Q1. (a) A radioactive source gives an initial count rate of 110 counts per second. After 10 minutes the count rate is 84 counts per second.

background radiation = 3 counts per second

(i) Give **three** origins of the radiation that contributes to this background radiation.

1 ....

2 ....

3 ....

(ii) Calculate the decay constant of the radioactive source in s^{-1}.

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(iii) Calculate the number of radioactive nuclei in the initial sample assuming that the detector counts all the radiation emitted from the source.

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(7)

(b) Discuss the dangers of exposing the human body to a source of α radiation. In particular compare the dangers when the α source is held outside, but in contact with the body, with those when the source is placed inside the body.

You may be awarded marks for the quality of written communication in your answer.

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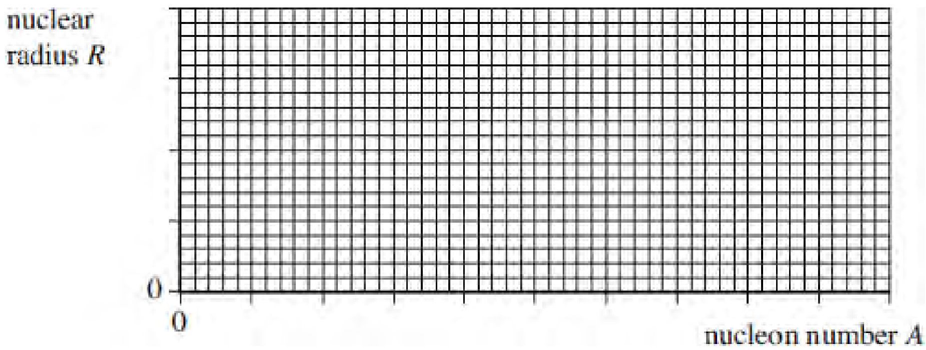
(3)
(Total 10 marks)

Q2. (a) On the figure below sketch a graph to show how the radius, *R*, of a nucleus varies with its nucleon number, *A*.



(1)

(b) (i) The radius of a gold-197 nucleus $^{197}_{79}\text{Au}$ is 6.87×10^{-15} m.
Show that the density of this nucleus is about 2.4×10^{17} kg m^{-3}.

(2)

(ii) Using the data from part (b)(i) calculate the radius of an aluminium-27 nucleus,

$^{27}_{13}\text{Al}$.

answer = ... m

(2)

(c) Nuclear radii have been investigated using α particles in Rutherford scattering experiments and by using electrons in diffraction experiments.
Make comparisons between these two methods of estimating the radius of a nucleus.
Detail of any apparatus used is not required.
For each method your answer should contain:

- the principles on which each experiment is based including a reference to an appropriate equation
- an explanation of what may limit the accuracy of each method
- a discussion of the advantages and disadvantages of each method.

The quality of your written communication will be assessed in your answer.

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(6)
(Total 11 marks)

Q3. The high energy electron diffraction apparatus represented in **Figure 1** can be used to determine nuclear radii. The intensity of the electron beam received by the detector is measured at various diffraction angles, *θ*.

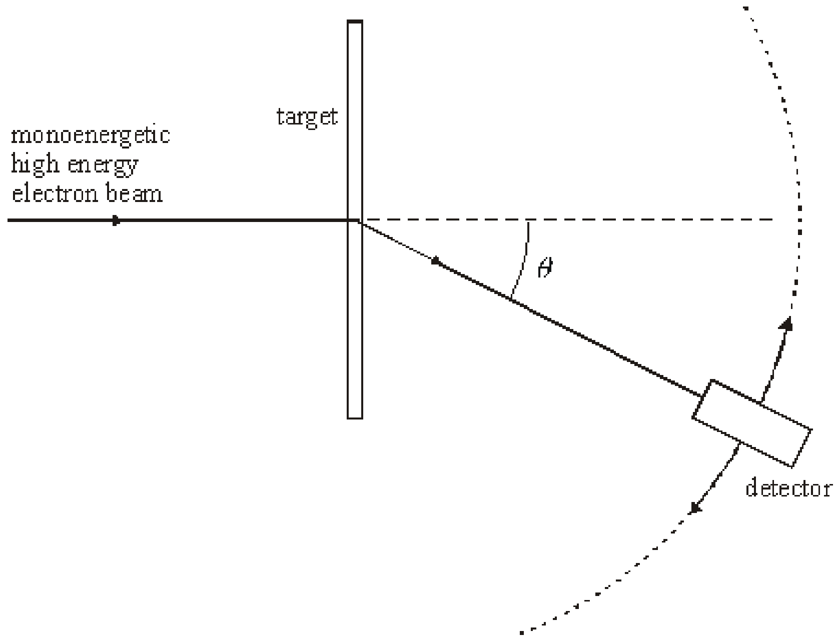
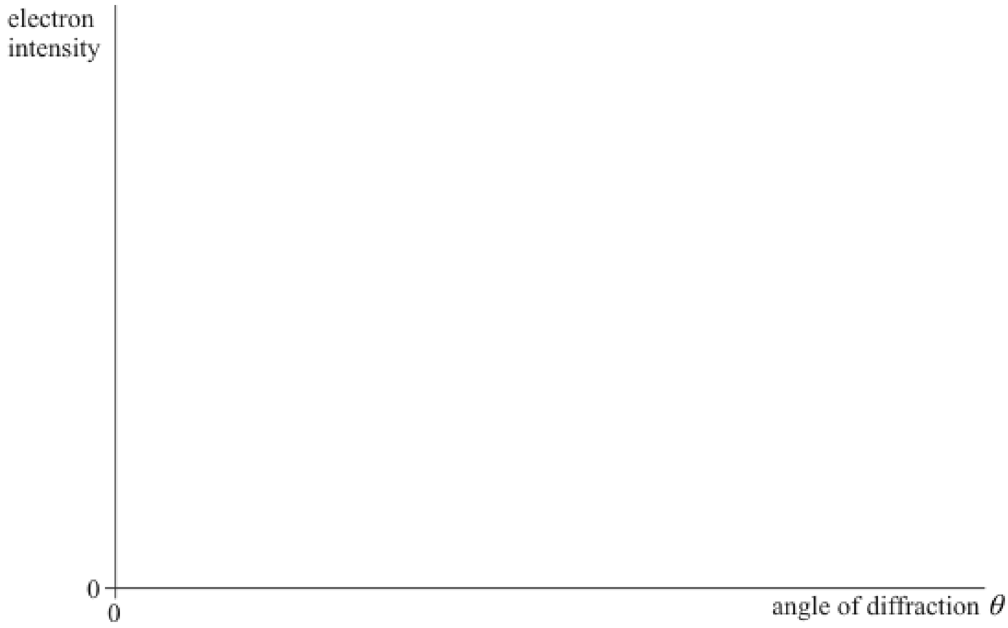


Figure 1

(a) Sketch on the axes below a graph of the results expected from such an electron diffraction experiment.



(2)

(b) (i) Use the data in the table to plot a straight line graph that confirms the relationship

$$R = r_0 A^{\frac{1}{3}}$$

element	**radius of nucleus, *R* 10^{-15}m**	**nucleon number; *A***	
lead	6.66	208	
tin	5.49	120	
iron	4.35	56	
ilicon	3 43	28	
carbon	2.66	12	

(ii) Estimate the value of r_0 from the graph.

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(5)

(c) Discuss the merits of using high energy electrons to determine nuclear radii rather than using α particles.

You may be awarded marks for the quality of written communication in your answer.

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(3)
(Total 10 marks)

Q4. (a) In a radioactivity experiment, background radiation is taken into account when taking corrected count rate readings in a laboratory. One source of background radiation is the rocks on which the laboratory is built. Give **two** other sources of background radiation.

source 1 ....

source 2 ....

(1)

(b) A γ ray detector with a cross-sectional area of 1.5×10^{-3} m^2 when facing the source is placed 0.18 m from the source.
A corrected count rate of 0.62 counts s^{-1} is recorded.

(i) Assume the source emits γ rays uniformly in all directions.
Show that the ratio

$$\frac{\text{number of } \gamma \text{ photons incident on detector}}{\text{number of } \gamma \text{ photons produced by source}}$$

is about 4×10^{-3}.

(2)

(ii) The γ ray detector detects 1 in 400 of the γ photons incident on the facing surface of the detector.
Calculate the activity of the source. State an appropriate unit.

answer = ... unit ....

(3)

(c) Calculate the corrected count rate when the detector is moved 0.10 m further from the source.

answer = ... counts s^{-1}

(3)
(Total 9 marks)

Q5. **Figure 1** shows a grid of neutron number against proton number. A nucleus ${}^{A}_{Z}X$ is marked.

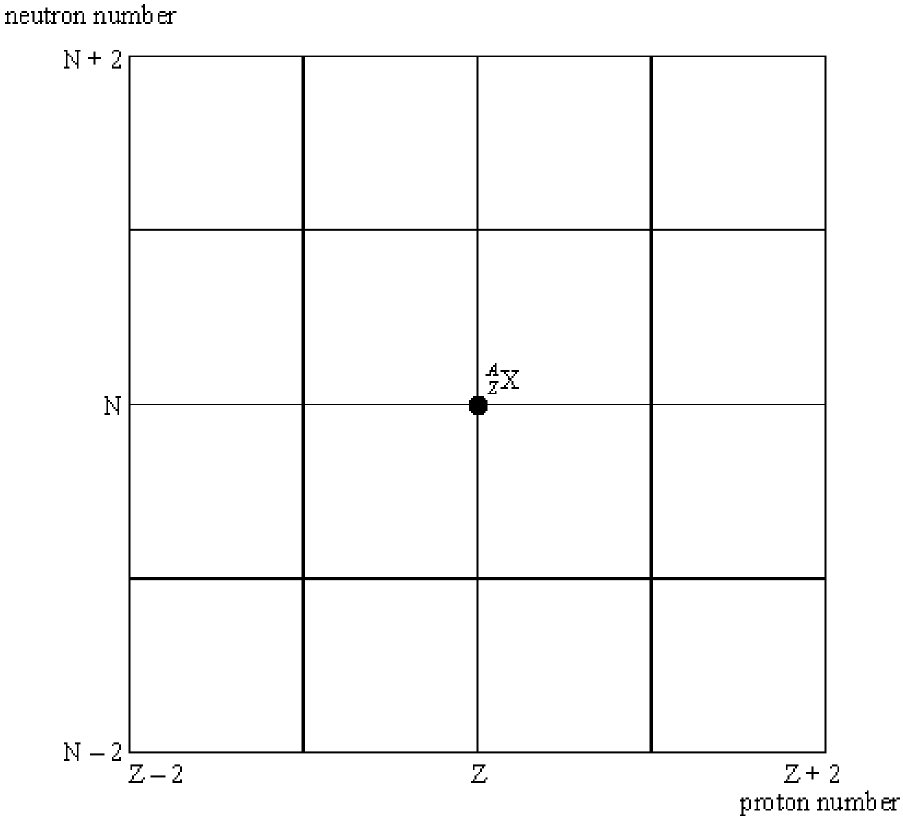

Figure 1

(a) Draw arrows on **Figure 1**, each starting on ${}^{A}_{Z}X$ and ending on a daughter nucleus after the following transitions:

(i) β^- emission (label this arrow A)
neutron emission (label this arrow B)
electron capture (label this arrow C).

(ii) Give the equation for electron capture by the nucleus ${}^{A}_{Z}X$.

....

(4)

(b) When $^{27}_{12}Mg$ decays to $^{27}_{13}Al$ by β^- decay, the daughter nucleus is produced in one of two possible excited states. These two states are shown in **Figure 2** together with their corresponding energies.

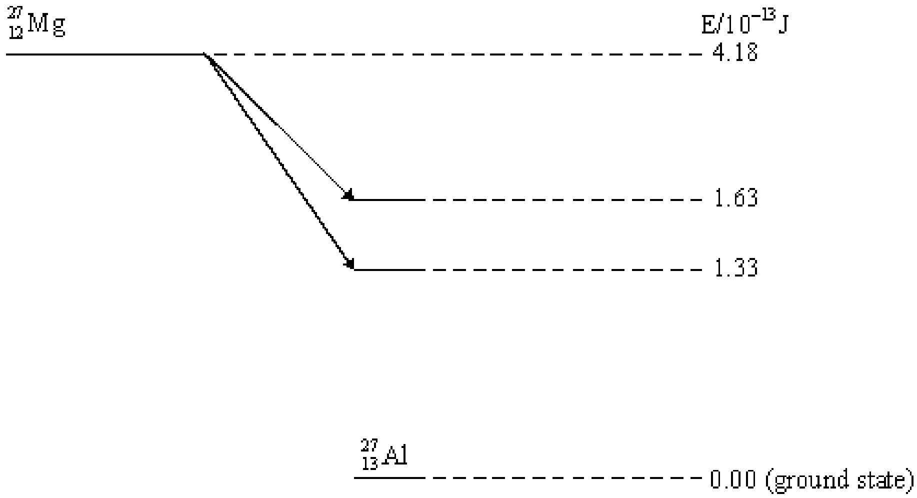

Figure 2

(i) Calculate the maximum possible kinetic energy, in J, which an emitted β^- particle can have.

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....

(ii) The excited aluminium nuclei emit γ photons. Calculate each of the three possible γ photon energies in J.

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....

(iii) Calculate the frequency of the most energetic γ photon emitted.

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(3)

(c) (i) State and explain **two** precautions that should be taken when working with a sample of $^{27}_{12}Mg$ in a school laboratory.

You may be awarded marks for the quality of written communication in your answer.

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(ii) Discuss which of the two types of radiation, β^- or γ, emitted from a sample of $^{27}_{12}Mg$ would be the more hazardous.

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(3)
(Total 10 marks)

Q6. (a) (i) State **two** physical features or properties required of the shielding to be placed around the reactor at a nuclear power station.

....

....

(ii) Which material is usually used for this purpose?

....

(3)

(b) Describe the effect of the shielding on the γ rays, neutrons and neutrinos that reach it from the core of the reactor. Also explain why the shielding material becomes radioactive as the reactor ages. You may be awarded marks for the quality of written communication provided in your answer.

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(4)
(Total 7 marks)

Q7. (a) In a thermal nuclear reactor, one fission reaction typically releases 2 or 3 neutrons. Describe and explain how a constant rate of fission is maintained in a reactor by considering what events or sequence of events may happen to the released neutrons.

The quality of your written communication will be assessed in this question.

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(7)

(b) Uranium is an α emitter. Explain why spent fuel rods present a greater radiation hazard than unused uranium fuel rods.

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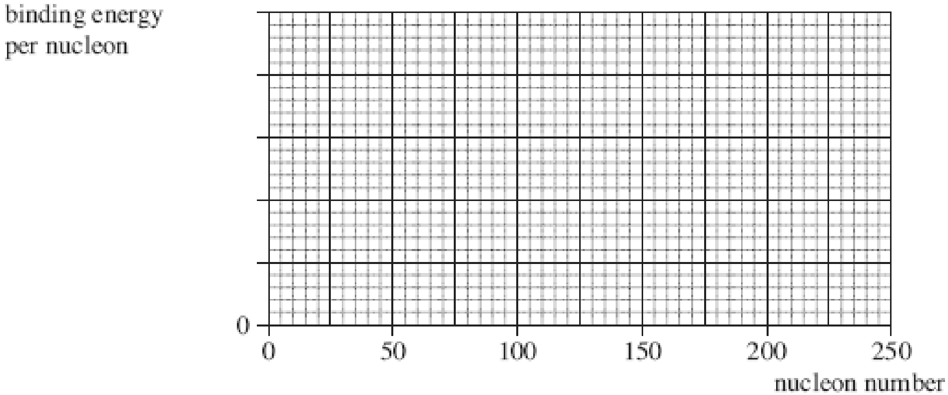
(3)
(Total 10 marks)

Q8. (a) Sketch a graph of binding energy per nucleon against nucleon number for the naturally occurring nuclides on the axes given in the figure below. Add values and a unit to the binding energy per nucleon axis.



(4)

(b) Use the graph to explain how energy is released when some nuclides undergo fission and when other nuclides undergo fusion.

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(3)
(Total 7 marks)

Q9. The first artificially produced isotope, phosphorus $^{30}_{15}P$, was formed by bombarding an aluminium isotope, $^{27}_{13}Al$, with an *α* particle.

(a) Complete the following nuclear equation by identifying the missing particle.

$$^{27}_{13}Al + \alpha \rightarrow {}^{30}_{15}P + \ldots\ldots$$

(1)

(b) For the reaction to take place the α particle must come within a distance, *d*, from the centre of the aluminium nucleus. Calculate *d* if the nuclear reaction occurs when the α particle is given an initial kinetic energy of at least 2.18×10^{-12} J.

The electrostatic potential energy between two point charges Q_1 and Q_2 is equal to $\frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$ where *r* is the separation of the charges and ε_0 is the permittivity of free space.

answer = ...m

(3)

(Total 4 marks)

Q10. The fissile isotope of uranium, $^{233}_{92}\text{U}$, has been used in some nuclear reactors. It is normally produced by neutron irradiation of thorium-232. An irradiated thorium nucleus emits a β^- particle to become an isotope of protactinium.

This isotope of protactinium may undergo β^- decay to become $^{233}_{92}\text{U}$.

(a) Complete the following equation to show the β^- decay of protactinium.

$$^{\ldots\ldots}_{\ldots\ldots}\text{Pa} \rightarrow {}^{233}_{92}\text{U} + \beta^- + \ldots\ldots\ldots$$

(2)

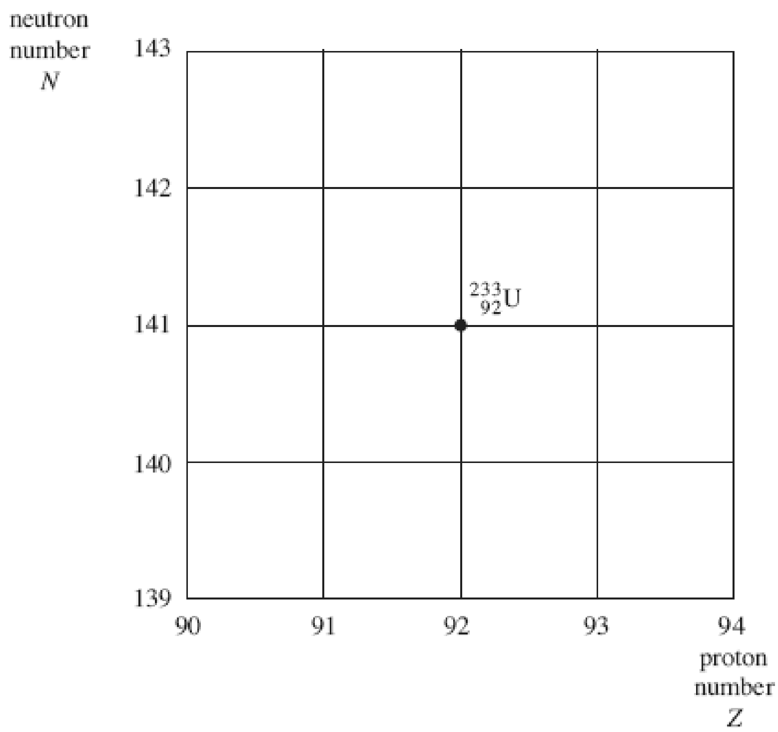
(b) Two other nuclei, **P** and **Q**, can also decay into $^{233}_{92}U$.

P decays by β^{+} decay to produce $^{233}_{92}U$.

Q decays by α emission to produce $^{233}_{92}U$.

The figure below shows a grid of neutron number against proton number with the position of the $^{233}_{92}U$ isotope shown.

On the grid label the positions of the nuclei **P** and **Q**.



(2)

(c) A typical fission reaction in the reactor is represented by

$$^{233}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{91}_{36}\text{Kr} + ^{139}_{56}\text{Ba} + x \text{ neutrons}$$

(i) Calculate the number of neutrons, x.

answer = ...neutrons

(1)

(ii) Calculate the energy released, in MeV, in the fission reaction above.

mass of neutron = 1.00867 u

mass of $^{233}_{92}\text{U}$ nucleus = 232.98915 u

ma of $^{91}_{36}\text{Kr}$ nucleu 90 90368 u

mass of $^{139}_{56}\text{Ba}$ nucleus = 138.87810 u

answer = ...MeV

(3)

(Total 8 marks)

Q11. The isotope of uranium, $^{238}_{92}\mathrm{U}$, decays into a stable isotope of lead, $^{206}_{82}\mathrm{Pb}$, by means of a series of α and β^- decays.

(a) In this series of decays, α decay occurs 8 times and β^- decay occurs *n* times.
Calculate *n*.

answer = ...

(1)

(b) (i) Explain what is meant by the binding energy of a nucleus.

....

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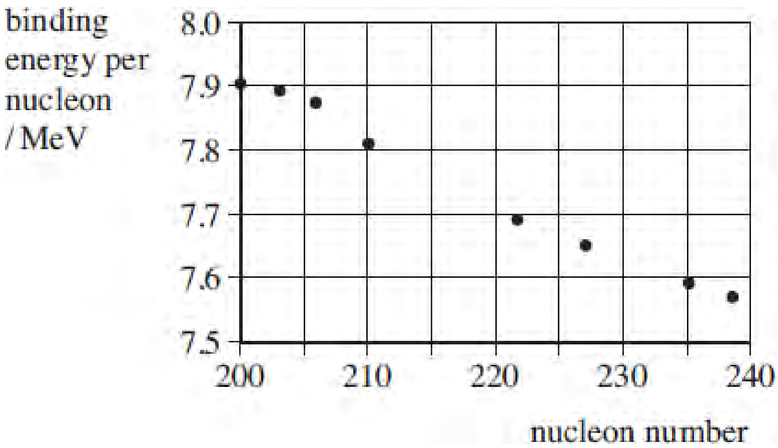
(2)

(ii) **Figure 1** shows the binding energy per nucleon for some stable nuclides.

Figure 1



Use **Figure 1** to estimate the binding energy, in MeV, of the $^{206}_{82}\mathrm{Pb}$ nucleus.

answer = ... MeV

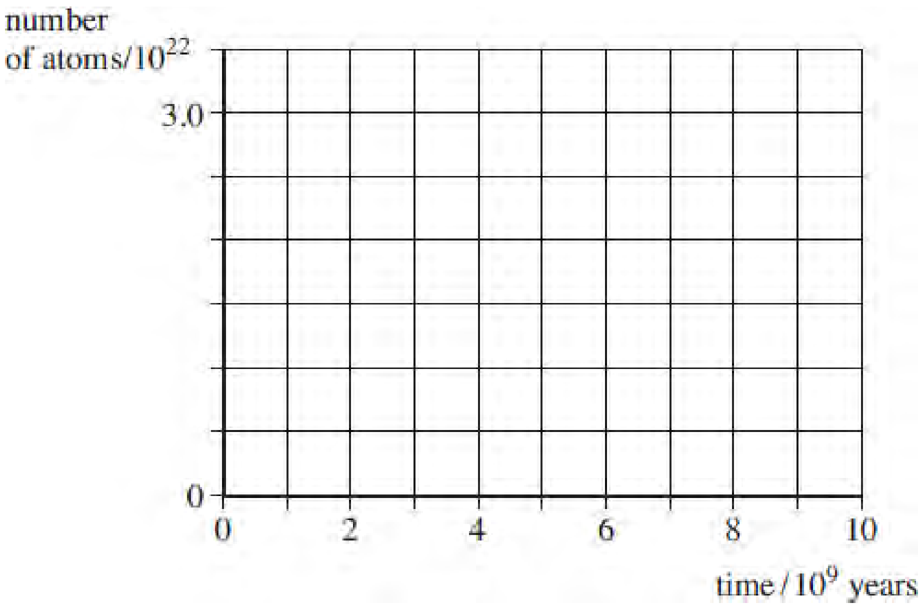
(c) The half-life of $^{238}_{92}U$ is 4.5 × 10^9 years, which is much larger than all the other half-lives of the decays in the series.

A rock sample when formed originally contained 3.0 × 10^{22} atoms of $^{238}_{92}U$ and no $^{206}_{82}Pb$ atoms.

At any given time most of the atoms are either $^{238}_{92}U$ or $^{206}_{82}Pb$ with a negligible number of atoms in other forms in the decay series.

(i) Sketch on **Figure 2** graphs to show how the number of $^{238}_{92}U$ atoms and the number of $^{206}_{82}Pb$ atoms in the rock sample vary over a period of 1.0 × 10^{10} years from its formation.
Label your graphs U and Pb.

Figure 2



(2)

(ii) A certain time, *t*, after its formation the sample contained twice as many $^{238}_{92}U$ atoms as $^{206}_{82}Pb$ atoms.

Show that the number of $^{238}_{92}U$ atoms in the rock sample at time *t* was 2.0 × 10^{22}.

(1)

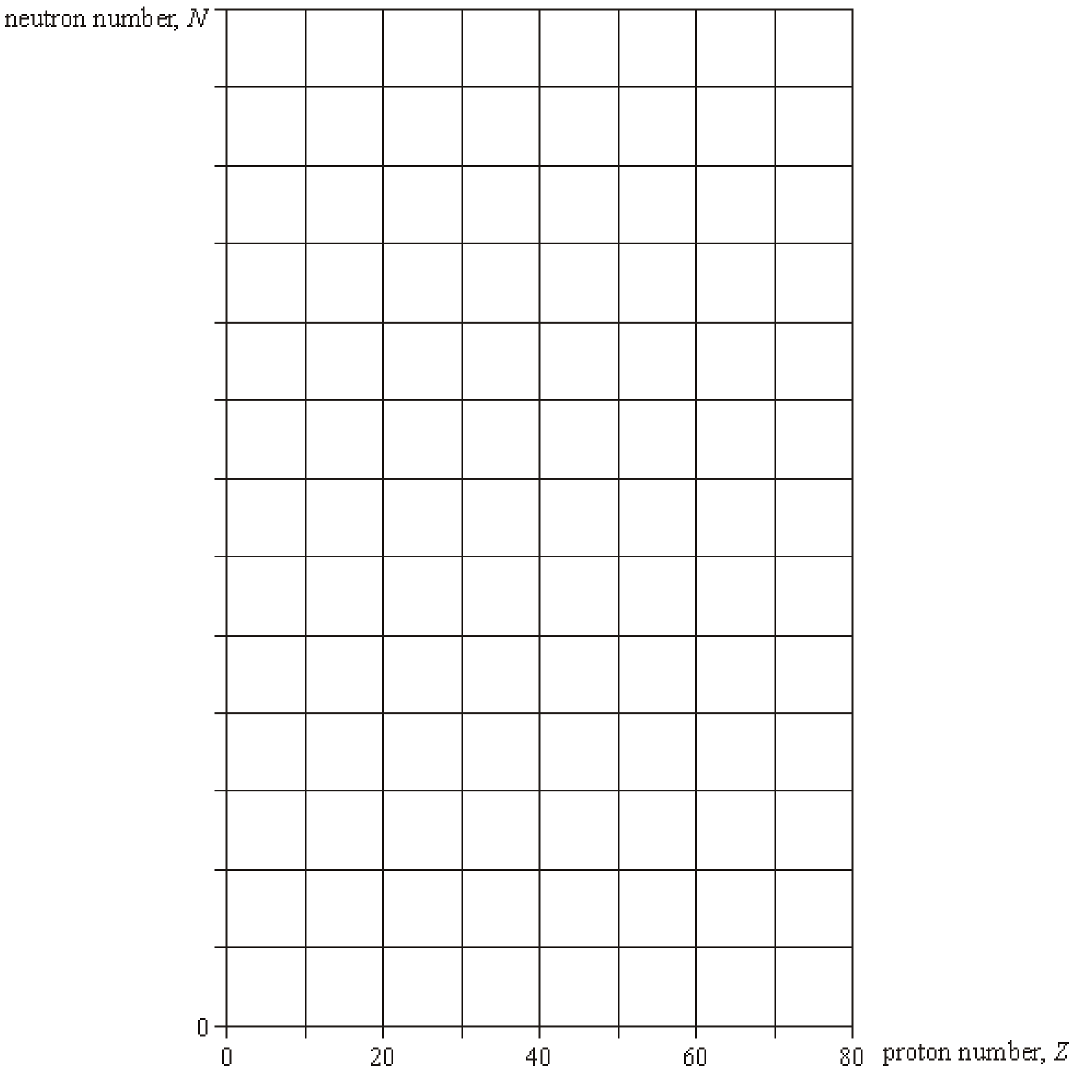
(ii) Calculate *t* in years.

answer = ... years

(3)

(Total 10 marks)

Q12. (a) Sketch, using the axes provided, a graph of neutron number, *N*, against proton number, *Z*, for stable nuclei over the range *Z* = 0 to *Z* = 80. Show suitable numerical values on the *N* axis.



(2)

(b) On the graph indicate, for each of the following, a possible position of a nuclide that may decay by

(i) α emission, labelling the position with **W**,

(ii) β^- emission, labelling the position with **X**,

(iii) β^+ emission, labelling the position with **Y**.

(3)

(c) The isotope $^{222}_{86}Rn$ decays sequentially by emitting *α* particles and β^- particles, eventually forming the isotope $^{206}_{82}Pb$. Four *α* particles are emitted in the sequence.

Calculate the number of β^- particles in the sequence.

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(2)

(d) A particular nuclide is described as proton-rich. Discuss **two** ways in which the nuclide may decay. You may be awarded marks for the quality of written communication in your answer.

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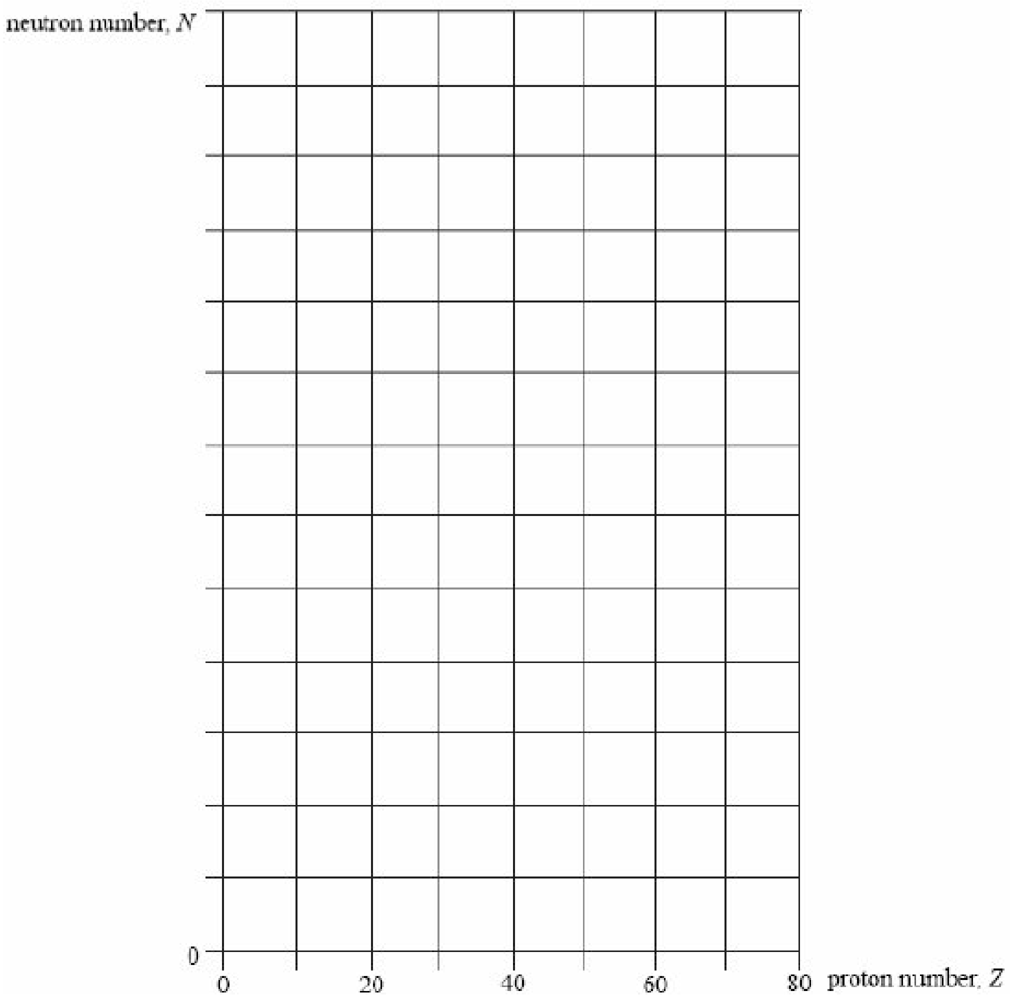
(3)
(Total 10 marks)

Q13. (a) Sketch, using the axes provided, a graph of neutron number, *N*, against proton number, *Z*, for stable nuclei over the range *Z* = 0 to *Z* = 80. Show suitable numerical values on the *N* axis.



(2)

(b) On the graph indicate, for each of the following, a possible position of a nuclide that might decay by

(i) α emission, labelling the position with **W**,

(ii) β^- emission, labelling the position with **X**,

(iii) β^+ emission, labelling the position with **Y**.

(3)

(c) Used fuel rods from a nuclear reactor emit β^- particles from radioactive isotopes that were not present before the fuel rod was inserted in the reactor. Explain why β^- emitting isotopes are produced when the fuel roads are in the reactor.

....

....

....

(3)

(d) A nuclear power station is a reliable source of electricity that does not produce greenhouse gases but it does produce radioactive waste. Discuss the relative importance of these features in deciding whether or not new nuclear power stations are needed.

The quality of your written answer will be assessed in this question.

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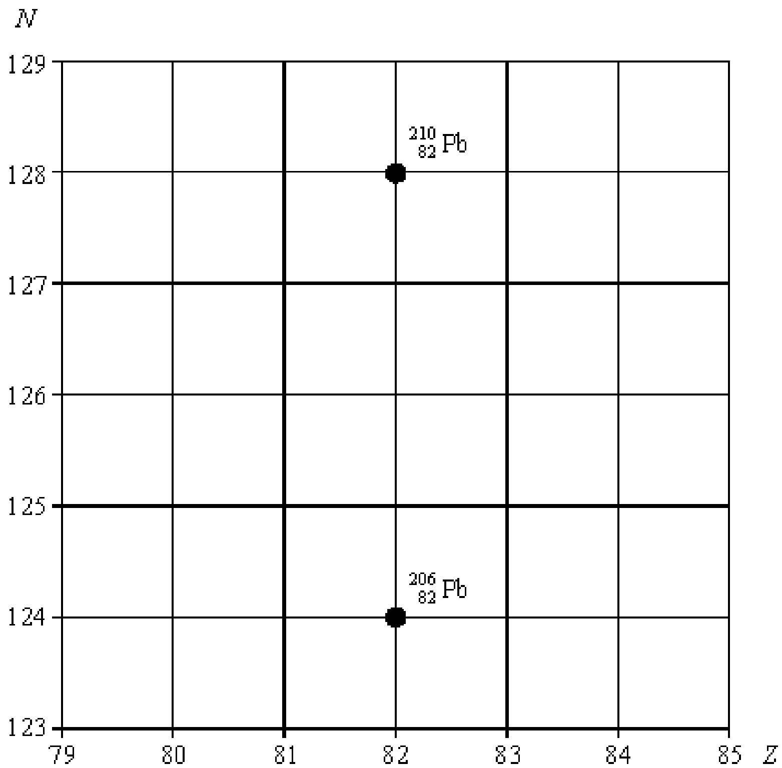
(6)
(Total 14 marks)

Q14. (a) The lead nuclide $^{210}_{82}\text{Pb}$ is unstable and decays in three stages through α and β emissions to a different lead nuclide $^{206}_{82}\text{Pb}$. The position of these lead nuclides on a grid of neutron number, *N*, against proton number, *Z*, is shown below.



On the grid draw **three** arrows to represent one possible decay route.
Label each arrow with the decay taking place.

(3)

(b) The copper nuclide $^{64}_{29}\text{Cu}$ may decay by positron emission or by electron capture to form a nickel (Ni) nuclide.
Complete the two equations that represent these two possible modes of decay.

positron emission $^{64}_{29}\text{Cu}$

electron capture $^{64}_{29}\text{Cu}$

(4)

(c) The nucleus of an atom may be investigated by scattering experiments in which radiation or particles bombard the nucleus.

Name **one** type of radiation or particle that may be used in this investigation and describe the main physical principle of the scattering process.

State the information which can be obtained from the results of this scattering.

You may be awarded marks for the quality of written communication in your answer.

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(3)
(Total 10 marks)

Q15. The age of an ancient boat may be determined by comparing the radioactive decay of $^{14}_{6}C$ from living wood with that of wood taken from the ancient boat.

A sample of 3.00×10^{23} atoms of carbon is removed for investigation from a block of living wood. In living wood one in 10^{12} of the carbon atoms is of the radioactive isotope $^{14}_{6}C$, which has a *decay constant* of 3.84×10^{-12} s^{-1}.

(a) What is meant by the decay constant?

....

....

....

(1)

(b) Calculate the half-life of $^{14}_{6}C$ in years, giving your answer to an appropriate number of significant figures.

1 year = 3.15×10^{7} s

answer = ... years

(3)

(c) Show that the rate of decay of the $^{14}_{6}C$ atoms in the living wood sample is 1.15 Bq.

(2)

(d) A sample of 3.00×10^{23} atoms of carbon is removed from a piece of wood taken from the ancient boat. The rate of decay due to the $^{14}_{6}C$ atoms in this sample is 0.65 Bq. Calculate the age of the ancient boat in years.

answer = ... years

(3)

(e) Give **two** reasons why it is difficult to obtain a reliable age of the ancient boat from the carbon dating described.

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(2)
(Total 11 marks)

M1. (a) (i) origins of background radiation:

cosmic rays
ground, rocks and buildings
air
nuclear weapons testing/nuclear accidents
nuclear power
discharge/waste from nuclear power
medical waste
any three **(1) (1)**
any two **(1)**

(ii) (use of $C = C_0 e^{-\lambda t}$ gives) $(84 - 3) = (110 - 3) e^{-\lambda \times 600}$ **(1)**

$\lambda = \frac{\ln(107 / 81)}{600}$ **(1)**

$= 4.6(4) \times 10^{-4}$ (s^{-1}) **(1)**

(iii) (use of $\frac{dN}{dt} = -\lambda N$ gives) $N = \frac{107}{4.64 \times 10^{-4}}$ **(1)**

= 2.3**(1)** × 10^5 (nuclei) **(1)**
(allow C.E. for value of λ from (ii)

7

(b) *α* radiation is highly **ionising**, hence causes cancer/damage cells/ DNA/kill cells **(1)**

outside: less damage plus reason
(e.g. absorbed by dead skin some *α*'s directed away from body) **(1)**
[or reference to burning]

inside: more damage plus reason
(e.g. all *α*'s absorbed living tissue will absorb *α* radiation can reach vital organs) **(1)**

3
QWC 1
[10]

M2. (a) graph starting (steeply) near/at the origin and decreasing in gradient ✓

1

(b) (i) (use of density = mass/volume)

$$\frac{197 \times 1.67 \times 10^{-27}}{\frac{4}{3}\pi(6.87 \times 10^{-15})^3}$$ ✓ ✓mark for top line and mark for bottom line

(allow use of 1.66 x 10^{-27})

Lose mass line mark if reference is made to mass of electrons

= 2.4(2) × 10^{17} kg m^{-3}

2

(ii) $$R_{Al} = R_{Au}\left(\frac{A_{Al}}{A_{Au}}\right)^{\frac{1}{3}} = 6.87 \times 10^{-15}\left(\frac{27}{197}\right)^{\frac{1}{3}}$$ ✓

= 3.54 × 10^{-15} m ✓

or

$$r_0 = \frac{R}{A^{\frac{1}{3}}} = \frac{6.87 \times 10^{-15}}{197^{\frac{1}{3}}} = 1.18 \times 10^{-15} \text{ m}$$ ✓

$$R = 1.18 \times 10^{-15} \times 27^{\frac{1}{3}} = 3.54 \times 10^{-15} \text{ m}$$ ✓

or

volume = mass/density = $$\frac{27 \times 1.67 \times 10^{-27}}{2.42 \times 10^{17}} = \frac{4}{3}\pi \times R^3$$ ✓

= 3.54 × 10^{-15} m ✓

2

(c) **The candidate' writing hould be legible and the pelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate makes 5 to 6 points concerning the principles of the method, the limitations to the accuracy and the advantages and disadvantages of a particular method

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate makes 3 to 4 points concerning the principles of the method, the limitations to the accuracy and the advantages and disadvantages of a particular method

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate makes 1 to 2 points concerning the principles of the method, the limitations to the accuracy and the advantages and disadvantages of a particular method

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences.

principles

- α scattering involves coulomb or electrostatic repulsion
- electron diffraction treats the electron as a wave having a de Broglie wavelength
- some reference to an equation, for example $\lambda = h/mv$; $eV = mv^2/2$; $Qq/4\pi\varepsilon_o r = E_\alpha$; $\sin\Theta = 0.61\lambda/R$
- reference to first minimum for electron diffraction

accuracy

- α's only measure the least distance of approach, not the radius
- α's have a finite size which must be taken into account
- electrons need to have high speed/kinetic energy
- to have a small wavelength or wavelength comparable to nuclear diameter, the wavelength determines the resolution
- the wavelength needs to be of the same order as the nuclear diameter for significant diffraction
- requirement to have a small collision region in order to measure the scattering angle accurately
- importance in obtaining monoenergetic beams
- cannot detect alpha particles with exactly 180° scattering
- need for a thin sample to prevent multiple scattering

advantages and disadvantages

- α-particle measurements are disturbed by the nuclear recoil
- Mark for α-particle measurements are disturbed by the SNF when coming close to the nucleus or electrons are not subject to the strong nuclear force.
- A second mark can be given for reference to SNF if they add electrons are leptons or alpha particles are hadrons.
- α's are scattered only by the protons and not all the nucleons that make up the nucleus
- visibility – the first minimum of the electron diffraction is often difficult to determine as it superposes on other scattering events

6

[11]

M3. (a) graph to show:
electron intensity decreasing with angle of diffraction **(1)**
to a non-zero first minimum **(1)**

2

(b) (i) last column of table completed correctly **(1)**
with either

$A^{1/3}$
5.93
4.93
3.83
3.04
2.29

or

$R^3/(10^{-45}m^3)$
295
165
82.3
40.4
18.8

axes cover more than 50% of graph sheet **(1)**
all points plotted correctly using labelled axes
(i.e. x-axis $A^{1/3}$, y-axis $R/10^{-15}$m or x axis A, y-axis $R^3/10^{-45}m^3$) **(1)**

(ii) gradient = r_0 **(1)** [or gradient = r_0^3]
gives $r_0 = (1.1 \pm 0.1) \times 10^{-15}$m **(1)**

5

(c) electrons are not subject to the strong nuclear force **(1)**
(so) electron scattering patterns are easier to interpret **(1)**
electrons give greater resolution
[or electrons are more accurate because they can get closer]
[or α particles cannot get so close to the nucleus because of electrostatic repulsion] **(1)**
electrons give less recoil **(1)**
(high energy) electrons are easier to produce
[or electrons have a lower mass/ larger *Q/m*, so easier to accelerate] **(1)**
(in Rutherford scattering) with *α* particles, the closest distance of approach, not *R* is measured **(1)**

max 3
QWC 1

[10]

M4. (a) any 2 from:

the sun, cosmic rays, radon (in atmosphere), nuclear fallout (from previous weapon testing), any radioactive leak (may be given by name of incident) nuclear waste, carbon-14 ✓

1

(b) (i) (ratio of area of detector to surface area of sphere)

ratio = $\dfrac{0.0015}{4\pi(0.18)^2}$ ✓

0.0037 ✓ (0.00368)

2

(ii) activity = 0.62/(0.00368 × 1/400) give first mark if either factor is used.

67000 ✓ Bq accept s^{-1} or decay/photons/disintegrations s^{-1} but not counts s^{-1} ✓ (67400 Bq)

3

(c) (use of the inverse square law)

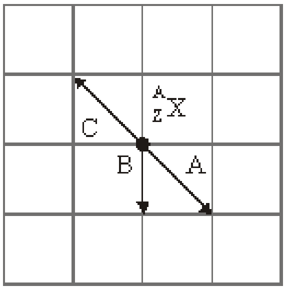
$\dfrac{I_1}{I_2} = \left(\dfrac{r_2}{r_1}\right)^2$ or calculating k = 0.020 from $I = k/x^2$ ✓

$I_2 = 0.62 \times \left(\dfrac{0.18}{0.28}\right)^2$ ✓ 0.26 counts s^{-1} ✓(allow 0.24-0.26)

3

[9]

M5. (a) (i)



correct arrows: A **(1)**
B **(1)**
C **(1)**

(ii) $e^{-1} + {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + v_e$ **(1)**

4

(b) (i) $((4.18 - 1.33) \times 10^{-13}) = 2.85 \times 10^{-13}$ (J) **(1)**

(ii) 1.33×10^{-13} (J)
0.30×10^{-13} (J) for 3 correct values **(1)**
1.63×10^{-13} (J)

(iii) (use of $\Delta E = hf$ gives) f $= 2.46 \times 10^{20}$ Hz **(1)**

(allow C.E. from (b)(ii)if largest value taken)

3

(c) (i) (**(1)**for each precaution <u>with</u> reason to $_{max}$2)

handle with (long) (30 cm) tweezers
because the radiation intensity decreases with distance

store in a lead box (immediately) when not in use to avoid
unnecessary exposure to radiation

[or any sensible precaution with reason]

QWC 2

(ii) γ rays are more penetrating and are therefore more hazardous
(to the internal organs of the body)

β^- particles are more hazardous because they are more ionising **(1)**
(1) for any argued case for either radiation)

3

[10]

M6. (a) (i) thick
high density
material giving minimal fatigue problems after irradiation
any other sensible property e.g. withstands high temperature
any two **(1)** **(1)**

(ii) (reinforced) concrete **(1)**

3

(b) effect of shielding:
γ ray inten ity (greatly) reduced **(1)**
neutrons - some absorption **(1)**
(or speed or energy reduced by collisions) **(1)**
neutrinos - very little effect **(1)**

why shielding becomes radioactive:
neutron absorption by nuclei or atoms **(1)**
makes <u>nuclei</u> (not particles) neutron rich or unstable **(1)**
become β^- emitters and/or γ emitters

max 4
QWC 2

[7]

M7. (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate can explain the role of the moderator and control rods in maintaining a critical condition inside the reactor. The explanation is given in a clear sequence of events and the critical condition is defined in terms of neutrons. To obtain the top mark some other detail must be included. Such as, one of the alternative scattering or absorbing possibilities or appropriate reference to critical mass or detailed description of the feedback to adjust the position of the control rods etc.

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate has a clear idea of two of the following:
the role of the moderator, the role of the control rods or can explain the critical condition.

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate explains that a released neutron is absorbed by uranium to cause a further fission. Alternatively the candidate may explain one of the following:
the role of the moderator, the role of the control rods or can explain the critical condition.

The explanation expected could include the following events that could happen to a released neutron.

a neutron is slowed by the moderator

taking about 50 collisions to reach thermal speeds

then absorbed by uranium-235 to cause a fission event

one neutron released goes on to cause a further fission is the critical condition

a neutron may leave the reactor core without further interaction

a neutron could be absorbed by uranium-238

a neutron could be absorbed by a control rod

a neutron could be scattered by uranium-238

a neutron could be scattered by uranium-235

max 7

(b) it is easy to stay out of range or easy to contain an α source or ß/γ have greater range/are more difficult to screen **(1)**

most (fission fragments) are (more) radioactive/unstable **(1)**

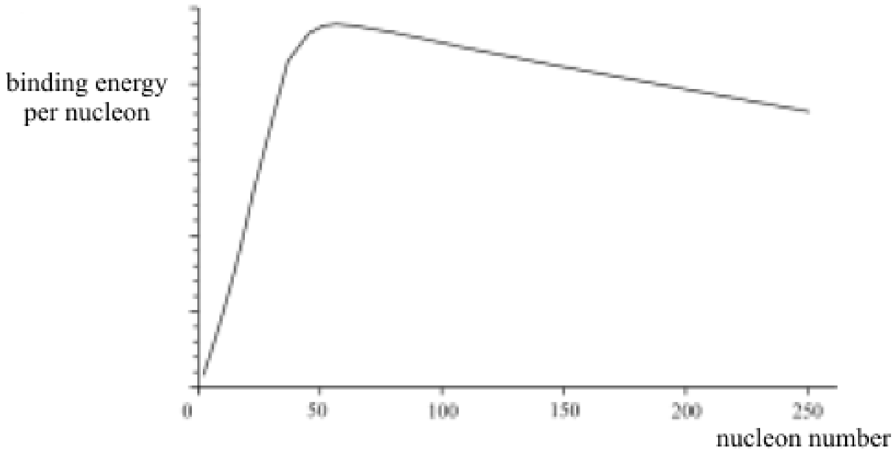
and are initially most likely to be beta emitters/(which also) emit γ radiation/are neutron **rich/heavy (1)**

ionising radiation damages body tissue/is harmful **(1)**

max 3

[10]

M8. (a)



peak 8.7 (accept 8.0 – 9.2)

in MeV ✓

(or peak 1.4 × 10^{-12} accept 1.3 – 1.5 × 10^{-12} in J ✓)

at nucleon number 50 – 60 ✓ accept 50 – 75

sharp rise from origin and moderate fall not below 2/3 of peak height ✓

4

(b) energy is released/made available when binding energy **per nucleon** is increased ✓

in fission a (large) nucleus splits and in fusion (small) nuclei join ✓

the most stable nuclei are at a peak

fusion occurs to the left of peak and fission to the right ✓

max 3

[7]

M9. (a) $^{27}_{13}Al + \alpha \rightarrow {}^{30}_{15}P + {}^{(1)}_{(0)}n$ ✓ 1

(b) kinetic energy lo t by the α particle approaching the nucleus is equal to the potential energy gain ✓

$$2.18 \times 10^{-12} = \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{13 \times 1.6 \times 10^{-19} \times 2 \times 1.6 \times 10^{-19}}{r}$$ ✓

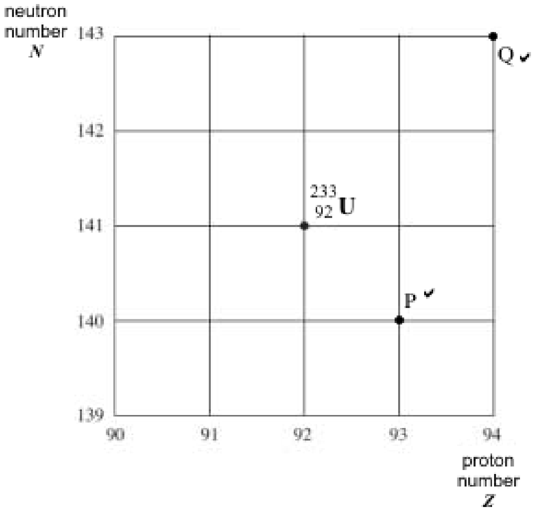
$r = 2.75 \times 10^{-15}$ (m) ✓ 3

[4]

M10. (a) $^{231}_{91}Pa$ ✓

anti (electron) neutrino ✓ 2

(b)



2

(c) (i) $x = 4$ ✓ 1

(ii) mass defect = [(232.98915 + 1.00867) – (90.90368 + 138.87810 + 4 × 1.00867)] u ✓

= 0.18136 u ✓ 3

energy released (= 0.18136 × 931) = 169 (MeV) ✓

[8]

M11. (a)

$$({}^{206}_{76}\mathrm{X} \rightarrow {}^{206}_{82}Pb + \beta \times {}^{0}_{-1}\beta + \beta \times \overline{v_e})$$

$\beta = 6$ ✓

1

(b) (i) the energy **required** to split up the nucleus ✓

into its individual neutrons and protons/nucleons ✓

(or the energy **released** to form/hold the nucleus ✓

from its individual neutrons and protons/nucleons ✓)

2

(ii) 7.88 × 206 = 1620 MeV ✓ (allow 1600-1640 MeV)

1

(c) (i) U, a graph starting at 3×10^{22} showing exponential fall passing through

0.75×10^{22} near 9×10^{9} years ✓

Pb, inverted graph of the above so that the graphs cross at 1.5×10^{22} near 4.5×10^{9} years ✓

2

(ii) (u represents the number of uranium atoms then)

$$\frac{u}{3 \times 10^{22} - u} = 2$$

$u = 6 \times 10^{22} - 2u$ ✓

$u = 2 \times 10^{22}$ atoms

1

(iii) (use of $N = N_o e^{-\lambda t}$)

$2 \times 10^{22} = 3 \times 10^{22} \times e^{-\lambda t}$ ✓

$t = \ln 1.5 / \lambda$

(use of $\lambda = \ln 2 / t_{1/2}$)

$\lambda = \ln 2 / 4.5 \times 10^{9} = 1.54 \times 10^{-10}$ ✓

$t = 2.6 \times 10^{9}$ years ✓(or 2.7×10^{9} years)

3

[10]

M12. (a) graph passes through N = 10/11 when Z = 10 and N increases as Z increases **(1)**

N = 115 → 125 when Z = 80 and graph must bend upwards **(1)**

(b) (i) **W** at Z > 60 just (within one diagonal of a square) below line **(1)**

(ii) **X** just (within one diagonal of a square) above line **(1)**

(iii) **Y** just (within one diagonal of a square) below line **(1)**

3

(c) working showing the change due to emission of four α particles **(1)**
four β^- particles **(1)**

1

(d) Any **two** from the following list of processes:

β^+
describe the changes to N (up by 1) and Z (down by 1)
[or allow p change to n]

α
move closer to line of stability
[or state the proton to neutron ratio is reduced]

p
only if nuclide is **very** proton rich
[or electrostatic repulsion has to overcome the strong nuclear force]
[or highly unstable]
[or rare process]

e^- capture
describe the changes to N (up by 1) and Z (down by 1)
allow p changes to n

marking: listing **two** processes **(1)**
discussing **each** of the two processes **(1) (1)**

3
QWC 1
[10]

M13. (a) graph passes through N = 100 to 130 when Z = 80 **(1)**

and N = 20 when Z = 20 **(1)**

2

(b) (i) **W** at Z > 60 just below line **(1)**

(ii) **X** just above line **(1)**

(iii) **Y** just below line **(1)**

3

(c) fission nuclei (or fragments) are neutron-rich and therefore unstable (or radioactive) **(1)**

neutron-proton ratio is much higher than for a stable nucleus (of the same charge (or mass)) **(1)**

β^- particle emitted when a neutron changes to a proton (in a neutron-rich nucleus) **(1)**

3

(d) The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of written communication but the quality of written communication will be one of the criteria used to assign the answer to one of three levels.

Level	**Descriptor** an answer will be expected to meet most of the criteria in the level descriptor	**Mark range**
Good **3**	– answer supported by appropriate range of relevant points – good use of information or ideas about physics, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of spelling, punctuation and grammar	**5-6**
Modest **2**	– answer partially supported by relevant points – good use of information or ideas about physics given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of spelling, punctuation and grammar	**3-4**
Limited **1**	– valid points but not clearly linked to an argument structure – limited use of information or ideas about physics – unstructured – errors in spelling, punctuation and grammar or lack of fluency	**1-2**
0	– incorrect, inappropriate or no response	**0**

examples of the sort of information or ideas that might be used to support an argument:

- reduction of greenhouse gas emissions is (thought to be) necessary to stop global warming **(1)**
- long term storage of radioactive waste is essential because the radiation from it damages (or kills) living cells **(1)**
- radioactive isotopes with very long half lives are in the used fuel rods **(1)**
- nuclear power is reliable because it does not use oil or gas from other countries **(1)**
- radioactive waste needs to be stored in secure and safe conditions for many years **(1)**

conclusion
either
nuclear power is needed; reduction of greenhouse gases is a greater problem than the storage of radioactive waste because

1 global warming would cause the ice caps to melt/sea levels to rise **(1)**
2 safe storage of radioactive waste can be done **(1)**

or
nuclear power is not needed; storage of radioactive waste is a greater problem than reduction of greenhouse gases because

1 radioactive waste has to be stored for thousands of years **(1)**
2 greenhouse gases can be reduced using renewable energy sources **(1)**

[14]

M14. (a) (on grid: first arrow to start from $^{210}_{82}\text{Pb}$;

arrows must be consecutive;

last arrow must end on $^{206}_{82}\text{Pb}$)

arrow showing the change for an α emission **(1)**
arrow showing the change for a β emission **(1)**
correct α and two β emissions in any order **(1)**

3

(b) (positron emission) $^{64}_{29}\text{Cu} \rightarrow {}^{64}_{28}\text{Ni} + \beta^{+} + \nu_{e}$ (+Q) **(1) (1)**

(electron capture) $^{64}_{29}\text{Cu} + {}^{0}_{-1}\text{e} \rightarrow {}^{64}_{28}\text{Ni} + \nu_{(e)}$ (+Q) **(1) (1)**

4

(c) (the following examples may be included)

α particles **(1)**
coulomb/electrostatic/electromagnetic repulsion
[or K.E. converted to P.E. (as α particle approaches nucleus)] **(1)**
information:
any of the following: proton number, nuclear charge,
upper limit to nuclear radius
mass of nucleus is most of the mass
of atom **(1)**

[alternative
(high energy) electron (scattering) **(1)**
diffraction of de Broglie Waves by nucleus **(1)**
information:
any of the following: nuclear radius, nuclear density **(1)**]

3
QWC 2
[10]

M15. (a) probability of decay per unit time/given time period

or fraction of atoms decaying per second

or the rate of radioactive decay is proportional to the number of (unstable) nuclei

and nuclear decay constant is the constant of proportionality **(1)**

1

(b) use of $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$

$T_{\frac{1}{2}}$ = ln2/3.84 × 10^{-12} s **(1)** (1.805 × 10^{11} s)
= (1.805 × 10^{11}/3.15 × 10^{7}) = 5730 y **(1)**

answer given to 3 sf **(1)**

3

(c) number of nuclei = N = 3.00 × 10^{23} × 1/10^{12} **(1)**

(= 3.00 × 10^{11} nuclei)

(using $\frac{\Delta N}{\Delta t} = -\lambda N$)

rate of decay = 3.84 × 10^{-12} × 3.00 × 10^{11} **(1)**

(= 1.15 Bq)

2

(d) ($N = N_0e^{-\lambda t}$ and activity is proportional to the number of nuclei $A \propto N$ use of $A = A_0e^{-\lambda t}$)

$0.65 = 1.15 \times e^{-3.84\times10^{-12}t}$ **(1)**

$$t = \frac{\ln\left(\frac{1.15}{0.65}\right)}{3.84\times10^{-12}} \text{ or } \frac{\ln\left(\frac{0.651}{1.15}\right)}{-3.84\times10^{-12}}$$

t = 4720 *y* **(1)**

3

(e) the boat may have been made with the wood some time after the tree was cut down

the background activity is high compared to the observed count rates

the count rates are low or sample size/mass is small or there is statistical variation in the recorded results

possible contamination

uncertainty in the ratio of carbon-14 in carbon thousands of years ago

any two ***(1)(1)***

2

[11]