Nuclear applications

Q1.

(a) Suggest, with a reason, which type of radiation is likely to be the most appropriate for the sterilisation of metallic surgical instruments.

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(1)

(b) Explain why the public need not worry that irradiated surgical instruments become radioactive once sterilised.

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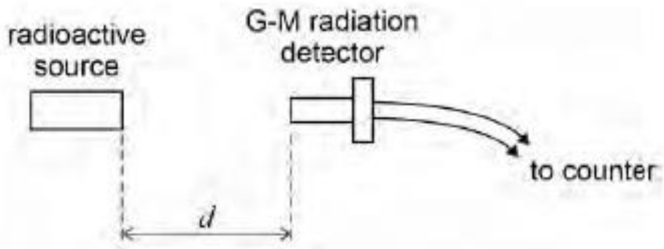
(1)

(c) A student detects the counts from a radioactive source using a G-M radiation detector as shown in the diagram.



The student measures the count rate for three different distances d. The table shows the count rate, in counts per minute, corrected for background for each of these distances.

d/m	Corrected count rate / counts per minute			
0.20	9013			
0.50	1395			
1.00	242			

Explain, with the aid of suitable calculations, why the data in the table are **not** consistent with an inverse-square law. You may use the blank columns for your working.

(2)

(d) State **two** possible reasons why the results do **not** follow the expected inverse-square law.

Reason 1 ____________________

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Reason 2 ____________________

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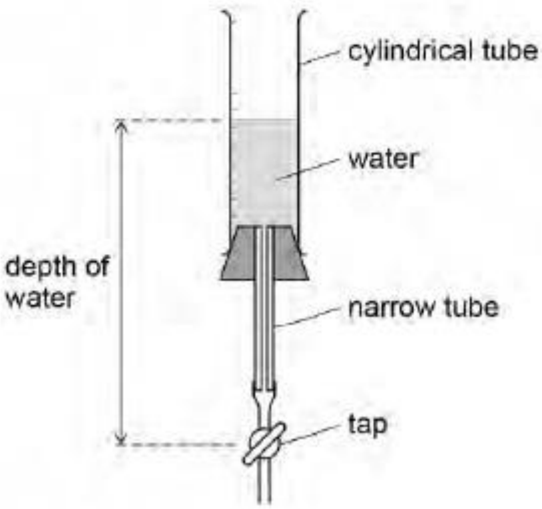
(2)

(Total 6 marks)

Q2.

Figure 1 shows how radioactive decay of one nuclide can be modelled by draining water through a tap from a cylindrical tube.

Figure 1

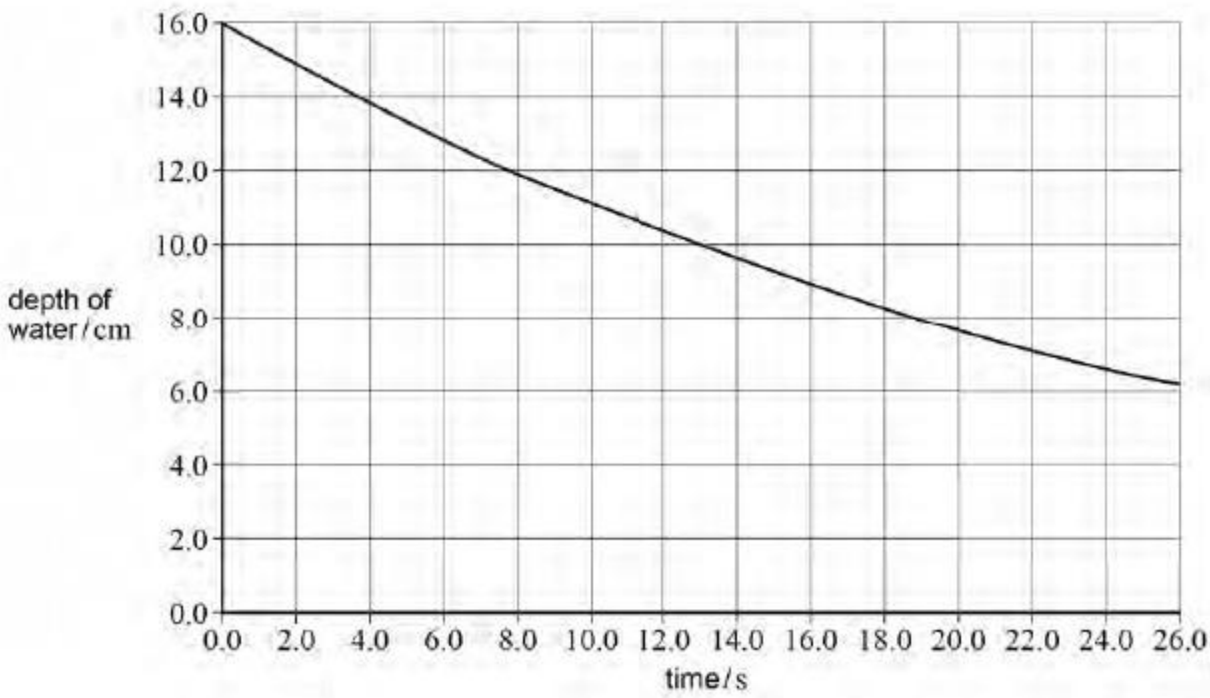


The water flow-rate is proportional to the pressure of the water. The pressure of the water is proportional to the depth of the water. Therefore the rate at which the depth decreases is proportional to the depth of the water.

Before the tap is opened the depth is 16.0 cm

The tap is opened and the depth is measured at regular intervals. These data are plotted on the graph in **Figure 2**.

Figure 2



(a) Determine the predicted depth of water when the time is 57 s

depth = ____________________ cm

(1)

(b) Suggest how the apparatus in **Figure 1** may be changed to represent a radioactive sample of the same nuclide with a greater number of nuclei.

____

____

(1)

(c) Suggest how the apparatus in **Figure 1** may be changed to represent a radioactive sample of a nuclide with a smaller decay constant.

____

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(1)

(d) The age of the Moon has been estimated from rock samples containing rubidium (Rb) and strontium (Sr), brought back from Moon landings.

$^{87}_{37}Rb$ decays to $^{87}_{38}Sr$ with a radioactive decay constant of 1.42×10^{-11} $year^{-1}$

Calculate, in years, the half-life of $^{87}_{37}Rb$

half-life = ____________________ years

(1)

(e) A sample of Moon rock contains 1.23 mg of ${}^{87}_{37}\text{Rb}$.

Calculate the mass, in g, of ${}^{87}_{37}\text{Rb}$ that the rock sample contained when it was formed 4.47×10^9 years ago.

Give your answer to an appropriate number of significant figures.

mass = ____________________ g

(3)

(f) Calculate the activity of a sample of ${}^{87}_{37}\text{Rb}$ of mass 1.23 mg

Give an appropriate unit for your answer.

activity = ____________________ unit ___________

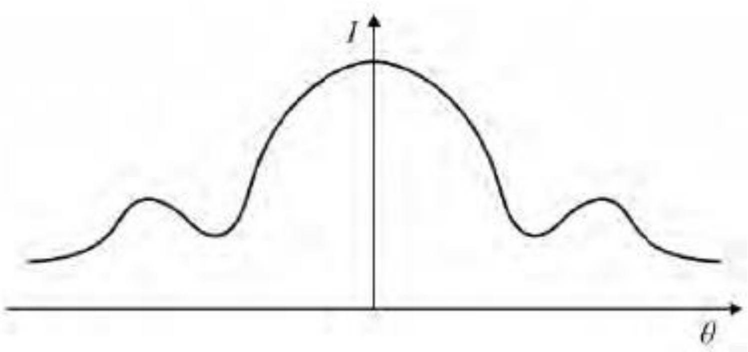
(3)

(Total 10 marks)

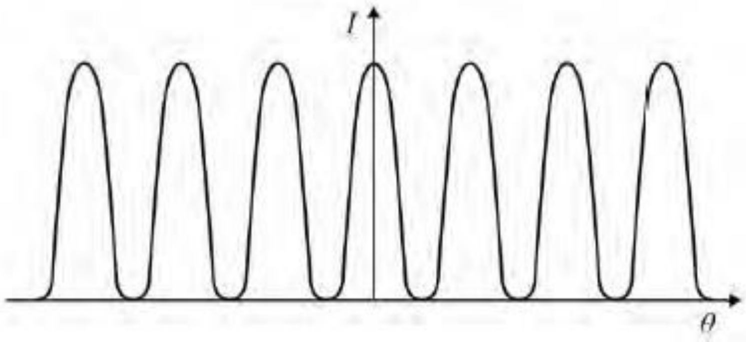
Q3.

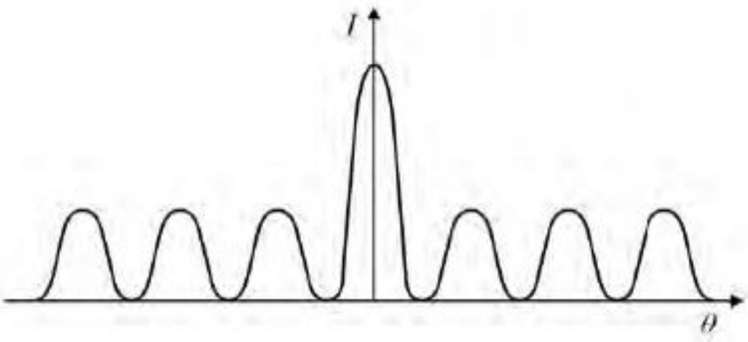
Which graph shows how intensity I varies with angle θ when electrons are diffracted by a nucleus?

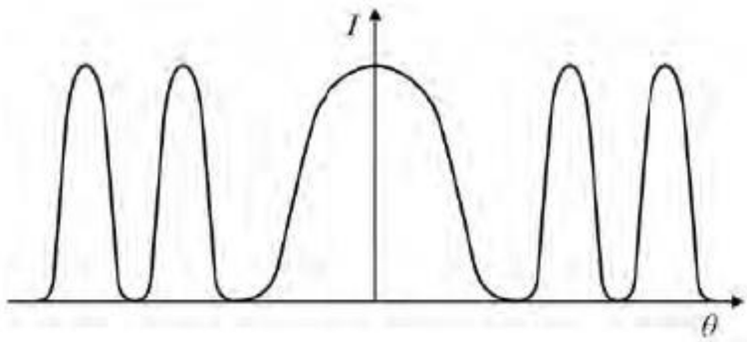
A



☐

B  ⬭

C  ⬭

D  ⬭

(Total 1 mark)

Q4.

The radius of a uranium $^{238}_{92}U$ nucleus is 7.75×10^{-15} m

What is the radius of a $^{12}_{6}C$ nucleus?

A 1.10×10^{-18} m ⬭

B 3.91×10^{-16} m ⬭

C 2.86×10^{-15} m ⬭

D 3.12×10^{-15} m ⬭

(Total 1 mark)

Q5.

The core of a thermal nuclear reactor contains a number of components that are exposed to moving neutrons.

(a) State what happens to a neutron that is incident on the moderator.

(1)

(b) State what happens to a neutron that is incident on a control rod.

(1)

(c) A slow-moving neutron is in collision with a nucleus of an atom of the fuel which causes fission.

Describe what happens in the process.

(3)

(d) A thermal nuclear reactor produces radioactive waste.

State the source of this waste and discuss some of the problems faced in dealing with the waste at various stages of its treatment.

Your answer should include:

- the main source of the most dangerous waste
- a brief outline of how waste is treated
- problems faced in dealing with the waste, with suggestions for overcoming these problems.

(6)

(Total 11 marks)

Q6.

A Geiger counter is placed near a radioactive source and different materials are placed between the source and the Geiger counter.

The results of the tests are shown in the table.

Material	**Count rate of Geiger counter / s^{-1}**
None	1000
Paper	1000
Aluminium foil	250
Thick steel	50

What is the radiation emitted by the source?

A α only

B α and γ

C α and β

D β and γ

(Total 1 mark)

Q7.

Nobelium-259 has a half-life of 3500 s.

What is the decay constant of nobelium-259?

A 8.7×10^{-5} s^{-1} ☐

B 2.0×10^{-4} s^{-1} ☐

C 1.7×10^{-2} s^{-1} ☐

D 1.2×10^{-2} s^{-1} ☐

(Total 1 mark)

Q8.

The radius of a nucleus of the iron nuclide $^{56}_{27}Fe$ is 4.35×10^{-15} m.

What is the radius of a nucleus of the uranium nuclide $^{238}_{92}U$?

A 2.69×10^{-15} m ☐

B 2.89×10^{-15} m ☐

C 6.55×10^{-15} m ☐

D 7.05×10^{-15} m ☐

(Total 1 mark)

Q9.

Uranium-236 undergoes nuclear fission to produce barium-144, krypton-89 and three free neutrons.

What is the energy released in this process?

Nuclide	Binding energy per nucleon / MeV
$^{236}_{92}U$	7.5
$^{144}_{56}Ba$	8.3
$^{89}_{36}Kr$	8.6

A 84 MeV ☐

B 106 MeV ☐

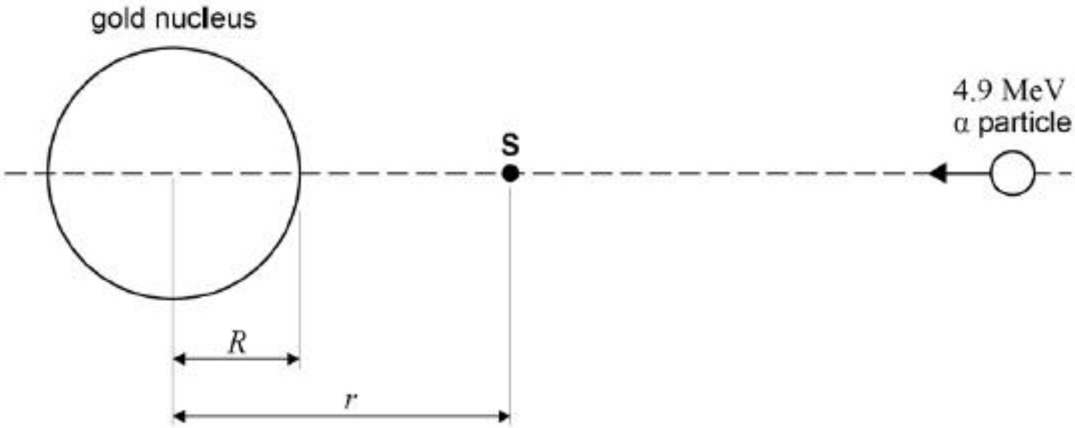
C 191 MeV ☐

D 3730 MeV ☐

(Total 1 mark)

Q10.

An α particle with an initial kinetic energy of 4.9 MeV is directed towards the centre of a gold nucleus of radius R which contains 79 protons. The α particle is brought to rest at point **S**, a distance r from the centre of the nucleus as shown in the diagram below.



(a) Calculate the electric potential energy, in J, of the α particle at point **S**.

electric potential energy = ____________________ J

(2)

(b) Calculate r, the distance of closest approach of the α particle to the nucleus.

r = ____________________ m

(3)

(c) Determine the number of nucleons in the gold nucleus.

R, radius of the gold nucleus = 7.16×10^{-15} m
$R_0 = 1.23 \times 10^{-15}$ m

number of nucleons = ________________

(3)

(d) The target nucleus is changed to one that has fewer protons. The α particle is given the same initial kinetic energy.

Explain, without further calculation, any changes that occur to the distance *r*. Ignore any recoil effects.

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(2)

(Total 10 marks)

Q11.

In the Rutherford scattering experiment most α particles passed through the foil undeflected.

What is a correct deduction from this result?

A	Most of the mass of an atom is within the nucleus.	☐
B	The diameter of the nucleus is much less than the diameter of the atom.	☐
C	The nucleus has a positive charge.	☐
D	The charge of the atom is neutral.	☐

(Total 1 mark)

Q12.

β particles are emitted from a radioactive source in a school laboratory.

What is correct for these particles?

A	A strong magnetic field will not deflect them.	☐
B	They are absorbed by aluminium.	☐
C	They do not damage human tissue.	☐
D	Their range in air is shorter than that of α particles.	☐

(Total 1 mark)

Q13.

A radioactive source contains a nuclide which has a half-life of 12 hours. A detector placed near the source records an average count rate of 180 counts per minute. The average background count rate is 20 counts per minute.

What will be the average count rate after 24 hours?

A 40 counts per minute

B 45 counts per minute

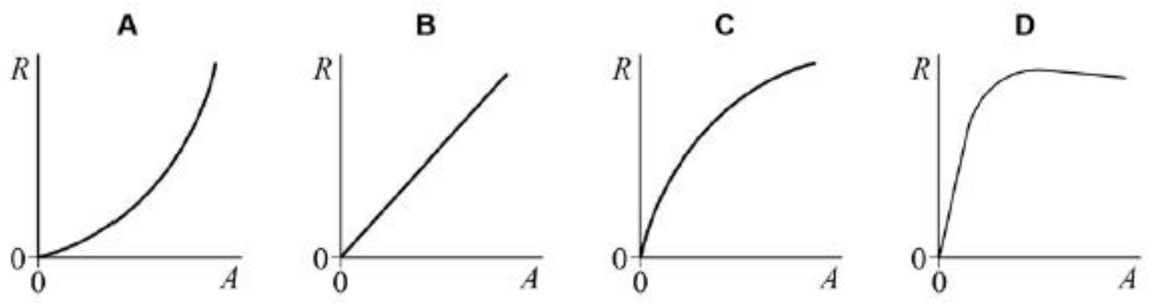
C 50 counts per minute

D 60 counts per minute

(Total 1 mark)

Q14.

Which graph best shows how the radius R of an atomic nucleus varies with the nucleon number A?



A

B

C

D

(Total 1 mark)

Q15.

The power output of a nuclear reactor is provided by nuclear fuel which decreases in mass at a rate of 4.0×10^{-6} kg hour^{-1}.

What is the maximum possible power output of the reactor?

A 28 kW

B 50 MW

C 100 MW

D 200 MW ☐

(Total 1 mark)

Q16.

The moderator of some nuclear reactors is made from graphite.

What is the principal purpose of the graphite?

A	to absorb all the heat produced	☐
B	to decrease the speed of neutrons	☐
C	to absorb α and β radiation	☐
D	to prevent the reactor from going critical	☐

(Total 1 mark)

Q22.

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

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

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

(a) State what is meant by isotopes.

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(2)

(b) Explain why two photons are formed instead of a single photon when a helium nucleus annihilates with the anti-helium nucleus.

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(2)

(c) Calculate, using data from the passage, the maximum frequency of the photons produced in this annihilation of a ${}^{4}_{2}\text{He}$ nucleus.

frequency = ____________________ Hz

(4)

(d) Complete this equation for the possible decay of an antineutron.

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

(2)

(e) What interaction would be responsible for the decay in **part (d)**?
Tick (✓) the correct answer in the right-hand column.

	✓ if correct
electromagnetic	
gravitational	
strong nuclear	
weak nuclear	

(1)
(Total 11 marks)

Q23.

A Radioisotope Thermonuclear Generator (RTG) is a device that uses some of the energy from radioactive decay to generate electricity. The Mars rover Curiosity includes an RTG that contains plutonium-238. The plutonium undergoes alpha decay and some of the energy is used to generate about 100 W of electrical power.

(a) Complete the equation for the alpha decay of plutonium-238.

$$^{238}_{94}\text{Pu} \rightarrow \, ^{\_\_}_{92}\text{U} + \, ^{\_\_}_{\_\_}\alpha$$

(2)

(b) Only 6% of the energy from the decay is used to generate electricity.

Calculate the rate at which energy is transferred from the decay of plutonium-238 on Curiosity.

rate of energy transfer = ____________________ W

(1)

(c) The RTG has a constant output voltage of 32 V.

Calculate the current when the output power is 100 W.

current = ____________________ A

(1)

(d) Calculate the maximum number of components, each of resistance 45 Ω, that can be connected in parallel across the RTG before the maximum output power is reached.

number of components = ____________________

(2)

(e) The alternative to using an RTG is to use a solar panel.
A typical solar panel installation on a house roof in the UK provides about 1000 kW h of electricity each year.

Calculate the average electrical power output of the installation.

average power output = ____________________ W

(2)

(f) The maximum intensity of the sunlight on the surface of Mars at its equator is similar to that in the UK.

Estimate, using your answer to **part (e)**, the area of the solar panel needed to provide an average power output of 100 W on Mars. Give your answer to an appropriate order of magnitude.

order of magnitude of area = ____________________ m^2

(1)

(Total 9 marks)

Q24.

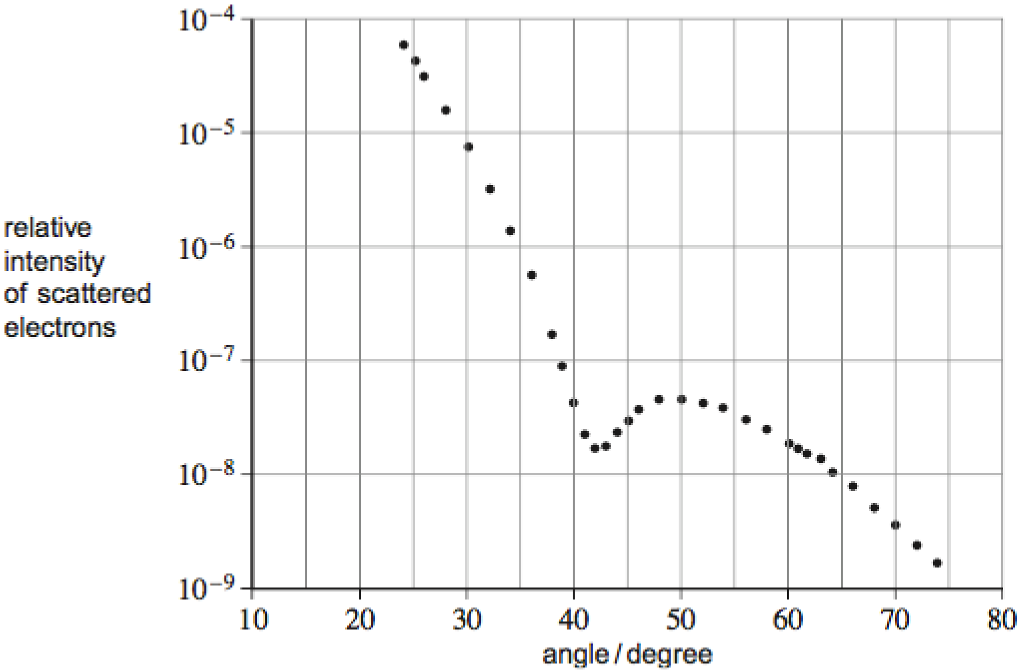
(a) The radius of a nucleus may be determined by electron diffraction. In an electron diffraction experiment a beam of electrons is fired at oxygen-16 nuclei. Each electron has an energy of 5.94×10^{-11} J.

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)

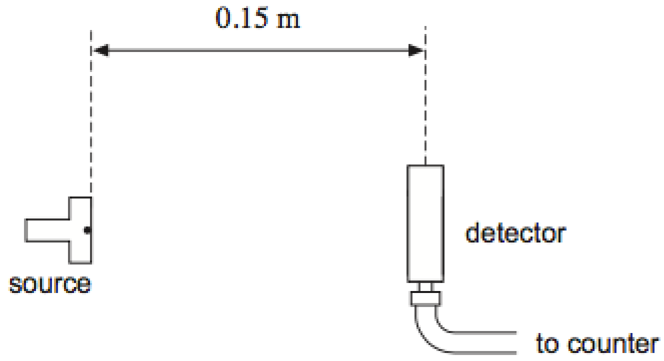
(Total 11 marks)

Q25.

(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.

(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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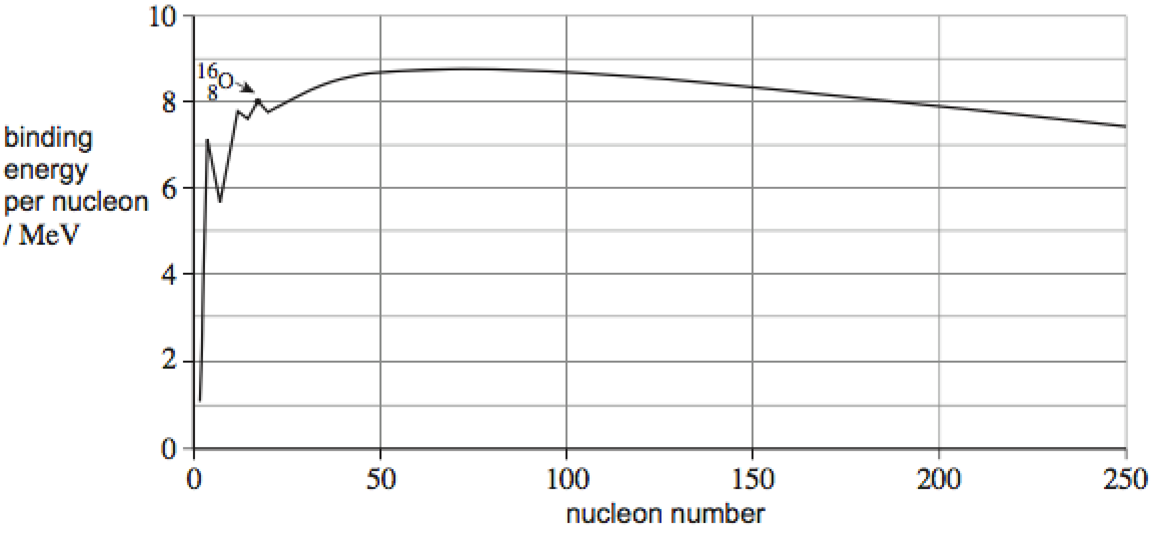
(2)
(Total 7 marks)

Q26.

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.

(2)

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

(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.

(1)

(Total 8 marks)

Q27.

(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.

(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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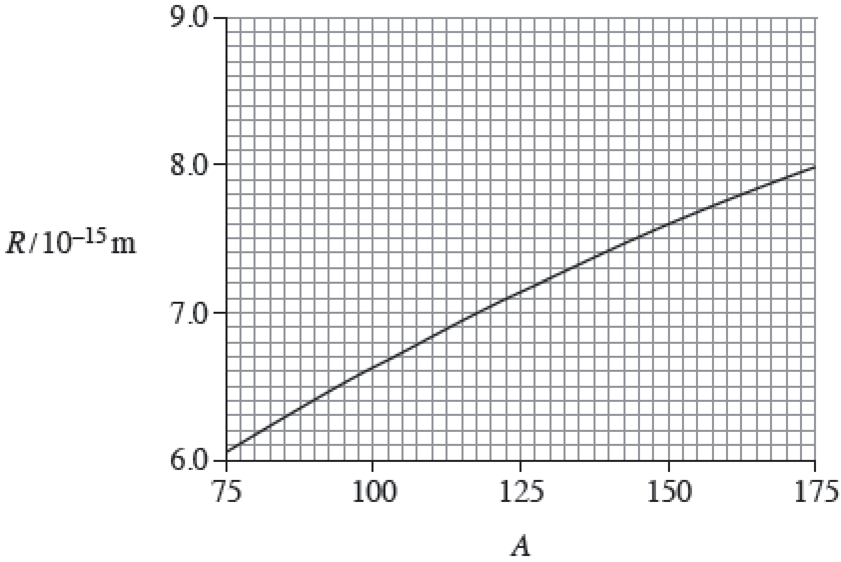
(1)

(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 $^{51}_{23}V$ nucleus is about 5×10^{-15} m.

(2)

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

State an appropriate unit for your answer.

density ____________________ unit __________

(3)

(Total 8 marks)

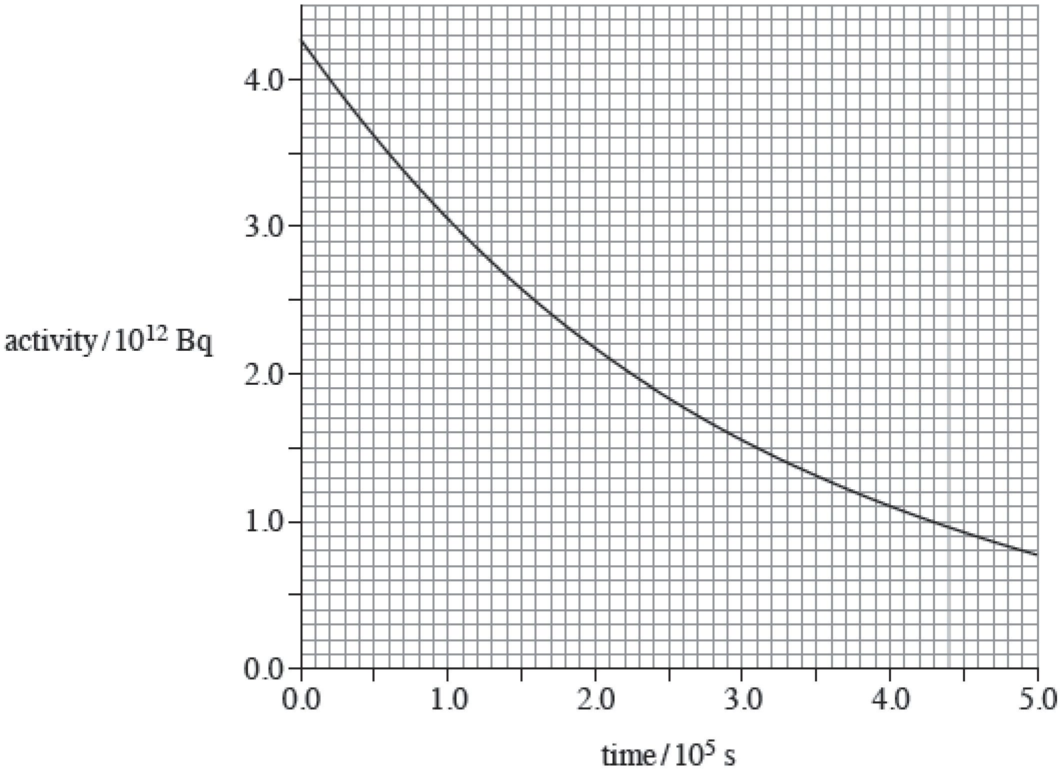
Q28.

A rod made from uranium−238 ($^{238}_{92}\mathrm{U}$) 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 ($^{239}_{93}\mathrm{Np}$), which in turn decays to plutonium−239 ($^{293}_{94}\mathrm{Pu}$).

(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)

Q29.

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

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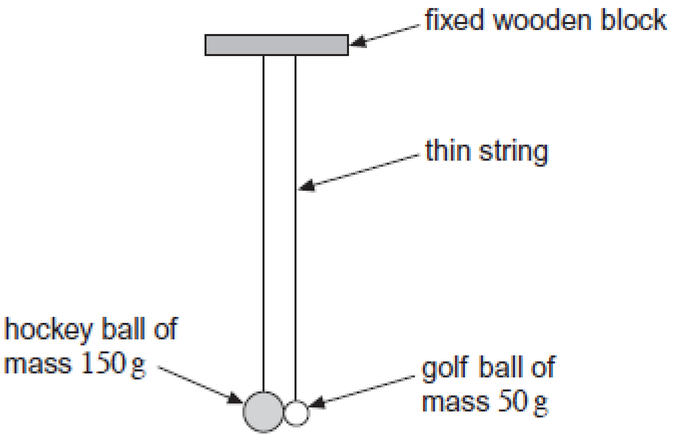
(2)

(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).

____

(1)

(Total 13 marks)

Q30.

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.

____

____

(1)

(Total 16 marks)

Q1.

(a) γ radiation because it is very / the most penetrating

OR

γ radiation because it is penetrating enough to irradiate all sides of the instruments

OR

γ radiation is penetrating so instruments can be sterilised without removing the packaging

✓ OWTTE

The quoted radiation must be gamma only and not a mixture

It is not sufficient to just state 'gamma'. The *mark is based on the reason* *for the choice*

1

(b) To become radioactive the nucleus has to be affected which (ionising) radiation does not do

OR

(Ionising) radiation only affects the outer electrons and not the nucleus

OR

The energy of the radiation is insufficient to induce radioactivity. (For this mark high energy is not the same as highly ionizing)

OR

(Ionising) radiation does not affect the nucleus ✓ owtte

1

(c) (Conclusion using the inverse square law $I = k/d^2$)

Make the point that $I \times d^2$ should be constant if the inverse square law is operating ✓ owtte

Show calculations using data from 3 rows

The column may be completed in the following ways ✓

Corrected count rate count s^{-1}	$I \times d^2$ Using I as count rate		$I \times d^2$ Using $I \propto$ count in 1.0 minute
150	6.00	Or	361
23.3	5.83		349
4.03	4.03		242

Accept 2 sig figs and 1 sig fig in the case of the 4 and 6 in *the second column shown here.*

The mark is mainly based on the technique used.

The written answer must be enough to indicate a conclusion.

This mark can be gained even if there is a slip in the table.

The conclusion mark can be gained even if the second mark is lost because only two data points are taken.

Look out for different approaches. E.g. use the CCR at one distance to predict the CCR at other distances if the inverse function is followed. E.g. CCR might be in order 9013,1440 and 360.

2

(d) **Mark given for any of these ideas (max 2)**

The random nature of the radiation count (although small in this case)

Dead-time in the G-M detector

d is not the real distance between source and detector **OR** source is not a point source

The source may not be a pure gamma emitter

(Gamma and beta is acceptable but not gamma and alpha together)

A reference to short half-life provided that an explanation of how this has an effect on separate measurements eg activity changes during the measurements

Assumes no absorption between source and detector(although small in this case) ✓✓

No credit for unexplained bland statements such as 'because of systematic errors' ***OR*** *'more data needs to be taken to be certain' etc.*

Note: reference to background count does not gain a mark because the corrected count-rate is supplied in the question.

2

[6]

Q2.

(a) 2.0 cm ✓ (allow 1.96 to 2.00 cm)

(Answer alone gains mark and ignore number of sig. figs)

(The depth halves in 19s. With the graph being exponential the depth will halve every 19s. 57/19 = 3 so the halving occurs 3 times. 16 cm → 8 cm → 4 cm → 2 cm)

1

(b) Use more water/greater depth/greater volume (in the existing cylinder)

(This should give the same half-life) ✓

Assume the word water is present in the answer if there is no reference to it. Eg 'greater depth' is taken as 'greater depth of water'.

1

(c) Closing the tap more

OR

Using a more viscous fluid (density is not the same as viscosity)

OR

Using a wider cylinder

OR

Use a smaller diameter capillary/narrow tube ✓

To decrease the decay constant the depth decrease rate should be reduced ie the cylinder should take longer to empty).

Changes to the tube need to be specific.

Also tube needs to be identified.

1

(d) (Using $T_{½}$ = ln 2/ λ = 0.693/1.42 × 10^{-11})

$T_{½}$ = 4.9(4.88) × 10^{10} (year) ✓

1

(e) (Use of $N = N_o e^{-\lambda t}$ mass is proportional to number so

$m = m_o e^{-\lambda t}$

$m_o = m\ e^{+\lambda t}$)

λt = 1.42 × 10^{-11} × 4.47 × 10^9 or 0.0635 ✓

(m_o = 1.23 × 10^{-3} $e^{1.42 \times 10{-11} \times 4.47 \times 10{9}}$)

m_o = 1.31 × 10^{-3} (g) ✓(allow and look out for unit being modified to mg)

Mark for 3 sig figs but must be attached to a final answer for mass with some attempt at a relevant exponential calculation ✓

May calculate N = 8.51(2) × 10^{18} and N_0 9.07 × 10^{18} but marks will be the same.

3

(f) (N = mass/87u = 1.23 × 10^{-6} /(87 × 1.661 × 10^{-27})

N = 8.5(1) × 10^{18} ✓

(This does not have to be calculated out for the mark)

(λ = 1.42 × 10^{-11} / (365 × 24 × 60 × 60) = 4.50 × 10^{-19})

($A = \lambda N$ = 4.50 × 10^{-19} × 8.51 × 10^{18})

A = 3.8(4) ✓ (this calculation must use in seconds)

Bq, B/becquerel, counts s^{-1} or s^{-1} ✓

In first mark is obtainable from calculating number of moles and then multiplying by Avogadro's number.

{$n = 1.23 \times 10^{-6}/87 = 1.41 \times 10^{-5}$

$N = 1.41 \times 10^{-5} \times 6.02 \times 10^{23}$}

A power of 10 error will count as an AE and will allow an error carried forward.

Answer must follow working showing correct process as correct answer can come from incorrect working.

3

[10]

Q3.

A

[1]

Q4.

C

[1]

Q5.

(a) (moderator) - the neutron undergoes an elastic collision / bounces off with less speed / kinetic energy ✓ (Any reference to absorption loses the mark)

Must have the idea that the neutron slow because of collisions

1

(b) (control rod) – the neutron is absorbed ✓

'stopped' will not get the mark.

If alternatives are given all must be correct to gain mark.

1

(c) the neutron is absorbed/U-236 is formed ✓
(causing) the nucleus (of fuel / uranium) to split into (two smaller) daughter nuclei / nuclei / fragments ✓
releasing (several fast-moving) neutrons ✓

1st mark can use words like absorbed / takes in /

*2nd mark: alternative words for nuclei are **not** acceptable (eg daughter ~~products~~)*

3rd mark 'neutrons' must be plural.

3

(d)

Descriptor	(Bullet point headings are detailed at the bottom end of the table)	Mark
High Level – Good to Excellent	6 marks = At least 6 points	5-6

All three bullet points must be addressed. The source must be identified and two stages in the treatment sequence must be given. Finally three problems encountered in the treatment of waste and how the problems are overcome should be stated. (Note discussion of a problem will often cover a stage of the treatment). *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.*	made coming from all three of the bullet point headings. (note some written points may count as answers to bullet point headings 2 and 3) 5 marks = 5 points made coming from all three of the bullet point headings. To be in this top band communication skills must be good and the ideas easy to follow.	
Intermediate Level – Modest to Adequate All three bullet points must be addressed. The source must be identified as well a stage in the treatment along with a problem encountered in the treatment of waste and how it is dealt with. One additional piece of information must be made from any of the bullet points listed below to be at the top of this band. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*	4 marks = 4 points made coming from at least 2 bullet point headings. 3 marks = 3 points made coming from at least 2 bullet point headings. To be in this moderate band communication skills must be good enough to understand the ideas easily even if the order is a little unclear.	3-4
Low Level – Poor to Limited To be at the top of this band two bullet points must be addressed which must include a problem encountered in the treatment of waste and how it is dealt with. A single mark is awarded if any of the information given in the bullet points listed below is given. *There may be many grammatical and spelling errors and the information may be poorly organised.*	2 marks = Two points made from any bullet point heading. 1 mark = any point made coming from any bullet point heading. Or the script as a whole shows some basic understanding of the issues.	1-2
The description expected in a competent answer should include: **1st bullet point** The (highly radioactive/ most		

dangerous) waste are the fission fragments from the fission of uranium-235 or from (spent) fuel rods. **2nd bullet point** The waste is initially placed in cooling ponds/water (close to the reactor for a number of years) plutonium/uranium is separated to be recycled high level waste is vitrified/made solid into (pyrex) glass then placed in (stainless) steel/lead/concrete cylinders/containers/bunkers to be stored <u>**deep**</u> underground (simply stating buried/underground is not enough) **3rd bullet point** (the problem and its solution must both be given, <u>some</u> examples are given below) the waste is (initially) is very hot/generates heat so has to be placed in water/cooling ponds (to remove the heat) the waste (initially) is highly radioactive and needs to be screened in water/cooling ponds (to absorb the radiation) the waste (initially) is highly radioactive and needs to be remotely handled (to avoid human contact with the waste). In liquid form the (high level) waste may leak hence the need to vitrify (and barrel in steel) The waste will be radioactive for hundreds/thousands of years so storage needs to be stable in a container hence the need to vitrify (and barrel in stainless steel) The waste will be radioactive for hundreds/thousands of years so long term storage needs to be in geologically stable areas (deep underground).		

Transporting waste presents a potential danger to the public so waste is transported enclosed in impact/crash resistant/extra thick and strong casings Or processed onsite or nearby.		

[11]

Q6.

D

[1]

Q7.

B

[1]

Q8.

D

[1]

Q9.

C

[1]

Q10.

(a) 1eV = 1.6×10^{-19} J

kinetic energy = $1.6 \times 10^{-19} \times 4.9 \times 10^{6} = 7.8(4) \times 10^{-13}$ J ✓

ke lost = pe gained = $7.8(4) \times 10^{-13}$ J ✓

2

(b) using $V = Q / 4\pi\varepsilon_0 r$ and $E_p = qV$

$r = qQ/4\pi\varepsilon_0 E_p$✓

$= (2 \times 1.6 \times 10^{-19})\ (79 \times 1.6 \times 10^{-19})/4\pi \times 8.85 \times 10^{-12} \times 7.84 \times 10^{-13}$✓

$r = 4.67(4.64) \times 10^{-14}$ m ✓

3

(c) $A = (R/R_0)^3$ ✓

$= (7.16 \times 10^{-15} / 1.23 \times 10^{-15}\text{ m})^3$ ✓

= 197 placed on the dotted line ✓

3

(d) r gets smaller ✓

less force so needs to travel further to lose same initial ke ✓

Fewer protons means that r will be smaller when alpha particle has the same electrostatic potential energy (as initial kinetic energy)

2

[10]

Q11.

B

[1]

Q12.

B

[1]

Q13.

D

[1]

Q14.

C

[1]

Q15.

C

[1]

Q16.

B

[1]

Q22.

(a) atoms/nuclei with same number of protons/atomic number ✓

atom/nuclei seen at least once

1

but different numbers of neutrons/mass number ✓

1

(b) momentum must be conserved ✓

1

so need two photons travelling in different directions ✓

1

(c) rest energy = 2 × 3728 = 7456 ✓ (MeV)

must show doubling OR explain that is halved because two photons OR implied because 1.193×10^{-9}

1

rest energy = 1.193×10^{-9} ✓ (J)

1

use of energy of each photon = hf ✓

no working but correct answer scores last three marks

1

$f = (1.193 \times 10^{-9}/2) / 6.63 \times 10^{-34} = 8.997 \times 10^{23}$ ✓ (Hz)

RANGE: $8.90 \times 10^{23} - 9.00 \times 10^{23}$

1

(d) ${}^{1}_{0}\overline{n} \rightarrow {}^{1}_{-1}\overline{p} + {}^{0}_{1}\overline{e} + \nu_{(e)}$ ✓✓

Can use e^+ OR β in place of e

1

Allow slight loop in bottom of neutrino but must not look like gamma

1

(e)

electromagnetic	
gravitational	
strong nuclear	
weak nuclear	✓

1

[11]

Q23.

(a) Top line: 234 4 ✓

bottom line: 2 ✓

the first mark is for the nucleon numbers correct

the second mark is for the correct proton number of the alpha particle

2

(b) use of $\dfrac{\text{electrical power output}}{\text{power generated by decay}} = 6\% = 0.06$

to give: power generated by decay = $\dfrac{100}{0.06}$ = 1700 W ✓

allow 2000, 1670, 1667 etc

1

(c) current = $\dfrac{P}{V} = \dfrac{100}{32}$ = 3.1 A ✓

allow 3, 3.13 and 3.125; condone 3.12

1

(d) each component requires $I = \dfrac{P}{R} = \dfrac{32}{45}$ = 0.71 A ✓

number of components = $\frac{3.1}{0.71}$ = 4.4; thus n = 4 ✓

alternative 1: use of power formula $\frac{V^2}{R} = \frac{32^2}{45} = 23$ W ✓

number of components = $\frac{100}{23}$ = 4.3; thus n = 4 ✓

condone '4' for both marks; if the answer is not rounded down to the greatest whole number, lose the last mark

if P = 1700 used rather than 100 allow ce

alternative 2: use of total resistance formula

$$R_T = \frac{V^2}{P} = \frac{32^2}{100} \quad or \quad \frac{P}{I^2} = \frac{100}{3.1^2} = 10.24$$ ✓

$$\frac{1}{R_T} = \frac{1}{10.24} = \frac{n}{45} \therefore n = \frac{45}{10.24} = 4.4\text{ ; thus } n = 4$$ ✓

2

(e) energy = 1000 kW h
= 1000 × 1000 × 3600
= 3.6 × 10^9 J ✓

average power = $\frac{3.6 \times 10^9}{265 \times 24 \times 3600}$ = 114 W ✓

allow 1 sf 100 W

for solution using Watt-hours

$\frac{10^6}{265 \times 24}$ ✓ = *114 W* ✓

2

(f) (as Sun's intensity is similar) area needed = (similar to that of UK domestic solar power installation =) 10m^2 (to an order of magnitude) ✓

allow ce for average power ie $\frac{1000}{\text{answer to 04.5}}$

1

[9]

Q24.

(a) (i) momentum (= E/c)
= 5.94 × 10^{-11} / 3.00 × 10^8 = 2.0 × 10^{-19} (kg m s^{-1})
(= 1.98 × 10^{-19} kg m s^{-1})
Or evidence of use of $E = hc / \lambda$ ✓
λ = (h / mv = 6.63 × 10^{-34} / 1.98 × 10^{-19}) = 3.35 × 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 λ / sin θ = 0.61 × 3.35 × 10^{-15} / sin 42°
= 3.1 × 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 x 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]

Q25.

(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 $I_{CCR90} = I_{CCR15}\left(\frac{d_{15}}{d_{90}}\right)^2$ √ $= 2010 \times (0.15 / 0.90)^2 = 55.8$

$I_{90CR} = 55.8 + 40$

$I_{90CR} = 96$ 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]

Q26.

(a) (i) Fission occurs at *A* values above the peak / above *A* of about 56 and 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

$= 8(1.00867+1.00728) - 15.991$ ✓

($\Delta m = 0.1366$ u

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

(range of answers $2.2 - 2.3 \times 10^{-28}$ kg)

Substitution may take the following form

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

$= 2.23 \times 10^{-28}$ (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 $\Delta m = 0.1366$ u (this must appear in b(i) for this approach)
BE $= 0.1366 \times 931.3 = 130$ (MeV) ✓ (127 MeV)

CE is allowed but only if the calculation is shown

Note answer = b(i) $\times 5.625 \times 10^{29}$

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]

Q27.

(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]

Q28.

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

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

First mark for uranium + neutron gives more neutrons.
Ignore which isotope of uranium is used.

(at least one of) <u>these neutrons</u> go on to cause further / more <u>splitting / fissioning</u> (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]

Q29.

(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 $mgh = \frac{1}{2} mv^2$ 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

<u>and</u> 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 *m*1.3^2
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]

Q30.

(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 difference 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 ($\times 1.6 \times 10^{-13}$) ***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 **and** correct powers of 10

C1

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

A1
3

(ii) Uses K*E* = 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]

Q1.

(a) About half of the students knew that gamma radiation was to be used. However, only 19.6% actually gained a mark because they did not know why gamma radiation was to be used. They either left out the reason or simply wrote something they knew about gamma radiation, whether it was relevant or not. “It is least ionising” or “it kills germs” are examples of statements that did not gain marks.

(b) It was clear that over 90% of students were not aware of how materials can become radioactive. There were extremely few references to nuclei. Students mainly wrote that the induced radioactivity was “too small to be of harm” or “has a short half-life” or “is only ionised a bit, so can be ignored”.

(c) More than half of the students (56.1%) gained full marks and they established that the constant of proportionality was not constant when an inverse square of distance relationship was used. Other students put the square on the count rate rather than the distance and did not gain any marks. Others only compared two rows of data rather than three, but these could score one of the marks.

(d) A great number of weak answers simply stated that the measurements were taken wrongly in some way because of human error. Examples included “the readings were copied wrongly” and “the GM tube was old and faulty”. The most common answer was to state that the background reading was changing or not accurate. It was also obvious that some students did not know how the inverse square law comes about, since they wrote “the detector captures fewer radiations as it moves away from the source”. Approximately one third of students could give one acceptable answer; 59.5% failed to score.

Q2.

(a) Nearly half of the students (44.6%) could produce the answer without too much trouble because they spotted that the half-life was 19 s. Other students either made a small error in reading off the graph and got close to the correct answer, or they did not spot the half-life approach and made a difficult question for themselves by trying to fit the exponential decay equation to the graph. Most of these students made mistakes.

(b) 62.4% of students found this to be an accessible question and gained the mark. The ‘near-miss’ answer put forward by many others was to write about increasing the volume of the cylindrical tube. The problem here is that it was not made clear that the height and not the diameter occupied by the water needs to be altered.

(c) Most students did realise that the water should take longer to empty if the decay constant represented was smaller. Some of these students suggested changing the geometry of one of the tubes but they did not make it clear which one they were referencing. The students who focussed on the tap scored the mark more often than not. A final error point seen frequently was to treat ‘density’ as having the same meaning as ‘viscosity’. 34.7% of students wrote a sufficiently detailed answer to gain the mark.

(d) This calculation was performed well by nearly 90% of the students. Most knew the relevant physics and errors only occurred in arithmetic items such as getting the wrong power of 10.

(e) This was another reasonably difficult question that about half of the students could do very well (45.3% scored all three marks). The most common approach was to use the exponential decay in the mass, but others successfully used the exponential decay in the number of molecules. A very small proportion of students calculated the number of half-lives that must have occurred and deduced the mass in this way. Most of these, unfortunately, did not retain three significant figures and so failed to gain one of the marks available. As expected in this type of question, a significant number of students made powers of ten errors and a similar number did not give their answer to three significant figures. 25% of students failed to score.

(f) This calculation caused far more problems for students than the previous calculation. Many attempted to work the activity out in counts per year, which was not accepted. So, the calculation was marked in essentially three independent parts: the number of molecules involved, the calculation giving an answer in becquerel, and finally the unit. Of the 68% of students who scored at least one mark, about one third, but not always the same one third, scored each mark.

Q3.

63.1% correct

Q4.

53.2% correct

Q5.

(a) A significant number of students were too brief in their answers to score a mark. To state “it slows” was not a sufficient answer. It was necessary to add the idea of a collision occurring. The least able students referred to absorption and in some cases fission.

(b) This was a very straightforward question done well by all but the least able students.

(c) Good students had knowledge of the physical process of fission and could express their ideas coherently. The middle to low ability students often did not express their ideas in a concise manner. The main failing was in not appreciating that the incident neutron was absorbed. Many thought it simply jogged the uranium nucleus in fission. The process of the nucleus splitting was often confused with other radioactive decays, and the ejected neutrons were not always mentioned. This group of students also wasted time trying to explain a chain reaction.

(d) It was clear that the vast majority of students did not have knowledge about nuclear waste management. Many just expanded on their reasonably sensible thoughts of ‘keep clear from it, and get rid of it’. For weaker students, this simply meant wearing protective clothing and sending the waste into space. The middle-ability students gave a better solution by suggesting handling the waste remotely, encasing the waste in a named and effective radiation shield, and placing it in a deep mine or trench away from people. It was only about 20% of students who seemed to write with knowledgeable authority. These students knew it was the spent fuel rods that posed the main problem, unlike others who could answer with any item that had to do with the reactor. It was also only these students that knew about waste producing heat or about vitrification. It was rare for any student to refer to reprocessing. In terms of the quality of the writing, it was clear that most students do not give themselves even a brief plan. Often the ideas presented did not follow a logical sequence.

Q22.

In this question students were required to extract information from an introductory passage. Part (a) was a straightforward starter but a significant proportion of answers were spoilt by a lack of precision. Students were required to mention atoms or nuclei in their responses and a significant proportion did not do this. Part (b) required an explanation as to why two photons were produced. A number of students seemed to think this was necessary due to energy conservation. Of those who realised this was due to momentum conservation, a significant proportion then failed to appreciate the importance of the photons travelling in different directions. Part (c) was an extended calculation and students were told to calculate the maximum frequency of the photons produced in the annihilation of the two nuclei. Maximum was necessary to indicate that the whole rest energy of the nuclei should be used and excluded the possibility of calculating the frequency of photons produced due to annihilation of individual nucleons within the helium and anti-helium nuclei. It is true that higher frequency photons would be produced if the nuclei had significant kinetic energy but students were told to use information from the passage in which there was no mention of kinetic energy. For full marks students needed to explain how they dealt with two nuclei annihilating and two photons being produced. Parts (d) and (e) were well answered and the only common error was a failure to identify the positron correctly in the equation.

Q23.

This question linked several parts of the AS specification together, including radioactivity, electricity and energy. It also allowed for the testing of some parts of the first chapter of the specification: "measurements and their errors".

(a) This question caused few students any difficulty. The few errors seen tended to be linked to using 2 for the nucleon number of the alpha particle.

(b) The equation needed for this question is on the data sheet, and it was therefore disappointing to see how many students were unable to perform the calculation correctly. Most commonly students confused output and input powers, obtaining an answer of 6W. A moment's reflection should have shown that this could not be sensible. Due to the use of 100 W in the stem, answers were accepted regardless of the number of significant figures but any rounding down had to be correct and recurring notation was rejected.

(c) This was much more accessible with only a few students being unable to get the correct answer. The few errors seen included answers that used 1700 W (i.e. the answer to (b)), perhaps carrying on the problem with input and output power in this context.

(d) There were several routes through this question and all were given credit. A popular solution was to calculate the total circuit resistance (10.24 Ω) for an output power of 100 W, then reverse-working using the parallel resistor formula (or perhaps just dividing 45 by 10.24) to find the (non-integer) result for number of resistors. Rounding down gave the required result but a few rounded up and forfeited a mark. Those using their result from 04.2 rather than 100 W were able to get some credit.

(e) There was evidence to suggest that many students were unfamiliar with this conversion and that some centres may have overlooked this part of the specification. The most popular approach was to find the equivalent J value of the kW h and divide by the number of seconds in a year but the same idea using energy in W h was also successful. Many near misses involved mixing units, dividing W h by 3600. Disappointingly many students did not attempt this question.

(f) Answers to this question suggested very few students were familiar with the idea of an ‘order of magnitude’ calculation. Many students who produced an answer for (e) did not then realise that the solar panel on Mars produced the same average power output as that on Earth. Given that the intensity of solar radiation was about the same in both situations they were looking for a solar panel with a surface area about the same as that in a typical domestic setup on Earth. Having grappled with this very few then appreciated that the answer required was to be given to the nearest power of ten (10 m^2 was the expected result). Again, many did not attempt the question.

Q24.

(a) (i) Most students could manipulate the equations to obtain the de Broglie wavelength, usually by calculating the momentum first in a two stage process. The most common error was to fail to show a completed evaluation to 3 significant figures. In many cases the equations and substitutions would be shown but followed by a jump to the answer given in the question. It is important for students to give answers to a ‘show that’ question to at least one more significant figure than the quoted answer as evidence of the correct calculation being carried out.

(ii) The use and rearrangement of the equation was done well by almost all students. It was choosing the correct angle from figure 1 which caused difficulties for some. Many chose to use 24 degrees, which is where the graph data began. Others were unable to correctly establish the 1st interference minimum to a reasonable precision.

(b) (i) Many of the diagrams were very rough and sketchy but were clear enough to show the main features. Most showed the basic purpose of the apparatus and included a source of a beam of alpha particles colliding with a gold film. Some students failed to score marks because of their lack of labels and many did not have a detector that surrounded or could move round the target area. A significant majority of all students did not indicate that the experiment should take place in a vacuum or the alpha particles need to be collimated.

(ii) In the extended response question many students showed the ability to give a good account of the main observations made by Rutherford and his team during the scattering experiment. Many students went on to explain the significance of each observation and how it refined the model of the atom, therefore securing an intermediate level mark. Fewer students were able to produce a high level response and explain, in sufficient detail, a method by which the scattering experiment results can be used to place an upper limit upon the nuclear radius. Those that had difficulty with the question fell into different groups. Some seemed to make a simple slip by discussing the scattering of electrons but gave descriptions that fit with alpha particles. Others went on to discuss electron diffraction and threw a little of everything into the mix. Another group of students had difficulty in knowing what the observations were. Many of these discussed the experiment by considering how close to the nucleus an alpha particle passed by and what path it would follow which they took as the observation, so they did not approach the task by considering the results of an experiment first. Another group failed to relate interpretations to observations and these students simply made a list of observations and a separate list of unrelated facts about atoms. Many of the moderate ability students were side tracked into discussing what Rutherford expected to see that was consistent with the 'plum pudding model'. There was nothing wrong with this as an introduction to an answer but in many cases it took up more than half the answer space even though it was not asked for in the question. The main issue in the interpretations was how the idea that atoms consisted of mainly open space was stated. 'There is lots of space between atom', the nucleus is mainly open space' and 'an atom is mainly made from air' and similar statements were seen. A minority of students showed how the results lead to an upper limit to the nuclear radius. The most successful were those that considered the least distance of approach with a head on collision. In the analysis however, it was common for the expression for the force between the nucleus and the alpha particle to be mistaken for the expression for potential energy. Most students that attempted to place an upper limit to the radius by considering how alpha particles are obstructed by the area of the nuclei failed to consider the thickness of the foil. It was a common misconception that a gold foil is one atom thick.

Q25.

(a) Acceptable answers were seen regularly and showed that many students understood the nature of the question about how modern military, industrial and medical practices and also the increased use of air travel by the public have led to an average increase in exposure to background radiation. A significant number of students failed to gain the mark by being too brief. They gave answers like, 'medicine' or 'flying'. With a few more words these could have been converted into scoring answers. There were also some students that simply quoted a source of background radiation such as 'cosmic rays' and 'radon gas'.

(b) (i) A majority of students could use the inverse relationship correctly. The main problem came in dealing with the background. About half subtracted the background from the 2050 but following the calculation very few of those added the background to obtain the expected reading.

(ii) A large number of students failed to refer to the randomness of the count-rate in any respect. They instead focused on the number of counts being reduced because of the distance from the source. Alternatively some tried to express the idea that the background had more effect at larger distances. The idea that a larger count helps reduce the statistical percentage uncertainty inherent in smaller readings proved too much for the vast majority of students.

(iii) A range of approaches were accounted for within the mark scheme and a range of responses were seen. The most direct, common and successful approach was the use of a sensible absorber placed between the source and detector. There were a number of students who did not know the approximate thickness of a material that would absorb most of the beta particles. The most common alternative approach was to consider the count- rate fall with distance. Using this approach a majority did not compare the count-rate with the expected inverse square function in and out of the range of beta particles. Most simply thought the count-rate would suddenly fall as the detector moved out of range of the beta particles. While some non-standard approaches could gain full marks, such as the use of magnetic/electric fields and cloud chambers, students were expected to say exactly how the nature of the suspected beta radiation would be revealed which proved too much for the majority who took these routes.

Q26.

(a) (i) At the higher ability range, students had no trouble in conveying the idea of splitting or joining of nuclei in different regions of the graph, which corresponded to fission and fusion. Weaker responses often did not make any reference to the graph. They simply referred to large and small nuclei taking part. Other students who struggled only tackled one aspect of the question and concentrated on fission or fusion alone. There was also a great deal of confusion about binding energy being given out in this question and in the following question.

(ii) Students were expected to explain that only an increase in B.E./A, based upon the diagram, from a nuclear reaction releases energy. It was clear that most students did not understand this relationship. Instead they discussed the process of fission or fusion in an attempt to explain a release of energy. Some students understood the relationship and gave succinct answers, however a few of these failed to gain full marks by choosing to use words like 'changed' binding energy per nucleon rather than 'increased' binding energy per nucleon. Although referred to in the question many scripts were seen that avoided any reference to the diagram.

(b) (i) Many students knew how to approach this question and appreciated the precision of the raw data required to obtain an answer. These students used the data sheet to obtain the mass of a neutron and proton separately. The weaker responses lumped the 16 nucleons together and used an average value for their mass in kg. Some even thought that the average value was 16 u. Some weaker responses also included electrons in their calculations even though the question was specific in terms of mass difference calculation for the nucleus.

(ii) When an error carried forward was taken into account most students could perform this calculation, which was essentially a unit conversion problem. The main errors involved computational mistakes.

(iii) The calculation was shown in full by many and most found the question very straightforward. Those that failed to achieve the mark usually did not refer to oxygen. They gave very general answers such as 'multiply the y-axis by the x-axis. Some students clutched at other ideas like finding an area under the graph or reading directly from the y-axis.

Q27.

The calculations involving the nuclear radius were done well but the question parts on alpha particle scattering were not answered as well as expected. In part (a)(i) a majority did refer to electrostatic or electromagnetic repulsion. There were however a significant number who chose to give the strong nuclear force or to simply refer to like changes repel. Interestingly there seemed to be a number of students, judging from their answers', who did not really understand the word 'interaction'. The response to (a)(i) was very polarised. Around half of the students understood that the charge of the nucleus did not change and neither did the scattering. The other half regarded the alpha particle as bouncing physically from the nucleus and therefore the radius or the change in nuclear size would have consequences. If contact had been made between the alpha particle and the nucleus the SNF would have put a stop to the scattering. In (b)(i) a majority of students had no problem in using the graph. There were a handful who only showed the equation without any working data. A few others incorrectly thought that the gradient of the graph could give the value of the constant. This last group should be distinguished from a number of students who linearised the data before they found a gradient ie the gradient of R against $A^{1/3}$. The main stumbling block for some in (b)(ii) was to not actually perform the calculation which they set up. They simply quoted the radius given in the question. Students found the calculation required very easy. The calculation of the last part (c) was done well by a majority. A very small number quoted the wrong units and a few made errors in the volume calculation by either quoting the wrong formula for the volume of a sphere or getting the powers of 10 wrong in the calculation.

Q28.

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

Q29.

(a) The majority of candidates were able to score at least 1 mark in this explanation. Only the best candidates were producing quality answers that gained full credit. Many candidates were unfamiliar with the term and offered answers suggesting that these were neutrons that were produced due to heat.

(b) (i) Surprisingly, only 50% of candidates gained full marks here. A significant proportion of candidates attempted to use the equations of motion and consequently were awarded no marks. Candidates must be aware that these equations only apply to situations were acceleration is constant. Some candidates lost marks by rounding the final answer to 1 significant figure.

Many lower achieving candidates failed to correctly rearrange $\frac{1}{2} m v^2 = m g h$, dropping the factor of $\frac{1}{2}$ was a common mistake.

(ii) This was another "Show that..." style question and again it posed problems for many candidates with just over 20% of candidates gaining 3 or 4 marks. A very large proportion of candidates did not attempt the elastic collision part of the question and limited themselves to 2 marks. Many of these candidates had difficulty with the vector nature of momentum and their signs were often inconsistent or incorrect. Grade A candidates typically presented well laid out workings that were easy-to-follow, convincing.

(iii) Most candidates achieved both marks here. However, some had casual use of powers of 10 errors on their KE calculations due to keeping the mass in grams. This of course cancelled due to the ratio aspect of the question. A number of candidates thought that 25% was the answer; this was due to not reading the question carefully enough.

(iv) Most candidates gained 1 mark for stating how the demonstration related to the moderation process. Only a small number of candidates were able to develop their answer by providing information that was more than the converse of the information provided, thus demonstrating a sound knowledge of the moderation process.

(v) Just under 80% of candidates knew that water was the moderator in a PWR. A few candidates incorrectly thought that the moderator was heavy water.

Q30.

(a) (i) These calculations were well known and competently completed by the vast majority of candidates. Where mistakes occurred these were more common in part (i) with significant number of candidates failing to convert their mass to kg or forgetting to square the speed of light in $E = m c^2$.

(ii) As above.

(b) (i) These calculations proved to be good discriminators with only the better candidates able to achieve all 6 marks. There were a significant number of non-attempts, 10% for this part.

(ii) There were a significant number of non-attempts, 23% for this part. There were lots of mistakes in the formula for potential energy with r^2 instead of r. Candidates were unsure about how to proceed in this part with many neglecting to divide the total kinetic energy by 2.

(c) (i) Just over 30% of candidates could recall that H-2 and H-3 were most likely. The most common answer seen was hydrogen and helium.

(ii) Candidates enjoyed more success in this part with over 50% able to state a method used to heat the plasma in the JET reactor.