AQA A-LEVEL PHYSICS · 7408

PHYSICS



EXAM QUESTION PACK

3.8.1 RADIOACTIVITY

SCORE	PERCENTAGE
/143	%

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Q1.

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

_____

_____

_____

(1)

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

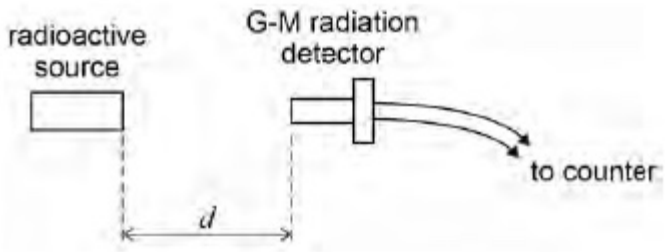
_____

_____

_____

(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.

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_____

_____

_____

_____

(2)

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

Reason 1 _____

_____

Reason 2 _____

_____

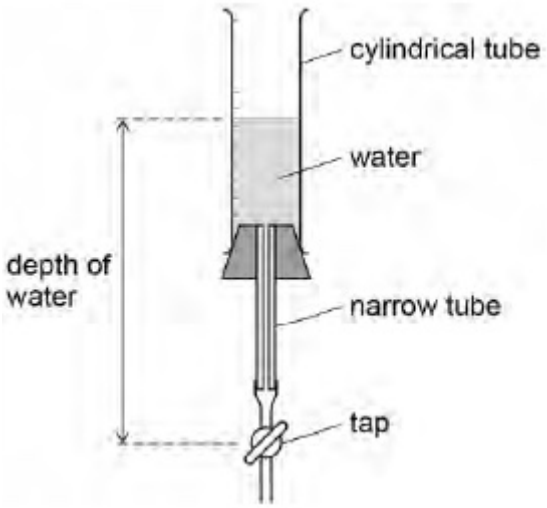
(2)

(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



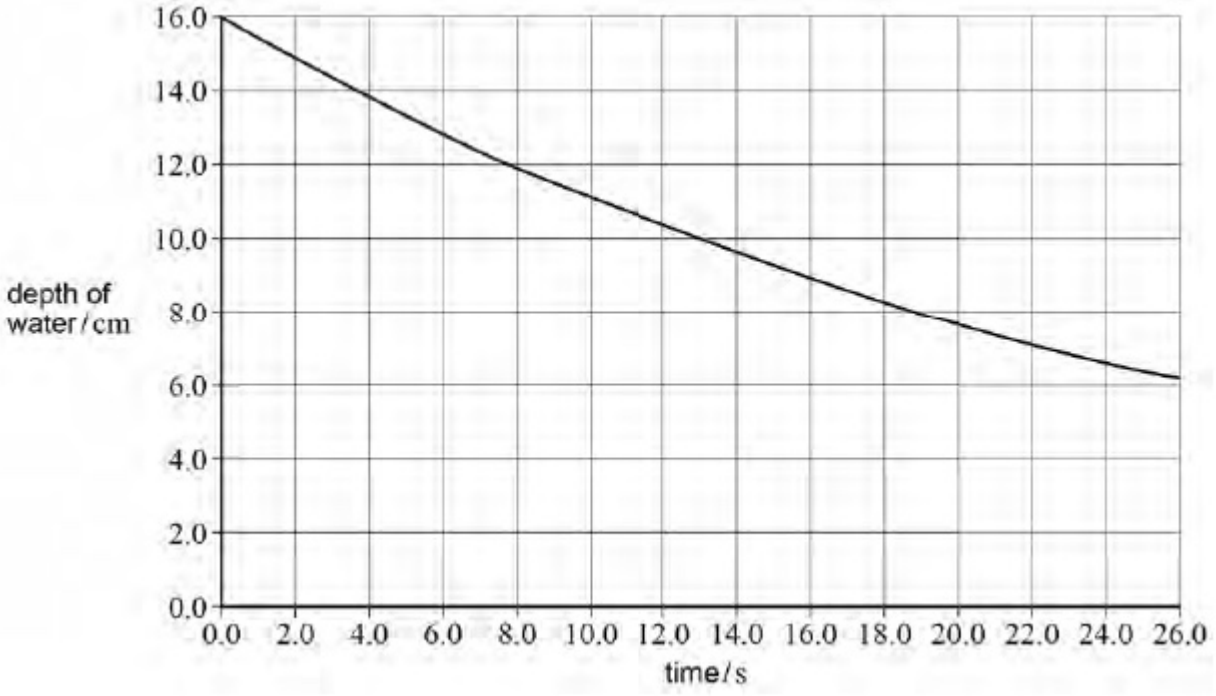
The water flow-rate is proportional to the pressure of the water. The pressure of the water is proportional to the depth of the water. Therefore the rate at which the depth decreases is proportional to the depth of the water.

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

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(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.

_____

_____

(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)

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

Calculate the mass, in g, of $^{87}_{37}\mathrm{Rb}$ 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 $^{87}_{37}\mathrm{Rb}$ of mass 1.23 mg

Give an appropriate unit for your answer.

activity = _____ unit _____

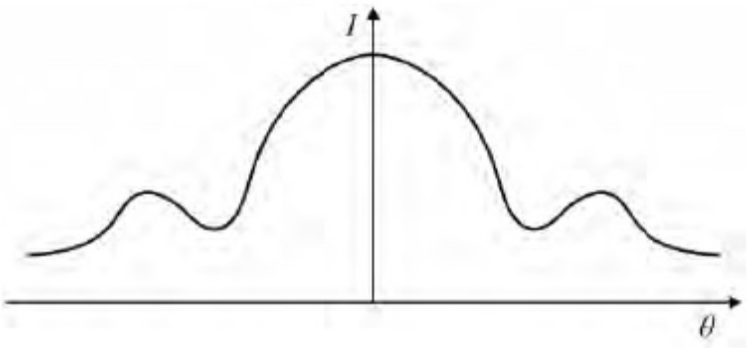
(3)

(Total 10 marks)

Q3.

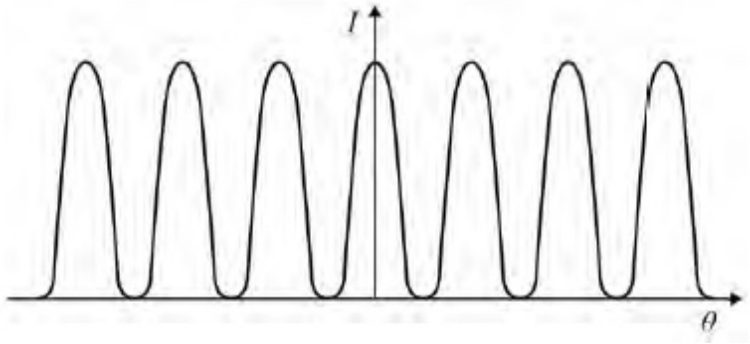
Which graph shows how intensity I varies with angle θ when electrons are diffracted by a nucleus?

A

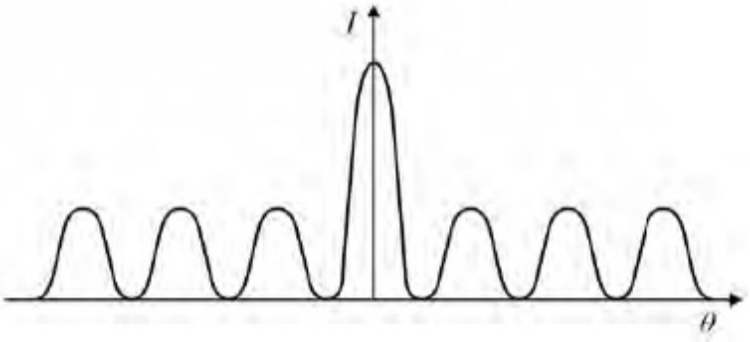


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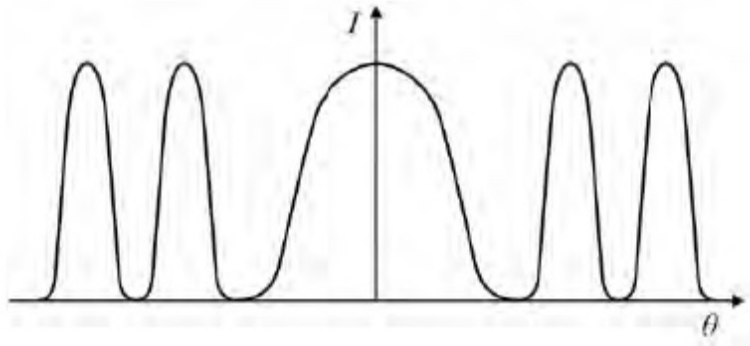
B



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)

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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.

_____

_____

_____

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(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 $8.7 \times 10^{-5}\ s^{-1}$ ⬭

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B $2.0 \times 10^{-4}\ s^{-1}$ ⬭

C $1.7 \times 10^{-2}\ s^{-1}$ ⬭

D $1.2 \times 10^{-2}\ s^{-1}$ ⬭

(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 ⬭

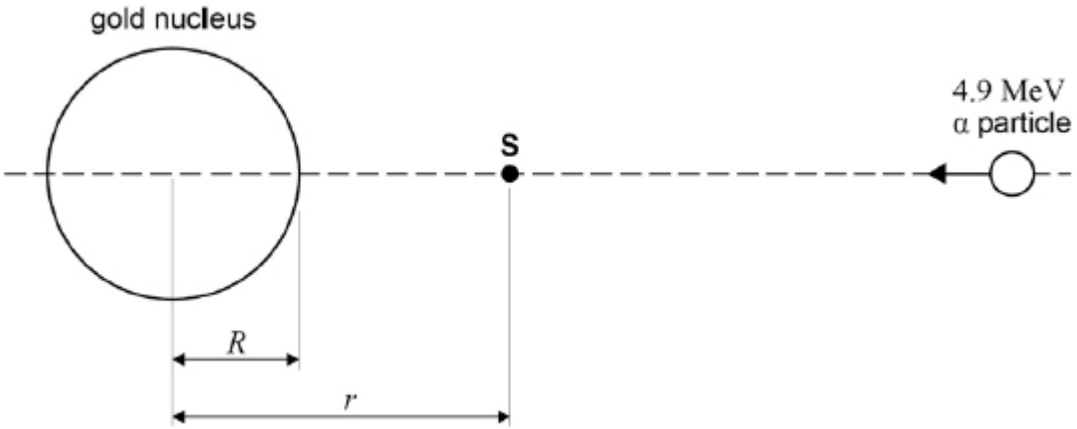
(Total 1 mark)

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

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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)

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(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.

_____

_____

_____

_____

(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.

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What will be the average count rate after 24 hours?

A 40 counts per minute ⬭

B 45 counts per minute ⬭

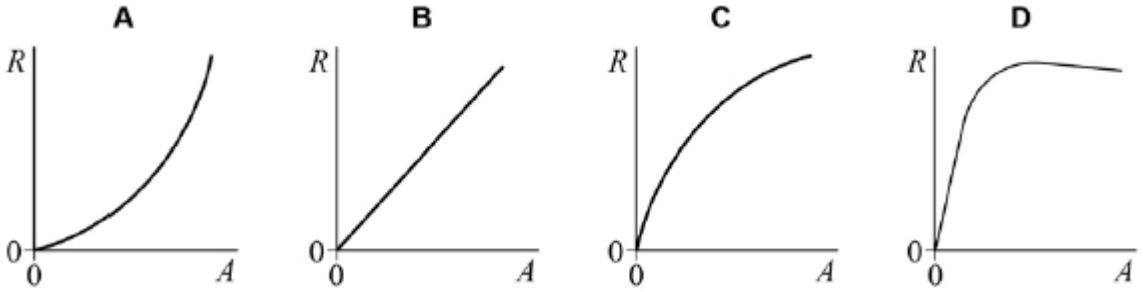
C 50 counts per minute ⬭

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)

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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.

_____

_____

_____

_____

(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 $^{4}_{2}He$ 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.

$$^{238}_{94}Pu \rightarrow ____U + ____\alpha$$

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(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.

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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.

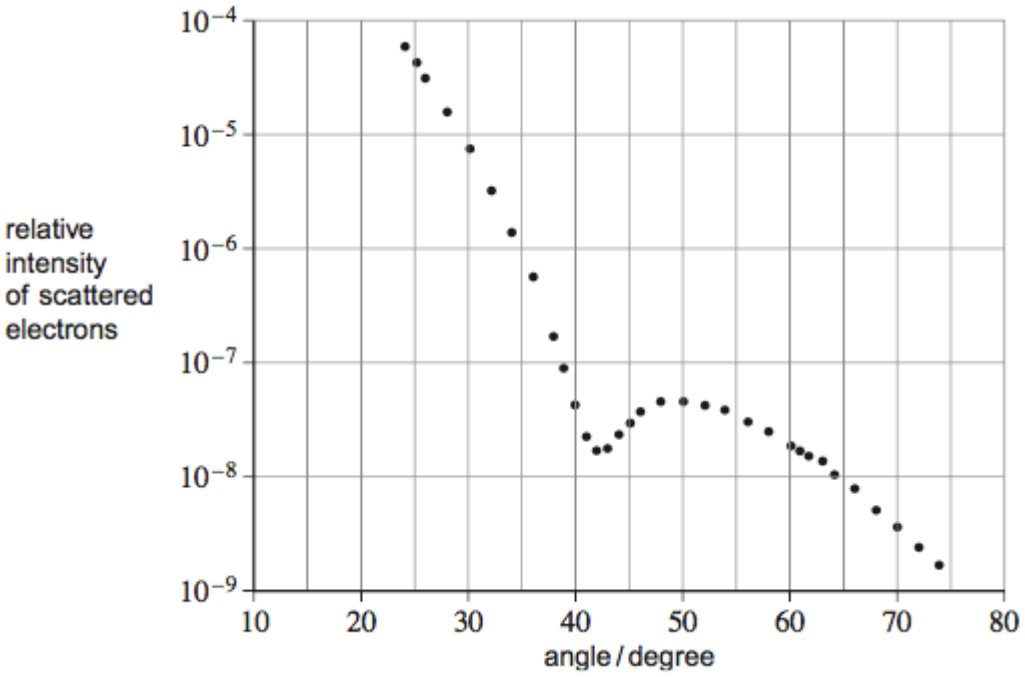
The approximation, momentum = $\frac{\text{energy}}{\text{speed of light}}$ can be used for electrons at this energy.

(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.

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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:

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- 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)

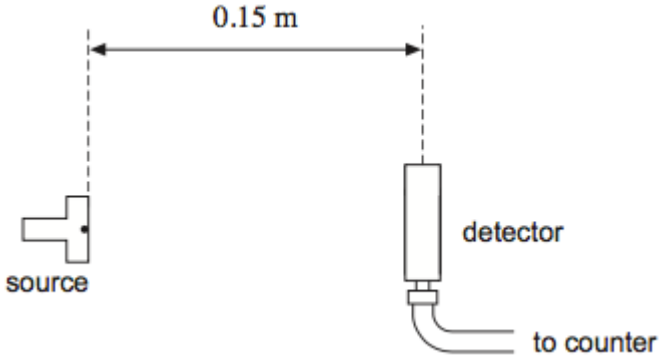
Q25.

(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.

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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.

_____

_____

_____

_____

(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.

_____

_____

_____

_____

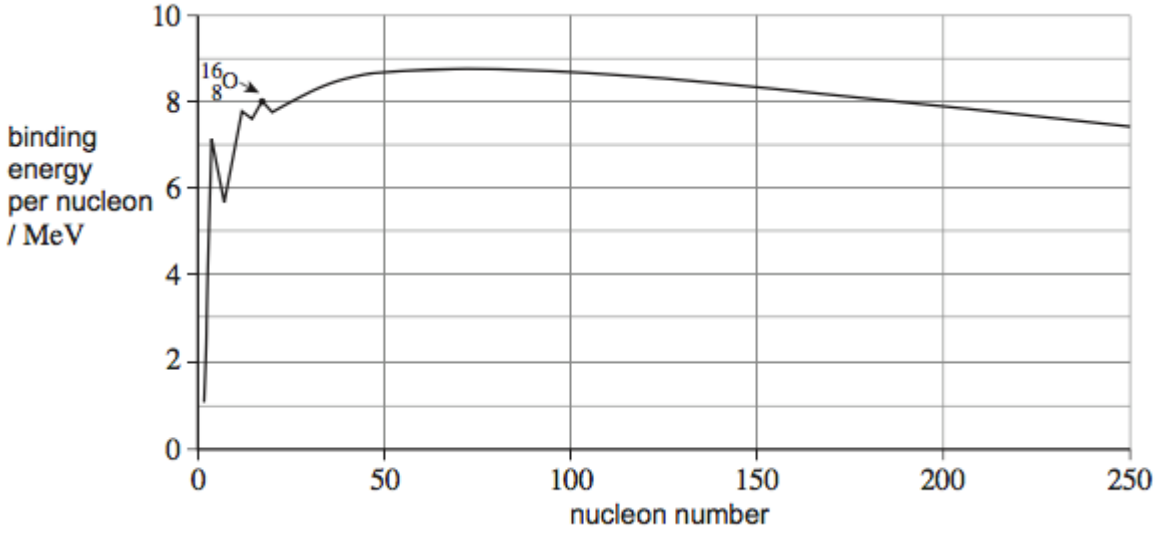
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(2)
(Total 7 marks)

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.

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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.

_____

_____

_____

(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)

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(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.

_____

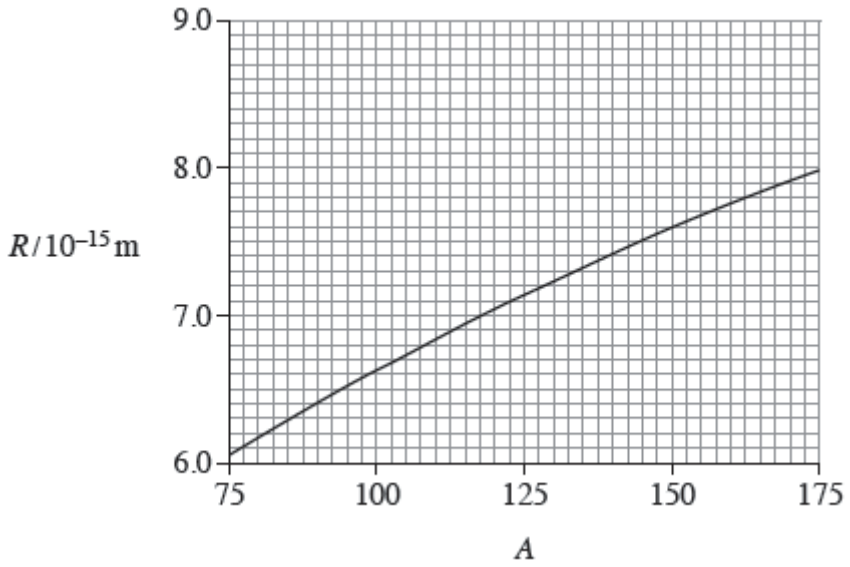
_____

_____

(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.

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(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.

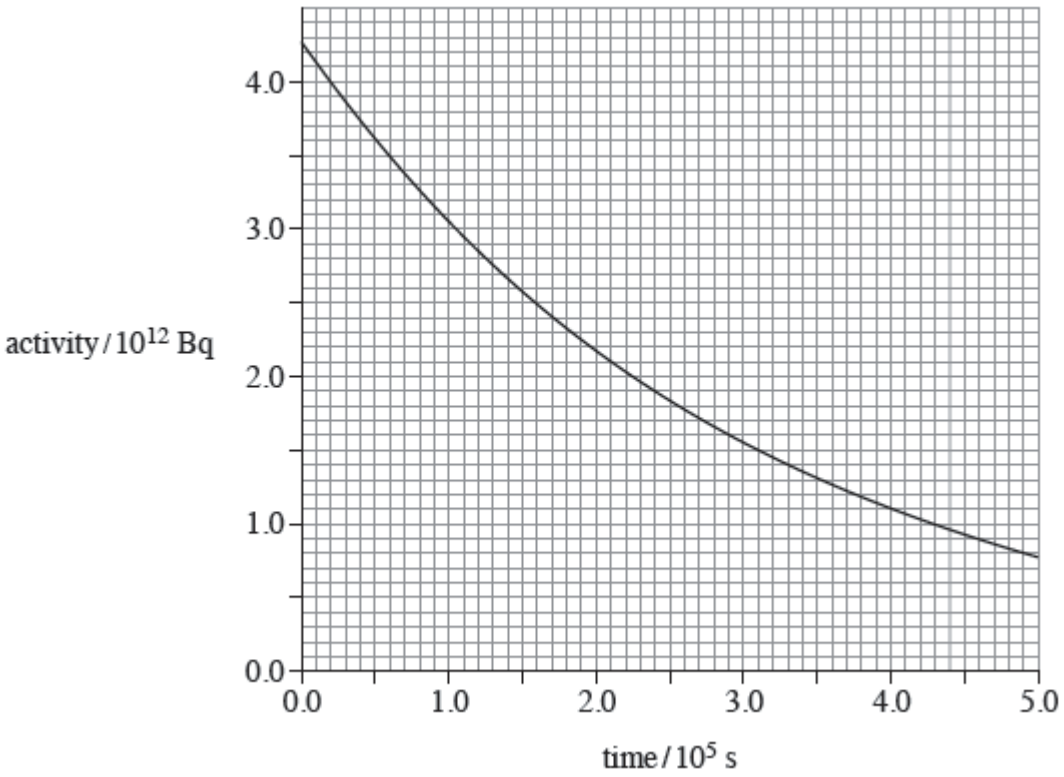
A rod made from uranium−238 ($^{238}_{92}\mathrm{U}$) is placed in the core of a nuclear reactor where it absorbs free neutrons.
When a nucleus of uranium−238 absorbs a neutron it becomes unstable and decays to neptunium−239 ($^{239}_{93}\mathrm{Np}$), which in turn decays to plutonium−239 ($^{293}_{94}\mathrm{Pu}$).

(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.

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(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.

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number of nuclei _____

(1)

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

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

_____

_____

_____

_____

(2)

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

_____

_____

_____

_____

_____

_____

(2)

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

Explain why the shielding becomes radioactive.

_____

_____

_____

_____

(2)

(Total 11 marks)

Q29.

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

_____

_____

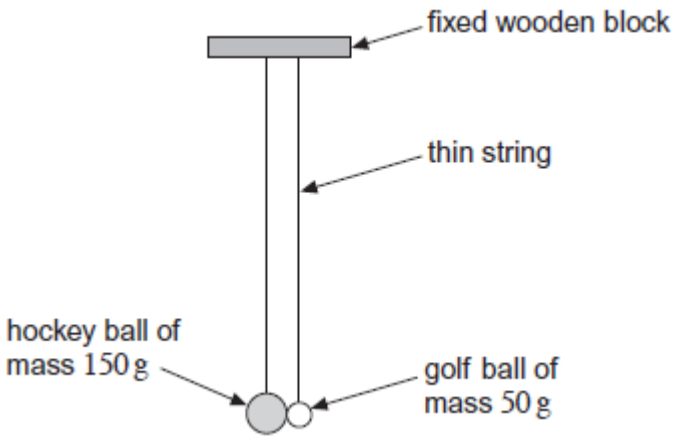
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_____

_____

(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.

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(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.

_____

_____

_____

_____

(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.

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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.

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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)

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