0 6 Helium is the second most abundant element in the universe. The most common isotope of helium is $^{4}_{2}\text{He}$ and a nucleus of this isotope has a rest energy of $3728\ \text{MeV}$.

In 2011, at the Relativistic Heavy Ion Collider, anti-helium nuclei were produced. Nuclei of anti-helium are made up of antiprotons and antineutrons.
It is suggested that an antineutron can decay to form an antiproton in a process similar to β^- decay.

In one particular collision between an anti-helium nucleus and a helium nucleus, the nuclei are annihilated and two photons are formed.

0 6 . 1 State what is meant by isotopes.

[2 marks]

0 6 . 2 Explain why two photons are formed instead of a single photon when a helium nucleus annihilates with the anti-helium nucleus.

[2 marks]

0 6 . 3 Calculate, using data from the passage, the maximum frequency of the photons produced in this annihilation of a $^{4}_{2}\mathrm{He}$ nucleus.

[4 marks]

frequency = ____________________ Hz

0 6 . 4 Complete this equation for the possible decay of an antineutron.

[2 marks]

$$^{1}_{0}\overline{\mathrm{n}} \rightarrow {}^{1}_{-1}\overline{\mathrm{p}} + {}^{\_\_}_{\_\_}\_\_\_\_ + \_\_\_\_$$

0 6 . 5 What interaction would be responsible for the decay in **Question 6.4**?
Tick (✓) the correct answer in the right-hand column.

[1 mark]

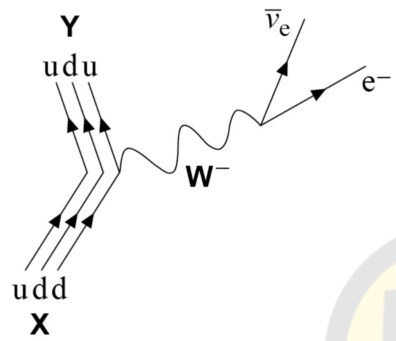
	✓ if correct
electromagnetic	
gravitational	
strong nuclear	
weak nuclear	

Question	Answer	Comments/ Guidance	Mark
06.1	atoms/nuclei with same number of protons/atomic number✓ but different numbers of neutrons/mass number✓	atom/nuclei seen at least once	1 1
06.2	momentum must be conserved✓ so need two photons travelling in different directions✓		1 1
06.3	rest energy = 2 × 3728 = 7456✓ (MeV) rest energy = 1.193×10^{-9} ✓ (J) use of energy of each photon = *hf*✓ $f = (1.193 \times 10^{-9}/2)/6.63 \times 10^{-34} = 8.997 \times 10^{23}$✓(Hz)	must show doubling OR explain that is halved because two photons OR implied because 1.193×10^{-9} no working but correct answer scores last three marks RANGE: 8.90×10^{23} - 9.00×10^{23}	1 1 1 1
06.4	$^{1}_{0}\overline{\mathrm{n}} \rightarrow {}^{1}_{-1}\overline{\mathrm{p}} + {}^{0}_{1}\overline{e} + \nu_{(e)}$ ✓✓	Can use e^+ OR β in place of e Allow slight loop in bottom of neutrino but must not look like gamma	1 1
06.5	electromagnetic: gravitational: strong nuclear: weak nuclear: ✓		1

0 1 **Figure 1** represents the decay of a particle **X** into a particle **Y** and two other particles.

The quark structure of particles **X** and **Y** are shown in the diagram.

Figure 1



0 1 . 1 Deduce the name of particle **X**.

[1 mark]

---

0 1 . 2 State the type of interaction that occurs in this decay.

[1 mark]

---

0 1 . 3 State the class of particles to which the **W⁻** belongs.

[1 mark]

---

0 1 . 4 Show clearly how charge and baryon number are conserved in this interaction.

You should include reference to all the particles, including the quarks, in your answer.

[2 marks]

0 1 . 5 Name the only stable baryon.

[1 mark]

0 1 . 6 A muon is an unstable particle.

State the names of the particles that are produced when a muon decays.

[1 mark]

7

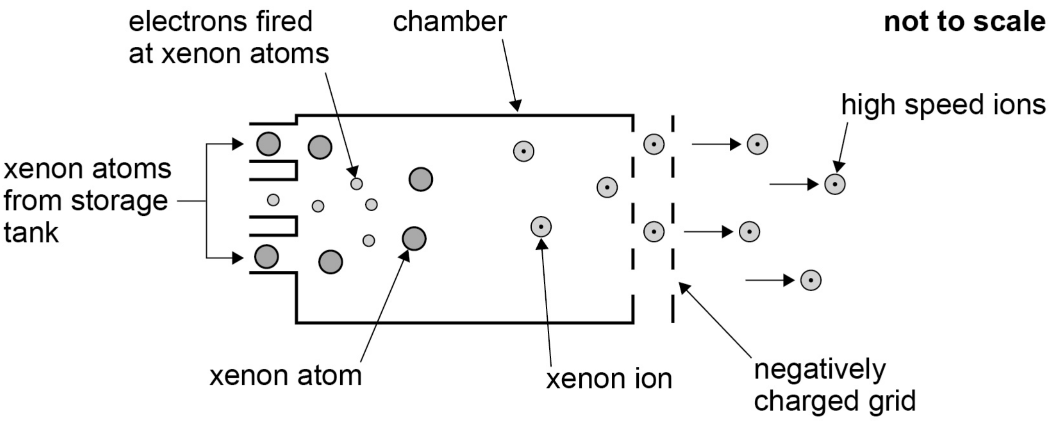
Question	Answer	Comments/Guidance	Mark
01.1	Neutron	Condone misspelling eg nuetron	1
01.2	Weak (interaction)	Ignore nuclear or references to beta	1
01.3	Bosons	Accept 'exchange particles' Do not allow 'force mediator'	1
01.4	charge number 2/3 -1/3 – 1/3 → 2/3 +-1/3 + 2/3 - 1 + 0✓ baryon number 1/3 + 1/3 + 1/3 → 1/3 + 1/3 + 1/3 + 0 + 0✓	Ignore equation if given, marking should be based on the numbers Allow 1 for both correct in terms of n & p instead of quarks: 0 → +1 + -1 + 0 1 → 1 + 0 + 0	2
01.5	proton	Allow 'free proton'	1
01.6	Electron + an electron antineutrino + muon neutrino	All 3 needed Condone anti-electron neutrino for electron anti-neutrino No credit given for symbols Allow antiparticle answer: positron, electron neutrino, muon antineutrino	1

0 4 **Figure 11** represents an ion propulsion unit used on a spacecraft launched in 1998.

Atoms of xenon-131 ($^{131}_{54}\text{Xe}$) were injected from a storage tank into a chamber where they became ionised due to collisions with electrons.

A negatively charged grid attracted the xenon ions, accelerating them out of the back of the ion propulsion unit and causing the spacecraft to be propelled forward.

Figure 11



0 4 . 1 The mass of a Xe^{+} ion is 2.18×10^{-25} kg.

Calculate the specific charge of a Xe^{+} ion.

Give an appropriate unit for your answer.

[2 marks]

specific charge = ____________________ unit __________

0 4 . 2 The storage tank contained 79 kg of xenon. When the ion propulsion unit was switched on it had an average power output of 2.1 kW.

Each xenon ion gained 1300 eV of energy as it was accelerated and ejected out of the propulsion unit.

Calculate the energy, in J, gained by each xenon ion.

[1 mark]

energy = ____________________ J

0 4 . 3 Determine the length of time the ion propulsion unit operated before all of the 79 kg of xenon was used up.

mass of xenon atom = 2.18×10^{-25} kg

[3 marks]

time = ____________________ s

Question 4 continues on the next page

Do not write outside the box

0 4 . 4 Ion propulsion units could use helium ions instead of xenon ions.

An ion of helium-4 (He^+) has a much higher specific charge than an ion of xenon-131 (Xe^+). Both ions would gain $1300\ eV$ of kinetic energy in being accelerated and ejected from an ion propulsion unit.

Suggest whether helium ions or xenon ions are better to use as a propellant in future space programmes. In your answer you should compare the relative speeds and momentum changes of the ions.

[3 marks]

9

Question	Answer	Additional Comments/Guidance	Mark
04.1	$7.3(4) \times 10^5$ ✓ C kg^{-1} ✓	Numerical answer (in terms of powers of 10) must match unit prefixes where used Penalise rounding errors (733944.9541) Do not allow use of solidus in unit: C / kg Condone a capital k or lower case c but not a capital g	2
04.2	(1300 (eV) =) 2.08×10^{-16}(J) OR 2.1×10^{-16}(J) ✓		1

04.3	Correct answer of 3.59×10^7 gains 3 marks (without working) (Number of Xe ions per second) = $\frac{2.1 \times 10^3}{\text{ans to } 4.2}$ OR $1(.01) \times 10^{19}$ seen ✓ (Mass of Xe ions per second) $= 2(.2) \times 10^{-6}$ ✓ (time $= \frac{total\ mass}{mass\ per\ second} = \frac{79}{2(.2) \times 10^{-6}} =$) 3.59×10^7 (s) or 3.6×10^7 (s)✓ OR (Total number of Xe ions) = $\frac{79}{2.18 \times 10^{-25}}$ OR 3.6×10^{26} seen ✓	Ecf form part 4.2 Ecf from part 4.2	3

	(total energy available) 3.6×10^{26} x (ans to 4.2) OR 7.5(4) x 10^{10} ✓ (time $= \frac{E}{P} = \frac{7.5(4) \times 10^{10}}{2.1 \times 10^{3}}$=) 3.59×10^{7} (s) ✓	Ecf from part 4.2 Ecf from part 4.2 If both 'methods' attempted, restrict marks awarded to optimum method.	

04.4	Speed of He ions will be greater ✓ (Momentum depends on mass and speed, although) He (has higher speed) has (considerably) less mass, therefore less momentum (gained by He ion during the acceleration) ✓ He ion exerts less thrust (on spacecraft therefore xenon is better) OR Xenon ion exerts more thrust (on spacecraft therefore xenon is better) ✓	**Must address these points** Other points (e.g. He smaller so more can be stored) are neutral: no credit awarded Must be clear about which ion candidate is discussing Condone use of terms such as 'heavier' / 'lighter'	3

Do not write outside the box

Section A

Answer **all** questions in this section.

0 1 An isotope of potassium $^{40}_{19}\mathrm{K}$ is used to date rocks. The isotope decays into an isotope of argon (Ar) mainly by electron capture.

0 1 . 1 The decay is represented by this equation:

$$^{40}_{19}\mathrm{K} + {}^{0}_{-1}\mathrm{e} \rightarrow {}^{\_\_}_{\_\_}\mathrm{Ar} + \_\_\_\_\_\_$$

Complete the equation to show the decay by filling in the gaps.

[2 marks]

0 1 . 2 Explain which fundamental interaction is responsible for the decay in question **01.1**.

[2 marks]

0 1 . 3 One decay mechanism for the decay of $^{40}_{19}\mathrm{K}$ results in the argon nucleus having an excess energy of $1.46\ \mathrm{MeV}$. It loses this energy by emitting a single gamma photon.

Calculate the wavelength of the photon released by the argon nucleus.

[3 marks]

wavelength = ______________________ m

0 1 . 4 The potassium isotope can also decay by a second decay process to form a calcium-40 nuclide ($^{40}_{20}Ca$).

Suggest how the emissions from a nucleus of decaying potassium can be used to confirm which decay process is occurring.

[3 marks]

10

Turn over for the next question

Question	Answers	Additional Comments/Guidelines	Mark
01.1	${}^{40}_{19}\mathrm{K} + {}^{0}_{-1}e \rightarrow {}^{40}_{18}\mathrm{Ar} + \nu_{(e)}$✓✓	first mark for 40 and 18 second mark for electron neutrino if negative superscript on neutrino mark not awarded	1 1
01.2	is the weak interaction/weak nuclear force✓ because involves leptons <u>and</u> hadrons/ because quark character/flavour/identity/type changed✓	allow change in quark composition allow second mark if applied to stated interaction e.g. up quark changes to down quark	1 1
01.3	(use of *E=hf*) energy in J = $1.46\times10^{6}\times1.6\times10^{-19}$ ✓ (= 2.336×10^{-13}) $f = (\frac{E}{h} =) = \frac{2.336\times10^{-13}}{6.63\times10^{-34}}$ AND $\lambda = \frac{3\times10^{8}}{f}$ ***OR*** $\lambda = \left(\frac{hc}{E} =\right)\frac{3\times10^{8}\times6.63\times10^{-34}}{2.336\times10^{-13}}$ seen directly✓ 8.51×10^{-13} m ✓	1 for the attempt at the conversion to J allowing POT 1 for attempt to sub in hf and c/λ (or hc/λ) allow energy substituted in MeV or eV for second mark 1 for the correct answer (not awarded if eV used or MeV or if POT error) Accept 8.52×10^{-13}	1 1 1
01.4	identifies the decay as beta emission ✓ *so will expect to see:* electron released (from nucleus) correct details of how electron detected antineutrino released no photon released } 2 from 4	If state incorrect interaction e.g. beta plus decay the wrong Physics and no consequential error(CE) and therefore zero. If no interaction stated then can score next 2 marks. e.g. cloud chamber or absorption If give correct equation for beta decay award mark for	3

		electron and antineutrino	

Total			**10**

Answer **all** questions.

0 1 . 1 Describe the interaction that is responsible for keeping protons and neutrons together in a stable nucleus.
You should include details of the properties of the interaction in your answer.

[3 marks]

0 1 . 2 Nuclei can decay by alpha decay and by beta decay.

In alpha decay only one particle is emitted but in beta decay there are two emitted particles.

Explain how baryon number is conserved in alpha and beta decay.

[3 marks]

0 1 . 3 Kaons are mesons that can be produced by the strong interaction between pions and protons.

The equation shows a reaction in which a kaon and a lambda particle are produced.

$$\pi^{-} + p \rightarrow K^{0} + \Lambda^{0}$$

Deduce the quark structure of the Λ^{0}

[2 marks]

quark structure = ____________________

0 1 . 4 The kaon decays by the weak interaction.

The equation shows an example of kaon decay.

$$K^{0} \rightarrow \pi^{+} + \pi^{-}$$

State **one** feature of this decay that shows it is an example of the weak interaction.

[1 mark]

____

____

0 1 . 5 There have been considerable advances in our understanding of particle physics over the past 100 years.

Explain why it is necessary for many teams of scientists and engineers to collaborate in order for these advances to be made.

[2 marks]

____

____

____

____

____

11

Turn over ►

Question	Answers	Additional Comments/Guidelines	Mark
01.1	THREE FROM: the strong interaction✓ has short range OR mention range (less than 5 fm)✓ attraction up to 5 fm✓ repulsive (any distance below 1fm)✓ is zero/negligible beyond 5 fm✓ only affects hadrons/ baryons and mesons✓ mediated by gluons/pions✓	If **wrong** interaction identified then zero marks If refer to strong interaction correctly then ignore any subsequent reference to other interactions	1 1 1 (3 MAX)
01.2	in alpha decay number of nucleons/protons and neutrons is unchanged OR baryons in parent nucleus equals the total number of baryons in daughter nucleus and the alpha particle✓ in beta decay a neutron changes into a proton (and both have same baryon number)✓ beta (-) particle and antineutrino have zero baryon number/beta(+) and neutrino have zero baryon number✓	If only refer to baryon number/nucleon number of alpha particle then do not award first mark Can be shown by equations e.g. ${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\alpha$ Second marking point can also be shown in equation	1 1 1
01.3	quark structure π^- = $\bar{u}$d and p = uud quark structure kaon = d$\bar{s}$✓ hence as strong interaction quark structure Λ^0 = uds✓	if two of the quark structures correct then 1 mark any correct answer (uds) full marks	1 1
01.4	strangeness is not conserved/lost✓		1
01.5	TWO FROM: results of experiments must be independently checked/validated/peer reviewed before they are accepted/can be confirmed✓ particle accelerators are very expensive and collaboration helps to spread the cost of building them✓ many skills and disciplines are required (which one team are unlikely to have)✓		1 1 (2 MAX)

Section B

Answer **all** questions in this section.

0 3 A radioactive source emits alpha particles each with 8.1×10^{-13} J of kinetic energy.

0 3 . 1 Show that the velocity of an alpha particle with kinetic energy 8.1×10^{-13} J is approximately $2 \times 10^{7}\ \text{m s}^{-1}$

specific charge of an alpha particle = $4.81 \times 10^{7}\ \text{C kg}^{-1}$

[2 marks]

0 3 . 2 The alpha particles travel through air in straight lines with a range of 3.5 cm

Calculate the average force exerted on an alpha particle as it is stopped by the air.

[2 marks]

average force = ______________________ N

0 3 . 3 An alpha particle transfers all its kinetic energy to air molecules and produces 5.1×10^4 ions per centimetre over its range of 3.5 cm

Calculate the average ionisation energy, in eV, of a molecule of air.

[3 marks]

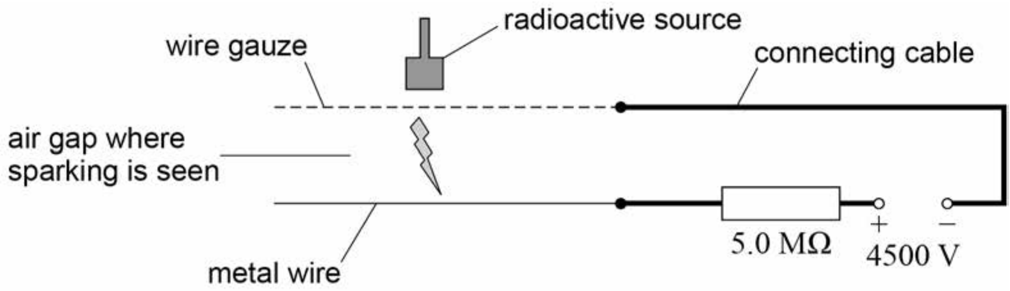
ionisation energy = ________________________ eV

Question 3 continues on the next page

Do not write outside the box

0 3 . 4 A spark counter consists of a wire gauze separated from a metal wire by a small air gap. A power supply with an output of 4500 V is connected in series with a 5.0 MΩ resistor and the spark counter as shown in **Figure 8**. When the radioactive source is moved close to the wire gauze, sparking is seen in the air gap.

Figure 8



Sparks are produced when alpha particles produce ionisation in the air gap. One ionisation event produces a current of 0.85 mA for a time of 1.2 ns

Calculate the number of charge carriers that pass a point in the connecting cable during this ionisation event.

[2 marks]

number of charge carriers = ____________________

Do not write outside the box

0 3 . 5 The radioactive source was positioned 10 cm above the wire gauze before being moved slowly towards the wire gauze leading to the ionisation event in question **03.4**.

Discuss how the potential difference across the air gap varied as the radioactive source was moved over this distance.

Assume the power supply has negligible internal resistance.

[3 marks]

12

Turn over for the next question

Question	Answers	Additional Comments/Guidance	Mark
03.1	Mass of alpha particle = $\frac{2\times1.6\times10^{-19}}{4.81\times10^{7}}$ =$6.6(53)\times10^{-27}$ (kg) **OR** Correctly re-arranged k.e. equation (with v^2 or v as subject) with 8.1×10^{-13} (J) substituted correctly₁✓ 1.56×10^{7} seen ₂✓	Allow mass = $2\times m_p + 2\times m_n = 6.696\times10^{-27}$ kg Allow mass = 4 x 1.66 x10^{-27} kg = 6.64×10^{-27} kg Allow mass = 4 x 1.67 x10^{-27} kg = 6.68×10^{-27} kg Allow slight rounding on mass (must be correct to 2 sf) Condone **incorrect mass** in otherwise correct substitution **with *v* or v² recognisable** as subject . Alternative approaches are: $v=\sqrt{\frac{E_k\times\text{specific charge}}{e}}$ $v=\sqrt{\frac{2\times E_k}{m_\alpha}}$ Must see answer to at least 2 sf Must see attempt to use one of the alternative approaches to support correct answer.	2

03.2	Use of $W = Fs$, $F = 8.1 \times 10^{-13} \div 3.5 \times 10^{-2}$ 1✓ $(F=)\ 2.3 \times 10^{-11}$ (N) 2✓ **OR** Use of an appropriate equation of motion to find a **and** $F=ma$ *(allow their mass and their velocity in this sub)* 1✓ (F=) 2.3×10^{-11} (N) 2✓ **OR** Use of an appropriate equation of motion to find t **and** $F=\Delta mv/t$ *(allow their mass and their velocity in this sub)* 1✓ (F=) 2.3×10^{-11} (N) 2✓	Condone POT error Correct answers gets 2 marks Condone POT error Condone POT [answer is $\frac{(\text{their speed})^2 \times (\text{their } m_\alpha)}{0.070}$ Using 2 x 10^7 m s^{-1} yields(5.71 x 10^{15} x their m_{α}) – allow 1 sf answer in this case. Expect to see 3.8 x 10^{-11} (N) or 4 x 10^{-11} (N)]	2
03.3	(Number of ions formed over range =) $5.1 \times 10^4 \times 3.5$ seen **or** 1.785×10^5 (ions) seen Or 8.1 x 10^{-13} converted to eV seen 1✓	Condone POT error in first mark Ignore units	3

	$8.1 \times 10^{-13} \div 1.785 \times 10^{5}$ **Or** $5.06 \times 10^{6} \div 1.785 \times 10^{5}$ seen ₂✓ 28 (.4) (eV) ₃✓	$8.1 \times 10^{-13} \div (5.1 \times 10^{4} \times 3.5)$ is worth 1st and 2nd marks Condone POT errors in second mark Correct answer obtains 3 marks 99(.3) (eV) scores 1 mark	
03.4	$(Q =)\ 0.85 \times 10^{-3} \times 1.2 \times 10^{-9} = 1.02 \times 10^{-12}$ **OR** $n =$ (their Q) $\div\ 1.6 \times 10^{-19}$ ₁✓ $n = 6.4 \times 10^{6}$ (c.a.o.) ₂✓	Condone one POT error for one mark.	2
03.5	At 3.5 cm the pd drops / the current begins **OR** When the source is 10 cm away no ionisation occurs in the air gap (because the alpha particles have insufficient range to reach the air gap) **OR** When the radioactive source is <u>close enough</u> (approx. 5 cm) ionisation occurs ✓ OR When beyond 3.5 cm no change in pd / current equals zero <u>When ionisation occurs / charge carriers are liberated in the air gap</u>: resistance has decreased **OR** current increases (from zero) **OR** the potential difference decreases (with a maximum current) (to its minimum value) (across the air gap)✓	Must be sense of abrupt change MAX 3 Allow more ionisation for second mark	3

	From 10 cm separation until 5 cm (approx) separation nothing changes / appreciates that pd is 4500 V / pd across gap = 4500 V until ionisation occurs ✓ Current is produced: the pd across 5 MΩ resistor is 4250 V / most pd is across the 5 MΩ resistor / small pd across air gap ✓ Current is produced and the pd across the air gap is 250 V✓ Current is produced and the pd across the air gap is 250 V✓		

Do not write outside the box

Section B

Answer **all** questions in this section.

0 3 This question is about two applications of photon energy and momentum: positron emission tomography (PET) and a solar sail.

The momentum of a photon is $\dfrac{\text{photon energy}}{\text{speed of light in a vacuum}}$

0 3 . 1 In preparing for a PET scan of a patient's brain, a small sample of a substance containing unstable nuclei is injected into the patient.
A positron is emitted when one of the unstable nuclei undergoes β^+ decay.

Explain how the change in quark character in β^+ decay affects the number of neutrons and the number of protons in the unstable nucleus.

[2 marks]

0 3 . 2 The positron interacts with an electron, resulting in annihilation. As a result, gamma photons are produced.
The energy of each gamma photon is 0.52 MeV.

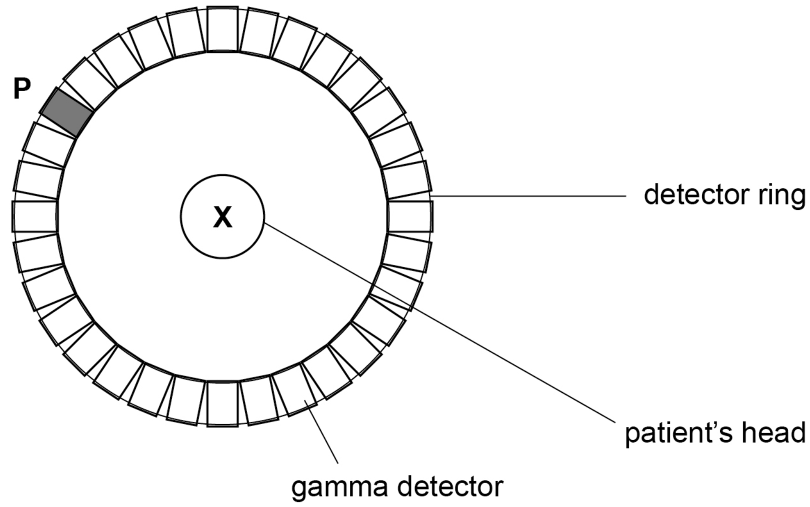
Calculate the momentum, in N s, of one of the gamma photons produced in this annihilation.

[2 marks]

momentum = ______________________ N s

0 3 . 3 **Figure 5** shows a cross-sectional view of the patient's head inside a ring of gamma detectors during the PET scan.

Figure 5



A positron and an electron meet and annihilate at position **X** shown in **Figure 5**. Assume they have negligible kinetic energy when they meet.

Gamma photons are produced in this annihilation and are detected. The arrival of one gamma photon at detector **P** triggers a signal. Detector **P** has been shaded in **Figure 5**.

Identify by shading any other detectors that will be triggered by this annihilation.

[1 mark]

0 3 . 4 Explain your answer to question **03.3**.

[2 marks]

Question 3 continues on the next page

0 3 . 5 **Figure 6** shows a stream of photons of light, emitted from the Sun, incident on a solar sail. A solar sail is an experimental spacecraft that uses photons of light to accelerate it.

Figure 6

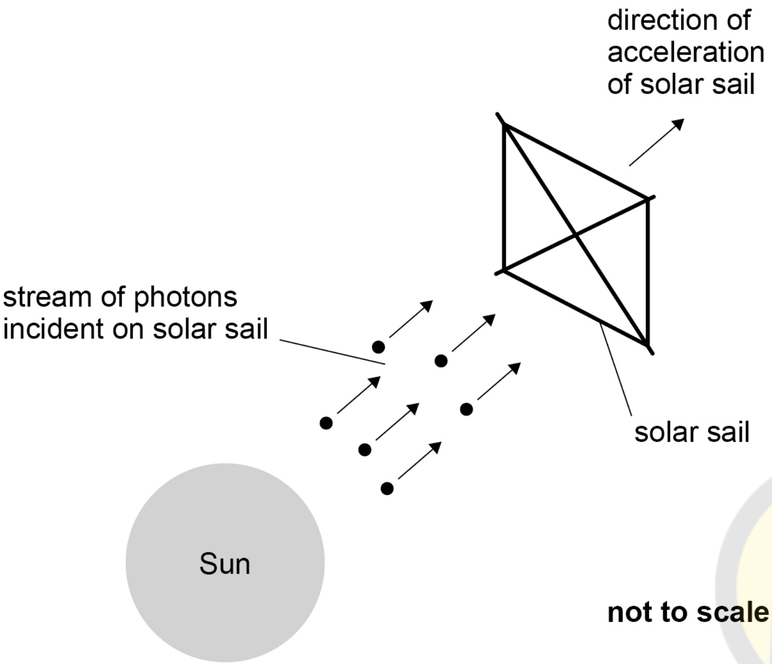
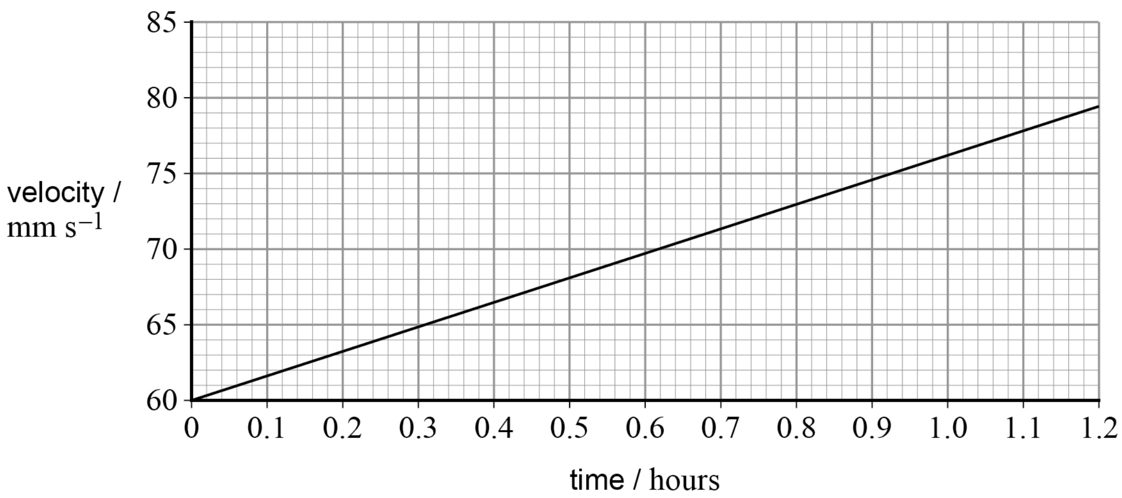


Figure 7 shows the velocity–time graph for the solar sail.

Figure 7



Do not write outside the box

Calculate the acceleration, in $m\ s^{-2}$, of the solar sail.

[2 marks]

acceleration = ______________________ $m\ s^{-2}$

0 3 . 6 The reflectance of a surface is proportional to the percentage of incident photons that are reflected off the surface.

Explain the effect of increasing the reflectance of the solar sail on the acceleration. Assume gravity has negligible effect on the solar sail.

[2 marks]

11

Question	Answers	Additional Comments/Guidelines	Mark
03.1	Neutron number increases by one **and** proton number decreases by one 1✓ Or A proton changes/decays to a neutron 1✓ (because) up (quark) changes to a down (quark) 2✓	Allow use of symbols: *N* increases by one and *Z* decreases by one Allow this expressed as an equation symbols for proton and neutron. Allow u (quark) changes to d (quark) Allow uud –> dud Where decay equation is attempted, condone incorrect leptons (quarks must be correct).	2

03.2	Conversion of 0.52 MeV to eV seen $_1$✓ Or Conversion of 0.52 MeV to J $_1$✓ Or Use of $p = \frac{E}{c}$ $_1$✓ $(p =)\ 2.77 \times 10^{-22}$ or 2.8×10^{-22} $_2$✓ **c.a.o**	5.2×10^5 (eV) seen Condone POT error in conversion to joule Expect to see: 8.32×10^{-14} (J) With substitution of student's value for E (where conversion hasn't been completed or completed incorrectly)	2
03.3	Shades detector opposite **P** ✓	The leader line from label 'patient's head' passes through a box. Expect to see shaded the box below the 'leader line' box. Allow either of the boxes adjacent to expected box. Penalise more than one box shaded.	1
03.4	2 photons (are produced) / Photons must move off in opposite directions (along the same line) $_1$✓ The photons must have equal and opposite momentum / must conserve momentum $_2$✓		2

03.5	Use of (gradient=) $\frac{\Delta v}{\Delta t}$ ₁✓ $4.5(1) \times 10^{-6}$ (m s^{-2}) ₂✓	Condone power of ten errors and leaving time in hours (or incorrect conversion to seconds) Correct read off; condone errors in read off that lead to $\pm$ 1mm s^{-1} in Δv and ± 0.02 h in Δt. For 1 mark expect to see (79-60)÷ 1.18 (65-60) ÷ 0.3 (70-60) ÷0.6 (75-60) ÷ 0.92 (76-60) ÷ 1 **Max 1** for answer where there is failure to notice false origin. MP2 is available in this case where there is only the false origin error. Range = $4.40\times 10^{-6} \leq accepted\ value < 4.65\times 10^{-6}$	2

03.6	Acceleration increases $_1$✓ Larger change in momentum (because more photons are reversing direction of motion) therefore a larger force on solar sail $_2$✓ **Or** More momentum gained per second (from the photons) $_2$✓ **Or** Larger force on photons therefore larger force on sail $_2$✓	Condone correct acceleration statement linked to incorrect explanation.	2
Total			**11**

Do not write outside the box

Answer **all** questions in the spaces provided.

0 1 . 1 Deuterium is an isotope of hydrogen. Its nucleus contains one proton and one neutron.

Calculate the specific charge of the deuterium nucleus.

[2 marks]

specific charge = ____________________________ C kg^{-1}

Do not write outside the box

0 1 . 2 The proton and neutron in the deuterium nucleus are held together by the strong nuclear force.

Which is an exchange particle of the strong nuclear force?
Tick (✓) **one** box.

[1 mark]

muon ☐

photon ☐

pion ☐

W^+ boson ☐

0 1 . 3 The deuterium nucleus is stable.

Describe how the variation of the strong nuclear force with distance contributes to the stability of the deuterium nucleus.

[3 marks]

Question 1 continues on the next page

Do not write outside the box

0 1 . 4 Tritium is an isotope of hydrogen. Its nucleus contains one proton and two neutrons. Tritium undergoes radioactive decay.

Three modes of radioactive decay are

- alpha decay
- beta minus (β^-) decay
- electron capture.

Deduce which of these modes could produce the nucleus of another element when the tritium nucleus decays.

[3 marks]

9

Question	Answers	Additional Comments/Guidance	Mark	ID details
01.1	Use of specific charge = charge / mass eg 1.60×10^{-19} / $(1.67(3) \times 10^{-27} + 1.67(5) \times 10^{-27})$ ✓ 4.8×10^{7} (C kg^{-1}) ✓	Any substitution or equation suggesting specific charge = charge/mass gains the first mark. Use of ½ × proton specific charge gains full credit.	2	AO2.1f
01.2	Pion ✓		1	AO1.1a
01.3	(Short-range) attraction up to about 3 fm ✓ (Very short-range) repulsion closer than 0.5 fm ✓ Prevent proton and neutron moving closer or further apart ✓	Allow 1-5 fm. Allow 0.5-1 fm. Allow 1 mark for stating both a value at which attraction occurs and a value at which repulsion occurs. MP3 is for a suggestion that an equilibrium point exists or that nucleus doesn't collapse. Any suggestion of electric forces between proton and neutron loses MP3.	3	AO1.1a AO2.1a

01.4	Correct description of alpha decay **OR** Consequence of alpha decay ✓ Correct description of electron capture **OR** Consequence of electron capture ✓ Correct description of beta decay, with explicit conclusion that this mode is valid ✓	Either MP1 or MP2 lost if answer suggests that decay mode is valid. Accept answers in terms of A and Z, or that use accepted nomenclature eg ${}^{4}_{2}\mathrm{He}$. Condone absence of antineutrino.	3	AO3.1b

Total			**9**

Question	Answers	Additional Comments/Guidance	Mark	ID details
02.1	Use of $P=VI$ or $P=I^2R$ or $\mathrm{P} = \frac{\mathrm{V}^2}{\mathrm{R}}$ ✓ Use of $\Delta W=P\Delta t$ ✓ **OR** Use of $\Delta Q=I\Delta t$ ✓ Use of $W=VQ$ ✓ 2.1×10^5 (J) ✓	2 marks if time not converted to seconds (3600 J)	3	AO2.1g

Do not write outside the box

0 6 Scientists at CERN have produced atoms of antihydrogen.
An atom of antihydrogen contains the antiparticle of the proton and the antiparticle of the electron.

0 6 . 1 State what is meant by an antiparticle.

[2 marks]

0 6 . 2 Complete **Table 2** with the names of the antiparticles in an atom of antihydrogen.

[2 marks]

Table 2

Name of particle	Name of antiparticle
proton	
electron	

0 6 . 3 The particles in antihydrogen can be made by pair production.

Calculate the total minimum energy, in J, needed to produce the particles in one atom of antihydrogen.

[3 marks]

energy = ______________________________ J

Do not write outside the box

0 6 . 4 Line emission spectra of hydrogen and antihydrogen have been compared.

Explain in terms of energy changes how line emission spectra are produced.

[3 marks]

10

Question	Answers	Additional Comments/Guidance	Mark	ID details
06.1	Particle with equal (rest) mass/energy ✓ but <u>opposite</u> charge/baryon number/lepton number ✓		2	AO1.1a
06.2	Antiproton ✓ Positron ✓	Do not accept antielectron for positron	2	AO1.1a
06.3	Rest energy of positron (0.510999) <u>and</u> antiproton (938.257) quoted, or 938.768 (MeV) seen ✓ Multiplies by 1.6 ✓ 1.5×10^{-10} (J) ✓	Allow valid use of $E=mc^2$. Allow any power of ten Allow credit for 3.0×10^{-10} (J) for proton–antiproton and electron–positron production	3	AO2.1f
06.4	Max 3 ✓ ✓ ✓ Idea that (atomic) energy levels/states are discrete, or (emitted) photon energy is discrete Idea that a photon is produced by electrons/atoms moving to <u>lower</u> energy levels/states Idea that wavelength/frequency relates to photon energy/ΔE Idea that different wavelengths/frequencies are produced	 Allow light/radiation for "photon" May see equation relating ΔE to f or λ	3	AO1.1a
Total			**10**	

0 1 . 1 Two isotopes of iodine are $^{125}_{53}\mathrm{I}$ and $^{131}_{53}\mathrm{I}$.

Determine, for these two isotopes, the difference between the constituents of the nuclei.

[1 mark]

0 1 . 2 A $^{131}_{53}\mathrm{I}$ nuclide undergoes beta (β^-) decay to form a xenon nuclide.

State the nucleon number of the xenon nuclide.

[1 mark]

0 1 . 3 A $^{125}_{53}\mathrm{I}$ nuclide decays by electron capture to form a tellurium nuclide.

State **two** differences between the constituents of the iodine nucleus and the tellurium nucleus it decays into.

[2 marks]

Do not write outside the box

0 1 . 4 Internal conversion is a process in which a nucleus in an excited state can release its excess energy. In internal conversion all of the excess energy is transferred from the nucleus to an orbital electron through the electromagnetic force. This orbital electron is ejected from the atom.

The tellurium nucleus formed in question **01.3** is in an excited state and can undergo internal conversion.

Discuss **three** differences between internal conversion and beta (β^-) decay.

[3 marks]

1 ____

____

____

2 ____

____

____

3 ____

____

____

7

Question	Answers	Additional Comments/Guidelines	Mark
01.1	Iodine-131 has <u>6 more neutrons</u> (than iodine-125) ✓	Condone iodine-131 has 78 neutrons and iodine-125 has 72 neutrons. Condone "6 fewer/less neutrons than iodine-131" Do not credit nucleons. Suggestion of difference in number of protons loses the mark.	1
01.2	131 (nucleons) ✓	If more than one number is given, the nucleon number must be explicit.	1
01.3	The tellurium has 1 more neutron (than iodine-125) ✓ The tellurium has 1 fewer proton (than iodine-125) ✓	Accept reverse arguments. Accept tellurium has 73 neutrons Accept tellurium has 52 protons Condone "proton number". Condone "number of neutrons/protons have increased/decreased <u>by one</u>" Treat any nuclear reactions as neutral. Discussion of electrons in nucleus scores max 1. Accept answer in terms of quarks (one more down and one fewer up). Ignore references to nucleons/mass number.	2

01.4	**A** (*internal conversion*: only electron released); *beta-decay*: (electron and) anti-neutrino released; ✓ **B (both statements required for mark)** *internal conversion*: all electrons released will have similar/discrete energies/momenta *beta-decay*: electrons will have a range of energies/momenta ✓ **C** (*internal conversion*: no change in constituents of nucleus/element does not change) *beta-decay*: neutron converted to proton (allow in terms of quarks)/element changes (to one with (one) more p, different Z, different proton number/different atomic number)) ✓ **D** (*internal conversion*: orbital electron lost) *beta-decay*: electron comes from nucleus / no change in orbital electrons ✓ **E (both statements required for mark)** *internal conversion*: mediated by electromagnetic force / virtual photons *beta-decay*: mediated by weak interaction / W^- ✓	Any 3. Treat each difference, as delimited by the answer book, as a single independent mark. Contradiction within a difference cancels the mark for that difference (on list basis). For a contradiction between separate differences treat the incorrect difference as neutral. Allow: **F (both statements required for mark)** *Internal conversion:* may be accompanied by X-ray photon *Beta*-decay: may be accompanied by gamma photon ✓ Allow "shells" for "orbitals". Do not award separate marks for force and exchange particle Condone "W boson" or "W particle" but not W^+ and W	3

Total			**7**

0 4 Scintillation counters are used to detect beta particles. A scintillation counter consists of a scintillation material and a photomultiplier tube (PMT).

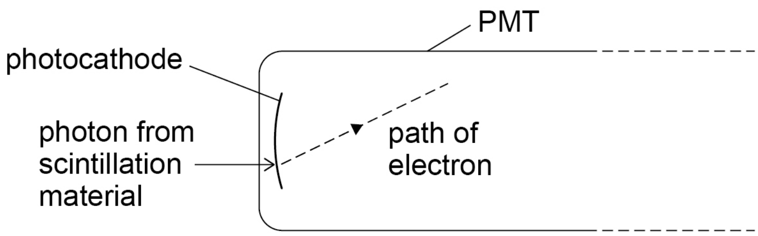
0 4 . 1 Beta particles collide with atoms in the scintillation material, which emits photons of light as a result.

Explain how photons are produced by collisions between beta particles and atoms.

[2 marks]

0 4 . 2 A photon of light from the scintillation material enters the PMT, as shown in **Figure 7**. The front of the PMT contains a thin photocathode. The photon strikes the photocathode to release an electron.

Figure 7



The longest wavelength of light that releases an electron from this photocathode is 630 nm.

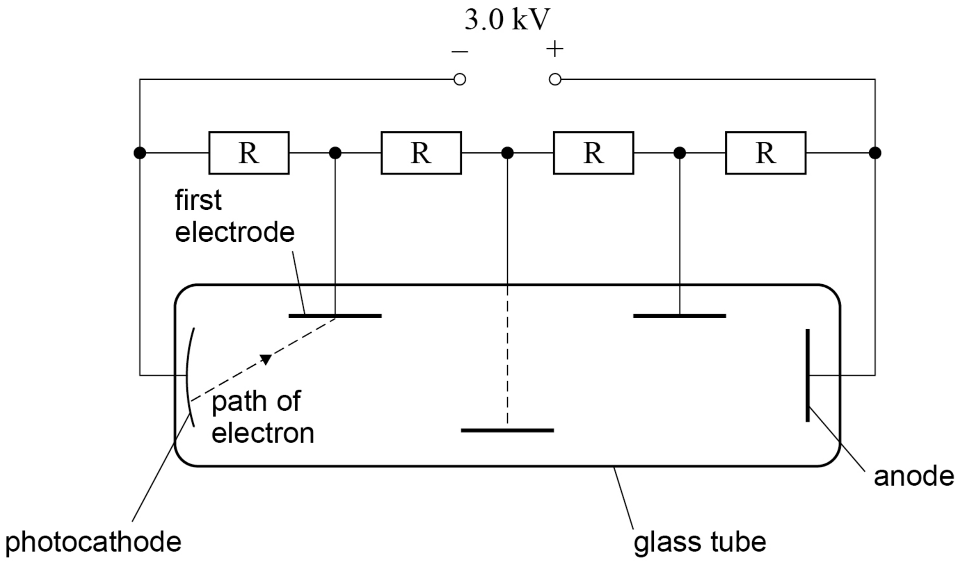
Calculate the minimum photon energy required to remove an electron from the photocathode.

[2 marks]

minimum photon energy = ______________________ J

0 4 . 3 The PMT consists of an evacuated glass tube containing the photocathode, an anode and three metal electrodes, as shown in **Figure 8**.

Figure 8



The electrodes, anode and photocathode are connected to a potential divider consisting of four identical resistors R. The emf of the electrical supply is 3.0 kV.

The potential difference between the photocathode and the first electrode accelerates the electron along the path shown in **Figure 8**.

Calculate, in J, the maximum kinetic energy transferred to the electron when it accelerates from the photocathode to the first electrode.

[2 marks]

maximum kinetic energy = ______________________ J

Question 4 continues on the next page

Do not write outside the box

0 4 . 4 The electron hits the first electrode and causes the release of several electrons. **Figure 9** shows how a series of accelerations and collisions produces a large number of electrons. These electrons hit the anode and produce a pulse of current in an ammeter.

Figure 9

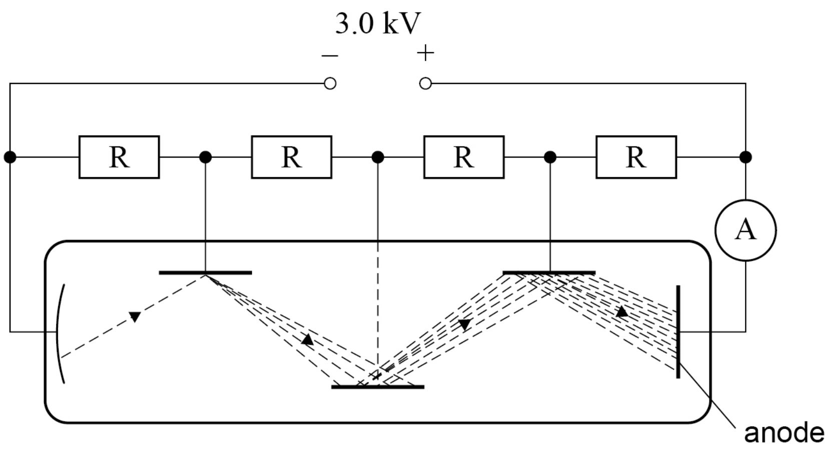
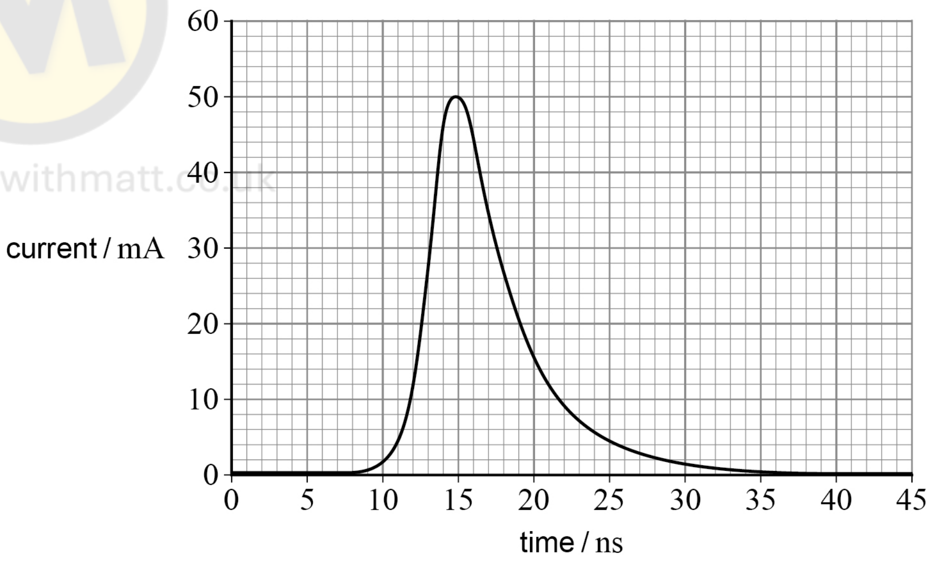


Figure 10 shows the variation of current in the ammeter with time due to this pulse.

Figure 10



Determine the number of electrons that flow through the ammeter.

[4 marks]

number of electrons = ______________________

10

END OF SECTION B

Question	Answers	Additional Comments/Guidance	Mark	AO details
04.1	Idea that atoms gains energy (from beta particle) eg atoms excited or atoms/electrons moved to higher energy levels ✓ Idea that atom loses energy by emission of light/photons eg atoms de-excite or electrons move to lower energy levels ✓	Allow ionisation as named process	2	1.1a 1.1a
04.2	Use of $E = \frac{hc}{\lambda}$ **OR** use of $c = f\lambda$ and $E = hf$ ✓ 3.2×10^{-19} (J) ✓	Condone POT error for λ Allow 3.1×10^{-19} (J) if 6.6×10^{-34} used	2	1.1a 1.1b
04.3	Use of $W = QV$ **OR** determines pd = 750 V ✓ 1.2×10^{-16} (J) ✓		2	2.1b 2.1f
04.4	Max 3 from: ✓ ✓ ✓ Attempt to count squares **OR** calculate unit area **OR** Statement that area under curve = charge flow Counts number of squares/Determines area Converts number of squares to charge Divides their total charge by 1.60×10^{-19} 2×10^{9} ✓	1 small square = 2×10^{-12} (C) ; 1 large square = 5×10^{-11} (C) Accept 140 to 180 small or 5.5–7 large squares Accept $\frac{1}{2}$ base × height for triangle of base 12–16 ns and height 50 mA Allow 1 sf answer	4	3.1a 2.1f 2.1f 2.1f
Total			**10**	

0 1 . 1 Determine whether the following reaction is a possible decay for the neutral pion π^0.

$$\pi^0 \rightarrow e^- + \mu^+ + \bar{\nu}_e$$

[2 marks]

0 1 . 2 State the **two** possible quark configurations of a π^0.

[1 mark]

1

2

0 1 . 3 A student suggests that the kaon K^0 and the anti-kaon $\overline{K^0}$ are the same particle.

Discuss whether this suggestion is correct.

[2 marks]

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Do not write outside the box

0 1 . 4 The nucleus is held together by a force. It was predicted that a particle exists that is responsible for this force. The particle itself must experience this force.

The particle would have a rest energy between that of an electron and half that of a nucleon.

Discuss whether a kaon, a muon and a pion **each** have the properties of the predicted particle.

Information about these three particles is in the Data and Formulae Booklet.

[4 marks]

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9

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Question	Answers	Additional comments/Guidelines	Mark	ID details
01.1	Award each mark independently Lepton number not conserved therefore not possible✓ Lepton numbers for particles correct ✓ Eg $0 = 1 - 1 - 1$ (for lepton number) OR 0 = 0 -1 +0 (for muon lepton number)	Any incorrect quantum number equation (for Q, B or S) loses MP2. Alternative for MP2 reference to missing muon neutrino in order to balance/conserve (muon) lepton number.	2	2× AO1a
01.2	up anti-up AND down anti-down✓	Either order Credit symbols But do not condone any use of capital letter	1	AO1a
01.3	Identification of quarks in either neutral kaon correct, ie kaon $d\,\bar{s}$ OR anti-kaon $\bar{d}\,s$ ✓ Identification of quarks in other kaon correct, with statement that they are not the same. ✓	Alternative: Kaon has strangeness +1✓ Anti-kaon has strangeness –1 and is therefore not the same.✓ **Allow max 1 if** • quark configurations wrong way round. • value of strangeness is wrong way round • statement that strangeness is different without reference to value. • strangeness and quarks given but one of them is incorrect.	2	AO1a AO1b

Question	Answers	Additional comments/Guidelines	Mark	ID details
01.4	Award each mark independently Links hadrons to strong nuclear force (snf) OR identifies snf as forcing holding nucleus together✓ Reason why it cannot be the kaon✓ Reason why it cannot be the muon✓ pion is the particle as it (has mass in range and) is a hadron (and therefore experiences snf) ✓	For MP2: kaon rest energy is not between those of electron and half that of nucleon. (values quoted from data booklet) OR (only) pion and muon have correct rest energy with no mention of kaon. For MP3: muon is a lepton (and does not experience snf) An incorrect statement amount a particle negates the mark for that particle. Rest energies/MeV: kaon 493.821 or 497.762 pion 139.576 or 134.972 muon 105.659 nucleon 938.257 or 939.551	4	AO3.1b
Total			**9**	

Do not write outside the box

Answer **all** questions in the spaces provided.

0 1 One strong interaction that occurs when two high-energy protons collide is

$$p + p \rightarrow p + \pi^{+} + \pi^{-} + \mathbf{X}$$

0 1 . 1 Determine the lepton number, strangeness and charge of particle **X**.

[2 marks]

lepton number = ____________________

strangeness = ____________________

charge = ____________________

0 1 . 2 Identify particle **X**.

[1 mark]

____

0 1 . 3 A possible decay of a negative pion is

$$\pi^- \rightarrow e^- + \mathbf{Y}$$

What is particle **Y**?
Tick (✓) **one** box.

[1 mark]

$\bar{\nu}_e$ ☐

ν_e ☐

π^0 ☐

${}^1_0n$ ☐

0 1 . 4 Some subatomic particles are classified as hadrons. There are two classes of hadrons.

Discuss the nature of hadrons.
Your answer should include:

- the identifying properties of hadrons
- the structure of a hadron in each class
- a discussion of the stability of free hadrons.

[6 marks]

Question	Answers	Additional Comments/Guidance	Mark	ID details
01.1	Lepton number = 0 **and** Strangeness = 0✓ charge = (+)1(e)✓	accept (+) 1.6 x 10^{-19} (C) condone lack of unit	2	AO2.1b AO2.1b
01.2	Proton / p / ^1_1H ✓	Apply ECF to answers any particle other than a proton. The particle must be correct for the given L, S and Q. (clip with 2.1)	1	AO2.1b
01.3	Tick in first box only✓	(electron) antineutrino $\bar{\nu}_{(e)}$	1	AO1.1a

<table>
<tr><th>Question</th><th>Answers</th><th>Additional Comments/Guidance</th><th>Mark</th><th>ID details</th></tr>
<tr>
<td>01.4</td>
<td>The marking scheme for this question includes an overall assessment for the quality of written communication (QWC). There are no discrete marks for the assessment of QWC but the candidate's QWC in this answer will be one of the criteria used to assign a level and award the marks for this question.
<table>
<tr><th>Mark</th><th>Criteria</th><th>QWC</th></tr>
<tr><td>6</td><td>All 3 areas A, B and C covered
Only allow minor omissions</td><td rowspan="2">The student presents the relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.</td></tr>
<tr><td>5</td><td>2 complete descriptions with one partial from A, B and C.</td></tr>
<tr><td>4</td><td>Full description of one area, with partial description of two other.
OR
Full description of two areas with very little on third or nothing at all.</td><td rowspan="2">The student presents relevant information in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.</td></tr>
<tr><td>3</td><td>A full description of one area and a partial description of one area.
OR
A partial discussion of all three areas.</td></tr>
<tr><td>2</td><td>A full description of one area.
OR
A partial discussion of two areas.</td><td rowspan="2">The student presents some relevant information in a simple form. The text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.</td></tr>
<tr><td>1</td><td>Only one area covered, and that partially.</td></tr>
<tr><td>0</td><td>No relevant information</td><td></td></tr>
</table>
</td>
<td>The following statements are likely to be present.

Area A
Hadrons properties:
• Identifies hadrons as consisting of quarks
• May interact via the strong nuclear force

Area B
General structure:
• Two classes are mesons and baryons
• quark-antiquark: meson
• Quark, quark, quark: baryon
Area C
Stability of free hadron:
• Only stable free baryon is proton
• Example of decay of a free meson or baryon e.g. kaon decay into pions / states neutron decays into a proton</td>
<td>6</td>
<td>AO1.1a
AO1.1a
AO1.1a
AO1.1a
AO1.1a
AO1.1a</td>
</tr>
</table>

Do not write outside the box

0 4 A sample of pure boron contains only isotope **X** and isotope **Y**.
A nucleus of **X** has more mass than a nucleus of **Y**.

0 4 . 1 The sample is ionised, producing ions each with a charge of $+1.6 \times 10^{-19}$ C.
The specific charge of an ion of **X** is 8.7×10^{6} C kg^{-1}.

Calculate the mass of an ion of **X**.

[1 mark]

mass of ion = ____________________ kg

0 4 . 2 Determine the number of nucleons in a nucleus of **X**.

mass of a nucleon = 1.7×10^{-27} kg

[2 marks]

number of nucleons = ____________________

0 4 . 3 Compare the nuclear compositions of **X** and **Y**.

[2 marks]

____

____

____

____

____

____

Question 4 continues on the next page

Do not write outside the box

0 4 . 4 Ions of **Y** have the same charge as ions of **X**.

State and explain how the specific charge of an ion of **X** compares with that of an ion of **Y**.

[2 marks]

0 4 . 5 **Table 1** contains data about two completely ionised samples of pure boron. Each sample contains only isotopes **X** and **Y**.

Table 1

Sample number	Number of ions in sample	Mass of sample / kg	Charge on each ion / C
1	3.50×10^{16}	6.31×10^{-10}	$+1.60 \times 10^{-19}$
2	3.50×10^{7}	6.20×10^{-19}	$+1.60 \times 10^{-19}$

Deduce which sample, **1** or **2**, contains a greater percentage of isotope **Y**.

[3 marks]

10

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.1	(mass of ion =) 1.8(4) × 10^{-26} (kg) ✓		1	AO2.1b
04.2	(Mass of ion divided by mass of nucleon=) 10.6 or 10.8✓ ECF (number of nucleons=) 11 ✓ **ECF**	allow 1 mark for 10 seen as final answer whole number not in standard form	2	AO2.1b AO2.1b
04.3	Same number of protons✓ **X** has more neutrons (than **Y**) Or **Y** has fewer neutrons (than **X**)✓	Allow 'same proton number' but **not** same 'atomic number' Allow: isotopes have same number of protons Condone any mention of electrons ' X has more nucleons' or 'Y has fewer nucleons' insufficient	2	AO1.1a AO2.1a

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.4	Specific charge on ion **X** is less than specific charge on **Y** Or Specific charge on ion **Y** is greater than specific charge on **X** ✓ Specific charge is inversely proportional to mass (for the same charge) ✓	Or words to that effect Where equation is stated, the symbols must be defined or standard symbols must be used.	2	AO2.1a AO2.1a

04.5	Specific charge of sample determined correctly✓ Specific charge of each sample determined correctly ✓ Sample 2 has a greater percentage **because** it has a higher specific charge ✓ **Or** Mean mass of a nucleon in a sample determined correctly✓ Mean mass of a nucleon in each sample determined correctly✓ Sample 2 has a greater percentage **because** the nucleons have a lower mean mass. ✓ Or Mean mass of a nucleon in a sample determined correctly✓ Multiples by this average by number of nuclei in the other sample✓ Sample 2 has a greater percentage **because** the nucleons in sample 2 have a lower average mass. Or Sample 2 because it has a lower mass if both samples had the same number of ions✓ **Or** 10^9 times smaller in number but more than 10^9 times smaller mass ✓ (Therefore) sample 2 must have a lower mean mass (than sample 1)✓ Sample 2 has a greater percentage of **Y because Y** has less mass than X ✓	Mean mass of a nucleon sample 1= 1.8×10^{-26} kg Mean mass of a nucleon sample 2 = 1.77×10^{-26} kg Specific charge of sample 1 = 8.8×10^6 (C kg^{-1}) Specific charge of sample 2 = 9.0×10^6 (C kg^{-1}) Conclusion must be supported by at least one relevant, correct calculation Condone one power of ten error in one calculation. Accept converse statements. Condone incorrect units	3	AO3.1a AO3.1a AO3.1a

Total			**10**

Answer **all** questions in the spaces provided.

0 1 . 1 Identify the number of neutrons in a nucleus of polonium-210 $\left({}^{210}_{84}\mathrm{Po}\right)$.

Tick (✓) **one** box.

[1 mark]

84 ☐

126 ☐

210 ☐

294 ☐

0 1 . 2 A polonium-210 nucleus is formed when a stationary nucleus of bismuth-210 decays. A beta-minus (β^-) particle is emitted in this decay.

Outline, with reference to β^- decay, why bismuth-210 and polonium-210 have different proton numbers.

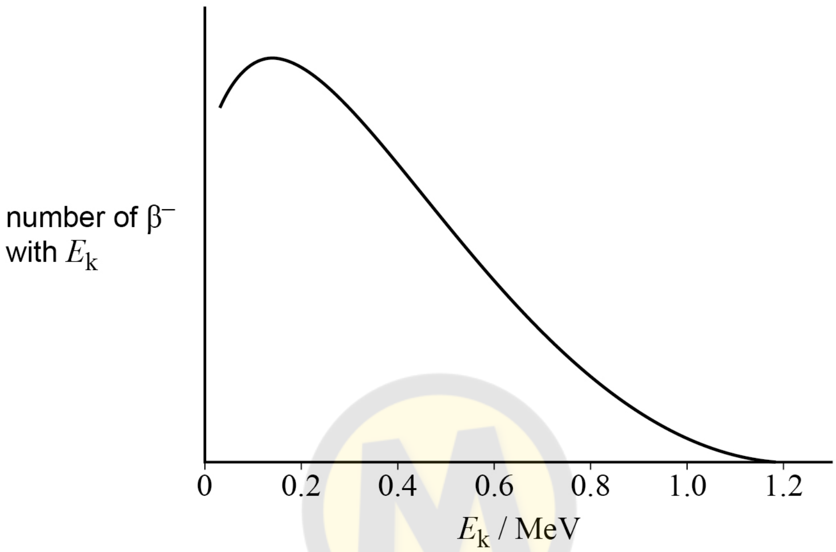
[2 marks]

The kinetic energies of β^- particles emitted from a sample of bismuth-210 are analysed. These β^- particles have a range of kinetic energies.

The total energy released when each nucleus of bismuth-210 decays to a nucleus of polonium-210 is 1.2 MeV.

Figure 1 shows the variation with E_k of the number of β^- particles that have the kinetic energy E_k.

Figure 1



0 1 . 3 Explain how the data in **Figure 1** support the hypothesis that a third particle is produced during β^- decay.

[2 marks]

Question 1 continues on the next page

Turn over ►

Do not write outside the box

0 1 . 4 This third particle is an electron antineutrino.

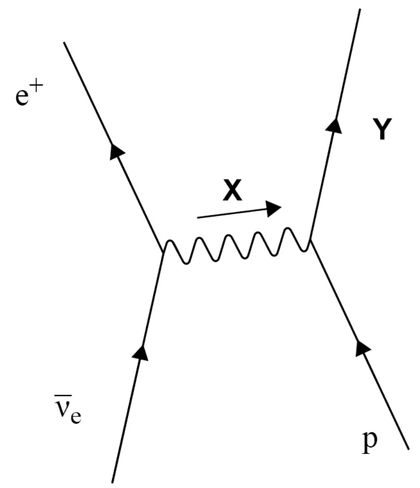
Explain why an electron antineutrino, rather than an electron neutrino, is produced during β^- decay.

[2 marks]

0 1 . 5 A large tank of water is used as part of an electron antineutrino detector.
An electron antineutrino $\overline{\nu}_e$ enters the tank and interacts with a proton (p).

Figure 2 represents this interaction.

Figure 2



Identify **X** and **Y**.

[2 marks]

X =

Y =

0 1 . 6 The positron produced in the interaction in **Figure 2** slows down and collides with a lepton in a molecule of water.

Describe the process that occurs when the positron collides with this lepton.
In your answer you should identify the lepton in the molecule of water.

[3 marks]

0 1 . 7 The range of the electromagnetic interaction is infinite.
Table 1 gives the range of the strong nuclear interaction and the range of the weak nuclear interaction.

Table 1

Interaction	Range / m
strong nuclear	10^{-15}
weak nuclear	10^{-18}

Deduce whether the positron or the electron antineutrino is likely to travel the shorter distance in the tank of water before interacting.

[3 marks]

15

Turn over ►

Question	Answers	Additional Comments/Guidance	Mark	AO
01.1	126 ✓		1	AO1.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
01.2	A neutron decays into a proton **Or** $n \rightarrow p + e^{(-)} + \bar{\nu}_e$ ✓ Proton number **increases by one** when Bi-210 decays and describes beta minus OR Bi-210 has **one fewer proton** (than Po-210) and describes beta minus in words OR Po-210 has **one more proton (**than Bi-210) and describes beta minus in words Or Proton number **increases from 83 to 84** and describes beta minus in words ✓	Allow a neutron changes to a proton. (owtte) Accept the decay equation of a neutron / bismuth • Statement that neutron converts to proton✓ • all numbers correct and context ✓ $^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e + ({}^{0}_{0}\bar{\nu}_e)$ Condone missing (or incorrect) neutrino or symbol for bismuth Allow proton number increases where there is a clear statement that a neutron has decayed into a proton.	2	AO2.1b AO2.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
01.3	(Missing) energy carried off by third particle Or (A third particle must be produced) for conservation of energy✓ There is missing energy (When) a beta (particle) has less than 1.2 MeV (of kinetic energy). Or The law of conservation of energy appears to be violated when beta (particle) has less than 1.2 MeV ✓	Accept energy is converted into mass of third particle. Where third particle is named must be a neutrino or an antineutrino. Identify there is difference between 1.2 MeV and E_k.	2	AO1.1a AO1.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
01.4	(It must be an electron antineutrino to) conserve lepton number✓ An electron and (electron) antineutrino have lepton numbers of opposite signs. Or An electron and (electron) antineutrino have a (total) lepton number of zero. ✓ **Alternative:** Producing an (electron) neutrino wouldn't conserve lepton number✓ An electron and (electron) neutrino have lepton numbers of the same sign. Or An electron and (electron) neutrino have a (total) lepton number equal to 2. ✓	Alternative for 2nd Marking point: Appropriate particle equation seen annotated with correct lepton numbers. Alternative 2nd marking point: Appropriate particle equation seen annotated with correct lepton numbers.	2	AO1.1a AO2.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
01.5	(**X** =) W-minus (boson) / W^- (boson) ✓ (**Y** =) neutron / n ✓		2	AO2.1a AO2.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
01.6	Lepton (in the water molecule) is an electron ✓ and **Max 2** from annihilation ✓ gamma photon**s** are produced ✓ Two (gamma) photons are produced (that travel) in opposite directions. ✓	Must state that lepton (in the water) is an electron for all 3 marks Penalise answers that list other products in MP3 annd MP4	3	AO2.1a AO1.1a AO1.1a

Question	Answers	Additional Comments/Guidance	Mark	AO
01.7	**Max 3** The positron because: positron is charged and the (electron) antineutrino ($\bar{\nu}_{(e)}$) is neutral ✓ The antineutrino only interacts via the weak interaction / The positron interacts via the electromagnetic interaction (and weak interaction)✓ The antineutrino's (weak) interaction is shorter range / the antineutrino is less likely to get close enough to interact (with particles in the water so will travel further) / the antineutrino will interact with fewer particles✓ The positron's (electromagnetic) interaction has a longer range / the positron does not have to be so close to interact (with particles in the water so will travel a shorter distance) / the positron will interact with more particles✓	Must have the correct conclusion for 3 marks.	3	AO3.1a AO3.1a AO3.1a

Total			15

0 1 Cosmic rays are high-energy particles that come from space. Most of these particles are protons. There are other particles in cosmic rays, including atomic nuclei.

Table 1 gives the data for one particular nucleus **X**.

Table 1

Mass / kg	8.02×10^{-26}
Specific charge / C kg^{-1}	4.39×10^{7}
Kinetic energy / MeV	215

0 1 . 1 Determine the number of neutrons in nucleus **X**.

[3 marks]

number of neutrons = ____________________

0 1 . 2 Calculate the speed of **X**.
Ignore relativistic effects.

[3 marks]

speed = ____________________ m s^{-1}

A pion (π^+) and a kaon (K^+) are produced when cosmic rays interact with the upper atmosphere.

0 1 . 3 The π^+ decays to produce a positron and an electron neutrino.

Show how the conservation laws apply to this decay.

[2 marks]

0 1 . 4 The K^+ decays to produce an anti-muon and a muon neutrino.

Explain how strangeness applies in this decay.

[2 marks]

0 1 . 5 Write an equation for a K^+ decay that involves only hadrons.

[2 marks]

12

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	MP1 is for evidence of determining the charge on the nucleus. ✓ MP2 is for evidence of determining either the number of protons OR the number of nucleons. ✓ MP3 is for determining number of neutrons. ✓	Charge = $4.39 \times 10^{7} \times 8.02 \times 10^{-26}$ kg (= 3.52×10^{-18} C) Number of protons = charge/1.6×10^{-19} (= 22) OR Number of nucleons = $8.02 \times 10^{-26} / 1.67 \times 10^{-27}$ (= 48) Number of neutrons = 48 – 22 = 26 Note use of 1.7 gives 27 neutrons and loses MP3	3	3×AO2.1f

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Evidence of conversion of MeV to J ✓ Substitution into KE equation ✓ Correct final answer ✓	Energy = $2.15 \times 10^{8} \times 1.6 \times 10^{-19}$ (= 3.44×10^{-11} J) - allow POT error in MP1 $v^2 = 2E/m = 8.58 \times 10^{14}$ $v = 2.9(3) \times 10^{7}$ m s^{-1}	3	1×AO1.1b 2×AO2.1f

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	$\pi^+ \rightarrow e^+ + \nu_e$ OR charge: $1 = 1 + 0$✓ B: $0 = 0 + 0$ AND L: $0 = -1 + 1$✓ (S: $0 = 0 + 0$)		2	2×AO1.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	$(K^+ \rightarrow \mu^+ + \nu_\mu)$ Correct strangeness $+1 = 0 + 0$ ✓ Weak interaction so strangeness can change (by 0, $+1$ or -1) ✓		2	2×AO1.1b

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Decay consistent with Q B L conservation✓ Equation involving pions ✓	e.g. $K^+ \rightarrow \pi^+ + \pi^+ + \pi^-$ $K^+ \rightarrow \pi^+ + \pi^0$	2	1×AO1.1a 1×AO1.1b
Total			**12**	

0 2 A sample of bromine gas contains a mixture of two isotopes. An experiment is done to find the percentage of each isotope in this sample.

0 2 . 1 In the experiment, the gas is ionised by a beam of electrons.

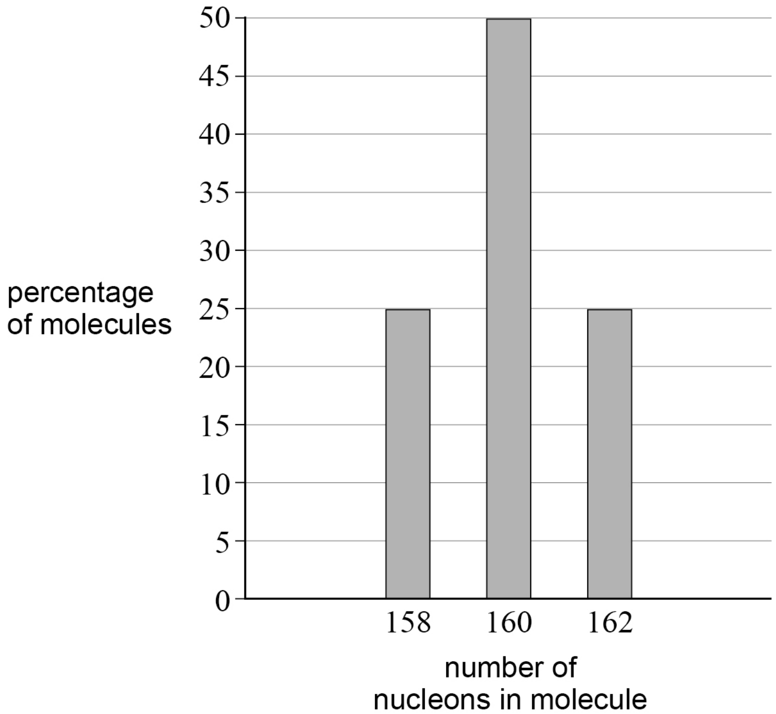
Explain how the beam of electrons causes a particle of the gas to have a charge of $+1e$.

[2 marks]

The gas consists of bromine molecules. Each molecule has two bromine atoms. The experiment finds that the bromine molecules contain 158, 160 or 162 nucleons.

Figure 1 shows the percentage of these different molecules in the sample.

Figure 1



Do not write outside the box

0 2 . 2 Bromine has a proton number of 35
The two isotopes in the sample have different nucleon numbers.

Calculate the number of neutrons for the isotope that has the greater nucleon number.
[2 marks]

number of neutrons = ____________________

0 2 . 3 Deduce the percentage of each isotope in the gas.
Justify your conclusion.
[2 marks]

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6

Turn over for the next question

Question	Answers	Additional Comments/Guidance	Mark	AO
02.1	An electron in the beam collides with an electron in the gas particle. **OR** An electron in the beam transfers (some of its kinetic) energy to an electron in the gas particle ✓ **One** (atomic) electron leaves the gas particle ✓	MP1 is awarded for the description of the electron-electron interaction or the resulting energy transfer between these electrons. Treat the gas particles are 'excited' as neutral, must mention an interaction between beam electron and (atomic) electron or an energy transfer from beam electron to (atomic) electron as cause of excitation Allow beam electron collides with / transfers energy to gas (particle) causing an atomic electron to gain energy Condone use of plurals in MP1 Penalise more than one electron leaving a gas particle Condone **One** (atomic) electron leaves the gas (atom)/ the gas (particle) has lost **one** electron Physics errors that relate the effect to annihilation or beta decay or PEE or electron capture gain zero marks.	2	1 x AO1 1 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
02.2	Finds the nucleon number of the more massive isotope: $162 \div 2 = 81$ **OR** $162 - (2 \times 35) = 92$✓ (answer =) 46 ✓ **c.a.o**	Alternative for **MP1**: subtracts proton number from their nucleon number / subtracts total number of protons from total number of nucleons. eg $80 - 35$ or $79 - 35$ or $160 - 70$ or $158 - 70$ Condone 45 or 44 on answer line without working for one mark. Do **not** allow $162 - 35$ or $160 - 35$ or $158 - 35$ Condone 92 on answer line without working for 1 mark. 90 or 88 on answer line without working no marks	2	2 x AO2

Question	Answers	Additional Comments/Guidance	Mark	AO
02.3	The percentage is the same for both isotopes / each isotope makes up 50% of the gas (by number) ✓ 158 is made of two atoms of the lighter isotope and 162 is made of two atoms of the heavier isotope and the percentages of 158 and 162 are: both 25% / both same /present in the same ratio **OR** Half of the 160 is made from the lighter isotope and all of the 158 is made from the lighter isotope (totalling 50%) **OR** Half of the 160 is made from the heavier isotope and all of the 162 is made from the heavier isotope (totalling 50%)✓	Do not allow 50% of 158 and 50% of 162 Where percentage stated must be 50 % Do not allow more than 2 isotopes Or words to that effect Accept equivalent discussion in terms of numbers of neutrons present in nuclei in molecules / nucleon numbers of nuclei in molecules. Restating the percentages of the molecules is insufficient for MP2.	2	2 x AO3

Total			**6**

0 1 Two stable isotopes of helium are ${}^{4}_{2}\mathrm{He}$ and ${}^{3}_{2}\mathrm{He}$.

0 1 . 1 An atom of ${}^{4}_{2}\mathrm{He}$ is produced in a rock that contains uranium. It is produced following the radioactive decay of a ${}^{238}_{92}\mathrm{U}$ atom. The decay also creates an atom of thorium (Th).

Write an equation for the decay of ${}^{238}_{92}\mathrm{U}$.

[2 marks]

${}^{238}_{92}\mathrm{U} \rightarrow$

0 1 . 2 A ${}^{3}_{2}\mathrm{He}$ nucleus can be produced by the decay of a tritium nucleus ${}^{3}_{1}\mathrm{H}$.

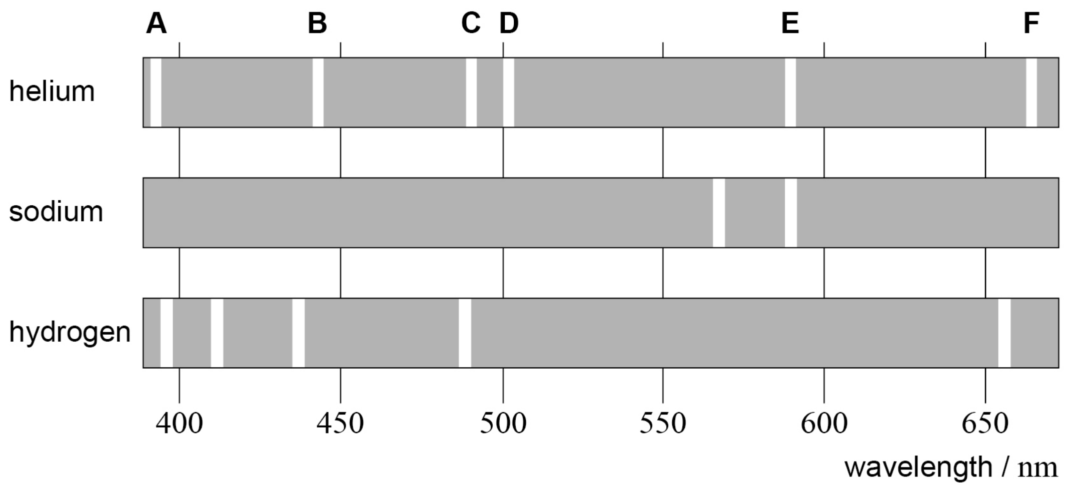
State and explain which exchange particle is responsible for this decay.

[2 marks]

Helium was discovered by analysing the light in the **absorption** spectrum of the Sun.

Figure 1 shows the positions of the brightest lines, labelled **A** to **F**, in the **emission** spectrum of helium. The brightest lines in the emission spectra of sodium and hydrogen are also shown.

Figure 1



0 1 . 3 Before helium was identified, some scientists suggested that the lines of the helium spectrum seen in the absorption spectrum of the Sun were due to the presence of sodium and hydrogen.

Discuss, with reference to the lines **A** to **F** in **Figure 1**, the evidence for and against this suggestion.

[2 marks]

0 1 . 4 Calculate, in eV, the change in energy level responsible for the spectral line labelled **E** in **Figure 1**.

[3 marks]

change in energy level = ____________________ eV

0 1 . 5 Explain, with reference to the processes within an atom, the difference between an emission spectrum and an absorption spectrum.

[3 marks]

12

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	Wavelength = 580 nm to 590 nm ✓ Use of $E = hc/$(their wavelength) ✓ Conversion of their E in J to eV ✓	Expect to see answer in range 2.11 to 2.14 (eV) ✓ When an energy difference between two spectral wavelengths is correctly calculated, only MP2 and MP3 can be scored.	3	1 x AO3 2 x AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Photon is energy carrier OWTTE ✓ In absorption atom becomes excited/moves to higher energy state/level (by absorbing photon) ✓ In emission atom de-excited/moves to lower energy state (by emitting photon) ✓	Condone omission of reference to energy states/levels in either MP2 or MP3 but not both. Treat discussion of any other irrelevant phenomenon or incorrect physics as talk out in that marking point. Allow “energy shell” but not “shell”. Condone electron for atom Suggestions that limit transitions to/from ground state penalise in either MP2 or MP3 once only.	3	3 x AO1
Total			**12**	

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	*(FOR:)* Lines **C** is in (both) hydrogen (and helium spectra) OR Line **E** is in (both) sodium (and helium spectra)✓ *(AGAINST:)* Line **D** is missing (is in neither the hydrogen nor the sodium spectra) ✓	Treat references to **A**, **B** and **F** in FOR or AGAINST as neutral. Must link line to an element Ignore any discussion of any “missing” lines in the helium spectrum. Condone use of 390 / 440 / 490 / 505 / 590 / 670 (nm) for **A/B/C/D/E/F** Condone emission for absorption	2	2 x AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	${}^{4}_{2}\alpha$ ✓+ ${}^{234}_{90}\mathrm{Th}$ ✓	1 mark each for alpha and Th; numbers must be correct Must see "+" for full marks Condone He for alpha If no other mark is given, one mark can be awarded if He-3 is used and A and Z are correct MAX 1 for extra particles but condone "+ $2e^{(-)}$" (not 2β) Ignore symbol that is used for Thorium	2	2 x AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	Idea that a neutron changes to proton/beta minus decay ✓ The particle is W^- because This is a weak interaction / it involves the weak force / there is a quark change and indication that charge is conserved ✓	For MP1 condone "down quark changes to up quark". Evidence for MP1 can be found in the form of equations or diagrams. Second mark requires some explanation of why particle is negative. MAX 1 for a complete consistent inverse interaction leading to W^+.	2	1 x AO2 1 x AO3

Do not write outside the box

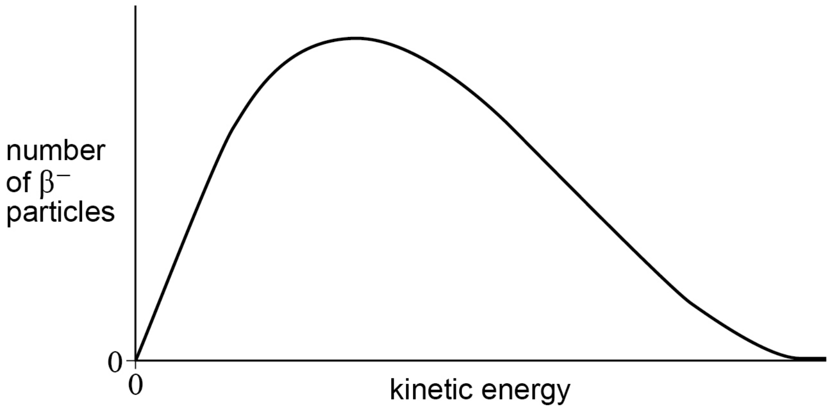
0 2 Carbon-14 decays into nitrogen-14 with the release of a beta (β^-) particle and an antineutrino ($\overline{\nu}_e$).

0 2 . 1 State the change of quark character in β^- decay.

[1 mark]

0 2 . 2 **Figure 2** shows the distribution of kinetic energies of β^- particles from the decay of carbon-14.

Figure 2



Explain how **Figure 2** supports the existence of the antineutrino.

[2 marks]

Question 2 continues on the next page

Do not write outside the box

The existence of the antineutrino was confirmed by experiments in which antineutrinos interact with protons. The equation for this interaction is:

$$\overline{\nu}_e + p \rightarrow e^+ + \mathbf{X}$$

0 2 . 3 Identify particle **X**.

[1 mark]

____

0 2 . 4 The positron released in this interaction is annihilated when it encounters an electron.
A pair of gamma photons is then produced.
Particle **X** can be absorbed by a nucleus. This produces another gamma ray.
Table 1 contains data for three gamma photons detected during an antineutrino–proton interaction experiment.

Table 1

Gamma photon	Photon energy / J
G1	5.0×10^{-14}
G2	6.6×10^{-14}
G3	1.0×10^{-13}

Deduce which of the three gamma photons could have been produced by positron annihilation.

[3 marks]

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7

Question	Answers	Additional comments/Guidelines	Mark	AO
02.1	down quark changes to up quark ✓	Allow "d→u" Condone udd→uud Condone U for u but not D for d. Do not accept answers with extra particles.	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Idea that (graph shows that) beta particles (from C-14) have a range of (kinetic) energies ✓ There is a fixed/maximum/total amount of energy (released by C-14) so there must be another particle that carries the energy differences/missing energy away ✓	A mention of conservation of energy on its own is insufficient for MP2.	2	2 x AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	neutron ✓	Condone "n" but not "N". Do not allow "udd".	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	Calculation of minimum energy produced in annihilation of positron and electron (from rest mass energy $\times 2$) E.g. 2×0.51 MeV $= 1.6 \times 10^{-13}$ J ✓ (2 photons produced so) energy per photon $= 8.2 \times 10^{-14}$ J ✓ Conclusion consistent with their calculated minimum energy. ✓ ALTERNATIVE One calculation of mass equivalence of photon energy✓ Calculation of remaining mass equivalents OR deduction about the other two photon energies ✓ Only G3 has sufficient energy to have been made in annihilation. ✓	Calculation of the photon energy based on one particle can get MP2. The 'correct' answer would be a conclusion leading to G3 only. If no other mark awarded, award one mark for determining rest energy of positron or electron in J. Allow mass equivalent calculations in (M)eV Allow explanation in terms of positron and electron for annihilation in alternative MP3	3	3 x AO3
Total			**7**	

Section A

Answer **all** questions in this section.

0 1 The neutral lambda particle Λ^0 is a baryon with a strangeness of -1

One possible decay for a Λ^0 is

$$\Lambda^0 \rightarrow \pi^0 + n$$

0 1 . 1 Deduce the quark structure of a Λ^0.

[1 mark]

0 1 . 2 State and explain which interaction is involved in this decay.

[2 marks]

0 1 . 3 An antiparticle of the neutral lambda particle decays into a neutral pion and particle **X**.

Identify **X**.

[1 mark]

Do not write outside the box

0 1 . 4 The rest energy of a Λ^0 is equal to the energy of a photon with a frequency of 2.69×10^{23} Hz.

Determine, in MeV, the rest energy of a Λ^0.

[1 mark]

rest energy = ____________________ MeV

0 1 . 5 The discovery of particles such as the Λ^0 is made by large international research teams.

Suggest **one** reason for this.

[1 mark]

____

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6

Turn over for the next question

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	uds ✓	Do not accept D for d. Penalise extra particles	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	weak (interaction / force)✓ strangeness changes (in this decay)✓ (from -1 to 0 and strangeness can only change in a weak interaction)	MP2: Reject negative arguments (eg 'strangeness is conserved in a strong interaction') Reject the idea that strangeness **always** changes in a weak interaction. General statement of strangeness conservation in the weak interaction on its own is insufficient. Accept "strangeness is not conserved (in this decay)". Condone "strangeness is lost".	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	anti-neutron ✓	Accept $\bar{n}$ Reject ambiguous answers unless supported by other evidence. Do not accept answer solely in terms of quarks	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	$1.1(1) \times 10^3$ (MeV) ✓	Reject incorrectly rounded answers. Accept: 1100 MeV (2sf) / 1110 MeV (3sf) / 1115 MeV (4sf) etc Calculator value: 1114.66875 MeV	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Any **one** from ✓ (teams must be large and international) because: • research is expensive / requires funding from many countries • both scientists and engineers are required (because the machines used for research are complex/large pieces of civil engineering) • research is multi-faceted / multi-disciplinary (because computation/theory/ etc. is required) • research is round-the-clock (so teams are large to work on shift basis) • they are needed to process the large amounts of data produced	Treat idea of peer review as neutral (this argues for independent teams). Do not accept idea that it 'avoids bias' or 'reproducibility'.	1	AO1

Total			**6**

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	uds ✓	Do not accept D for d. Penalise extra particles	1	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	weak (interaction / force)✓ strangeness changes (in this decay)✓ (from -1 to 0 and strangeness can only change in a weak interaction)	MP2: Reject negative arguments (eg 'strangeness is conserved in a strong interaction') Reject the idea that strangeness **always** changes in a weak interaction. General statement of strangeness conservation in the weak interaction on its own is insufficient. Accept "strangeness is not conserved (in this decay)". Condone "strangeness is lost".	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	anti-neutron ✓	Accept $\bar{n}$ Reject ambiguous answers unless supported by other evidence. Do not accept answer solely in terms of quarks	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	$1.1(1) \times 10^3$ (MeV) ✓	Reject incorrectly rounded answers. Accept: 1100 MeV (2sf) / 1110 MeV (3sf) / 1115 MeV (4sf) etc Calculator value: 1114.66875 MeV	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.5	Any **one** from ✓ (teams must be large and international) because: • research is expensive / requires funding from many countries • both scientists and engineers are required (because the machines used for research are complex/large pieces of civil engineering) • research is multi-faceted / multi-disciplinary (because computation/theory/ etc. is required) • research is round-the-clock (so teams are large to work on shift basis) • they are needed to process the large amounts of data produced	Treat idea of peer review as neutral (this argues for independent teams). Do not accept idea that it 'avoids bias' or 'reproducibility'.	1	AO1
Total			**6**	

Section A

Answer **all** questions in this section.

0 1 . 1 State the names of the four fundamental interactions.

[1 mark]

1 ____________________

2 ____________________

3 ____________________

4 ____________________

0 1 . 2 State the products of the decay of a free neutron.

[1 mark]

____

0 1 . 3 Explain which of the fundamental interactions is responsible for the decay of the neutron.

[2 marks]

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0 1 . 4 The forces between two moving electrons cause their paths to change.

Explain, using the concept of exchange particles, why the electron paths change.

[3 marks]

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7

0 2 A positive pion collides with a neutron and the following interaction is observed:

$$\pi^+ + n \rightarrow K^+ + \Sigma^0$$

Σ^0 is a neutral sigma particle with a strangeness of -1

The interaction can be used to deduce the classifications of the Σ^0.

0 2 . 1 Identify the classifications of each particle in **Table 1**.
Tick (✓) the appropriate boxes for each particle.

[2 marks]

Table 1

Particle	**Baryon**	**Hadron**	**Lepton**	**Meson**
π^+				
n				
K^+				
Σ^0				

0 2 . 2 A conservation rule predicts that the following interaction **cannot** occur:

$$\pi^- + n \rightarrow K^- + \Sigma^0$$

State the conservation rule.
Go on to explain your answer.

[3 marks]

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Question 2 continues on the next page

Turn over ►

Question	Answers	Additional comments/Guidelines	Mark	AO
01.1	gravity, weak (nuclear), strong (nuclear), electromagnetic ✓	Any order, all four must be correct. Condone any reference to "interaction" or "force" Condone "gravitational" Do not accept 'electrostatic', 'gravitational potential', 'em', 'EM'	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.2	proton, beta minus, (electron) antineutrino all correct ✓	Allow alternative ways of writing beta minus: electron/ e / e^- / β^- Accept p and P for proton and $\overline{\upsilon}_e$ or $\overline{\upsilon}$ for antineutrino Condone 'anti electron neutrino'	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.3	weak (nuclear) ✓ it involves leptons (which do not experience strong interaction/force) **OR** there is a change in quark (flavour) ✓	Accept reference to W^- or W together with transfer of charge (from neutron) Accept d (quark) converted to u (quark) MP2 is conditional on award of MP1	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
01.4	idea that the exchange particle is a (virtual) photon ✓ (virtual) photons/the exchange particles have momentum ✓ conservation of momentum (means that photon interchange) enables the electron momentum/path to change ✓	Accept γ for photon.	3	AO1
Total			**7**	

One way in which neutral pions decay is

$$\pi^0 \rightarrow e^- + e^+ + \gamma$$

0 2 . 3 Compare the rest energies of the particles involved in this decay.

[2 marks]

0 2 . 4 The decay of the neutral pion leads to the production of further gamma photons.

Explain why.

[1 mark]

0 2 . 5 The Standard Model is a theory that classifies elementary particles.
Evidence for the theory has been collected since about 1950. However, the term Standard Model has only been used since 1973.

Suggest why progress in particle physics is slow.

[1 mark]

9

Question	Answers	Additional comments/Guidelines	Mark	AO
02.1	All four rows correct $_1$✓$_2$✓ Any two rows correct $_1$✓	<table><tr><th>Particle</th><th>Baryon</th><th>Hadron</th><th>Lepton</th><th>Meson</th></tr><tr><td>π^+</td><td></td><td>✓</td><td></td><td>✓</td></tr><tr><td>n</td><td>✓</td><td>✓</td><td></td><td></td></tr><tr><td>K^+</td><td></td><td>✓</td><td></td><td>✓</td></tr><tr><td>Σ^0</td><td>✓</td><td>✓</td><td></td><td></td></tr></table>Accept any reasonable notation for ✓	2	1 × AO1 1 × AO2

Question	Answers	Additional comments/Guidelines	Mark	AO
02.2	Identifies strangeness as the consideration as interaction would be strong/not weak ✓ K^- and Σ^0 have same strangeness of -1✓ Demonstration that LHS and RHS strangeness not equal AND that the LHS is zero ✓	Do not award MP1 for suggestion that any other quantum number is not conserved. Evidence for MP2 and MP3 can be seen in a correct use of strangeness values e.g. $0 + 0 \rightarrow -1 -1$	3	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
02.3	clear assignment of each particle to its correct rest mass including the photon ✓ idea that LHS mass > RHS mass✓	Electron AND positron rest energy = 0.510999 MeV π^0 rest energy = 134.972 MeV Gamma/photon rest mass = 0 Allow rounded values for rest mass.	2	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.4	annihilation of the positron with an electron ✓	Do not allow answers such as 'elimination'	1	AO1

Question	Answers	Additional comments/Guidelines	Mark	AO
02.5	Idea that international collaboration/co-operation/verification is required OR (investment in) expensive equipment/hardware/ infrastructure is required ✓	Accept idea that (people with) particular/specialist talents/technology/infrastructure must be in place. Ignore references to peer review or vague statements such as ‘it takes a long time’ or ‘it/the research is expensive’.	1	AO1
Total			**9**	

Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	ray through A links to ray in B AND ray in B horizontal by eye ✓	Ignore any arrow directions.	1	AO2

Do not write outside the box

0 4 The deuterium–tritium (D–T) reaction is a nuclear reaction between two isotopes of hydrogen.
The D–T reaction is

$$^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + \text{n}$$

The energy from this reaction is transferred to the kinetic energy of the helium nucleus and the kinetic energy of the neutron.
Assume that the kinetic energies of the hydrogen nuclei are zero just before the reaction occurs.

0 4 . 1 Show that the kinetic energy of the neutron represents approximately 80% of the total energy transferred.

[2 marks]

0 4 . 2 The combined kinetic energy of the helium nucleus and the neutron is 2.82×10^{-12} J.

Calculate the initial speed of the neutron.

[2 marks]

initial speed = ______________________ m s^{-1}

4

Question	Answers	Additional comments/Guidelines	Mark	AO
04.1	Either appreciation of mass of He = 4 × mass of neutron OR idea that n and He have equal (and opposite) momenta ✓ Combination of momentum and KE equations (to give idea that KE is inversely proportional to m with same p) and therefore KE of neutron = 4 × KE of He ✓	Expect to see KE $= \frac{p^2}{2m}$	2	AO3

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	calculates KE of neutron OR uses mass of neutron from data booklet with *their calculated KE* in a KE equation✓ $v = 5.2 \times 10^{7}$ m s^{-1} ✓	$80\% \times 2.82 \times 10^{-12} = 2.26 \times 10^{-12}$ (J) Do not allow use of 2.82×10^{-12} as *their calculated KE.* m_n=1.67(5) × 10^{-27} kg Accept answers of 5.18×10^{7} or 5.19×10^{7} m s^{-1} Calculator values: 5.1823878×10^{7}; (using 1.68) 5.1901169×10^{7}; (using 1.675) 5.1978807×10^{7} (using 1.67)	2	AO2
Total			**4**	

0 1 A common type of smoke detector contains a very small amount of

americium-241, $^{241}_{95}\mathrm{Am}$

0 1 . 1 Determine the number of each type of nucleon in one americium-241 nucleus.

[2 marks]

type of nucleon ______________________ number ________________

type of nucleon ______________________ number ________________

0 1 . 2 Americium-241 is produced in nuclear reactors through the decay of

plutonium, $^{241}_{94}\mathrm{Pu}$

State the decay process responsible for the production of americium-241. Explain your answer.

[2 marks]

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0 1 . 3 An americium-241 nucleus decays into nuclide X by emitting an alpha particle.

Write an equation for the decay of the nucleus and determine the proton number and nucleon number of X.

[3 marks]

nucleon number ________________

proton number ________________

0 1 . 4 The alpha radiation produced by americium-241 causes the ionisation of nitrogen and oxygen molecules in the smoke detector.

State what is meant by ionisation.

[1 mark]

___

___

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0 1 . 5 A friend who has not studied physics suggests that a smoke detector containing radioactive material should not be sold.

Use your knowledge of physics to explain why a smoke detector containing americium-241 does not provide any risk to the user.

[2 marks]

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Question	Answers	Additional Comments/Guidance	Mark
01.1	95 protons ✓ 241 – 95 = 146 neutrons ✓		1 1
01.2	Beta minus decay. ✓ There is no change in the number of nucleons. The number of protons increases by 1.✓	Marks can be given for a correct equation Ignore omitted antineutrino.	1 1
01.3	$^{241}_{95}\text{Am} \rightarrow {}^{A}_{Z}\text{X} + {}^{4}_{2}\alpha$ ✓ Nucleon number = A = 241 – 4 = 237 ✓ Proton number = Z = 95 −2 = 93 ✓		1 1 1
01.4	Ionisation is the removal (or addition) of electrons from (to) an atom or molecule ✓		1

01.5	Only a small quantity of material is needed ✓ The particles it emits do not travel more than a few centimetres ✓	 Alternative for 2nd mark: Would be stopped before reaching the outside of the detector	1 1

02.1	P at the end of linear section ✓		1
02.2	Measure original length and diameter ✓ Determine gradient of linear section to obtain F/extension ✓ E = $\frac{F}{e} \times \frac{length}{\pi\left(\frac{d}{2}\right)^2}$ ✓	Alternative: Convert to stress–strain graph and determine gradient.	1 1 1
02.3	Line from A Parallel to straight section of original Ending at horizontal axis ✓		1
02.4	Plastic deformation has produced permanent extension/re-alignment of bonds in material hence intercept non-zero✓ Gradient is same because after extension identical forces between bonds✓		1 1