Nuclear Revision Pack - practice

A level physics (Greenford High School)

Nuclear Revision Pack

Name: ______________________

Class: ______________________

Date: ______________________

Time:	**358 minutes**
Marks:	**320 marks**
Comments:	

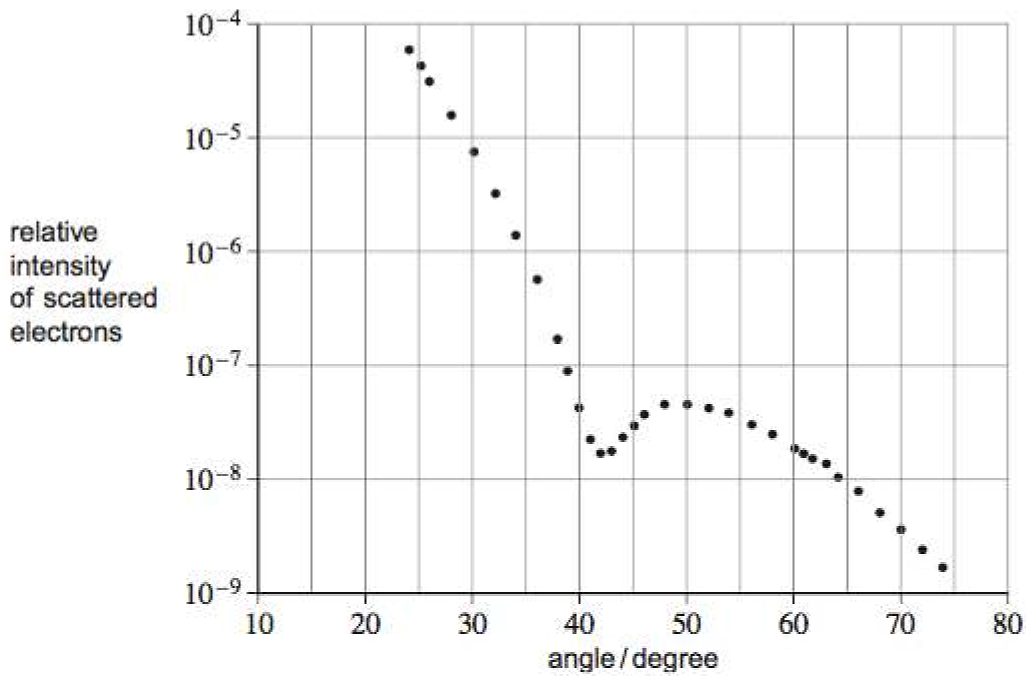
1 (a) The radius of a nucleus may be determined by electron diffraction. In an electron diffraction experiment a beam of electrons is fired at oxygen-16 nuclei. Each electron has an energy of 5.94×10^{-11} J.

The approximation, momentum = $\frac{\text{energy}}{\text{speed of light}}$ can be used for electrons at this energy.

(i) Show that the de Broglie wavelength λ of each electron in the beam is about 3.3×10^{-15} m.

(2)

(ii) The graph shows how the relative intensity of the scattered electrons varies with angle due to diffraction by the oxygen-16 nuclei. The angle is measured from the original direction of the beam.



The angle θ of the first minimum in the electron-diffraction pattern is given by

$$\sin\theta = \frac{0.61\lambda}{\text{nuclear radius}}$$

Calculate the radius of an oxygen-16 nucleus using information from the graph.

radius = ____________________ m

(1)

(b) Rutherford used the scattering of α particles to provide evidence for the structure of the atom.

(i) Sketch a labelled diagram showing the experimental arrangement of the apparatus used by Rutherford.

(2)

(ii) State and explain the results of the scattering experiment.
Your answer should include the following:

- the main observations
- the significance of each observation
- how the observtions placed an upper limit on the nuclear radius.

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

(6)
(Total 11 marks)

2 (a) The exposure of the general public to background radiation has changed substantially over the past 100 years.
State **one** source of radiation that has contributed to this change.

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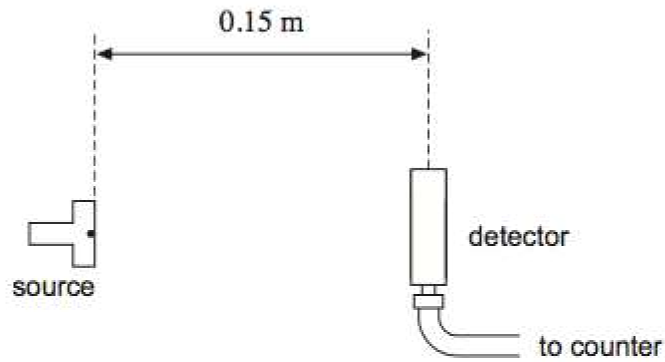
(1)

(b) A student measures background radiation using a detector and determines that background radiation has a mean count-rate of 40 counts per minute. She then places a γ ray source 0.15 m from the detector as shown below.



With this separation the average count per minute was 2050.

The student then moves the detector further from the γ ray source and records the count-rate again.

(i) Calculate the average count-rate she would expect to record when the source is placed 0.90 m from the detector.

count-rate = ____________________ min^{-1}

(3)

(ii) The average count per minute of 2050 was determined from a measurement over a period of 5 minutes. Explain why the student might choose to record for longer than 5 minutes when the separation is 0.90 m.

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(1)

(iii) When the detector was moved to 0.90 m the count-rate was lower than that calculated in part **(b)(i)**. It is suggested that the source may also emit β particles.

Explain how this can be checked.

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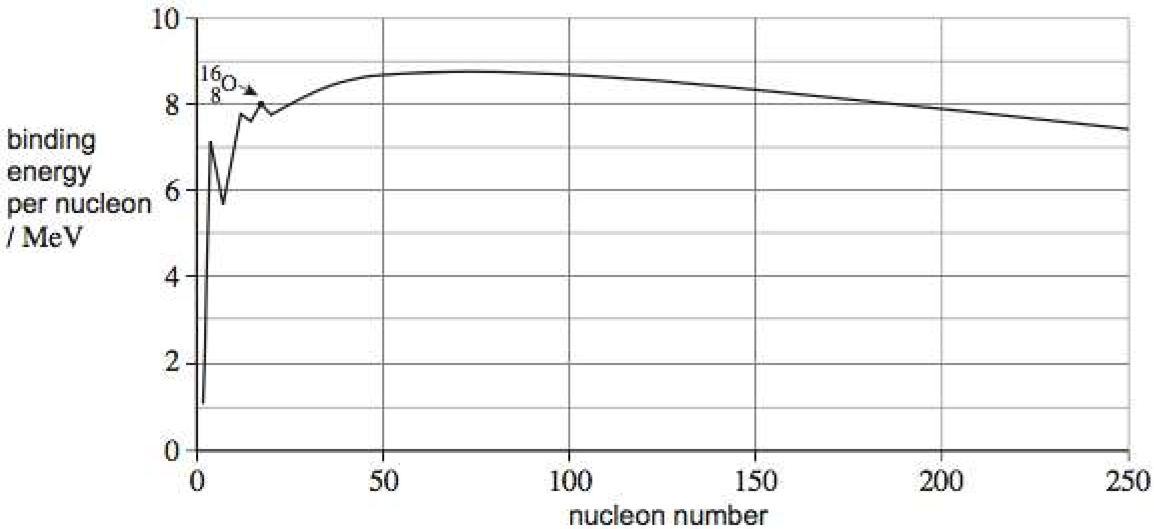
(2)
(Total 7 marks)

3 The diagram shows how the binding energy per nucleon varies with nucleon number.



(a) (i) Fission and fusion are two nuclear processes in which energy can be released. Explain why nuclei that undergo fission are restricted to a different part of the graph than those that undergo fusion.

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(2)

(ii) Explain, with reference to the diagram, why the energy released per nucleon from fusion is greater than that from fission.

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(2)

(b) (i) Calculate the mass difference, in kg, of the $^{16}_{8}O$ nucleus.

mass of $^{16}_{8}O$ nucleus = 15.991 u

mass difference = ____________________ kg

(2)

(ii) Using your answer to part **(b)(i)**, calculate the binding energy, in MeV, of an oxygen $^{16}_{8}O$ nucleus.

binding energy = ____________________ MeV

(1)

(iii) Explain how the binding energy of an oxygen $^{16}_{8}O$ nucleus can be calculated with information obtained from the diagram.

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(1)

(Total 8 marks)

4 An ancient sealed flask contains a liquid, assumed to be water. An archaeologist asks a scientist to determine the volume of liquid in the flask without opening the flask. The scientist decides to use a radioactive isotope of sodium ($^{24}_{11}Na$) that decays with a half-life of 14.8 h.

(a) She first mixes a compound that contains 3.0×10^{-10} g of sodium-24 with 1500 cm^3 of water. She then injects 15 cm^3 of the solution into the flask through the seal.
Show that initially about 7.5×10^{10} atoms of sodium-24 are injected into the flask.

(1)

(b) Show that the initial activity of the solution that is injected into the flask is about 1×10^6 Bq.

activity = _____________Bq

(3)

(c) She waits for 3.5 h to allow the injected solution to mix thoroughly with the liquid in the flask. She then extracts 15 cm^3 of the liquid from the flask and measures its activity which is found to be 3600 Bq.

Calculate the total activity of the sodium-24 in the flask after 3.5 h and hence determine the volume of liquid in the flask.

(3)

(d) The archaeologist obtained an estimate of the volume knowing that similar empty flasks have an average mass of 1.5 kg and that mass of the flask and liquid was 5.2 kg. Compare the estimate that the archaeologist could obtain from these masses with the volume calculated in part 4.3 and account for any difference.

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(2)

(Total 9 marks)

5 (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.

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(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.

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(2)

(Total 6 marks)

6 (a) Scattering experiments are used to investigate the nuclei of gold atoms.
In one experiment, alpha particles, all of the same energy (monoenergetic), are incident on a foil made from a single isotope of gold.

(i) State the main interaction when an alpha particle is scattered by a gold nucleus.

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(1)

(ii) The gold foil is replaced with another foil of the same size made from a mixture of isotopes of gold. Nothing else in the experiment is changed.

Explain whether or not the scattering distribution of the monoenergetic alpha particles remains the same.

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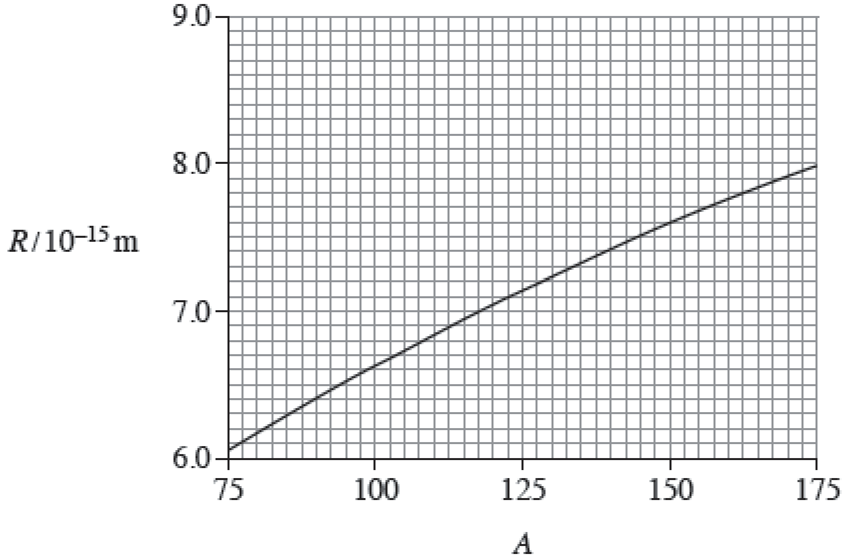
(1)

(b) Data from alpha−particle scattering experiments using elements other than gold allow scientists to relate the radius R, of a nucleus, to its nucleon number, A.
The graph shows the relationship obtained from the data in a graphical form, which obeys the relationship $R = r_0 A^{\frac{1}{3}}$



(i) Use information from the graph to show that r_0 is about 1.4×10^{-15} m.

(1)

(ii) Show that the radius of a $^{51}_{23}\mathrm{V}$ nucleus is about 5×10^{-15} m.

(2)

(c) Calculate the density of a $^{51}_{23}\text{V}$ nucleus.

State an appropriate unit for your answer.

density ____________________ unit __________

(3)

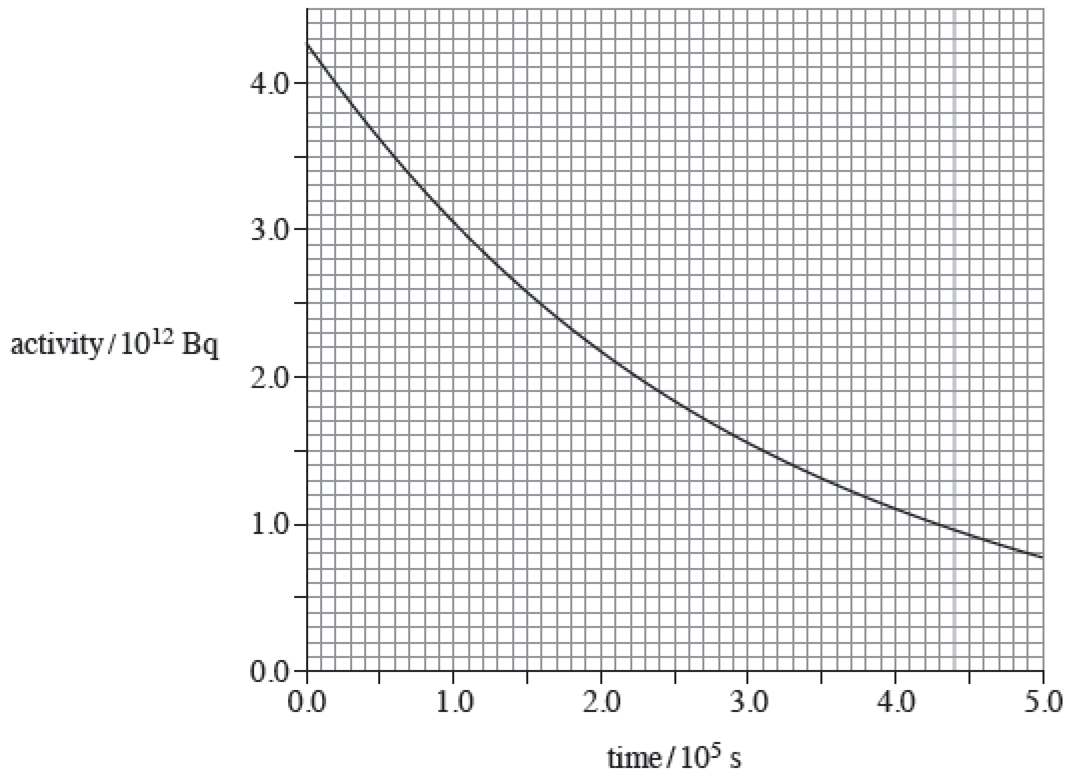
(Total 8 marks)

7 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.

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(2)

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

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(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.

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(2)

(Total 11 marks)

8 (a) Explain what is meant by a **thermal** neutron.

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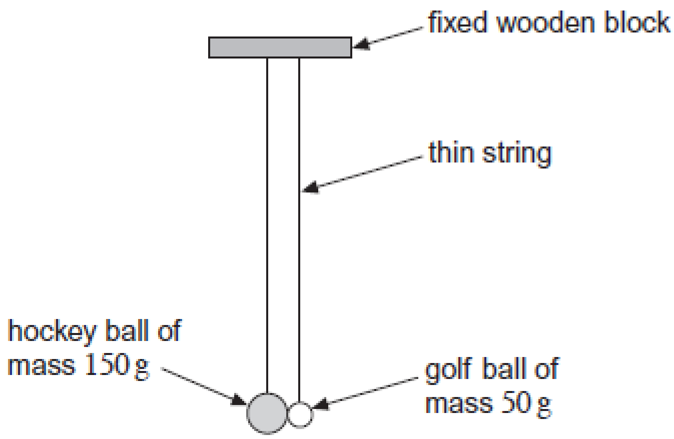
(2)

(b) A student sets up the arrangement, shown in the diagram below, to demonstrate the principle of moderation in a nuclear reactor.



A golf ball of mass 50 g is initially hanging vertically and just touching a hockey ball of mass 150 g. The golf ball is pulled up to the side and released. It has a speed of 1.3 m s^{-1} when it collides head-on with the hockey ball. After the collision the balls move in opposite directions with equal speeds of 0.65 m s^{-1}.

(i) Calculate the height above its initial position from which the golf ball is released. Assume that there is no air resistance.

height ____________________ m

(2)

(ii) Show that momentum is conserved in the collision and that the collision is perfectly elastic.

(4)

(iii) Calculate the percentage of the kinetic energy of the golf ball transferred to the hockey ball during the collision.

percentage transferred ____________________ %

(2)

(iv) Explain how this demonstration relates to the moderation process in a reactor and state **one** way in which the collisions in a reactor differ from the collision in the demonstration.

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(2)

(v) Name the substance used as the moderator in a pressurised water reactor (PWR).

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(1)

(Total 13 marks)

9 In stars, helium-3 and helium-4 are formed by the fusion of hydrogen nuclei. As the temperature rises, a helium-3 nucleus and a helium-4 nucleus can fuse to produce beryllium-7 with the release of energy in the form of gamma radiation.

The table below shows the masses of these nuclei.

Nucleus	**Mass / u**
Helium-3	3.01493
Helium-4	4.00151
Beryllium-7	7.01473

(a) (i) Calculate the energy released, in J, when a helium-3 nucleus fuses with a helium-4 nucleus.

energy released ____________________ J

(4)

(ii) Assume that in each interaction the energy is released as a single gamma-ray photon.

Calculate the wavelength of the gamma radiation.

wavelength ____________________ m

(3)

(b) For a helium-3 nucleus and a helium-4 nucleus to fuse they need to be separated by no more than 3.5×10^{-15} m.

(i) Calculate the minimum total kinetic energy of the nuclei required for them to reach a separation of 3.5×10^{-15} m.

total kinetic energy ____________________ J

(3)

(ii) Calculate the temperature at which two nuclei with the average kinetic energy for that temperature would be able to fuse.
Assume that the two nuclei have equal kinetic energy.

temperature ____________________ K

(3)

(c) Scientists continue to try to produce a viable fusion reactor to generate energy on Earth using reactors like the Joint European Torus (JET). The method requires a plasma that has to be raised to a suitable temperature for fusion to take place.

(i) State **two** nuclei that are most likely to be used to form the plasma of a fusion reactor.

1. ____

2. ____

(2)

(ii) State **one** method which can be used to raise the temperature of the plasma to a suitable temperature.

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(1)

(Total 16 marks)

10 (a) State what is meant by the binding energy of a nucleus.

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(2)

(b) (i) When a $^{235}_{92}\mathrm{U}$ nucleus absorbs a slow-moving neutron and undergoes fission one possible pair of fission fragments is technetium $^{112}_{43}\mathrm{Tc}$ and indium $^{122}_{49}\mathrm{In}$.

Complete the following equation to represent this fission process.

$$^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{112}_{43}\mathrm{Tc} + {}^{122}_{49}\mathrm{In} + \ldots\ldots\ldots\ldots\ldots$$

(1)

(ii) Calculate the energy released, in MeV, when a single $^{235}_{92}\mathrm{U}$ nucleus undergoes fission in this way.

binding energy per nucleon of $^{235}_{92}\mathrm{U}$ = 7.59 MeV

binding energy per nucleon of $^{112}_{43}\mathrm{Tc}$ = 8.36 MeV

binding energy per nucleon of $^{122}_{49}\mathrm{In}$ = 8.51 MeV

energy released ____________________ MeV

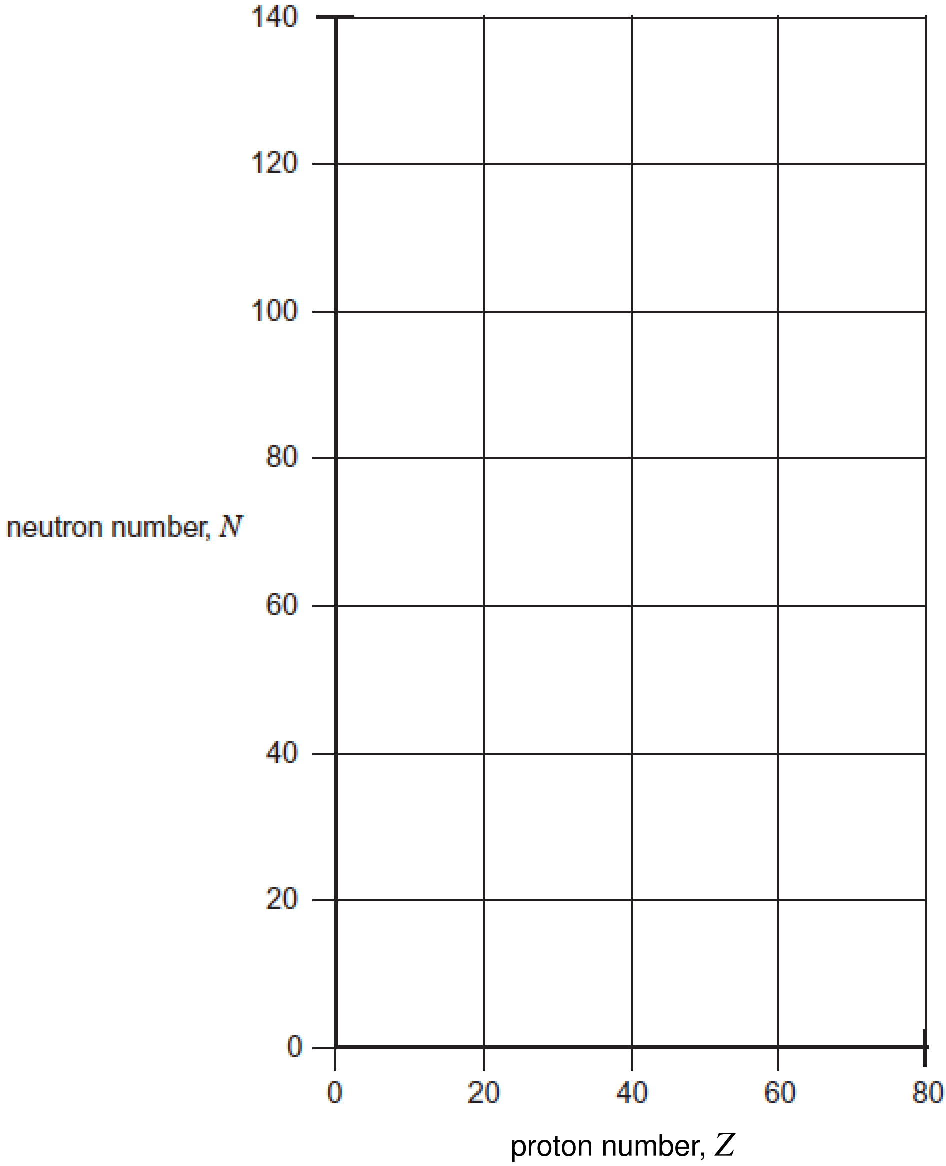
(3)

(iii) Calculate the loss of mass when a $^{235}_{92}U$ nucleus undergoes fission in this way.

loss of mass ____________________ kg

(2)

(c) (i) On the figure below sketch a graph of neutron number, N, against proton number, Z, for stable nuclei.



(1)

(ii) With reference to the figure, explain why fission fragments are unstable and explain what type of radiation they are likely to emit initially.

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(3)

(Total 12 marks)

11 The carbon content of living trees includes a small proportion of carbon-14, which is a radioactive isotope. After a tree dies, the proportion of carbon-14 in it decreases due to radioactive decay.

(a) (i) The half-life of carbon-14 is 5740 years.
Calculate the radioactive decay constant in yr^{-1} of carbon-14.

decay constant ____________________ yr^{-1}

(1)

(ii) A piece of wood taken from an axe handle found on an archaeological site has 0.375 times as many carbon-14 atoms as an equal mass of living wood.
Calculate the age of the axe handle in years.

age ____________________ yr

(3)

(b) Suggest why the method of carbon dating is likely to be unreliable if a sample is:

(i) less than 200 years old,

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(ii) more than 60 000 years old.

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(2)
(Total 6 marks)

12 (a) (i) Define the atomic mass unit.

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(1)

(ii) State and explain how the mass of a ${}^{4}_{2}He$ nucleus is different from the total mass of its protons and neutrons when separated.

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(2)

(b) Explain why nuclei in a star have to be at a high temperature for fusion to take place.

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(3)

(c) (i) In massive stars, nuclei of hydrogen $^{1}_{1}H$ are processed into nuclei of helium $^{4}_{2}He$ through a series of interactions involving carbon, nitrogen and oxygen called the CNO cycle.

Complete the nuclear equations below that represent the last two reactions in the series.

$$^{\cdots\cdots}_{8}O \rightarrow {}^{15}_{7}N + \ldots\ldots\ldots\ldots + \nu_e$$

$$^{15}_{7}N + {}^{1}_{1}H \rightarrow {}^{\cdots\cdots}_{6}C + {}^{4}_{2}He$$

(3)

(ii) The whole series of reactions is summarised by the following equation.

$$4\,^{1}_{1}\text{H} \rightarrow \,^{4}_{2}\text{He} + 2\text{e}^{+} + 2\nu_{e}$$

Calculate the energy, in Me V, that is released.

nuclear mass of $^{4}_{2}\text{He}$ = 4.00150 u

energy ____________________ Me V

(3)

(Total 12 marks)

13 (a) Describe the changes made inside a nuclear reactor to reduce its power output and explain the process involved.

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(2)

(b) State the main source of the highly radioactive waste from a nuclear reactor.

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(1)

(c) In a nuclear reactor, neutrons are released with high energies. The first few collisions of a neutron with the moderator transfer sufficient energy to excite nuclei of the moderator.

(i) Describe and explain the nature of the radiation that may be emitted from an excited nucleus of the moderator.

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(2)

(ii) The subsequent collisions of a neutron with the moderator are elastic.

Describe what happens to the neutrons as a result of these subsequent collisions with the moderator.

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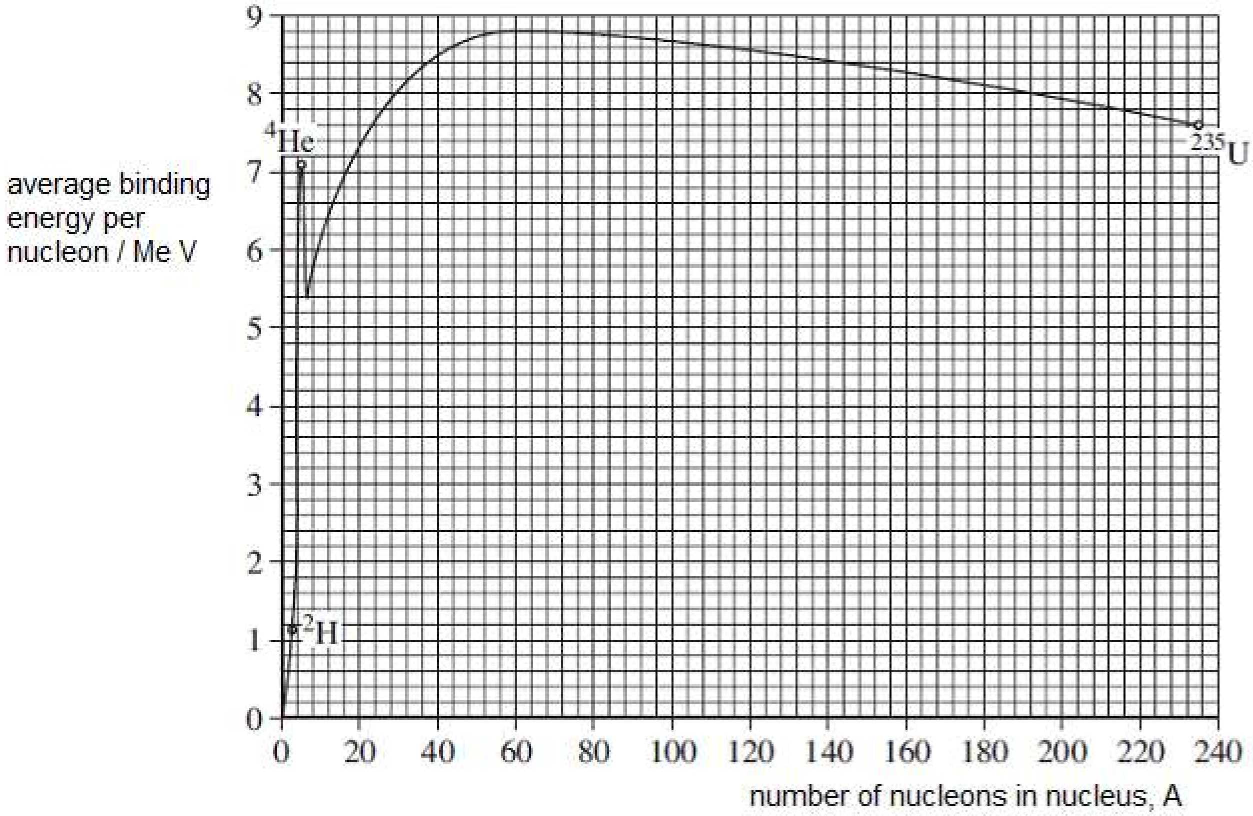
(2)

(Total 7 marks)

14 The figure below shows the variation in binding energy per nucleon with nucleon number.



(a) A uranium-235, ^{235}U, nucleus fissions into two approximately equally sized products. Use data from the graph to show that the energy released as a result of the fission is approximately 4×10^{-11} J.
Show on the graph how you have used the data.

(4)

(b) Using the data below, show that the energy available from the fusion of two hydrogen-2,^{2}H, nuclei to make a helium-4,^{4}He, nucleus is approximately 3.7×10^{-12} J.

mass of ^{2}H = 2.0135 u
mass of ^{4}He = 4.0026 u

(4)

(c) Compare the energy available from the complete fission of 1 kg of uranium-235 with the energy available from the fusion of 1 kg of hydrogen-2.

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(3)

(d) Fission and fusion reactions release different amounts of energy. Discuss other reasons why it would be preferable to use fusion rather than fission for the production of electricity, assuming that the technical problems associated with fusion could be overcome.

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(2)
(Total 13 marks)

15 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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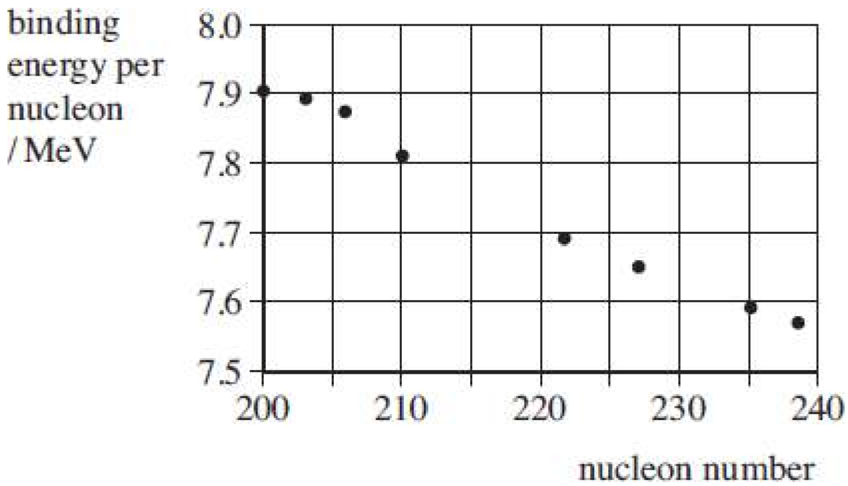
(2)

(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 $^{206}_{82}Pb$ nucleus.

answer = ____________________ MeV

(1)

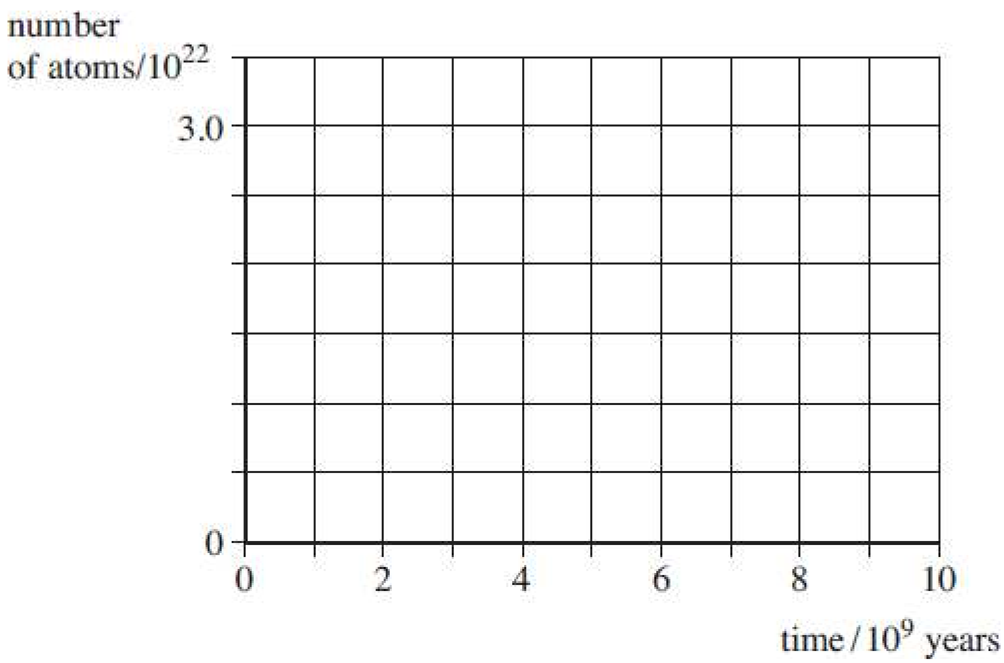
(c) The half-life of $^{238}_{92}\mathrm{U}$ is 4.5 × 10^9 years, which is much larger than all the other half-lives of the decays in the series.

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

At any given time most of the atoms are either $^{238}_{92}\mathrm{U}$ or $^{206}_{82}\mathrm{Pb}$ 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 $^{238}_{92}\mathrm{U}$ atoms and the number of $^{206}_{82}\mathrm{Pb}$ 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 $^{238}_{92}\mathrm{U}$ atoms as $^{206}_{82}\mathrm{Pb}$ atoms.
Show that the number of $^{238}_{92}\mathrm{U}$ 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)

16 (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)

17 The Sun's energy is produced by the fusion of protons. Near the Sun's surface the protons have a mean kinetic energy of 0.75 eV which is too low for fusion to take place. The core, however, has a temperature of about 1.5×10^6 K and a pressure of about 1.0×10^{16} Pa. This core consists of a plasma of (mainly) protons. Within the core the density, pressure and temperature of the proton plasma are sufficiently high for nuclear fusion to occur.
The energy is thought to be produced mainly by a cycle called the hydrogen cycle. The overall effect in one cycle is that 4 protons fuse to form a helium nucleus. The total mass of hydrogen that fuses each second is 7.0×10^{11} kg of which about 5.0×10^9 kg per second is converted into energy that is radiated.

When answering the following questions assume, where necessary, that the plasma behaves like an ideal gas.

(a) (i) Use the mean value of the kinetic energy of protons near the Sun's surface to calculate the temperature near its surface.

temperature near the Sun's surface ____________________ K

(3)

(ii) Calculate the closest distance of approach for two protons near the Sun's surface.

closest distance of approach ____________________ m

(3)

(iii) Explain why fusion cannot occur near the surface.

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(3)

(b) (i) Calculate the number of protons in each cubic metre of the Sun's core.

number of protons ____________________

(3)

(ii) Calculate the density of the Sun's core.

density of the Sun's core ____________________ kg m $^{-3}$

(2)

(c) (i) Show that the data given in the passage in question (a) suggest that every second, about 4×10^{38} protons fuse to form helium nuclei.

(2)

(ii) The total binding energy of a helium nucleus is 4.5×10^{-12} J.
Determine with an appropriate calculation whether the mass that is converted into radiant energy, stated in the passage, is consistent with this value.

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(4)

(Total 20 marks)

18 The table shows the binding energy per nucleon for two nuclei.

nucleus	binding energy per nucleon/10^{-12}J
helium-4	1.1332417
beryllium-8	1.1314027

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

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(1)

(ii) It is more usual to quote binding energies of nucleons in MeV rather than J. Calculate the total binding energy, in MeV, of a beryllium-8 nucleus.

binding energy ________________________ MeV

(3)

(b) (i) Calculate the change in mass that occurs when two helium-4 nuclei fuse to form a beryllium-8 nucleus.

mass change ________________________ kg

(2)

(ii) Two helium-4 nuclei are initially separated by a large distance and are travelling toward one another. The helium nuclei become influenced by the strong force when their centres are separated by a distance of 3.82×10^{-15} m.
Calculate the total initial kinetic energy of the nuclei needed for them to reach this separation.

kinetic energy ____________________ J

(3)

(iii) Explain why the kinetic energy calculated in part (b)(ii) will not enable the helium nuclei to fuse and produce a beryllium-8 nucleus.

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(3)

(Total 12 marks)

19 In a nuclear reactor the mean energy produced by each uranium-235 nucleus that undergoes induced fission is 3.0×10^{-11} J. In one pressurised water reactor, PWR, the fuel rods in the reactor contain 2.0×10^4 kg of uranium-235 and 40% of the energy produced per second is converted to 500 MW of electrical output power. It is assumed that all the energy produced in the reactor core is removed by pressurised water in the coolant system. The pressure of the water is approximately 150 times greater than normal atmospheric pressure. The water enters the reactor at a temperature of 275 °C ad leaves at a temperature of 315 °C. Under the operational conditions of the reactor the mean density of water in the coolant circuit is 730 kg m^{-3} and the specific heat capacity of water is approximately 5000 J kg^{-1} K^{-1}.

normal atmospheric pressure = 1.0×10^5 Pa
molar mass of uranium-235 = 0.235 kg

(a) The equation below gives one induced fission reaction that takes place in a reactor.

$$^{235}_{92}U + ^{1}_{0}X \Rightarrow ^{n}_{56}Br + ^{90}_{p}Kr + 2^{1}_{0}X$$

(i) State the name of the particle represented by **X**.

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(1)

(ii) State the proton and nucleon numbers represented by *p* and *n*.

p ______________________

n ______________________

(2)

(b) (i) Calculate the number of fission reactions that occur in the reactor each second.

number of fission reactions per second ______________________

(2)

(ii) The reactor fuel rods contain 2.0×10^4 kg of uranium-235. Assume that all this uranium-235 could be used.
Calculate the maximum time, in years, for which the reactor could operate.

time ______________________ years

(4)

(iii) Suggest why it is not possible to use all the uranium-235 in the reactor fuel rods.

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(2)

(c) Calculate the force exerted by the pressurised water on each square centimetre of the wall of the reactor.

force ______________________ N

(2)

(d) Calculate, in $m^3\ s^{-1}$, the flow rate of the water through the PWR reactor.
You will need to use data from the passage at the beginning of the question.

flow rate ______________________ $m^3\ s^{-1}$

(4)

(e) In a PWR the cooling water also acts as the moderator in the reactor and boron rods are used to control the power output. Describe the physical processes that take place in the moderator and control rods.

(4)

(Total 21 marks)

20 The fissile isotope of uranium, $^{233}_{92}U$, 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 $^{233}_{92}U$.

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

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

(2)

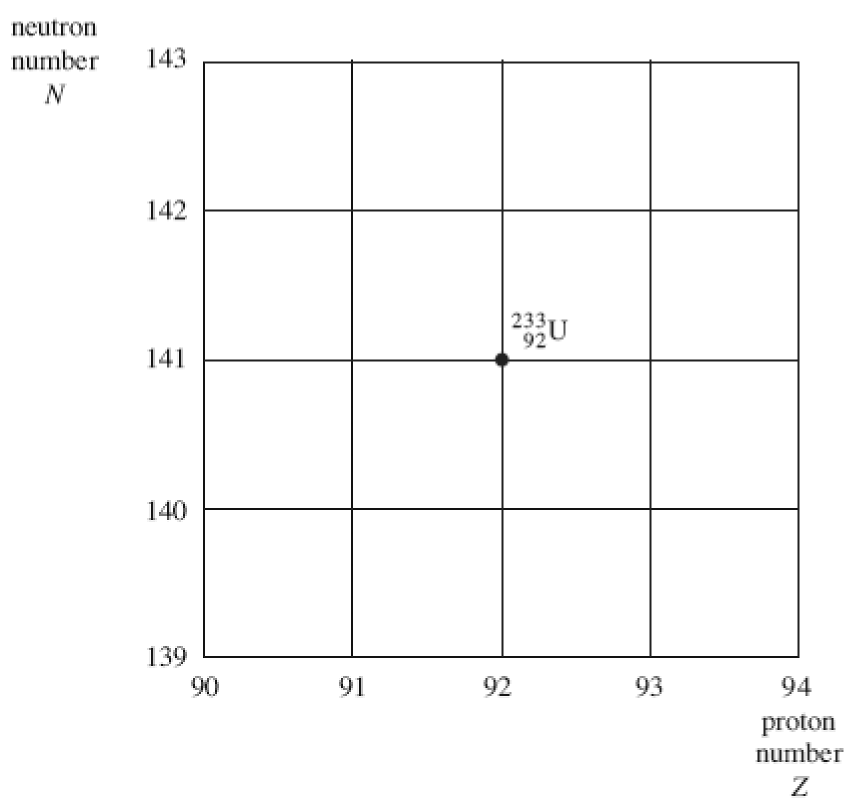
(b) Two other nuclei, **P** and **Q**, can also decay into $^{233}_{92}U$.

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

mass of $^{91}_{36}\text{Kr}$ nucleus = 90.90368 u

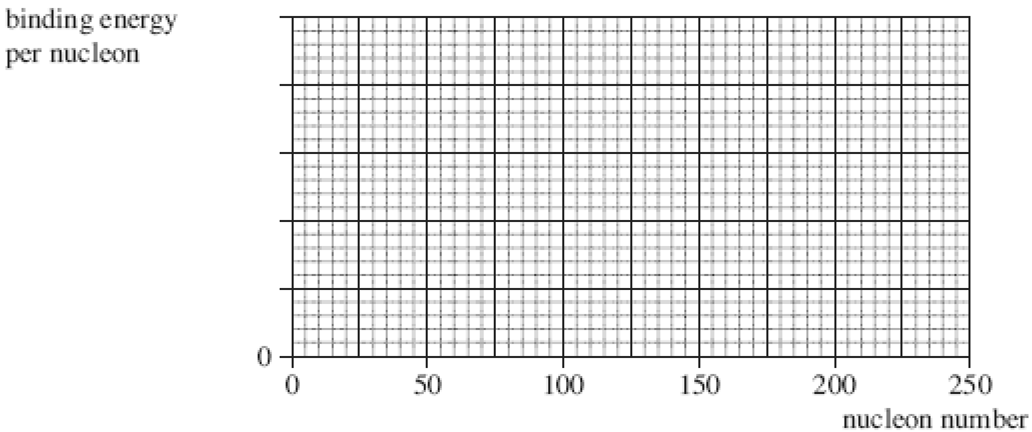
mass of $^{139}_{56}\text{Ba}$ nucleus = 138.87810 u

answer = ______________________MeV

(3)

(Total 8 marks)

21 (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)

22

Radioisotope thermoelectric generators (RTGs) are electrical generators powered by radioactive decay. As a radioisotope decays some of the energy released is converted into electricity by means of devices called thermocouples. In this way RTGs have been used as power sources in satellites, space probes and heart pacemakers.

The Cassini space probe was launched in 1997. It carried three RTGs each containing 11 kg of a nuclear fuel, plutonium oxide (a compound having two oxygen atoms combined with every plutonium-238 atom). In 1997, when the probe was launched, the power released from one gram of plutonium oxide was 500 mW.

Plutonium-238 $^{238}_{94}Pu$ is an alpha emitter, decaying into uranium(U).
The half-life of the decay is 87.7 years.

mass of one mol of plutonium-238 = 238 g
mass of one mol of oxygen atoms = 16 g

(a) State and explain why environmentalists might have been concerned by the use of such a large quantity of plutonium-238.

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(2)

(b) State and explain whether the activity of a given number of atoms of plutonium is affected when they are in the form of plutonium oxide.

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(2)

(c) (i) Calculate the decay constant, in s^{-1}, for plutonium-238.

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decay constant ___________________ s^{-1}

(2)

(ii) Calculate the number of plutonium-238 atoms in the total mass of the plutonium oxide in the Cassini probe at the beginning of its mission.

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number of plutonium-238 atoms ______________________

(5)

(iii) Calculate the initial activity of the plutonium-238 in the Cassini probe. Give a suitable unit for your answer.

____

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____

initial activity of plutonium-238 ______________________ unit ___________

(3)

(d) (i) Write a nuclear equation for the $\left({}^{238}_{94}\text{Pu}\right)$ decay.

____

(2)

(ii) Assume the power released by the RTGs' fuel originated as the kinetic energy of the alpha particles emitted in the decay of $\left({}^{238}_{94}\mathrm{Pu}\right)$.

Calculate the maximum kinetic energy of each alpha particle.

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kinetic energy of alpha particle ______________________ J

(4)

(Total 20 marks)

23 A nuclide of manganese $\left({}^{52}_{25}\mathrm{Mn}\right)$ undergoes beta⁺ decay to form a nuclide of chromium (Cr).

(a) Complete the equation for this decay process.

$${}^{52}_{25}\mathrm{Mn} \rightarrow {}^{\cdots}_{24}\mathrm{Cr} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^{+} + {}^{\cdots\cdots}_{\cdots\cdots}$$

(2)

(b) State the name of the exchange particle involved in this beta⁺ decay.

____

(1)

(Total 3 marks)

24 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)

25 (a) $^{212}_{83}Bi$ can decay into $^{208}_{82}Pb$ by a β^- followed by an α decay, or by an α followed by a β^- decay. One or more of the following elements is involved in these decays:

$$_{80}Hg,\ _{81}Tl,\ _{84}Po,\ _{85}At.$$

Write out decay equations showing each stage in both of these decays.

First decay path	**Second decay path**

(6)

(b) (i) Describe how you would perform an experiment that demonstrates that gamma radiation obeys an inverse square law.

(ii) Explain why gamma radiation obeys an inverse square law but alpha and beta radiation do not.

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(9)

(Total 15 marks)

26 (a) When a nucleus of uranium -235 fissions into barium -141 and krypton -92, the change in mass is 3.1×10^{-28} kg. Calculate how many nuclei must undergo fission in order to release 1.0 J of energy by this reaction.

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(2)

(b) A nuclear power station produces an electrical output power of 600 MW. If the overall efficiency of the station is 35%, calculate the decrease in the mass of the fuel rods, because of the release of energy, during one week of continuous operation.

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(4)

(Total 6 marks)

27 (a) Calculate the radius of the $^{238}_{92}U$ nucleus.

$r_0 = 1.3 \times 10^{-15}$ m

(2)

(b) At a distance of 30 mm from a point source of γ rays the corrected count rate is *C*. Calculate the distance from the source at which the corrected count rate is 0.10 *C*, assuming that there is no absorption.

(2)

(c) The activity of a source of b particles falls to 85% of its initial value in 52 s. Calculate the decay constant of the source.

(3)

(d) Explain why the isotope of technetium, $^{99}Tc_m$, is often chosen as a suitable source of radiation for use in medical diagnosis.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

(3)

(Total 10 marks)

28 In a geothermal power station, water is pumped through pipes into an underground region of hot rocks. The thermal energy of the rocks heats the water and turns it to steam at high pressure. The steam then drives a turbine at the surface to produce electricity.

(a) Water at 21°C is pumped into the hot rocks and steam at 100°C is produced at a rate of 190 kg s^{-1}.

(i) Show that the energy per second transferred from the hot rocks to the power station in this process is at least 500 MW.

specific heat capacity of water = 4200 J kg^{-1} K^{-1}
specific latent heat of steam = 2.3×10^6 J kg^{-1}

(ii) The hot rocks are estimated to have a volume of 4.0×10^6 m^3. Estimate the fall of temperature of these rocks in one day if thermal energy is removed from them at the rate calculated in part (i) without any thermal energy gain from deeper underground.

specific heat capacity of the rocks = 850 J kg^{-1} K^{-1}
density of the rocks = 3200 kg m^{-3}

(7)

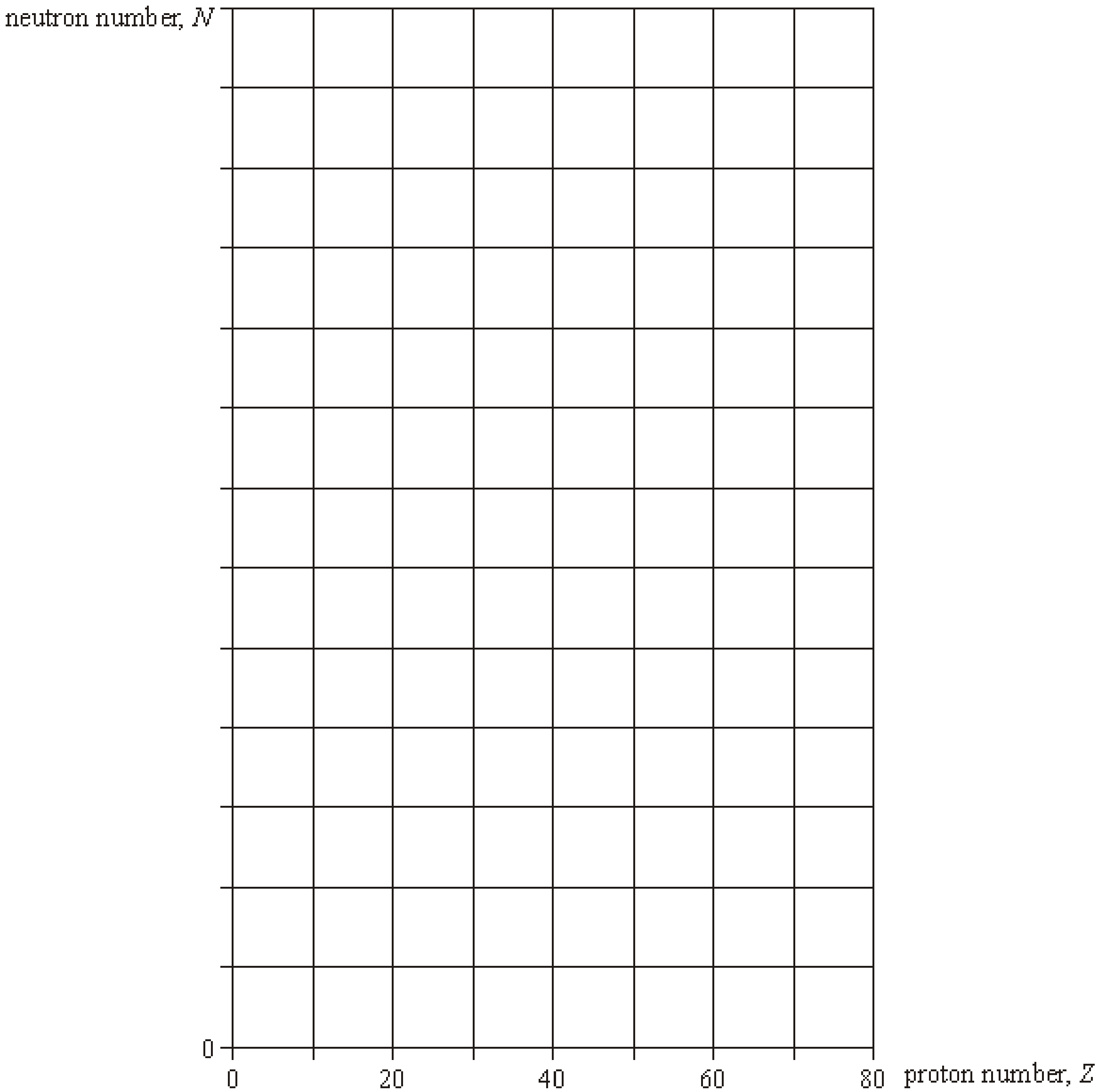
(b) Geothermal energy originates as energy released in the radioactive decay of the uranium isotope $^{238}_{92}U$ deep inside the Earth. Each nucleus that decays releases 4.2 MeV. Calculate the mass of $^{238}_{92}U$ that would release energy at a rate of 500 MW.

half-life of $^{238}_{92}U$ = 4.5×10^9 years

molar mass of $^{238}_{92}U$ = 0.238 kg mol^{-1}

(5)
(Total 12 marks)

29 (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.

(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.

(3)

(Total 10 marks)

30 (a) Suggest **two** reasons why an α particle causes more ionisation than a β particle of the same initial kinetic energy.

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

(2)

(b) A radioactive source has an activity of 3.2×10^9 Bq and emits α particles, each with kinetic energy of 5.2 Me V. The source is enclosed in a small aluminium container of mass 2.0×10^{-4} kg which absorbs the radiation completely.

(i) Calculate the energy, in J, absorbed from the source each second by the aluminium container.

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(ii) Estimate the temperature rise of the aluminium container in **1 minute**, assuming no energy is lost from the aluminium.

specific heat capacity of aluminium = 900 J kg^{-1} K^{-1}

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(5)

(Total 7 marks)

1 (a) (i) momentum (= E/c)

$= 5.94 \times 10^{-11} / 3.00 \times 10^{8} = 2.0 \times 10^{-19}$ (kg m s^{-1})

(= 1.98×10^{-19} kg m s^{-1})

Or evidence of use of $E = hc / \lambda$ ✓

$\lambda = (h / mv = 6.63 \times 10^{-34} / 1.98 \times 10^{-19}) = 3.35 \times 10^{-15}$ (m) ✓

(allowable range 3.32×10^{-15} - 3.37×10^{-15} m)

3.348×10^{-15} m alone may score 1 mark

A completed calculation to at least 3 sf must be seen for 2nd mark

2

(ii) nuclear radius = $0.61\,\lambda / \sin\theta = 0.61 \times 3.35 \times 10^{-15} / \sin 42°$

$= 3.1 \times 10^{-15}$ (m) ✓ (allow 2.95 – 3.1×10^{-15} m which is a range incorporating 3.32×10^{-15} - 3.37×10^{-15} m and 42° – 43°)

(The answer must be to 2 sf or better

note 3.3×10^{-15} , 42° gives 3.008×10^{-15} m i.e. 3.0×10^{-15})

1

(b) (i) diagram to show a labelled α source, foil target and detector (which is not simply a forward facing screen so there must be some indication it can move around the target e.g. a curved arrow / positioned at an angle / or screen curved round target or detectors shown in at least two positions) ✓

with evacuated vessel or an item to collimate the beam ✓ (the evacuated vessel does not have to be drawn so a simple label of 'in a vacuum' will gain the mark.) (A tube or a plate(s) must be drawn with a collimator label or a label on an emergent alpha beam from the drawn item (which is distinct from the source) will gain a mark)

'detector' has alternatives e.g. fluorescent screen / scintillator / zinc sulphide

2

(ii) The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).

Descriptor

High Level – Good to Excellent

Both observations should be given ie most α particles pass straight through the foil and that some α's are backscattered. Again both of these must be explained. Additionally one approach to finding the upper limit to the radius must be given and interpreted.

The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.

6 marks = all 3 bullet points covered in full.

5 marks = Same as 6 marks but one explanation is omitted or poorly expressed

5 - 6

Intermediate Level – Modest to Adequate
Both observations should be given ie most α particles pass straight through the foil and that some α's are backscattered. Both of these observations can be explained or one of them explained along with the observation necessary to obtain the upper limit to the nuclear radius but without the explanation of how to use the data.
The grammar and spelling may have a few shortcomings but the ideas must be clear.

4 marks = for first two bullet points covered in full.

Alternatively both observations given but only one explained along with an observation necessary to find the upper limit to the nuclear radius.

3 marks = for both observations given but only one explained

3 - 4

Low Level – Poor to Limited
Any two observations or interpretations but an interpretation must come with the appropriate observation.
There may be many grammatical and spelling errors and the information may be poorly organised.

2 marks for two observations or one observation along with its interpretation.

1 mark = Any observation..

1 - 2

The description expected in a competent answer should include:

1. most α particles pass straight through
2. which suggests an atom is composed of mainly open space
3. α particles can be backscattered or scattered by more than 90°
4. which suggests

i. they have collided with something more massive than themselves (using momentum considerations)

ii. they have been repelled by a concentrated positive charge (using coulomb repulsion)

these together suggest a 'solar system' configuration for the atom.

5. Consider the proportion of α's passing straight through the foil, i.e. how much of the straight through beam is stopped by the foil.

Or

Appreciate that scattering of α's close to 180° takes place which means the α's have not touched the nuclear surface.

6. First alternative data can be related to how much of the beam is intercepted by nuclei. Using the number of atomic layers / thickness of foil and the nuclear cross-sectional area the upper limit to the radius may be found

Or If second alternative is used some detail is needed to gain this point.
Either a discussion of the loss KE = gain PE to find upper limit to the radius
Or the idea that backscattering is not observed / falls off if the alpha comes close to the nucleus because the strong nuclear force (SNF) takes over and so provides an upper limit to the radius.
(owtte)

Do not award 'large space between atoms'.

The question is a QWC and not all the points are expected to be given as detailed on the left. This check list gives a brief idea of the main parts expected.

(note the pairing of 1 and 2, 3 and 4, 5 and 6 where the second of each pair cannot be given in isolation but the first of each pair does not have to perfect)

If it is obvious the candidate is talking about an alpha particle but calls it something different do not over penalise. E.g. miss out a pairing of marks then mark as if alpha)

Quick check list.

1. Most alpha's go straight on

2. Because an atom has mainly empty space

3. A few alpha's are backscattered

4. Because of nuclear positive charge or large nuclear mass

5. Method suggested to find R (drop in straight on beam Or backscattering means α's have not touched nucleus)

6. Some detail such as ref. to (nuclear) area <u>and</u> (foil) thickness Or alpha KE to PE giving r Or if α's touch surface SNF stops scattering.

[11]

2 (a) nuclear fallout / testing / weapons / nuclear accidents / Chernobyl / nuclear waste / nuclear medicine / X-rays / specific uses of radioactive sources eg medical tracers CT scan etc. / cosmic rays as a result of air travel ✓

(Any source of radiation that an individual may encounter which would not have existed 100 years ago)

No mark for general answers such as 'medical' or Nuclear Power / nuclear plant.

If a list is given all must be correct but ignore generalisations such as medical or nuclear power.

1

(b) (i) I_{15CCR} = 2050 – 40 = 2010 ✓

Use of inverse square law eg $I_{CCR90} = I_{CCR15}\left(\frac{d_{15}}{d_{90}}\right)^2$ √ = 2010 × (0.15 / 0.90)^2 = 55.8

I_{90CR} = 55.8 + 40

I_{90CR} = 96 counts min^{-1} ✓

regardless of order:

1st mark subtraction of background in original data

2nd mark is for using inverse square function

3rd mark is for the answer

3

(ii) (reduce impact of) random error / decrease the (percentage) uncertainty / improve the statistics (because the percentage error is proportional to the inverse square-root of the count) ✓ (owtte)

The answer must be an uncertainty related statement and not increases reliability / accuracy or increased chance of a reading (although these ideas can accompany a correct answer) Ignore comparisons with the background count.

1

(iii) use (sensible) absorber between source and detector ✓ (sensible absorber means it must have a noticeable effect e.g. 1mm of metal / aluminium sheet / 5mm perspex but do not allow metal foil / paper sheets. Also its effect must not be so great that it reduces the gamma rays noticeably)

(These two marks are independent)
β shown by count rate falling when sheet of aluminium absorber is used ✓ Or (using the existing apparatus)
Compare the results (at various distances) in air with the expected inverse square law ✓
Below the range of beta law does not work but above range it does. ✓

2nd mark no mark given if count rate falls to zero as γ is still present

(magnetic deflection is not common but if seen.

Use of magnetic deflection ✓ correct deflection of beta from the beam ✓)

(If a cloud chamber is suggested. Observe the tracks in a cloud chamber ✓ beta tracks have varying lengths or they are curly / not straight ✓

(The value of the range of beta is not a marking point so accept 15 – 80 cm if a number is given)

2

[7]

3 (a) (i) Fission occurs at *A* values above the peak / above *A* of about 56 <u>and</u> fusion occurs at *A* values below the peak / below *A* of about 56 ✓

Fission is the splitting of a nucleus (into two smaller ones) *and* fusion is the joining of two nuclei ✓

First mark uses the graph so 'fission occurs in very large nuclei' does not gain a mark. (allow other interpretations that use the graph eg gradients)

2nd Mark splitting into 2 is not required for fission but if the answer implies something different like the separating of all the nucleons the mark may not be given.

2

(ii) Energy is released when the binding energy (per nucleon) is increased ✓
fusion energy is greater as the increase in BE(/A) for fusion > increase in BE(/A) for fission (owtte) ✓

The last point can be given for a reference to the larger gradient at small values of A (fusion region) compared to the gradient at large values of A (fission region)

2

(b) (i) $\Delta m = (8m_p + 8m_n) - M_{oxygen}$
mark for substituting data into the above equation in any workable consistent units

= 8(1.00867+1.00728) − 15.991 ✓

(Δm = 0.1366 u

$\Delta m = 0.1366 \times 1.661 \times 10^{-27}$) = 2.3×10^{-28} (kg) ✓

(range of answers 2.2 - 2.3 × 10^{-28} kg)

Substitution may take the following form

$8(1.673 \times 10^{-27})+8(1.675 \times 10^{-27})-(15.991 \times 1.661 \times 10^{-27})$ ✓

= 2.23×10^{-28} (kg) ✓

Correct answer gains full marks.

Look out for a physics error in which u is not taken as 1.661×10^{-27} kg

2

(ii) $E = m \times c^2 = 2.3 \times 10^{-28} \times (3.00 \times 10^8)^2 = 2.07 \times 10^{-11}$ J
BE = $2.07 \times 10^{-11} / 1.6 \times 10^{-13}$ = 130 (MeV) ✓ (129 MeV)
Or using
using Δm = 0.1366 u (this must appear in b(i) for this approach)
BE = 0.1366 × 931.3 = 130 (MeV) ✓ (127 MeV)

CE is allowed but only if the calculation is shown

Note answer = b(i) × 5.625×10^{29}

answer only is acceptable for one mark.

(factor may be 931 or 931.5)

1

(iii) read from the graph the BE/A for ${}^{16}_{8}O$ and multiply by the number of nucleons (or 16) ✓
Or show the calculation
BE = 8(Mev) × 16(nucleons) = 130 (MeV) ✓ (128 MeV)✓

There must be a reference to ${}^{16}_{8}O$ position on the graph.

with the calculation allow BE = 8.1(Mev) × 16(nucleons) = 130 (MeV)

A calculation may lead to an answer in joule

1

[8]

4 (a) $(3.0 \times 10^{-10}/24) \times 6.02 \times 10^{23}$ seen✓

(7.52×10^{10})

1

(b) Decay constant = (0.69 / 14.8 h^{-1}) or 1.3×10^{-5} s^{-1} ✓

$A = 1.30 \times 10^{-5} \times 7.5 \times 10^{10}$ ✓

9.75×10^5 Bq ✓

Allow 2 or 3 sf

Allow use of $A = \lambda N$ with an incorrectly calculated decay constant

3

(c) Activity 3.5 h later should be $A = 9.8 \times 10^5 e^{-0.0466 \times 3.5}$ ✓

8.33×10^5 Bq ✓

Volume of liquid = $(8.33 \times 10^5 / 3600) \times 15 = 3470$ cm^3 ✓

3

(d) Estimate gives 3700 compared with 3500✓

Flask has more mass than average / liquid is not water✓

2

[9]

5 (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 inverse 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 ingested / taken into the body / breathed in ✓

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]

6 (a) (i) electromagnetic / electrostatic / Coulomb (repulsion between the alpha particles and the nuclei) ✓

The interaction must be named not just described.

1

(ii) the scattering distribution remains the same (because the alpha particles interact with a nucleus) whose charge / proton number / atomic number remains the same or the (repulsive) force remains the same

The mark requires a described distribution and the reason for it.

Or
the scattering distribution changes / becomes less distinct because there is a mixture of nuclear masses (which gives a mixture of nuclear recoils) ✓
(owtte)

A reference must be made to mass and not density or size.

1

(b) (i) use of graph to find r_0
e.g. $r_0 = 6.0 \times 10^{-15} / 75^{1/3}$ ✓
(or $8.0 \times 10^{-15} / 175^{1/3}$)
($r_0 = 1.43 \times 10^{-15}$ m)

Substitution and calculation t must be shown.

Condone a gradient calculation on R against $A^{1/3}$ graph (not graph in question) as $R \propto A^{1/3}$

1

(ii) **Escalate if clip shows $^{27}_{13}$Al in the question giving R ≈ 4 × 10^{-15} m.**

(using $R = r_0 A^{1/3}$)
$R = 1.43 \times 10^{-15} \times 51^{1/3}$ ✓
$R = 5.3 \times 10^{-15}$ (m) ✓
($R = 5.2 \times 10^{-15}$ m from
$r_0 = 1.4 \times 10^{-15}$ m)

First mark for working.

Second mark for evaluation which must be 2 or more sig figs allow CE from (i) R = 3.71 × (i).

Possible escalation.

2

(c) **Escalate if clip shows $^{27}_{13}$ in the question and / or the use of 27 in the working.**

density = mass / volume
$m = 51 \times 1.67 \times 10^{-27}$
(= 8.5×10^{-26} kg)

Give the first mark for substitution of data into the top line or bottom line of the calculation of density.

$v = 4/3\pi\ (5.3 \times 10^{-15})^3$
($6.2(4) \times 10^{-43}$ m^3)

In the second alternative the mark for the substitution is only given if the working equation is given as well.

Or
density = $A \times u / 4/3\pi\ (r_0\ A^{1/3})^3$
= $u / 4/3\pi\ (r_0\ )^3$

$51 \times 1.67 \times 10^{-27}$ would gain a mark on its own but 1.66×10^{-27} would need $u / 4/3\ \pi(r_0)^3$ as well to gain the mark.

top line = 1.66×10^{-27}

bottom line = $4/3\pi\ (1.43 \times 10^{-15})^3$

✓ for one substitution

density = 1.4×10^{17} ✓
(1.37×10^{17})
kg m^{-3} ✓

Expect a large spread of possible answers. For example If $R = 5 \times 10^{-15}$ $V = 5.24 \times 10^{-43}$ and density = 1.63×10^{17}.

Possible escalation.

3

[8]

7

(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]

8 (a) ANY 2 from

- Slow moving neutrons or low (kinetic) energy neutrons

B1

- (They are in) thermal equilibrium with the moderator / Are in thermal equilibrium with other material (at a temperature of about 300 K)

B1

- Have energies of order of 0.025 eV
- Have (range of) KE similar to that of a gas at 300 K or room temperature

2

(b) (i) Use of $mgh = ½\ mv^2$ by substitution or rearranges to make h the subject

PE for use of equation of motion (constant acceleration)

C1

0.086(1) (m) or 0.086(2) (m)

A1

2

(ii) Correct equation for conservation of momentum

$m_1u_1\ (+\ m_2u_2) = m_1v_1 + m_2v_2$

or states momentum before = momentum after **or** $p_{before} = p_{after}$

B1

(Correct clear Manipulation =) 0.065 (+ 0) = − 0.0325 + 0.0975

or −0.065 (+ 0) = 0.0325 − 0.0975 must see signs

Condone non−SI here:
65 (+0) = − 32.5 + 97.5

B1

States initial kinetic energy = final kinetic energy **or**
States kinetic energy is conserved

Allow equivalent on RHS where masses are summed in one KE term

B1

(Correct clear Manipulation=) 0.04225 = 0.0105625 + 0.0316875

Or equivalent workings with numbers seen

and 0.04225 = 0.04225 / KE before = KE after

B1

4

(iii) (Percentage / fraction remaining after 1 collision =) ¼ = 25% **seen**

C1

OR

% remaining = 100 × ½ $m(1.3^2 − 0.65^2)$/ ½ $m1.3^2$
or hockey ball = 0.0317 **and** initial ke = 0.04225
or their KE $_{hb}$ / 0.04225 or their KE_{hb} / their KE_T

75(%) range 75 to 76

A1

2

(iv) **Demonstrates:**
Slowing down / loss of KE of golf ball is like neutrons slowed down / Neutrons can lose KE by elastic collisions also

B1

Differs:
Collisions in a reactor are not always / rarely head-on
or
KE loss is variable
or
Collisions are not <u>always</u> elastic
or
Ratio of mass of neutron to mass of nucleus is usually much smaller in a reactor

B1

2

(v) Water

B1

1

[13]

9 (a) (i) (Mass change in u=) 1.71×10^{-3} (u)
or (mass Be−7) – (mass He−3) – (mass He−4) seen with numbers

C1

2.84×10^{-30} (kg)
or Converts their mass to kg

Alternative 2nd mark:
Allow conversion of 1.71×10^{-3} (u) to MeV by multiplying by 931 (=1.59 (MeV)) ***seen***

C1

Substitution in $E = mc^2$ *condone their mass* <u>*difference*</u> *in this sub but must have correct value for c^2 $(3\times10^8)^2$ or 9×10^{16}*

Alternative 3rd mark:
Allow their MeV converted to joules ($\times$ 1.6×10^{-13}) ***seen***

C1

2.55×10^{-13} (J) to 2.6×10^{-13} (J)

Alternative 4th mark:
Allow 2.5×10^{-13} (J) for this method

A1

4

(ii) Use of $E=hc/\lambda$ ***ecf***

C1

Correct substitution in rearranged equation with λ *subject* ***ecf***

C1

7.65×10^{-13} (m) to 7.8×10^{-13} (m) ecf

A1

3

(b) (i) Use of E_p formula:

C1

Correct charges for the nuclei <u>**and**</u> correct powers of 10

C1

$2.6(3)\times 10^{-13}$ J

A1

3

(ii) Uses $KE = 3 / 2\ kT$: ***or*** *halves* KE_T, $KE = 1.3 \times 10^{-13}$ *(J)* ***seen ecf***

C1

Correct substitution of data **and** makes T subject **ecf**
Or uses KE_T value **and** divides T by 2

C1

6.35×10^9 (K) or 6.4×10^9 (K) or 6.28×10^9(K) or 6.3×10^9 (K) **ecf**

A1

3

(c) (i) Deuteron / deuterium / hydrogen−2

B1

Triton / tritium / hydrogen−3

B1

2

(ii) Electrical heating / electrical discharge / inducing a current in plasma / use of e−m radiation / using radio waves (causing charged particles to resonate)

B1

1

[16]

10 (a) the amount of energy required to separate a nucleus ✓
into its separate neutrons and protons / nucleons ✓
(or energy released on formation of a nucleus ✓
from its separate neutrons and protons / constituents ✓)

1st mark is for correct energy flow direction

2nd mark is for binding or separating nucleons (nucleus is in the question but a reference to an atom will lose the mark)

ignore discussion of SNF etc

both marks are independent

2

(b) (i) $2\,{}^{1}_{0}\text{n}$ or ${}^{1}_{0}\text{n} + {}^{1}_{0}\text{n}$ ✓

must see subscript and superscripts

1

(ii) binding energy of U

= 235 × 7.59 ✓ (= 1784 (MeV))

binding energy of Tc and In

= 112 × 8.36 + 122 × 8.51 ✓

(= 1975 (MeV))

energy released (= 1975 – 1784) = 191 (MeV) ✓ (allow 190 MeV)

1st mark is for 235 × 7.59 seen anywhere

2nd mark for 112 × 8.36 + 122 × 8.51 or 1975 is only given if there are no other terms or conversions added to the equation (ignore which way round the subtraction is positioned)

correct final answer can score 3 marks

3

(iii) energy released

= 191 × 1.60 × 10^{-13} ✓

(= 3.06 × 10^{-11} J)

loss of mass (= E / c^2)

= 2.91 × 10^{-11} / (3.00 × $10^8)^2$)

= 3.4 × 10^{-28} (kg) ✓

or

= 191 / 931.5 u ✓ (= 0.205 u)

= 0.205 × 1.66 × 10^{-27} (kg)

= 3.4 × 10^{-28} (kg) ✓

allow CE from (ii)

working must be shown for a CE otherwise full marks can be given for correct answer only

note for CE

answer = (ii) × 1.78 × 10^{-30}

(2.01 × 10^{-27} is a common answer)

2

(c) (i) line or band from origin, starting at 45° up to Z approximately = 20 reading Z = 80, N = 110→130 ✓

initial gradient should be about 1 (ie Z = 20 ; N = 15 → 25) and overall must show some concave curvature. (Ignore slight waviness in the line)

if band is shown take middle as the line

if line stops at N > 70 extrapolate line to N = 80 for marking

1

(ii) fission fragments are (likely) to be above / to the left of the line of stability ✓

fission fragments are (likely) to have a larger N / Z ratio than stable nuclei

or

fission fragments are neutron rich owtte ✓

and become neutron or β^- emitters ✓

ignore any reference to α emission
a candidate must make a choice for the first two marks
stating that there are more neutrons than protons is not enough for a mark

1st mark reference to graph

2nd mark – high N / Z ratio or neutron rich

3rd mark beta minus
note not just beta

3

[12]

11 (a) (i) λ (= ln 2 / $T_{1/2}$ = 0.693 / 5740) = 1.2 × 10^{-4} (yr^{-1}) ✓

(1.21 × 10^{-4} yr^{-1})

only allow 3.83 × 10^{-12} s^{-1} if the unit has been changed
working is not necessary for mark

1

(ii) (use of $N_t = N_o e^{-\lambda t}$ and activity is proportional to N

$A_t = A_o e^{-\lambda t}$)

0.375 = exp - (1.21 × 10^{-4} × t) ✓

$t = \frac{\ln\left(\frac{1}{0.375}\right)}{1.21\times10^{-4}}$ ✓

t = 8100 or 8200(yr) ✓

1st mark substitution, allow EC from (i)

2nd mark rearranging, allow EC from (i)

Allow t / $T_{1/2}$ = 2^n approach

3rd mark no EC (so it is not necessary to evaluate a CE)
so max 2 for a CE
full marks can be given for final answer alone. A minus in the final answer will lose the last mark

3

(b) (i) (it is difficult to measure accurately)
the small drop / change in activity / count-rate
the small change / drop in the ratio of C-14 to C-12 ✓

the activity would be very small / comparable to the background
or the ratio of C-14 to C-12 is too small
or there are too few C-14 atoms
or there is very little decay
or the level of C-14 (in the biosphere) is uncertain (this long ago) ✓

1st mark needs some reference to a change in count-rate or activity for the mark

be lenient in 2nd mark

in reading a script assume C-14 is the subject. Eg 'there is little activity to work with' scores mark. Also allow any reasonable suggestion. Eg carbon may have been removed by bonding to surrounding material

Don't allow, 'All the carbon has decayed'

2

[6]

12

(a) (i) 1/12 the mass of an (atom) of $^{12}_{6}C$ / carbon−12 / C12 ✓

a reference to a nucleus loses the mark

1

(ii) separated nucleons have a greater mass ✓ (than when inside a nucleus)

an answer starting with 'its' implies the nucleus

because of the (binding) energy added to separate the nucleons or energy is released when a nucleus is formed (owtte) ✓

marks are independent

direction of energy flow or work done must be explicit

2

(b) nuclei need to be close together (owtte) for the Strong Nuclear Force to be involved or for fusion to take place ✓

e.g. first mark – within the range of the SNF

but the electrostatic / electromagnetic force is repulsive (and tries to prevent this) ✓

(if the temperature is high then) the nuclei have (high) kinetic energy / speed (to overcome the repulsion) ✓

3rd mark is for a simple link between temperature and speed / KE

3

(c) (i) 15 ✓

give the middle mark easily for any e or β with a + in any position

e^+ ✓ (or β^+, $^{0}_{1}\beta$, $^{0}_{1}e$)

12 ✓

3

(ii) Δmass = 4 × 1.00728 − 4.00150 − (2 × 9.11 × 10^{-31} / 1.661 × 10^{-27})
or
Δmass = {4 × 1.00728 − 4.00150 − 2 × 0.00055}(u) ✓

(4×1.00728=4.02912)

1st mark – correct subtractions in any consistent unit. use of m_p = 1.67 × 10^{-27} kg will gain this mark but will not gain the 2nd as it will not produce an accurate enough result

Δmass = 0.02652(u) ✓

2nd mark - for calculated value

0.02652u

4.405 × 10^{-29} kg

3.364 × 10^{-12} J

Δbinding energy (= 0.02652 × 931.5) {allow 931.3}

Δbinding energy = 24.7 MeV ✓

3rd mark – conversion to Mev

conversion mark stands alone

award 3 marks for answer provided some working shown - no working gets 2 marks

(2sf expected)

3

[12]

13 (a) insert control rods (further) into the nuclear core / reactor ✓

a change must be implied for 2 marks
marks by use of (further) or (more)

allow answers that discuss shut down as well as power reduction

which will absorb (more) neutrons (reducing further fission reactions) ✓

If a statement is made that is wrong but not asked for limit the score to 1 mark (e.g. wrong reference to moderator)

2

(b) fission fragments / daughter products or <u>spent / used</u> fuel / uranium rods (allow) plutonium (produced from U-238) ✓

not uranium on its own

1

(c) (i) γ (electromagnetic radiation is emitted) ✓

A reference to α or β loses this first mark

as the energy gaps are large (in a nucleus) as the nucleus de-excites down discrete energy levels to allow the nucleus to get to the ground level / state ✓
mark for reason

2nd mark must imply energy levels or states

2

(ii) momentum / kinetic energy is transferred (to the moderator atoms)
or
a neutron slows down / loses kinetic energy (with each collision) ✓

(eventually) reaching speeds associated with thermal random motion or reaches speeds which can cause fission (owtte) ✓

2

[7]

14 (a) Draws appropriate triangle on graph or other mark on graph at ~ 118

B1

Change of approx 1 Me V per nucleon is multiplied by 235

B1

Multiplies by 1.6×10^{-13}

B1

Quotes their answer of approx 3.8×10^{-11} to more than 2 sf

B1

4

(b) (2 × 2.0135) – 4.0026 seen or 0.0244 (u)

C1

Multiplies u by 1.7×10^{-27}

C1

$E = mc^2$ seen or multiplies by $(3 \times 10^8)^2$

C1

3.67×10^{-12}J

A1

4

(c) Multiplies 3.8×10^{-11} or their (b) by 6×10^{23}

M1

attempts to convert to energy per kg by multiplying by 1000 / 4 or 1000 / 235

M1

Compares 5.5×10^{14} (J) (Hydrogen) with 9.6×10^{13} (J) (Uranium) in some way eg by stating that the fusion reaction gives more energy (per kg) than the fission or very similar values – must be consequent on some correct analysis

A1

3

(d) Availability of fuel easier for fusion

B1

Doesn't produce radioactive fission products / no waste management problem

B1

2

[13]

15

(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) $7.88 \times 206 = 1620$ 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 $N = N_0 e^{-\lambda t}$)

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

$t = \ln 1.5 / \lambda$

(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]

16 (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)

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

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)

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

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

3

[9]

17 (a) (i) Attempt to use KE = 3/2 kT expect $0.75 = 3/2 \times 1.38 \times 10^{-23}\ T$

C1

Or correct conversion to J $0.75 \times 1.6 \times 10^{-19}$

Correct equations $0.75 \times 1.6 \times 10^{-19} = 3/2\ 1.38 \times 10^{-23}\ T$

C1

5800 K

A1

3

(ii) Attempt to use energy = $qQ/4\pi\varepsilon_o r$

C1

arrives at 1.9(2) $\times 10^{-9}$ or uses (2 × 0.75) or twice candidate's energy from (i)

C1

9.6×10^{-10} m

A1

3

(iii) For fusion nuclei have to touch or separation has to be nuclear diameter

energy has to be sufficient to overcome the nuclear repulsion (between protons)

B1

Close enough for nuclear strong force to act

B1

answer to 4 a (ii) is much greater that 10^{-15} m

B1

or is greater that atomic radius

or is greater than the range of the strong force

3

(b) (i) Use of *pV=NkT*

C1

(Allow incorrect powers of 10 or rearrangement to make *N* subject)

$1\times10^{16}\times1=N\times1.38\times10^{-23}\times1.5\times10^{6}$

C1

$4.8\ (3)\times10^{32}$

A1

3

(ii) 1.67×10^{-27} or 1.7×10^{-27} used

C1

$8.0 - 8.2\times10^{5}$ (kg m^{-3}) Allow ecf for *N* from (b)(i)

A1

2

(c) (i) Number of protons = moles of proton/mass of protons / Mass per second × Avogadro constant used

B1

Or

No of protons = mass per second/proton mass

(allow if numerical equation seen with a subject)

4.18 or 4.19 or 4.21 × 10^{38} correct to at least 2 sf from correct working

B1

2

(ii) Attempt to use $E = mc^2$ with any mass and substitution for c

C1

Energy radiated = 5 × 10^9 × c^2 energy radiated 4.5 × 10^{26} J

A1

Number of helium nuclei formed = 1.05×10^{38} (allow 1 × 10^{39})

B1

Approximate BE per nucleon from article = 4.28(4.5) × 10^{-12} J

B1

(Which is consistent)

4

[20]

18 (a) (i) energy released when the separate nucleons combine to form the nucleus

or energy needed to separate the nucleus into individual nucleons owtte

B1

1

(ii) BE in J = 8 × 1.1314027 × 10^{-12} (9.05122 × 10^{-12})

C1

BE in eV = 5.6570135 × 10^{7} eV or BE/nucleon
= 7.07 × 10^{6} MeV

C1

56.570135 (MeV) (condone 3 sf consistent with electron charge)

A1

3

(b) (i) change in BE = 0.0147120 (× 10^{-12}) J

C1

use of $E = mc^2$ with their energy 1.635 × 10^{-31} kg

A1

2

(ii) use of charge on alpha particles = 2 e

C1

attempt to substitute in PE = $\frac{qQ}{4\pi\varepsilon_0 r}$

C1

2.4(2.39) × 10^{-13} J

A1

3

(ii) the mass of Be > mass of 2 He nuclei

B1

explains that when they touch there is zero KE
only mass available is that of the two alpha particles

B1

extra KE provides the increase in mass of the beryllium-8
compared with the 2 He nuclei

B1

3

[12]

19 (a) (i) neutron

B1

1

(ii) p = 36

B1

n = 144

B1

2

(b) (i) total energy produced = $\frac{500 \times 100}{40}$ MJ each second

C1

number of reaction = 4.2×10^{19} per second

A1

2

(ii) 1 kg contains (1000/235) × 6.02 × 10^{23} atoms of uranium

C1

total number of fissions = (1000/235) × 6.02 × 10^{23} × 2 × 10^4
(5.1 × 10^{28})

C1

time = total fissions available/number per second or 1.2 × 10^9s

C1

38.7(39) years

A1

4

(iii) too few neutrons produced to maintain the chain reaction

B1

probability of a neutron colliding with a uranium nucleus too low

B1

more absorption of neutrons in non–fission capture

B1

2

(c) pressure = 150 × 10^5 (Pa) or $F = PA$

C1

force on 1 cm^2 = 1500N

A1

2

(d) energy removed each second

$E = \frac{500 \times 100}{40}$ MJ = 1.25 × 109 J or $E = mc\Delta\theta$

C1

$1.25 \times 10^9 = m\,5000 \times 40$

C1

mass per second = 6250 kg

C1

volume per second = 8.6(8.56) m^3

A1

4

(e) **control rods**

neutrons are absorbed

B1

by the nucleus of the boron/atoms

B1

moderator

neutrons are slowed down

B1

when colliding with the protons/hydrogen nucleus

B1

4

[21]

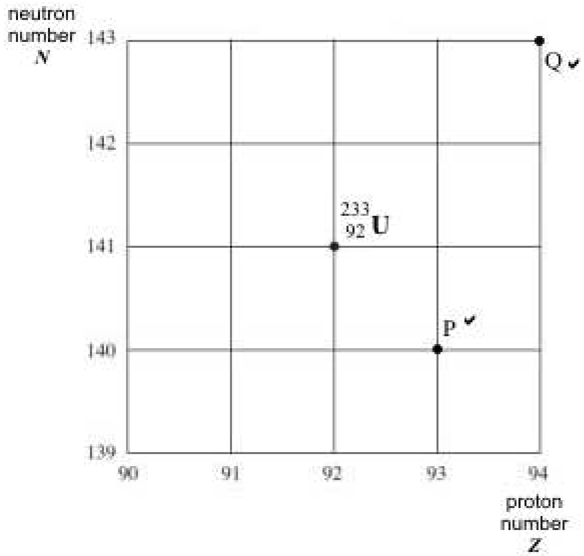
20

(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 ✔

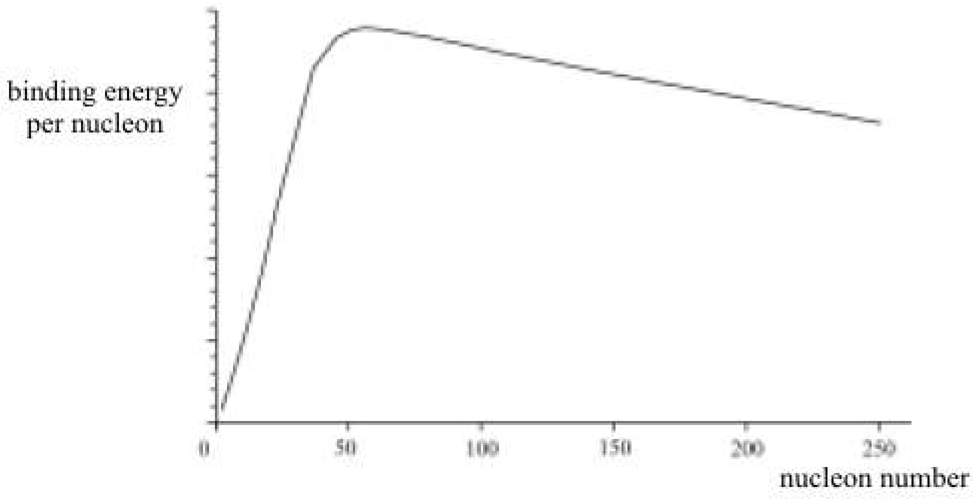
= 0.18136 u ✔

3

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

[8]

21 (a)



peak 8.7 (accept 8.0 – 9.2)

in MeV ✓

(or peak 1.4×10^{-12} accept $1.3 - 1.5 \times 10^{-12}$ 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]

22 (a) plutonium is toxic/large mass of plutonium

B1

harmful if released into atmosphere/explosion occurred

B1

alphas dangerous when ingested/during launch etc

B1

max2

(b) unaffected B1

chemical bonding involves electrons (atomic) radioactivity is nuclear (owtte)/same number of nuclei present B1

2

(c) (i) $T_{½} = \ln 2/\lambda$ C1

2.51×10^{-10} A1

2

(ii) molar mass calculated (0.270 kg) C1

use of 33 kg C1

number of moles in sample (122.2) C1

multiplication of value by Avogadro's number C1

7.36×10^{25} A1

5

(iii) (c) (i) × (c) (ii) C1

1.83×10^{16} cao A1

Bq B1

3

(d) (i) uranium correct (234,92)

B1

alpha correct (4,2) – accept He or α symbol

B1

2

(ii) use of 1 g generating 500 mW

C1

16500 W total

C1

recognition that activity × energy of one alpha = power

C1

9.00×10^{-13} (J)

A1

4

[20]

23 (a) correct numbers for beta+ (0, (+)1) and chromium (52)

B1

(electron) neutrino with correct numbers (0,0)

B1

2

(b) W^+/W/(intermediate vector) boson (not Z boson)

B1

1

[3]

24 (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 $T_{\frac{1}{2}} = \frac{ln2}{\lambda}$

$T_{\frac{1}{2}}$ = 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 µ N use of $A = A_0e^{-\lambda t}$)

0.65 = 1.15 × $e^{-3.84\times10^{-12}t}$ **(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]

25 (a) number correct for alpha **(1)**

number correct for beta **(1)**

alpha decay first goes via Tl **(1)**

numbers correct for Tl (208, 81) **(1)**

beta decay first goes via Po **(1)**

numbers correct for Po (212, 84) **(1)**

6

(b) (i) use of GM tube + counter/rate-meter **(1)**
measurement of count rate **(1)**
at range of distances + suitable ruler or tape measure **(1)**
specifies suitable range **(1)**
determines background & corrects **(1)**
safety precaution given **(1)**
graph of count rate or corrected count rate against $1/d^2$ **(1)**

max 6

(ii) gamma not absorbed **(1)**
spreads uniformly from a point source/spherically symmetrically **(1)**
area over which it spreads is proportional to radius squared **(1)**
alpha and beta are absorbed in addition to spreading out **(1)**

max 3

[15]

26 (a) for one reaction ΔE (= $\Delta m\, c^2$) = $3.1 \times 10^{-28} \times (3.00 \times 10^8)^2$ **(1)**
= (2.79×10^{-11}J)

number of nuclei required = $\frac{1}{2.79 \times 10^{-11}}$ = $3.5(8) \times 10^{10}$ **(1)**

[or equivalent credit for any other valid method]

2

(b) output power from reactor = $\frac{600}{0.35} = 1700$ (MW) **(1)**

(1714 MW)

energy output from fuel rods in one week
= $1.70 \times 10^9 \times 24 \times 7 \times 3600$ **(1)**

(= 1.03×10^{15} J)

$\Delta m \left(= \frac{\Delta E}{c^2}\right) = \frac{1.03 \times 10^{15}}{(3.0 \times 10^8)^2}$ **(1)**

= 1.14×10^{-2} kg **(1)**

[or equivalent credit for any other valid method]

4

[6]

27 (a) $R\ (= r_0A^{1/3}) = 1.3 \times 10^{-5} \times (238)^{1/3}$ **(1)**
= $8.0(6) \times 10^{-15}$m **(1)**

2

(b) (use of inverse square law e.g. $\frac{I_1}{I_2} = \left(\frac{x_1}{x_2}\right)^2$ gives)

$10 = \left(\frac{x_2}{0.03}\right)^2$ **(1)**

x = 0.095 m **(1)**
(0.0949 m)

2

(c) (use of $A = A_0 exp(-\lambda t$ gives) 0.85 = 1.0 exp ($-\lambda$52) **(1)**

$\lambda = \frac{\ln(100/0.85}{52}$ **(1)**

= $3.1(3) \times 10^{-3}s^{-1}$ **(1)**

3

(d) it only emits γ rays **(1)**
relevant properties of γ radiation e.g. may be detected outside the body/weak ioniser and causes little damage **(1)**
it has a short enough half-life and will not remain active in the body after use **(1)**
it has a long enough half-life to remain active during diagnosis **(1)**
the substance has a toxicity that can be tolerated by the body **(1)**
it may be prepared on site **(1)**

any three **(1)(1)(1)**

3

[10]

28 (a) (i) heat water to 100 °C, energy (= 190 × 4200 × 79) = 63 (MJ) **(1)**
vapourise water, energy
(=190 × 2.3 × 10^6) = 440(MJ) **(1)**
(437MJ)

energy transferred (per sec) = (437 + 63) MJ **(1)**
(= 500 MJ)

(ii) mass of rocks (= 4.0 × 10^6 × 3200)

= 1.3 × 10^{10}(kg) **(1)**
(1.28 × 10^{10})

temperature fall of ΔT in one day, energy removed
(= 1.28 ×10^{10} × 850 × ΔT) = 1.1 × 10^{13} ΔT **(1)**
(1.09 x 10^{13} AT)
(allow C.E. for value of mass of rocks)

energy transfer in one day (= 500 × 10^6 × 3600 × 24)
= 4.3 × 10^{13} (J) **(1)**

in one day $\Delta T\left(= \frac{4.3 \times 10^{13}}{1.1 \times 10^{13}}\right) = 3.9(1)$ K **(1)**

7

(b) number of nuclei in 1 kg of ^{238}U $= \left(\frac{6.02 \times 10^{23}}{0.238}\right) = 2.5(3) \times 10^{24}$ **(1)**

activity of lkg of ^{238}U = $\frac{\ln 2}{T_{1/2}} \times 2.53 \times 10^{24}$ **(1)**

$\left(= \frac{\ln 2}{4.5 \times 10^9 \times 3.1 \times 10^7} \times 2.53 \times 10^{24}\right) = 1.2(6) \times 10^7 (s^{-1})$ **(1)**

energy released per sec per kg of ^{238}U

= 1.2(6) × 10^7 × 4.2 × 1.6 × 10^{-13}(J) **(1)**
(8.47 × 10^{-6}(J))

mass of ^{238}Uneeded = $\frac{500 \times 10^6}{8.47 \times 10^{-6}}$ = 5.9(0) × 10^{13}kg **(1)**

5

[12]

29 (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)**

2

(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]

30 (a) reasons:
α particle has much more mass/momentum than β particle
α particle has twice as much charge as a β particle
α particle travels much slower than a β particle any **two** **(1) (1)**

2
QWC 1

(b) (i) energy absorbed per sec (= energy released per sec)
$= 3.2 \times 10^9 \times 5.2 \times 10^6 \times 1.6 \times 10^{-19}$ **(1)**
$= 2.7 \times 10^{-3}$ (J) **(1)** (2.66×10^{-3} (J))

(ii) temperature rise in 1 minute $\left(= \frac{\text{energy absorbed in 1 minute}}{\text{mass} \times \text{specific heat capacity}} \right)$

$= \frac{2.7 \times 10^{-3} \times 60}{0.20 \times 10^{-3} \times 900}$ (for numerator) **(1)** (for denominator) **(1)**

= 0.90 K (or °C) **(1)**

(allow C.E. for incorrect value in (i))

5

[7]