIONS

2 questions in this booklet



3 This question is about a space probe which is in orbit around the Sun.

(a) Define **gravitational potential energy** of an object at a point in a gravitational field.

.....
 [1]

(b) The space probe has mass 810 kg. The orbital radius of the space probe is 1.5×10^{11} m. The orbital period of the space probe around the Sun is 3.16×10^7 s. The mass of the Sun is 2.0×10^{30} kg.

(i) Show that the magnitude of the gravitational potential energy of the space probe is about 7×10^{11} J.

[2]

(ii) Show that the kinetic energy of the space probe is half the value of your answer to (b)(i).

[3]

(iii) Calculate the total energy of the space probe.

total energy = ... J [1]

- (c) The power source for the instrumentation on board the space probe is plutonium-238, which provides 470 W initially.

Plutonium-238 decays by α -particle emission with a half-life of 88 years.
The kinetic energy of each α -particle is 8.8×10^{-13} J.

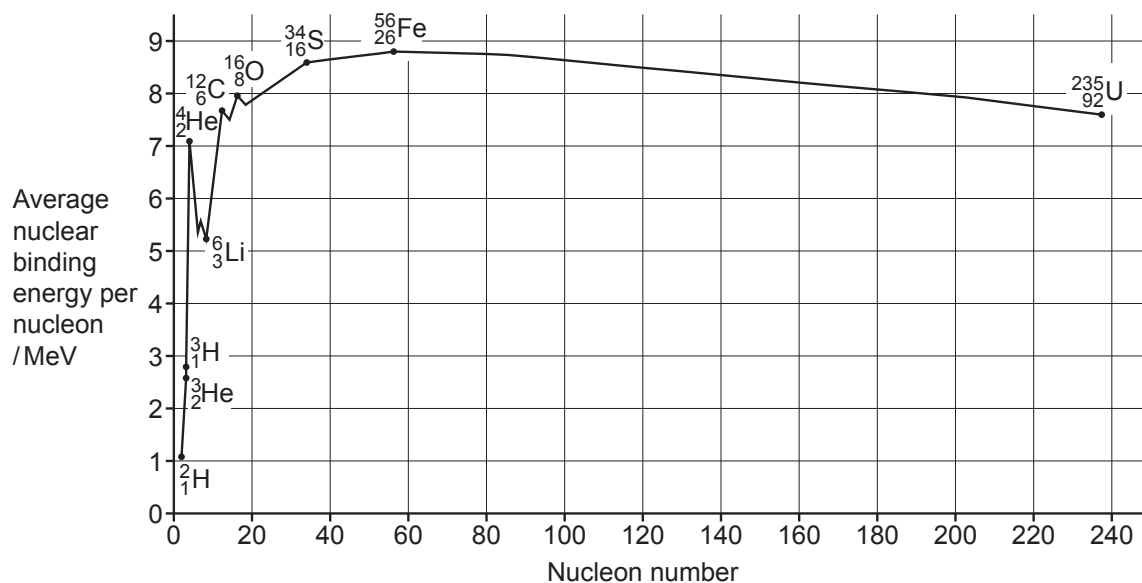
- (i) Calculate the number N of plutonium-238 nuclei needed to provide the power of 470 W.

$N = \dots\dots\dots$ [3]

- (ii) Calculate the power P still available from the plutonium-238 source 100 years later.

$P = \dots\dots\dots$ W [3]

- 20 The diagram below shows the average nuclear binding energy per nucleon for a number of different isotopes.



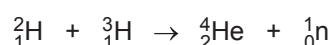
- (a) Explain what is meant by *nuclear binding energy* of a nucleus.

.....
 [1]

- (b) Suggest why the ^1_1H isotope of hydrogen has **not** been included on the above diagram.

.....
 [1]

- (c) The main nuclear fusion reaction in the Sun is between nuclei of deuterium (^2_1H) and tritium (^3_1H). This reaction can be written as shown below.



- (i) Explain why isotopes with low mass numbers, such as hydrogen, are those which undergo nuclear fusion.

.....

 [1]

- (ii) Use the diagram given at the start of this question to show that, for the reaction of deuterium and tritium, the energy released in each fusion event is approximately 3×10^{-12} J.

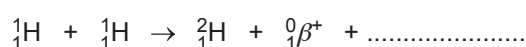
[3]

- (iii) The Sun's mass decreases by 4.3×10^9 kg every second. Assume that the mass loss is only due to this reaction.

Calculate the number of fusion events per second occurring in the Sun.

number of fusion events per second = ... s^{-1} [2]

- (d) In the Sun, deuterium (${}^2_1\text{H}$) is produced from fusion of two hydrogen (${}^1_1\text{H}$) nuclei, as shown below. There is a particle missing.



- (i) Determine the charge of the missing particle.

..... [1]

- (ii) The missing particle is a lepton. Name this lepton.

..... [1]

- (iii) In the fusion reaction above, determine the total number of up quarks at the **start** of the reaction.

..... [1]

- (e) Tritium (${}^3_1\text{H}$) is another isotope of hydrogen which is formed in stars. On the Earth, tritium is a radioactive element which decays by β^- emission.

Write down the equation for β^- decay in terms of quarks.

[2]

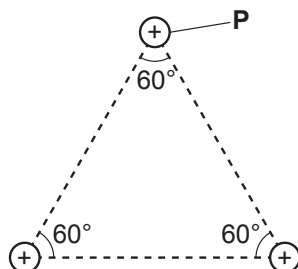
Turn over

14-MARK QUESTIONS

1 question in this booklet



- 23 (a)** 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 $1.0 \times 10^{-15}\text{m}$.

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

$F = \dots\dots\dots \text{N}$ [4]

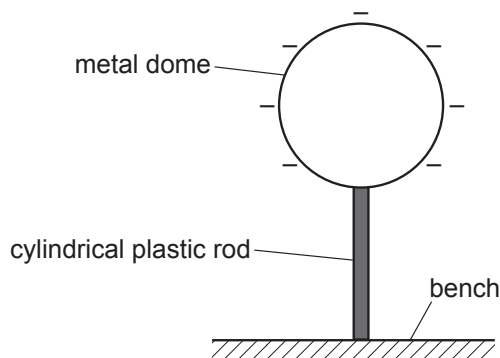
- (ii) On the diagram above, draw an arrow to show the direction of the electric force F experienced by **P**. [1]

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

.....

 [2]

- (b) A spherical metal dome shown below is charged to a potential of -12 kV .



The dome is supported by a cylindrical plastic rod. The radius of the dome is 0.19 m .

- (i) Show that the magnitude of the total charge Q on the dome is $2.5 \times 10^{-7}\text{ C}$.

[2]

- (ii) The dome discharges slowly through the plastic rod. It takes 78 hours for the dome to completely discharge.

- 1 Show that the mean current I in the plastic rod is about $9 \times 10^{-13}\text{ A}$.

[2]

- 2 The average potential difference across the plastic rod during discharge is 6000 V . The rod has cross-sectional area $1.1 \times 10^{-4}\text{ m}^2$ and length 0.38 m .

Calculate the resistivity ρ of the plastic.

$$\rho = \dots\dots\dots \Omega\text{ m} \text{ [3]}$$

Turn over

15-MARK QUESTIONS

2 questions in this booklet



- 2 $^{60}_{27}\text{Co}$ 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.

- (a) Complete the nuclear equations for these two processes.



- (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.

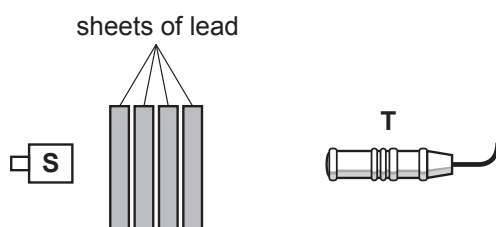


Fig. 2.1

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

Explain why this would not affect the experiment.

.....
 [1]

Question 2 continues on page 6

- (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	10	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]

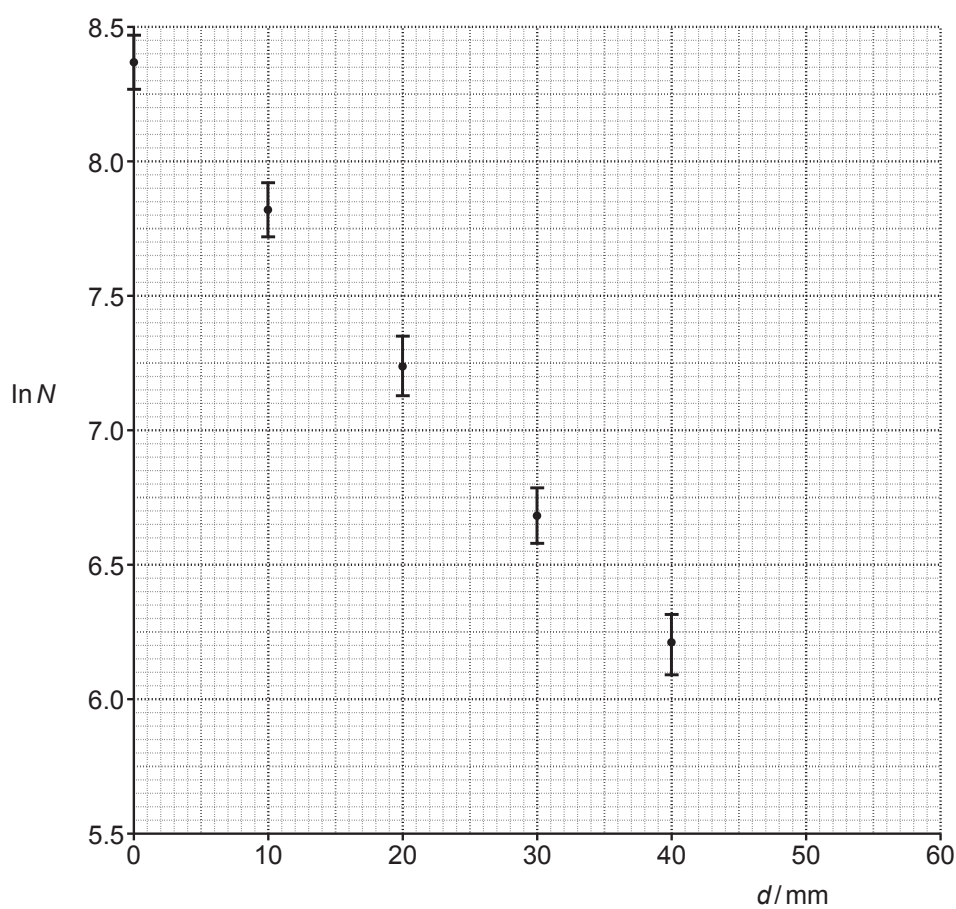


Fig. 2.2

Question 2 continues on page 8

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

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

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

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

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Question 3 begins on page 10.



- 21 (a) In the 1800s, the atom was considered to be a fundamental particle. It was an indivisible particle of matter. Modern physics shows that this idea is not correct.

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

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..... [4]

- (b) 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]

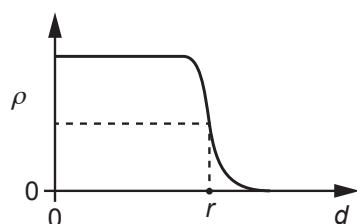
- (iii) State **one** assumption made in the calculation in (ii).

.....

..... [1]



(c)* A graph of the density ρ of a nucleus against distance d from the centre of the nucleus is shown below.



The radius of the nucleus r is taken as the distance d where the density is half the maximum density.

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

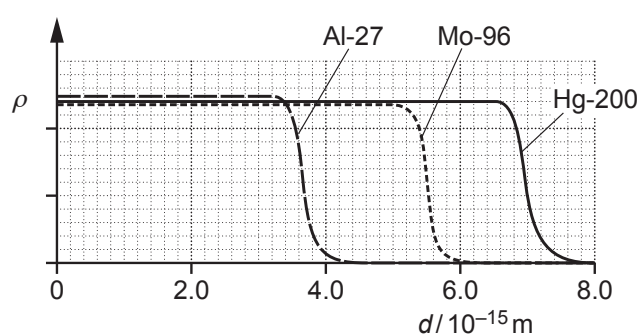


Fig. 21.1

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.

[6]

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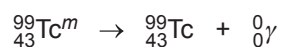
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16-MARK QUESTIONS

1 question in this booklet



- 21 Technetium-99m ($^{99}_{43}\text{Tc}^m$) is a metastable radioisotope which can be used as a tracer in medical diagnosis. It is injected into the body and decays by gamma emission into technetium-99 according to the following chemical equation.



(a)

- (i) Explain what is meant by a *tracer*.

.....
 [1]

- (ii) $^{99}_{43}\text{Tc}^m$ only emits gamma radiation.

Give **two** advantages of using a tracer which only emits gamma radiation.

1

 2
 [2]

(b)

- (i) A technetium-99m tracer with an activity of 900 MBq is injected into a body. The half-life of technetium-99m is 6.01 hours.

Calculate the number of technetium-99m nuclei initially present in the tracer.

number = ... [3]

- (ii) Calculate the time in hours taken for the activity of the tracer to have fallen to 3.0% of its initial activity.

time = ... hours [3]

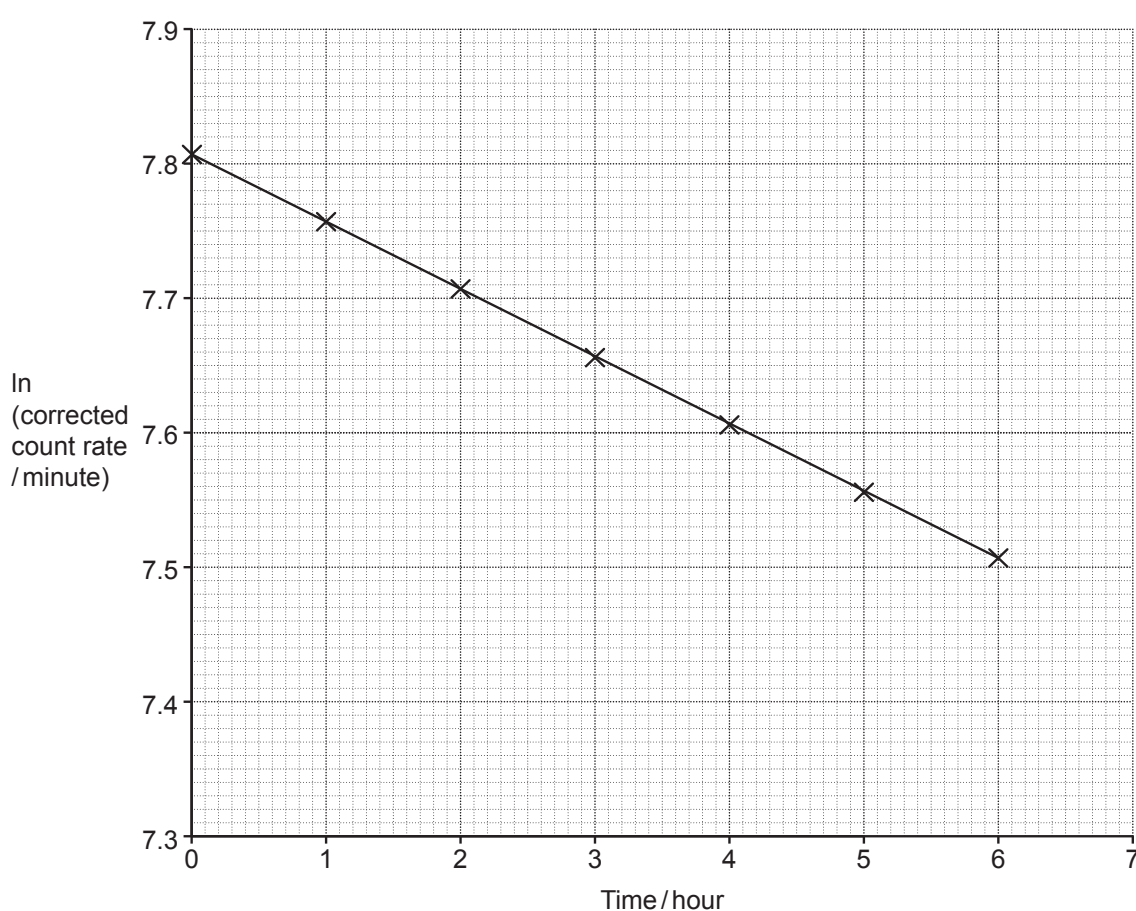
- (c) The daughter nucleus ($^{99}_{43}\text{Tc}$) decays by beta emission with a half-life of a little over 200 000 years. Approximately 50% of it is stored in the bones, and 50% is passed out of the body.

Suggest why the presence of this remaining $^{99}_{43}\text{Tc}$ in the body causes little additional risk to the patient.

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 [1]

- (d)* The half-life of a different radioisotope is to be determined using suitable apparatus. Each count represents one decay. The number of counts is measured for one minute every hour over a period of 6 hours. When the data has been collected, a graph of $\ln(\text{corrected count rate / minute})$ against time is plotted and shown below.



- Describe an appropriate method that could be used to obtain this data, naming any apparatus and safety precautions taken.
- Use the graph given above to determine the half-life of this radioisotope showing clear working.

[6]

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MARK SCHEMES

official OCR mark schemes



10	C		1	
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12	A		1	
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14	C		1	
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15	A	1	
	Total	15	

5

SECTION B

Question	Answer	Marks	Guidance
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10	C	1	
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11	B	1	
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9	C	1	
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10	B	1	
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12	A	1	
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13	A	1	
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15	C	1	
	Total	15	

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SECTION B

General rule: For substitution into an equation, allow any subject – unless stated otherwise in the guidance

Question	Answer	Marks	Guidance
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2	C		1	
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3	C		1	
---	---	--	---	--



4	D	1	
---	---	---	--



5	A		1	
---	---	--	---	--



13	D	1	
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3	C	1	
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6	D	1	
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9	D	1	
---	---	---	--



13	D	1	
----	---	---	--



2	D	1	
---	---	---	--



7	B	1	
---	---	---	--



12	C	1	
----	---	---	--



13	D	1	
----	---	---	--



2	C	1	
-	-	-	



3	D	1	
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5	C	1	
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6	A	1	
–	–	–	



9	C	1	
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22			The positrons / beta-plus particles <u>annihilate</u> electrons (within the patient)	B1	
			Two gamma-photons are produced	B1	Allow 'two gamma rays' instead of 'two gamma-photons'
			these (photons / rays) travel in opposite directions	B1	Allow gamma symbol
			The difference in the arrival times at the detectors is used to locate the point of annihilation / nuclei	B1	Allow delay time
			Total	4	

23	(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
	(b)	(i) proton = u u d or neutron = u d d	B1	
		(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 β^-
	(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
		Total	7	

24	(a)	${}^2_1\text{H}$ has two nucleons binding energy per nucleon = 1.1 <u>MeV</u> (per nucleon)	B1 B1	Allow 1.76×10^{-13} <u>J</u> (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
	(c)	$E = hc/\lambda$ and $E = mc^2$ 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
		Total	7	

20	(a)		$F = BQv$ and $F = mv^2/r$ or $B = mv/Qr$ (Any subject) $(B =) \frac{1.4 \times 10^{-25} \times 4.8 \times 10^4}{1.6 \times 10^{-19} \times 0.18}$ $B = 0.23$ (T)	C1 C1 A1	Allow e
	(b)	(i)	Electron and (electron) antineutrino	B1	Allow beta-minus (particle) / β^- ; $\bar{\nu}_{(e)}$ Allow anti electron neutrino
		(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 1.15×10^{17} (s); this will score 2 marks
			Total	7	

25	(a)	(i)	Material X because of the shorter half-life	B1	Must be comparative Allow explanation in terms of decay constant
		(ii)	(Alpha particles are stopped by the glass but) the beta-particles are not (AW)	B1	Allow symbols
	(b)	(i)	1	B1	
		(ii)	Either: mass of nucleus $14.000 \times 1.66 \times 10^{-27}$ $(= 2.324 \times 10^{-26} \text{ kg})$ Or: mass of nucleons $= 8 \times 1.675 \times 10^{-27} + 6 \times 1.673 \times 10^{-27}$ $(= 2.3438 \times 10^{-26} \text{ kg})$ $(\Delta m =) 2.3438 \times 10^{-26} - 2.324 \times 10^{-26} = (1.98 \times 10^{-28} \text{ kg})$ $(\Delta E =) 1.98 \times 10^{-28} \times (3.00 \times 10^8)^2$ (BE per nucleon $=) 1.782 \times 10^{-11}/14$ binding energy per nucleon $= 1.27 \times 10^{-12} \text{ (J per nucleon)}$	C1 C1 C1 A1	$\Delta m = 1.9262 \times 10^{-28} \text{ kg}$ Ignore sign throughout $\Delta E = 1.782 \times 10^{-11} \text{ J}$ Allow for any mass difference $\times (3.00 \times 10^8)^2$ Note A mark for correct answer to 3sf only
			Total	7	



25	(a)	The patient is surrounded by (gamma) detectors or Increased activity is where F-18 accumulates (AW) The positrons (from the F-18) <u>annihilate</u> electrons (inside the patient) Each annihilation produces two gamma photons travelling in <u>opposite</u> directions The arrival times are used to locate position (of increased activity)	B1 B1 B1 B1	Allow 'diametrically opposite detectors' Not gamma rays / radiation Allow 'delay time'
	(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
	(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	
		Total	8	



Question	Answer	Mark	Guidance
23 (a) (i)	$(N \text{ at } 15^\circ / N \text{ at } 150^\circ =) 10^{5.1} \div 10^{1.5} \text{ or } 10^{3.6} (\approx 4000)$	B1	
(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 ...
(b) (i)	Kinetic energy (of proton) changes to potential (energy) or Potential energy increases as the kinetic energy (of the proton) decreases or Potential energy increases as work is done against the field / against repulsion / positive charge	B1	Allow 'it' / PE for (electric) potential energy Allow KE / E_k
(ii)	energy = $0.52 \times 10^6 \times 1.60 \times 10^{-19}$ or $8.3(2) \times 10^{-14}$ (J) $\frac{1.60 \times 10^{-19} \times 27 \times 1.60 \times 10^{-19}}{4\pi\epsilon_0 R} = 8.32 \times 10^{-14}$ $R = 7.5 \times 10^{-14}$ (m)	C1 C1 A1	Allow 2 mark for 1.6×10^{-13} (m); Z = 59 used Allow 2 mark for 8.9×10^{-14} (m); Z = 32 used Allow 1 mark for 2.8×10^{-15} (m); Z = 1 used Allow 1 mark for 1.2×10^{-32} (m); energy = 5.2×10^5 used
	Total	8	

23	(a)	Control rods: absorb the <u>neutrons</u> (without further fission) Moderator: Slow down the <u>neutrons</u> / decrease KE of <u>neutrons</u>	B1 B1	Not collide for absorb
	(b)*	Level 3 (5–6 marks) Clear description and clear calculations of energy per kg <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) Clear description OR Clear calculations of energy per kg OR Some description and some calculations <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 description OR Limited calculations <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 • Energy is produced in both reactions • More energy produced (per reaction) in fission • The (total) binding energy of ‘products’ is greater • In fusion, nuclei repel (each other) • Fusion requires high temperatures / high KE • Fission reactions are triggered by (slow-)neutrons • Chain reaction possible in fission Calculations • 1 kg of uranium has 4.26 mols / 2.56×10^{24} nuclei • 1 kg of deuterium has 500 mol / 3.01×10^{26} nuclei / 1.50×10^{26} ‘reactions’ • $200 \text{ MeV} = 3.2 \times 10^{-11} \text{ J}$ • $4 \text{ MeV} = 6.4 \times 10^{-13} \text{ J}$ • Uranium: $\sim 10^{14} \text{ (J kg}^{-1}\text{)}$ (actual value 8.2×10^{13}) • Deuterium: $\sim 10^{14} \text{ (J kg}^{-1}\text{)}$ (actual value 9.6×10^{13}) • The energy per kg is roughly the same
		Total	8	

Question		Answer	Marks	Guidance
3	(b)*	Level 3 (5–6 marks) Detailed method and analysis which clearly distinguishes between gamma, beta-plus and beta-minus <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 method and analysis which clearly distinguishes between any two of the sources <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 method or limited analysis <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× 6	Use level of response annotations in RM Assessor Indicative scientific points may include: Method • Measure background count and subtract from source count • Clamp source pointing away from you • Safety precautions (handle source with tongs, limit time etc.) • Record count over fixed time period • Investigate variation of count rate with range • Place aluminium sheets between source and radiation counter • Set up magnetic field at right angles to emission direction in order to investigate deflection of charged particles • Move radiation counter to find direction of deflection Analysis • Gamma has longest range in air, beta minus and beta plus have similar range (or β^+ has shortest range due to annihilation in air) • Gamma penetrates aluminium <u>which is (more than a few mm) thick</u> whereas beta does not • Gamma is undeflected by magnet (because neutral) • Beta radiation is deflected by magnet (because charged particles) • Beta plus and beta minus are deflected in opposite directions • because they have opposite charges / beta plus particle is a positron and beta minus particle is an electron • Use Fleming's left-hand rule to determine charge on beta particle through the direction of its deflection • With beta-plus, current is in same direction as motion of particle (opposite for beta-minus)
		Total	8	



Question	Answer	Marks	Guidance
1	(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
	(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
	(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
	Total	9	

Question	Answer	Marks	Guidance
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24	(a)	(i)	alpha-particle / ${}^4_2\text{He}$ / ${}^4_2\alpha$	B1	
		(ii)	nucleon number for Bi = 209	B1	
			antineutrino / ${}^{(0)}_{(0)}\bar{\nu}_{(e)}$	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'
		(ii)	$(\lambda =) \ln 2 / 3.3 \text{ (h}^{-1})$ or $(\lambda =) 0.21 \text{ (h}^{-1})$ $(A_0 =) 12 \times 10^3 / e^{-(0.21 \times 7.0)}$ 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 $(\lambda =) \ln 2 / [3.3 \times 3600] \text{ (s}^{-1})$ or $(\lambda =) 5.835 \times 10^{-5} \text{ (s}^{-1})$ $(N =) 1.2 \times 10^4 / 5.835 \times 10^{-5}$ or 2.057×10^8 $(N_0 =) 2.057 \times 10^8 / e^{-(0.21 \times 7.0)}$ 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 $2.057 \times 10^8 \div (0.5)^{7.0/3.3}$
			Total	9	

5	(a)	(i)	$(W = \frac{1}{2} C V^2 \text{ so})$ $400 \times 10^6 = 0.5 \times C \times (24 \times 10^3)^2$ C = 1.4 (F)	C1 A1	Allow $W = \frac{1}{2} Q V$ and $C = Q / V$ $(Q = 3.3 \times 10^4 \text{ (C) so})$ $C = Q / V = 3.3 \times 10^4 / 24 \times 10^3$
		(ii)	(putting capacitors in parallel) increases the total capacitance ORA	B1	Allow $C_T = C_1 + C_2 + \dots$ or capacitors add together (in parallel) Ignore capacitors in parallel can store more charge/energy
	(b)		power $\approx 400 \times 10^6 / 10^{-3} = 4.0 \times 10^{11} \text{ (W)}$ power required is equivalent to output of ≈ 400 power stations or time taken for power station to release stored energy $= 400 \times 10^6 / 10^9 = 0.40 \text{ s}$ 0.4s is (much) longer than 1 ms	M1 A1 (M1) (A1)	Allow ECF (a)(i) for incorrect POT in 400GW Allow this is <u>much</u> more than could be provided by one power station or $4.0 \times 10^{11} \text{ (W)} \gg 1 \text{ GW}$ Ignore comments about household supply Allow ECF (a)(i) for incorrect POT in 400GW Allow it would take more time / too long

5	(c)	(mass defect in u =) $(2.014102 + 3.016049 - 4.002603 - 1.008665) \text{ u}$ $(= 0.018883 \text{ u})$ (mass defect in kg =) $0.018883 \times 1.661 \times 10^{-27}$ $(= 3.1365 \times 10^{-29})$ (energy per fusion reaction in J = mc^2 =) $3.1365 \times 10^{-29} \times (3.00 \times 10^8)^2$ $(= 2.82 \times 10^{-12})$ (number of fusion reactions = $\frac{\text{energy needed}}{\text{energy per fusion reaction}} =$ $400 \times 10^6 / 2.82 \times 10^{-12} =$) 1.4×10^{20}	Allow ECF for mass defect throughout unless XP C1 Mark is for correct working leading to the answer. Answer does not need to be calculated but 0.018883 u (not just 0.018883) implies C1 Allow negative answer C1 Mark is for substituting $u = 1.661 \times 10^{-27} \text{ (kg)}$, seen anywhere in the working Allow 1.66×10^{-27} or 1.67×10^{-27} for 1.661×10^{-27} Answer need not be calculated but 3.1365×10^{-29} implies first two C1 marks C1 Mark is for multiplying mass defect by $(3.00 \times 10^8)^2$, seen anywhere in the working Answer need not be calculated but 2.82×10^{-12} implies all three C1 marks A1 Ignore unit if given Allow ECF (a)(i) or (b) for incorrect POT in 400GW Note for markers: calculation in kg $3.34542 + 5.00966 - 6.64832 - 1.67539 (\times 10^{-27})$ $= (8.35508 - 8.32372) \times 10^{-27} (= 3.136 \times 10^{-29} \text{ kg})$ Note for markers: calculation in J $3.01088 + 4.50869 - 5.98349 - 1.50785 (\times 10^{-10})$ $= (7.51957 - 7.49134) \times 10^{-10} (= 2.82 \times 10^{-12} \text{ J})$
		Total	9



21	(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'
		(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'
	(b)	(i)	More neutrons produced (from each fission reaction) Go on to produce further (fission) reactions / splitting (of nuclei) / energy	B1 B1	
		(ii)	Control rod(s) used These absorb the neutrons (without fission)	B1 B1	Allow boron / cadmium / indium / silver Not moderator Not neutrons slowed down and/or stopped
		(iii)	 $(\Delta m =) 0.190 \times 1.66 \times 10^{-27}$ or 3.15×10^{-28} (kg) $(\Delta E =) 0.190 \times 1.66 \times 10^{-27} \times (3.0 \times 10^8)^2$ or 2.84×10^{-11} (J) $\frac{1.00}{0.235} \times 6.02 \times 10^{23}$ or 2.56×10^{24} (energy = $0.03 \times 2.56 \times 10^{24} \times 2.84 \times 10^{-11}$) energy = 2.2×10^{12} (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 7.3×10^{13} (J); 3.0% omitted Allow 3 marks for 1.3×10^{39} (J); 1.66×10^{-27} omitted
			Total	10	

20	(a)	Mark first two named forces only Strong (nuclear force) Any one from: short-range / range of about 3 fm / attractive between 0.5 fm to about 3 fm / repulsive below 0.5 fm Gravitational (force) Any one from: long (infinite) range / attractive / negligible / follows inverse square law	M1 A1 M1 A1	Ignore any comments on the weak nuclear force Penalise any clearly incorrect statements. Implication that strong is always attractive will lose A mark Allow 'gravity' Penalise any clearly incorrect statements
	(b)	Level 3 (5–6 marks) Clear description including at least one correct comment on quarks and analysis of 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 of density or clear description or clear analysis of 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) Limited description or Limited analysis <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× 6	Indicative scientific points may include: Description (max L2 if either alpha or beta not described) ${}^{14}_6\text{C} \rightarrow {}^0_{-1}\text{e} + {}^{14}_7\text{X}$ (ignore identification of X) - Before: 6 protons and 8 neutrons - After: 7 protons and 7 neutrons - Neutron $\rightarrow$ u d d and/or Proton $\rightarrow$ u u d - Neutron changes into proton (+ electron + antineutrino) - Down quark changes into an up quark (+ electron + antineutrino) ${}^{235}_{92}\text{U} \rightarrow {}^4_2\alpha + {}^{231}_{90}\text{Y}$ (ignore identification of Y) - Before: 92 protons and 143 neutrons - After: 90 protons and 141 neutrons 2 neutrons and 2 protons removed (by alpha particle) - Has 6 fewer u quarks and 6 fewer d quarks Density (max L2 if analysis done without use of data) - masses: 14.0(u) and 235.0(u) - ratios: masses = 16.8; radii = 2.55; volumes = 16.6 - volume $\sim 2.9^3$ and 7.4^3 (ignore $4/3\pi$ and 10^{-15}) - densities calculated (about $2.3 \times 10^{17} \text{ kgm}^{-3}$) - density shown to be (roughly the) same
		Total	10	

22	(a)	${}^{18}_{9}\text{F} \rightarrow {}^{18}_{8}\text{O} + {}^0_1\beta^+ (+\nu)$	C1 A1	Correct fluorine isotope Correct equation ALLOW numbers written to right of symbol ALLOW e / e ⁺ / $\bar{e}$ / β for positron symbol with correct numbers IGNORE gamma in products ALLOW ${}^0_0\nu$ for neutrino ALLOW ν_e for neutrino
	(b)	$E = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2$ $= 8.2 \times 10^{-14} \text{ (J)}$ $E = hc / \lambda = 8.2 \times 10^{-14} = 6.63 \times 10^{-34} \times 3 \times 10^8 / \lambda$ $\lambda = 3.00 \times 10^8 \div 1.2367 \times 10^{20} = \mathbf{2.4 \times 10^{-12} \text{ (m)}}$	C1 C1 A1	Working leading to evaluation of E ALLOW factor of 2 leading to $1.6 \times 10^{-13} \text{ (J)}$ NOT use of $\lambda = h/mv$ where v is 3×10^8 alone XP ALLOW use of $\lambda = hc/mc^2$ or $\lambda = h/mc$ ALLOW Use of electron mass = 0.511 MeV giving $8.2 \times 10^{-14} \text{ (J)}$ Correct to at least 2 significant figures Answer of 4.9×10^{-12} or 1.2×10^{-12} allow 2/3 due to incorrect accounting for factor of 2
	(c)	X-rays formed when <u>electrons</u> (in an atom) de-excite	B1	ALLOW X-rays may be produced by acceleration / deceleration of (fast moving) electrons / X-rays are produced when (fast moving) electrons are incident on a metal target / X-rays may be produced when electrons lose kinetic energy

Question			Answer	Mark	Guidance
			Gamma rays come from the decay of <u>nuclei</u> (in unstable isotopes)	B1	ALLOW gamma rays come from (the decay of) radioactive <u>nuclei</u> / gamma rays come from the <u>nucleus</u> of unstable atoms / gamma rays come from the de-excitation of <u>nuclei</u> / gamma rays come from <u>annihilation</u> of particle-antiparticle (pairs) / IGNORE gamma from fission
	(d)		The half-life is short Advantage: Exposure of the patient to <u>ionising</u> radiation is kept as low as possible. Disadvantage: (Radiographers have a) short time to scan/diagnose the patient	B1 B1 B1	ALLOW activity is high IGNORE it decays quickly ALLOW F18 has to be manufactured on site before use / high activity means exposure is high during handling IGNORE short time to treat the patient

19	(a)	Hadrons experience the strong force / hadrons are not fundamental particles / hadrons are made of quarks	B1	IGNORE references to mass IGNORE number of quarks
		Leptons do not experience strong force / leptons are fundamental / leptons are not made of quarks	B1	
19	(b)	Positron and (electron) neutrino	B1	Both required for the mark ALLOW anti-electron / beta-plus for positron IGNORE symbols
19	(c)	Decay constant = $\ln 2 / 1220 = (5.7 \times 10^{-4} \text{ s}^{-1})$	C1	Decay constant = $\ln 2 / 20.3 = (0.034 \text{ min}^{-1})$
		$A = 800 \times e^{-(5.7 \times 10^{-4} \times 300)}$	C1	ALLOW $A = 800 \times e^{(-0.034 \times 300)}$
		$A = (800 \times 0.84333) = 670 \text{ (Bq)}$	A1	Correct to at least 2 significant figures (675 Bq) Value using t in minutes with decay constant in s^{-1} gives 798 (Bq) is MAX 2
19	(d)	Positron emission tomography / PET (scan)	B1	IGNORE (gamma) waves and (gamma) radiation ALLOW γ for gamma
		Two <u>gamma</u> rays / <u>gamma</u> photons produced	B1	
		(Gamma rays) travel in opposite directions / 180°	B1	
		Arrival time(s) (at detector) used to locate position	B1	

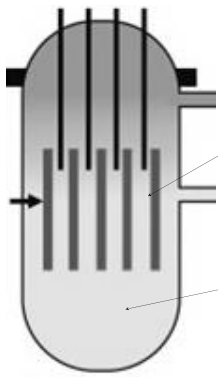
Question		Answer	Mark	Guidance

Question	Answer	Mark	Guidance
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25	(a)	(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 $0.21 \times 10^{-11} \text{ (J)}$ $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^8}{0.21 \times 10^{-11}}$ (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 one from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	M1 A1	
	(b)		X-ray (tube) moves around the patient A thin (fan-shaped X-ray) beam is used (Images / scans of) cross-sections through the patient are taken Any one from: - A three-dimensional image is produced (Soft) tissues can be identified	B1 B1 B1 B1	Allow 'X-rays passed through different angles.' Allow 'slice(s)' Allow 'good contrast image'
			Total	11	

24	(a)	(i)	$(E =) \frac{4000}{0.080}$ $(F =) \frac{4000}{0.080} \times 1.6 \times 10^{-19}$ $(a =) \frac{8.0 \times 10^{-15}}{9.11 \times 10^{-31}} \quad \text{or} \quad 8.78 \times 10^{15}$ $a = 8.8 \times 10^{15}$	C1 C1 C1 A0	$E = 5.0 \times 10^4 \text{ (V m}^{-1}\text{)}$ $F = 8.0 \times 10^{-15} \text{ (N)}$ Allow this mark if the working is shown. If only value is given, then the answer must be 3SF or more
		(ii)	$(t =) \frac{0.12}{6.0 \times 10^7}$ $(t = 2.0 \times 10^{-9} \text{ s})$	M1 A0	
		(iii)	$(x =) \frac{1}{2} \times 8.78 \times 10^{15} \times (2.0 \times 10^{-9})^2$ $x = 1.8 \times 10^{-2} \text{ (m)}$	C1 A1	Allow $a = 8.8 \times 10^{15}$
	(b)		Downward curved path Same x	B1 B1	Ignore any line outside of the plates Expect same x by eye
	(c)		Apply a magnetic field at right angles to electric field electric force = magnetic force No resultant vertical force, so only beta-particles with a specific speed will travel horizontally	B1 B1 B1	Note this mark is for the idea that E and B are <u>perpendicular</u> even if direction of B is incorrect Allow 'apply horizontal magnetic field' Allow $Eq = Bqv$ Allow $v = E/B$ in this arrangement
			Total	11	

21	(a)	(i) (ii) 	B1 ALLOW any correctly named fuel e.g. uranium (oxide) for (i) ALLOW any correctly named moderator e.g. (heavy) water for (ii) ALLOW coolant for (ii) B1 ALLOW any correctly named coolant (e.g. CO₂) for (ii)
	(b)*	Level 3 (5–6 marks) Clear description and full correct calculation. <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) Clear description or full correct calculation. or Some description and some calculation <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>	6 x B1 Use level of response annotations in RM Assessor Indicative scientific points may include: Description • Absorption of neutron by U-235 • U-235 nuclei become unstable U236 nuclei • U-236 undergoes fission • Resulting in smaller nuclei daughter products and additional fast neutrons • Moderator slows neutrons so that they can be absorbed by U-235 nuclei • Process repeats to form a chain reaction • Rate of chain reaction controlled by raising or lowering control rods • Which absorb excess neutrons

Question			Answer	Mark	Guidance
			Level 1 (1–2 marks) Limited description or Limited calculation <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>		To allow one neutron per fission to cause further fission Calculation Use of ${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{36}^{92}\text{Kr} + {}_{56}^{141}\text{Ba} + 3{}_0^1\text{n}$ Mass of U236 = $235.04395 + 1.00867 = 236.05262\text{u}$ Total mass of fission products = $140.91440 + 91.92617 + (3 \times 1.00867) = 235.86658\text{u}$ Difference = 0.18604 u Mass defect = $0.18604 \times 1.661 \times 10^{-27} = 3.0901244 \times 10^{-28}\text{ kg}$ Energy equivalence per fission event = $3.0901244 \times 10^{-28} \times (3 \times 10^8)^2 = 2.78111 \times 10^{-11}\text{J}$ Alternative: Energy equivalence per fission in MeV = 174 MeV
	(c)		Marks may be awarded for the following considerations only: technology, reaction, fuel, waste, safety. Technology: Fission: technology already established / Fusion: technology not yet established	4 x B1	ALLOW 1 mark for basic comparison within each consideration if no other marks are awarded.

Question			Answer	Mark	Guidance
			Reaction: - Fission: chain reaction self-sustaining once initiated - Fusion: very high temperatures/pressures /amounts of energy required to initiate and continue reaction / challenges with storage and containment of plasma Fuel: - Fission: finite amount of uranium / needs to be enriched - Fusion: (unlimited) fuel available from (sea) water Waste: - Fission: Produces highly / high level / long half-life / long storage time radioactive waste - Fusion: Produces (effectively) no radioactive waste (products) / only radioactive material in contained in the reactor Safety: - Fission: Possibility of serious accident / leakage of radioactive material / “meltdown” AND/OR Fusion: very unlikely to produce serious accident (due to near instant shut down of reaction) / no leakage of radioactive material		ALLOW hydrogen is easier to source (than uranium) for 1 mark ALLOW Fission produces radioactive waste and fusion does not for 1 mark. IGNORE nuclear for radioactive

3	(a)		GPE is the work done in bringing an object from infinity (to that point)	B1	Ignore any equations
	(b)	(i)	GPE = (-) GMm/r GPE = (-) $6.67 \times 10^{-11} \times 2 \times 10^{30} \times 810 / 1.5 \times 10^{11}$ GPE = (-) 7.2×10^{11} (J)	C1 C1 A0	Mark is for full substitution, including 6.67×10^{-11} for G
		(ii)	$v = 2\pi r/T = 2\pi \times 1.5 \times 10^{11} / 3.16 \times 10^7$ (= 29.8 km s ⁻¹) KE = $\frac{1}{2}mv^2 = 0.5 \times 810 \times (29.8 \times 10^3)^2$ KE = 3.6×10^{11} (J)	C1 M1 A1	Allow proof by algebraic method for full marks e.g. $mv^2/r = GMm/r^2$ so $mv^2 = GMm/r$ Therefore KE/GPE = $\frac{1}{2}mv^2 / (GMm/r) = \frac{1}{2}$
		(iii)	total energy = (-) ($7.2 \times 10^{11} - 3.6 \times 10^{11}$) total energy = (-) 3.6×10^{11} (J)	M1 A0	working must be shown; ECF (i) and (ii)
	(c)	(i)	$A = 470 / 8.8 \times 10^{-13} = 5.3 \times 10^{14}$ (Bq) $\lambda = \ln 2 / (88 \times 3.16 \times 10^7)$ (= 2.5×10^{-10} s ⁻¹) ($A = \lambda N$); N (= $5.3 \times 10^{14} / 2.5 \times 10^{-10}$) = 2.1×10^{24}	C1 C1 A1	Mark is for correct calculation of A (in Bq or decays per s) Mark is for correct working to give λ in s ⁻¹
		(ii)	$P = P_0 \exp(-\lambda t)$ $P = 470 \exp(-\ln 2 \times 100 / 88)$ $P = 210$ (W)	C1 C1 A1	Allow formula in terms of N or A Allow calculation in terms of N or A ; allow ECF for N or A
			Total	13	

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H556/03

Mark Scheme

October 2021

Question	Answer	Marks	Guidance
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20	(a)		(Minimum) energy required to separate the nucleons (to infinity)	B1	Allow protons and neutrons for nucleons Allow energy released when the nucleus forms from the nucleons Do not allow mathematical descriptions such as (mass defect $\times c^2$)
	(b)		H-1 is a single proton / nucleon AND there is no binding energy / it is not bound to anything	B1	
	(c)	(i)	The product has a higher binding energy (per nucleon)	B1	Allow the fusion of low Z number nuclei will result in a nucleus higher up the curve making it more stable Ignore statements regarding electrostatic repulsion
		(ii)	Energy before = $(1.1 \times 2) + (2.8 \times 3)$ (= 10.6 MeV) Energy after = 7.1×4 (= 28.4 MeV) Energy released = $28.4 - 10.6 = 17.8$ MeV = $17.8 \times 10^6 \times 1.6 \times 10^{-19} = 2.8 \times 10^{-12}$ (J)	C1 C1 A1	Allow ± 0.1 MeV tolerance on binding energy values from graph Answer to at least 2sf (2.848) MAX value of energy within tolerances = 2.99×10^{-12} MIN value of energy within tolerances = 2.70×10^{-12}
		(iii)	Energy released per second = $4.3 \times 10^9 \times (3 \times 10^8)^2$ = 3.87×10^{26} (J) No of reactions = $3.87 \times 10^{26} / 2.85 \times 10^{-12}$ = 1.4×10^{38} (s⁻¹)	C1 A1	Alternative method: Mass per reaction = $2.85 \times 10^{-12} / (3 \times 10^8)^2$ = 3.2×10^{-29} (kg) No of reactions = $4.3 \times 10^9 / 3.2 \times 10^{-29} = 1.4 \times 10^{38}$ (s⁻¹) Allow use of 3×10^{-12} to give 1.29×10^{38}



Question			Answer	Mark	Guidance
					Allow use of (c)(ii) tolerance range for energy released value from to final answer in range 1.29 – 1.43 ($\times 10^{38}$) Correct to at least 2sf
	(d)	(i)	0 / neutral	B1	Unit not necessary, but penalise incorrect unit
		(ii)	(electron) neutrino	B1	Do not allow antineutrino Ignore symbols If answer line is blank, then the name in the missing space in the equation can be taken as the answer
		(iii)	4	B1	
	(e)		$d \rightarrow u$ $+ {}^0_{-1}e^- + \bar{\nu}$	B1 B1	Correct change of quark Allow udd to uud Correct symbols for other two particles Allow e^- or ${}^0_{-1}e$ for electron Allow beta symbol for electron Numbers for the neutrino do not need to be present, but must be correct if given ${}^0_0\bar{\nu}$

23	(a)	(i)	$(\text{force}) = \frac{(1.6 \times 10^{-19})^2}{4\pi\epsilon_0 \times (1.0 \times 10^{-15})^2}$ $(F =) 230 \text{ (N)}$ $F^2 = 230^2 + 230^2 - 2 \times 230 \times 230 \times \cos 120^\circ$ or $F = 2 \times 230 \cos 30^\circ$ $F = 400 \text{ (N)}$	C1 C1 C1 A1	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 $230 \cos 30^\circ$ 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'
	(b)	(i)	$12000 = \frac{Q}{4\pi\epsilon_0 r}$ $12000 = \frac{Q}{4\pi\epsilon_0 \times 0.19}$ $Q = 2.5(4) \times 10^{-7} \text{ (C)}$	C1 C1 A0	Allow $E = (V/d) = 6.316 \times 10^4$ C1 and $E = 6.316 \times 10^4 = \frac{Q}{4\pi\epsilon_0 \times 0.19^2}$ C1
		(ii)1	$t = 78 \times 3600$ $(I =) \frac{2.5 \times 10^{-7}}{78 \times 3600}$ $I = 8.9 \times 10^{-13} \text{ (A)}$	C1 C1 A0	There is no ECF from (b)(i) Note 2.54×10^{-7} gives an answer $9.0 \times 10^{-13} \text{ A}$
		(ii)2	$(R =) \frac{6000}{9.0 \times 10^{-13}} \text{ or } 6.7 \times 10^{15} \text{ (}\Omega\text{)} \text{ or } V = IR \text{ and } R = \frac{\rho L}{A}$ $\frac{6000}{9.0 \times 10^{-13}} = \frac{\rho \times 0.38}{1.1 \times 10^{-4}}$ $\rho = 1.9 \times 10^{12} \text{ (}\Omega \text{ m)}$	C1 C1 A1	There is no ECF from (b)(ii)1 Take 12000 V as TE for this C1 mark, then ECF Note $8.9 \times 10^{-13} \text{ (A)}$ gives an answer $2.0 \times 10^{12} \text{ (}\Omega \text{ m)}$
			Total	14	



2	(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
	(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
		(ii)1	$\ln N = -\mu d + \ln N_0$ compared to $y = mx + c$ (so $m = -\mu$ and $c = \ln N_0$)	B1	or $\ln N = \ln(N_0 e^{-\mu d}) = \ln N_0 - \mu d$
		(ii)2	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
		(ii)3	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)

H556/03			Mark Scheme		June 2019
Question			Answer	Marks	Guidance
		(ii)4	gradient of best fit line = $(-) \mu = (-) 54 \text{ (m}^{-1}\text{)}$	B1	Allow 51 to 56 Allow value of μ up to 4 SF ECF(ii)3 for wrongly plotted point
			large triangle used to determine gradient of best fit line	B1	$\Delta d > 25\text{mm}$ (seen from graph or working)
			calculation of absolute uncertainty using their values in the formula $(\text{wfl gradient} - \text{bfl gradient})$	B1	ECF (ii)3 for worst fit line Ignore any POT error in gradients Allow value of absolute uncertainty up to 3 SF only
			uncertainty and value of μ to same number of dp	B1	e.g. 53.4 ± 5.6 or 54 ± 6
		(ii)5	$\mu d_{1/2} = \ln 2$ (or 0.693)	C1	ECF (ii)4 for μ Alternative method: $\ln(N_0/2) = 7.67$ (C1)
			$d_{1/2} = 0.013 \text{ (m)}$	A1	then use of graph to give $d_{1/2} = 0.013 \pm 0.001 \text{ (m)}$ (A1)
			Total	15	

H556/03		Mark Scheme		June 2019	
Question	Answer	Marks	Guidance		



21	(a)		Electrons and quarks identified as fundamental particles There are 6 electrons, 6 protons and 8 neutrons Composition of proton $\rightarrow$ u u d Composition of neutron $\rightarrow$ u d d	B1 B1 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'
	(b)	(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 $= 2100 \text{ (y)}$	C1 C1 A1	Note $1 = 0.78e^{-\lambda t}$ is XP ; answer is negative (- 2100 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	

	(c)*	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 $\rho \approx Am_n \div \text{diameter}^3$ $m_n \approx 1.7 \times 10^{-27} \text{ (kg)}$; $\rho = 2.3 \times 10^{17} \text{ (kg m}^{-3}\text{)}$ for at least one of the nuclei given in the figure or table
		Total	15	



21	(a)	(i)	Material (introduced into the body and) used so its position in the body can be detected / function of organ can be determined	B1	Allow “used to produce images” for “detected” Do not allow “trace” for “position detected” Ignore treatment
		(ii)	(Very) little ionisation (Most can) pass through the body tissue / can be detected outside / highly penetrating	B1 B1	Allow less ionising / least ionising Do not allow “zero ionisation” Allow other radiation would be absorbed within the body
	(b)	(i)	$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{6.01 \times 3600} (= 3.20 \times 10^{-5} \text{ s}^{-1})$ ($A = \lambda N$) $900 \times 10^6 = 3.20 \times 10^{-5} \times N$ $N = 2.8 \times 10^{13}$	C1 C1 A1	Correct to at least 2sf (2.81) Special case: Calculation of decay constant in hour^{-1} gives 0.115 leading to $N = 7.8 \times 10^9$ maximum 1 mark Calculation of decay constant in min^{-1} gives 1.9×10^{-3} leading to $N = 4.7 \times 10^{11}$ maximum 1 mark
		(ii)	(Correct use of $A = A_0 e^{-\lambda t}$) $0.03 = e^{-3.2 \times 10^{-5} t}$ $\ln(0.03) = -3.2 \times 10^{-5} t$ $t = 109\,500 \text{ s} = 30 \text{ hours}$	C1 C1 A1	Or use of λ as 0.115 hour^{-1} ecf for λ from (b)(i) $\ln(0.03) = -0.115 t$ Allow final answer that rounds to 30 or 31 hours



Question			Answer	Mark	Guidance
					Special case: if fall of 3% ($A = 0.97A_0$) calculated, leading to 0.26 hours then max 1
	(c)		Activity is low compared to background	B1	Allow activity is very low Allow decays very slowly / very little decay for low activity Allow rate of emission for activity Ignore references to long half life
	(d)		Level 3 (5–6 marks) Clear description and full correct calculation <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) Clear description or full correct calculation OR Some description and some calculation <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 description or limited calculation <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i>	B1×6	Use level of response annotations in RM Assessor Indicative scientific points may include: Expect to see appropriate safety precaution for clear description Description: • Take background count • Over (at least) 3 minutes • Take count due to source • Over the same time • Measured using a stopwatch • Calculate the corrected count • Calculate the corrected count per minute • Use a Geiger-Muller tube and counter • Hold source at arms length when transferring • Keep in lead lined box at other times • Use tongs to hold source

Question			Answer	Mark	Guidance
			0 marks <i>No response or no response worthy of credit</i>		Calculation • $C = C_0 e^{-\lambda t}$ • $\ln C = \ln C_0 - \lambda t$ • e.g $7.51 = 7.81 - (\lambda \times 6)$ • λ around 0.05 hour^{-1} • $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ • $T_{\frac{1}{2}} = 13.9 \text{ hours}$ (allow any answer that round to 14 hours) • $T_{\frac{1}{2}} = 830 \text{ minutes}$ or $49\,900 \text{ seconds}$ (allow some tolerance for slight graph reading discrepancies) • Or by a graphical method

Question	Answer	Mark	Guidance
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