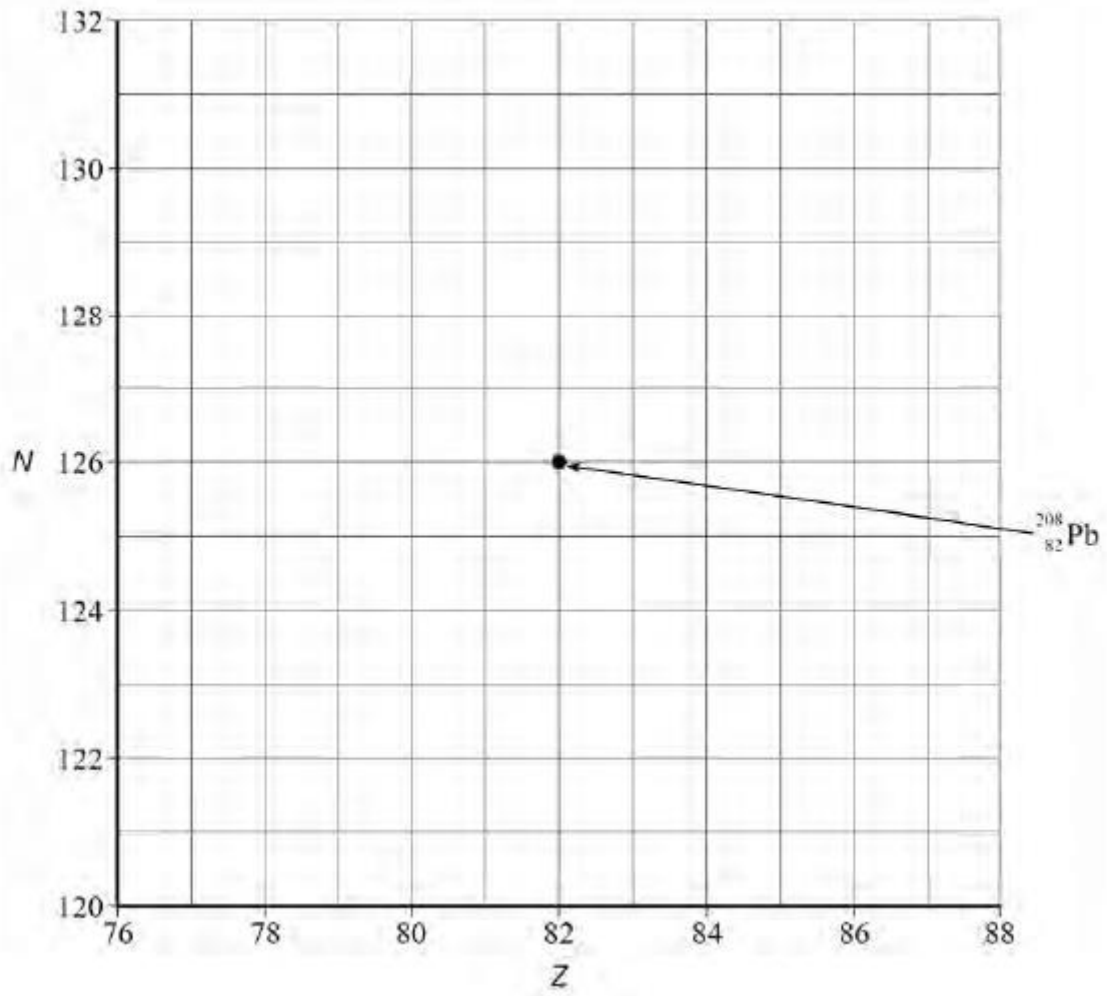
Nuclear instability

Q1.

A nucleus of polonium Po may decay to the stable isotope of lead $^{208}_{82}\text{Pb}$ through a chain of emissions following the sequence α β⁻ β⁻ α.

The graph shows the position of the isotope $^{208}_{82}\text{Pb}$ on a grid of neutron number *N* against proton number *Z*.



(a) Draw **four** arrows on the graph to show the sequence of changes to *N* and *Z* that occur as the polonium nucleus is transformed into $^{208}_{82}\text{Pb}$.

(2)

(b) A nucleus of the stable isotope $^{208}_{82}\text{Pb}$ has more neutrons than protons.

Explain why there is this imbalance between proton and neutron numbers by referring to the forces that operate within the nucleus. Your explanation should include the range of the forces and which particles are affected by the forces.

___

___

(4)

(c) Many, but not all, isotopes of lead are stable. For example, $^{208}_{82}Pb$ decays by electron capture to become an isotope of thallium, Tl.

Write the equation to represent this decay, including the isotope of thallium produced.

(1)

(d) The thallium nucleus is formed in an excited state. Electromagnetic radiation is emitted from the thallium atom following its formation.

Explain the origin and location of **two** sources of this radiation.

Source 1 ___

Source 2 ___

(2)

(e) Other nuclides also emit electromagnetic radiation.

Explain why the metastable form of the isotope of technetium $^{99}_{43}\text{Tc}$ is a radioactive source suitable for use in medical diagnosis.

(2)

(Total 11 marks)

Q2.

During a single fission event of uranium-235 in a nuclear reactor the total mass lost is 0.23 u. The reactor is 25% efficient.

How many events per second are required to generate 900 MW of power?

A 1.1×10^{14} ⬭

B 6.6×10^{18} ⬭

C 1.1×10^{20} ⬭

D 4.4×10^{20} ⬭

(Total 1 mark)

Q3.

Which of the following substances can be used as a moderator in a nuclear reactor?

A Boron ⬭

B Concrete ⬭

C Uranium-238 ⬭

D Water ⬭

(Total 1 mark)

Q4.

(a) Calculate the binding energy, in MeV, of a nucleus of $^{59}_{27}\text{Co}$.

nuclear mass of $^{59}_{27}\text{Co}$ = 58.93320 u

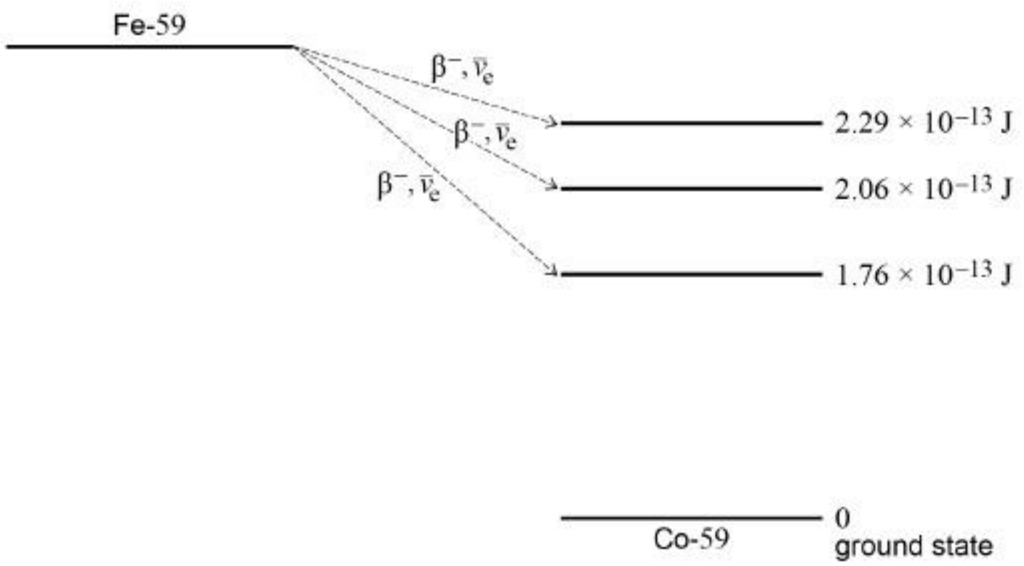
binding energy = ____________________ MeV

(3)

(b) A nucleus of iron Fe-59 decays into a stable nucleus of cobalt Co-59. It decays by β^- emission followed by the emission of γ-radiation as the Co-59 nucleus de-excites into its ground state.

The total energy released when the Fe-59 nucleus decays is 2.52×10^{-13} J.

The Fe-59 nucleus can decay to one of three excited states of the cobalt-59 nucleus as shown below. The energies of the excited states are shown relative to the ground state.



Calculate the maximum possible kinetic energy, in MeV, of the β^- particle emitted when the Fe-59 nucleus decays into an excited state that has energy above the ground state.

maximum kinetic energy = ____________________ MeV

(2)

(c) Following the production of excited states of $^{59}_{27}Co$, γ-radiation of discrete wavelengths is emitted.

State the maximum number of discrete wavelengths that could be emitted.

maximum number = ____________________

(1)

(d) Calculate the longest wavelength of the emitted γ-radiation.

Longest wavelength = ____________________ m

(3)

(Total 9 marks)

Q5.

A pure sample of nuclide **X** containing N nuclei has an activity A.
The half-life of **X** is 6000 years.

A pure sample of nuclide **Y** containing $3N$ nuclei has an activity $6A$.

What is the half-life of nuclide **Y**?

A 1000 years

B 3000 years

C 12 000 years

D 18 000 years

(Total 1 mark)

Q6.

Cobalt-60 has a half-life of 5.27 years.

What is the total activity of 1.0 g of cobalt-60?

A 4.2×10^{13} Bq

B 2.2×10^{14} Bq

C 2.5×10^{15} Bq ○

D 1.3×10^{21} Bq ○

(Total 1 mark)

Q7.

$^{232}_{90}Th$ is an unstable nuclide in a radioactive decay series. It decays by emitting an α particle. The next two nuclides in the series emit β^- particles.

What nuclide is formed after these three decays have taken place?

A $^{230}_{90}Th$ ○

B $^{228}_{92}U$ ○

C $^{228}_{88}Ra$ ○

D $^{228}_{90}Th$ ○

(Total 1 mark)

Q11.

(a) State the condition for momentum to be conserved in a system.

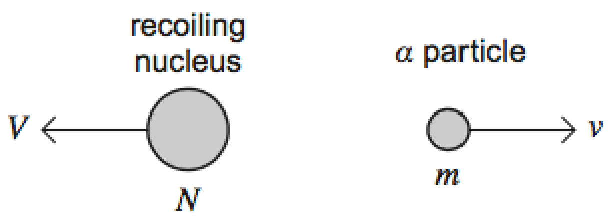
____

____

____

(1)

(b) When a stationary unstable nucleus emits an α particle with velocity v the resulting nucleus recoils with velocity V, as shown in the diagram.



The mass of the α particle is m and the mass of the recoiling nucleus is N.

(i) Show how the principle of conservation of momentum may be used to derive an expression for V in terms of N, m and v.

(2)

(ii) Assume that all of the energy released in the emission process is transferred as kinetic energy to the α particle and the recoiling nucleus. The total energy released is E.
Use your result from part **(b)(i)** to show that the kinetic energy of the α particle is given by

$$E_\alpha = \left(\frac{N}{N+m}\right)E$$

(4)

(c) (i) The isotope of radon $^{220}_{86}\text{Rn}$ decays by emitting an α particle.

State the nucleon number of the recoiling nucleus.

nucleon number = ____________________

(1)

(ii) The total energy released when a nucleus of $^{220}_{86}\text{Rn}$ decays is 1.02×10^{-12} J.

Calculate the magnitude of the momentum of the α particle.
State an appropriate unit for your answer.

Mass of a nucleon = 1.66×10^{-27} kg

momentum = _______________ unit __________

(4)

(d) Explain why the expressions in parts **(b)(i)** and **(b)(ii)** could **not** be applied when an unstable nucleus decays by emitting a β^- particle.

____

____

____

____

(1)
(Total 13 marks)

Q12.

(a) Which ionizing radiation produces the greatest number of ion pairs per mm in air?
Tick (✓) the correct answer.

α particles	
β particles	
γ rays	
X−rays	

(1)

(b) (i) Complete the table showing the typical maximum range in air for α and β particles.

Type of radiation	Typical range in air / m
α	
β	

(2)

(ii) γ rays have a range of at least 1 km in air.

However, a γ ray detector placed 0.5 m from a γ ray source detects a noticeably smaller count-rate as it is moved a few centimetres further away from the source.

Explain this observation.

___

___

___

(1)

(c) Following an accident, a room is contaminated with dust containing americium which is an α−emitter.

Explain the most hazardous aspect of the presence of this dust to an unprotected human entering the room.

___

___

(2)
(Total 6 marks)

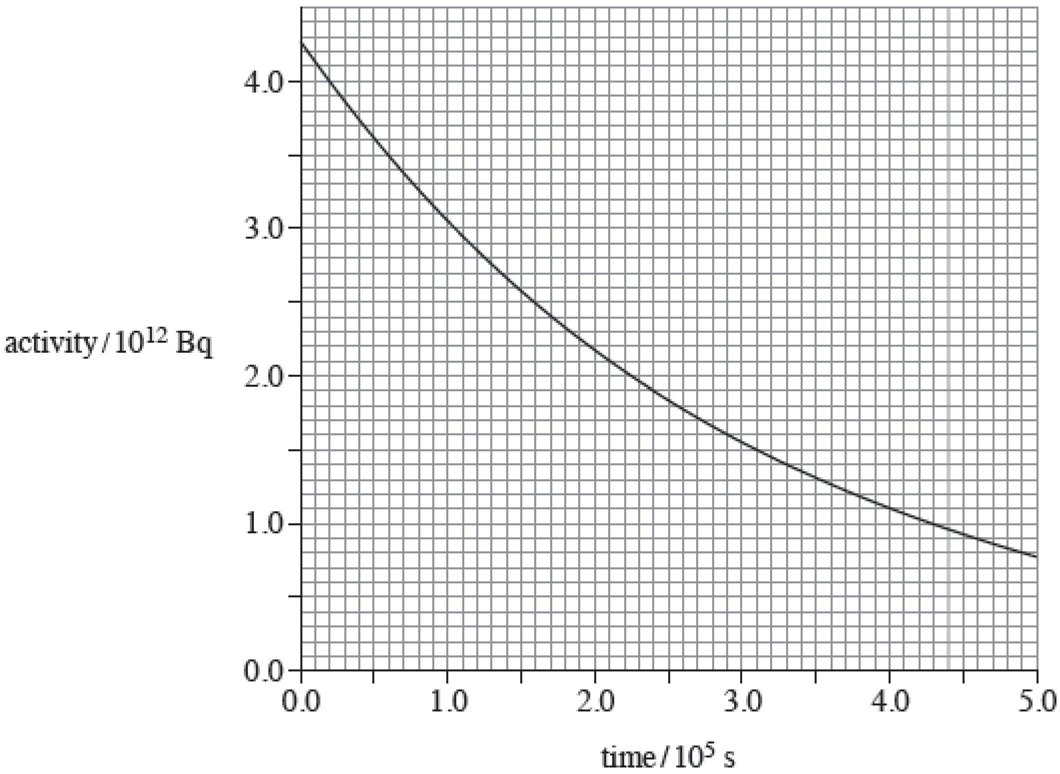
Q13.

A rod made from uranium−238 ($^{238}_{92}\text{U}$) is placed in the core of a nuclear reactor where it absorbs free neutrons.
When a nucleus of uranium−238 absorbs a neutron it becomes unstable and decays to neptunium−239 ($^{239}_{93}\text{Np}$), which in turn decays to plutonium−239 ($^{293}_{94}\text{Pu}$).

(a) Write down the nuclear equation that represents the decay of neptunium−239 into plutonium−239.

(2)

(b) A sample of the rod is removed from the core and its radiation is monitored from time t = 0 s.
The variation of the activity with time is shown in the graph.



(i) Show that the decay constant of the sample is about 3.4×10^{-6} s^{-1}.

(2)

(ii) Assume that the activity shown in the graph comes only from the decay of neptunium.

Estimate the number of neptunium nuclei present in the sample at time $t = 5.0 \times 10^5$ s.

number of nuclei ____________________

(1)

(c) (i) A chain reaction is maintained in the core of a thermal nuclear reactor that is operating normally.

Explain what is meant by a chain reaction, naming the materials and particles involved.

____

____

____

____

(2)

(ii) Explain the purpose of a moderator in a thermal nuclear reactor.

____

____

____

____

____

____

(2)

(iii) Substantial shielding around the core protects nearby workers from the most hazardous radiations. Radiation from the core includes α and β particles, γ rays, X−rays, neutrons and neutrinos.

Explain why the shielding becomes radioactive.

____

____

____

____

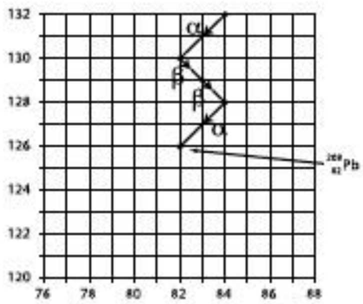
(2)

(Total 11 marks)

Q1.

(a) First mark for either both α's or both β⁻'s arrows shown correctly ie α arrow moving down 2 and left 2 or β⁻ arrow moving down 1 and right 1 ✓(must be sequential)

Second mark for fully correct ✓



The first mark is independent of the start position.

The question asks for arrows, so a series of positions marked does not gain marks.

One mark can be awarded if all the lines with arrows are included but in wrong direction with lines.

2

(b) **Any 3 marking points from 1 to 5**

[1]Strong nuclear force (SNF) affects nucleons or protons and neutrons. ✓

[2]SNF attraction extends up to 3 fm (allow 1–4 fm) ✓

[3]The SNF is repulsive below about 0.8 fm (allow 0.3 to 1 fm and prevents the nucleus totally collapsing) ✓

[4]Electromagnetic/electrostatic repulsive force (only) acts between protons ✓

[5]EM forces are long range/infinite/acts across whole nucleus/acts on all protons(so increases as proton number increases) ✓

PLUS one of following that explains the imbalance

More neutrons are needed to hold nucleus together / add to binding force/increase instability/reduce stability (owtte)

OR

Fewer protons are required so as to reduce the repulsion/reduce instability/increase stability (owtte) ✓

Baryons/hadrons may replace nucleons.

If 'strong force' rather than 'strong nuclear force' is used only penalise once.

Any wrong statement made in the first group of marking points then this section has a maximum 2 marks out of 3.

Max 4

(c) $^{205}_{82}\text{Pb} + {}^{0}_{-1}\text{e} = {}^{205}_{81}\text{Tl} + \upsilon_{(e)}$

✓ Mark for full equation

The electron may be represented by e^- or β^- without the super and subscript.

Q may be added to the end of the equation.

Encouraged by the following question 'gamma' might appear on the RHS of the equation. Simply ignore gamma.

1

(d) Orbiting electrons in the atom fall (to fill the positions vacated by inner orbiting electrons releasing their energy as em (gamma) radiation ✓

The excited nucleus emits gamma radiation (as it de-excites)✓

Mark leniently in first mark. Just need to see photons are related to outer electron movement.

Allow radiation due to it being above 0 kelvin.

For the second mark 'nucleus' must be mentioned but electrons must not.

2

(e) It is because:

It only emits λ-rays

λ-rays are weakly ionising/cause less damage to body than other radiations

λ-rays can penetrate/escape from the body

It has low toxicity

Half-life is short enough not to remain in the body for too long after the medical examination

Half-life is long enough to complete the diagnosis

It can be prepared in the hospital/close to the hospital

Any 2 ✓✓

2

[11]

Q2.

C

[1]

Q3.

D

[1]

Q4.

(a) (using mass defect = Δm = Z m_p + N m_n – M_{Co})
Δm = 27 × 1.00728 + 32 × 1.00867 – 58.93320 (u) ✓
Δm = 0.5408 (u) ✓
Binding Energy = 0.5408 × 931.5 = 503.8 (MeV) ✓ (CE this mark stands alone for the correct energy conversion even if more circular routes are followed.

Look at use of first equation and if electrons are used or mass of proton and neutron confused score = 0.

If subtraction is the wrong way round lose 1 mark.

Data may come from rest mass eg m_n =939.551 MeV or 1.675×10^{-27} kg or 1.00867 u.

So if kg route used $\Delta m = 8.83 \times 10^{-28}$ kg BE = 7.95×10^{-28} J and 497 Mev.

Conversion mark (2nd) may come from a wrong value worked through. 0.47(5)

3

(b) $(2.52 – 1.76) \times 10^{-13} = 7.6 \times 10^{-14}$ J ✓

$7.6 \times 10^{-14} / 1.60 \times 10^{-13}$ = 0.47 or 0.48 MeV ✓(0.475 MeV)

Correct answer scores both marks.

2

(c) 6 (specific wavelengths)

1

(d) (longest wavelength = lowest frequency = smallest energy)
$(2.29 \times 10^{-13} – 2.06 \times 10^{-13}) = 2.3 \times 10^{-14}$ (J) ✓
λ (= $h\,c\,/\,E$) = $6.63 \times 10^{-34} \times 3.00 \times 10^{8} / 2.3 \times 10^{-14}$ ✓
λ = 8.6 - 8.7 × 10^{-12} (m) ✓ (8.6478 × 10^{-12} m)

Allow a CE in the second mark only if the energy corresponds to an energy gap including those to the ground state.

The allowed energy gaps for CE are:

2.29, 2.06, 1.76, 0.53, 0.30 all × 10^{-13}

Note substitution rather than calculation gains mark.

The final mark must be as shown here and not from a CE above.

3

[9]

Q5.

B

[1]

Q6.

A

[1]

Q7.

D

[1]

Q11.

(a) no external forces (act on the system of particles)

[**or** forces between particles are internal forces] ✓

Allow "in a closed system".

1

(b) (i) $N V = (-) m v$ [**or** $N V + m v = 0$] ✓

(*gives*) $V = (-)\frac{mv}{N}$ ✓

For 2nd mark, V must be the subject of the eqn.

2

(ii) $\frac{1}{2} NV^2 + \frac{1}{2} mv^2 = E$ ✓

substitution for V gives $\frac{1}{2}N\left(\frac{mv}{N}\right)^2 + E_a = E$ ✓

from which $\frac{1}{2}\left(\frac{m}{N}\right)mv^2 + E_a = E$ and $\left(\frac{m}{n}+1\right)E_\alpha = E$ ✓

rearrangement gives $E_\alpha = \frac{E}{\left(\frac{m+N}{N}\right)} = \left(\frac{N}{N+m}\right)E$ ✓

The 4 marks are for

- *conservation of energy*
- *substitution for V*
- *separation of E and E_α, with v eliminated*
- *rearrangement to give final result*

Allow ECF for incorrect V expression from (b)(i): for 1st and 2nd marks only (ie max 2).

4

(c) (i) nucleon number = 216

1

(ii) $E_\alpha = \left(\frac{216}{220}\right) \times 1.02 \times 10^{-12}$ **or** $= 1.00 \times 10^{-12}$ (J) ✓

momentum of $\alpha = m\sqrt{\frac{2E_\alpha}{m}}$ or $= \sqrt{2mE_\alpha}$ ✓

[**or** $\frac{1}{2} \times 4 \times 1.66 \times 10^{-27} \times v^2 = 1.00 \times 10^{-12}$

gives momentum of $\alpha = 4 \times 1.66 \times 10^{-27} \times \sqrt{\frac{2 \times 1.00 \times 10^{12}}{4 \times 1.66 \times 10^{-27}}}$]

∴ momentum of $\alpha = \sqrt{(2 \times 4 \times 1.66 \times 10^{-27} \times 1.00 \times 10^{-12})}$ ✓

$= 1.2\ (1.15) \times 10^{-19}$ ✓

N s **or** kg m s^{-1} ✓

Allow ECF for wrong value of A from (c)(i).

***Alternative solution** for first three marks: energy of nucleus*

= 0.0185 × 10^{-12} (J) ✓

momentum of nucleus = $\sqrt{2NE_N}$ ✓

$\sqrt{(2 \times 216 \times 1.66 \times 10^{-27} \times 0.0185 \times 10^{-12})}$ = 1.2 (1.15) × 10^{-19} ✓

Unit mark is independent.

4

(d) an (anti)neutrino is emitted

OR

two particles are emitted by unstable nucleus in β^- decay

[**or** calculation must account for momentum of (anti)neutrino] ✓

[**or** momentum is shared between three particles] ✓

1

[13]

Q12.

(a) A α particles ✓

[auto mark question]

1

(b) (i)

type of radiation	Typical range in air / m
α	0.04 ✓
β	0.40 ✓

Allow students to use their own distance units in the table
α allow 0.03 → 0.07 m
β allow 0.20 → 3.0 m.
If a range is given in the table use the larger value.
A specific number is required e.g. not just a few cm.

2

(ii) reference to the <u>inverse</u> square law of (γ radiation)
or
reference to lowering of the solid angle (subtended by the detector as it moves away)
or
radiation is spread out (over a larger surface area as the detector is moved away) ✓

(owtte)
Ignore any references to other types of radiation.
Any contradiction loses the mark. For example, follows inverse square law so intensity falls exponentially.

1

(c) dust may be <u>ingested / taken into the body / breathed in</u> ✓

First mark for ingestion not just on the body

causing (molecules in human tissue / cells) to be made cancerous / killed / damaged by ionisation ✓

Second mark for idea of damage from ionisation

2

[6]

Q13.

(a) $^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} + {}^{(0)}_{(-1)}\beta^- + {}^{(0)}_{(0)}\bar{\nu}$ ✓✓

First mark for one anti-neutrino or one beta minus particle in any form e.g. e^-. If subscript and superscripts are given for these they must be correct but ignore the type of neutrino if indicated.
The second mark is for both particles and the rest of the equation.
Ignore the full sequence if it is shown but the Np to Pu must be given separately for the mark.

2

(b) (i) $T_{1/2}$ 2.0 → 2.1 × 10^5 s ✓
then substitute and calculate
$\lambda = \ln 2 / T_{1/2}$ ✓

$T_{1/2}$ may be determined from graph not starting at zero time.
Look for the correct power of 10 in the half-life – possible AE.

Or
(substitute two points from the graph into $A = A_o e^{-\lambda t}$)
e.g. $0.77 \times 10^{12} = 4.25 \times 10^{12} \exp(-\lambda \times 5 \times 10^5)$ ✓
then make λ the subject and calculate ✓
(the rearrangement looks like
$\lambda = [\ln (A_o / A)] / t$
or $\lambda = -[\ln (A / A_o)] / t$)

Allow the rare alternative of using the time constant of the decay
$A = A_o \exp(-t / t_{tc})$
from graph t_{tc} = 2.9→3.1 × 10^5 s✓
$\lambda = 1 / t_{tc} = 3.4 \times 10^{-6}\ s^{-1}$ ✓
No CE is allowed within this question.

both alternatives give
λ = 3.3 → 3.5 × 10^{-6} s^{-1} ✓

For reference
$T_{1/2} = 2.0 \times 10^5$ s gives
$\lambda = 3.5 \times 10^{-6}\ s^{-1}$ and
$T_{1/2} = 2.1 \times 10^5$ s gives
$\lambda = 3.3 \times 10^{-6}\ s^{-1}$.

2

(ii) (using $A = N\lambda$
$N = 0.77 \times 10^{12} / 3.4 \times 10^{-6} = 2.2(6) \times 10^{17}$)

allow 2.2 → 2.4 × 10^{17} nuclei ✓

A possible route is find $N_o = A_o / \lambda$

then use $N = N_o e^{-\lambda t}$.

Condone lone answer.

1

(c) (i) uranium (– 235 captures) a neutron (and splits into 2 smaller nuclei / fission fragments) releasing more neutrons ✓

First mark for uranium + neutron gives more neutrons.

Ignore which isotope of uranium is used.

(at least one of) these neutrons go on to cause further / more splitting / fissioning (of uranium– 235) ✓

Second mark for released neutron causes more fission.
The word 'reaction' may replace 'fission' here provided 'fission / splitting of uranium' is given somewhere in the answer.

2

(ii) **Escalate if clip shows critical mass in the question.**
the moderator slows down / reduces the kinetic energy of neutrons ✓
so neutrons are absorbed / react / fission (efficiently) by the uranium / fuel ✓

owtte
Possible escalation.

2

(iii) neutrons are absorbed / collide with (by the nuclei in the shielding) ✓

Second mark is only given if neutrons appear somewhere in the answer.

converting the nuclei / atoms (of the shielding) into unstable isotopes (owtte)

No neutrons = no marks.

Making it neutron rich implies making them unstable.

2

[11]

Q1.

(a) Nearly one third of the students drew the sequence on the grid totally correctly and scored two marks. Many students started on the final isotope and drew the sequence of decays; these could score one mark only. The other group scoring one mark usually got the two alpha decay arrows following the correct lines but, because they started in the wrong position, just drew two beta arrows to finish in the correct position. About two thirds of the students scored at least one mark.

(b) This question discriminated very well; there was a very good spread from zero to four marks. It was only the very weak students who did not understand that the question was about describing the contributions made by the strong nuclear force and the electromagnetic force. These students introduced the weak nuclear force and gravity as having some influence on the situation. Most students scored marks by knowing that the electromagnetic force is repulsive for protons in the nucleus and that the SNF is attractive between nucleons at short range. The variation in the marks came from students giving different amounts of detail, which could be about the specific ranges involved and the fact that the SNF is repulsive at very short range. Only the best students appreciated how the main forces lead to the requirement for more neutrons.

(c) Just over half of the students made some mistake in writing down the equation. The most common error was to write the wrong proton number for thallium, followed closely by students thinking an antineutrino was emitted.

(d) A good number of students, approaching half, either gave the source of radiation as coming from orbiting electrons or coming from an excited nucleus. Only a few (9.4%) gave two sources. A large number of answers were not specific enough to award marks. “The electrons give off radiation” and “the thallium atom gives off radiation” are examples. It was evident that some students did not fully understand the question and simply quoted situations when radiation is emitted.

(e) Many students had problems in avoiding absolute statements that disqualified them from a potential mark. Some examples are “It does not ionise, so causes no harm to the body” and “It has a short half-life so is not dangerous at all”. Many students did know that this source gave off gamma rays, but not that these were alone. Also, there were just as many references to the half-life being long as there were to it being short. These references only gained marks if the benefit was explained, for example ‘long enough to complete the investigation’.

Q2.

54.6% correct

Q3.

70.1% correct

Q4.

(a) Almost half the students tackled the calculation in a straightforward way as in the mark scheme. Other students’ responses ranged from this fully correct method down to simply trying to convert the nuclear mass of Co-59 to MeV units. The students using approaches in between these two obtained a difference in mass between the nucleons and the complete nucleus, but used a variety of units and data which sometimes did not yield the precision required; for example, using the mass of any nucleon as 1.67×10^{-27} kg. A clue about the precision required should have been understood from the number of significant figures used for the nuclear mass given in the question. Some students did pick up a mark for converting the units throughout their calculation, to correctly end up with an answer in MeV.

(b) A majority of students understood the situation and performed the calculation without error. A significant number of others missed seeing the longest energy gap between iron and cobalt. Many of these gave a variety of calculations using energy gaps that did not correspond to beta energies.

(c) Only 50% of students got the correct answer of 6 and the answer 3 featured regularly.

(d) Only the bottom 10% of students could make no headway in this question. A majority could obtain the equation relating wavelength to energy, and could perform the numerical calculation. It was choosing the incorrect energy gap that let many students down.

Q11.

Part (a) caused the usual confusions to surface over the condition under which momentum is conserved, with “no loss of kinetic energy” or “perfectly elastic” often being given. “In a closed system” was accepted as an alternative to the anticipated answer, “no external forces acting”.

Most students were successful in part (b)(i), where momentum is conserved at a zero value by making NV in one direction equal to mv in the opposite direction. For both marks to be awarded V was expected to be the subject of the final equation written down. The algebra in part (b)(ii) presented a much stiffer test for the majority of students, several of whom filled a number of additional pages whilst trying to arrive at the given expression. The first two marks only were commonly awarded, for giving an expression representing the conservation of energy followed by a correct substitution in it by using $V = mv/N$. The key to making further progress, which was missed by most, was recognising $\frac{1}{2} mv^2$ within their expressions as E_α.

The reduction of 4 in nucleon number produced by α decay was well known in part (c)(i). Part (c)(ii) was quite challenging, but many answers were successful. The equation from (b)(ii) was the straightforward approach, yet some chose to go back to first principles. Complete misunderstanding of the physics was shown by those who used an incorrect ratio – typically (220/224) or (220/216) instead of (216/220) – when calculating the proportion of the released energy that would pass to the α particle. An even more serious error was to assume that the whole of the 1.02×10^{-12} J would pass to the emitted particle. The students who arrived at a correct value for E_α were then usually able to calculate its speed and momentum correctly, although some did encounter difficulty by substituting its mass incorrectly.

Successful answers to part (d) required an appreciation of the fact that β^- decay is a three body process, involving the emission of an antineutrino as well as the β^- particle. Therefore there is no unique way in which either the momentum or the energy can be divided, meaning that the equations in part (b) cannot be applied.

Q12.

Most students understood the questions about the range and dangers of ionising radiations but many failed to gain marks over the details. Part (a) was done well by a majority of students but in part (b)(i) there was a great deal of uncertainty about the range of alpha and beta particles. It was common to see alpha particles having ranges over 10 cm. However, almost all students did put the range of beta particles larger than alpha particles. Part (b)(ii) was done very well with a majority of students referring to the inverse square relationship between intensity and distance. A few did contradict themselves by quoting the inverse square relationship but then they talked about the intensity falling off exponentially. The other successful students discussed the spreading of the rays. Part (c) was again done well. Most realised that the dust had the potential to be ingested usually by breathing it in. Some students did struggle with the mark on the dangers of the ionising radiation. Some gave details of the damage that may be caused but failed to say that the damage is caused by the ionisation. Others did not explicitly say humans might be harmed or damaged, they simply said ionisation could occur in the body.

Q13.

This question was quite discriminating overall because of its synoptic nature and other mixed components. A majority of students got part (a) correct without too much difficulty. Those that did not, either missed off the antineutrino or they thought this stage of the decay was initiated by a neutron. Most students could perform the calculations required in part (b)(i). Most found the half-life and progressed from there. A significant number of successful students substituted data from the graph into a decay equation. Most of the students who succeeded in (b)(i) also succeeded in (b)(ii). The most common mistake was to leave out the power of 10 from the activity reading from the graph. Part (c)(i) caused students a number of problems. Many spent too much time saying what a chain reaction was in very general terms without reference to the specific situation. Many scripts started, ‘A chain reaction is when a process does something that creates an item that is needed for another process to take place...’ Usually this was given in a much more verbose fashion. When it did come down to the specifics students were not very careful about using the correct terms. Although not penalised here a majority who mentioned uranium used the 238 rather than the 235 isotope. It was also common to see words like react or decay being used where fission should have been used. Also when a single stage of the process had been written down the next stage was not explained in sufficient detail. The words, ‘and so on’ came far too early. In (c)(i) it was only the stronger students who knew the part played by the critical mass. These students tended to gain both marks available for this part question because they knew how it had an effect on the chain reaction. The majority of the other students thought the mass had something to do with the mass of individual nuclei and its effect on an individual fission process. The final part (c)(iii) was done poorly by all but the most able students. Most thought that the ionisation caused by radiation made atoms radioactively unstable. Very few were aware of the problems caused by exposure to a flux of neutrons.