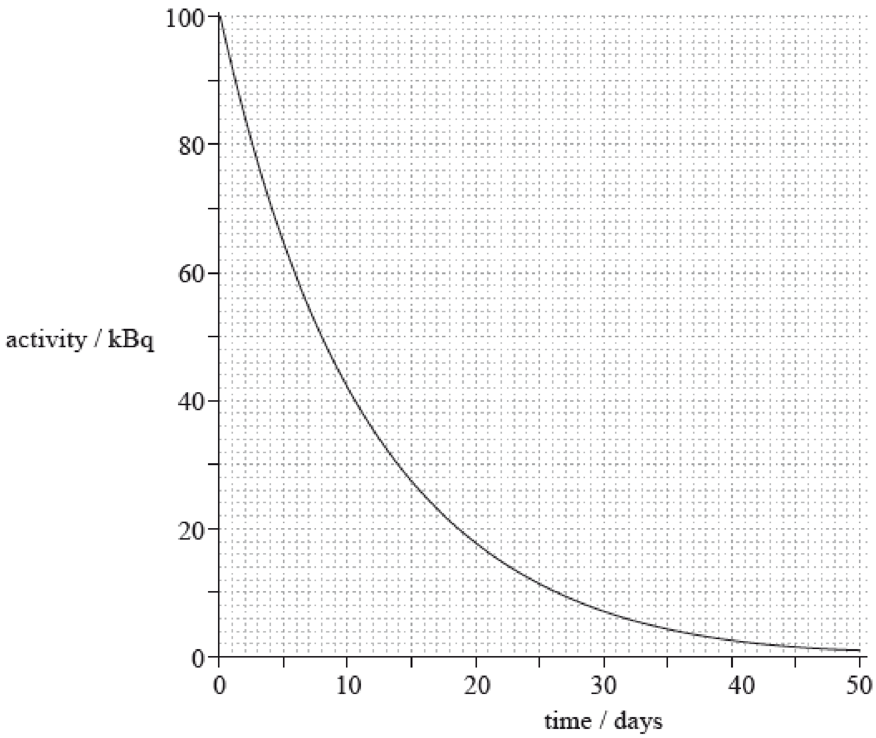
SL Paper 2

This question is about radioactive decay.

A nucleus of an iodine isotope, I-131, undergoes radioactive decay to form a nucleus of the nuclide xenon-131. Xe-131 is stable.

The initial activity of a sample of I-131 is 100 kBq. The subsequent variation of the activity of the sample with time is shown in the graph.



a. Explain what is meant by an isotope. [2]

b. Identify the missing entries to complete the nuclear reaction for the decay of I-131. [1]

$$^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{\ldots\ldots}\mathrm{Xe} + \beta^{-} + \ldots\ldots\ldots\ldots\ldots$$

c.i. The I-131 can be used for a medical application but only when the activity lies within the range of $(20 \pm 10)\ \mathrm{kBq}$. Determine an estimate for the time during which the iodine can be used. [2]

c.ii. A different isotope has half the initial activity and double the half-life of I-131. On the graph in (c), sketch the variation of activity with time for this isotope. [2]

This question is about binding energy and mass defect.

a. State what is meant by mass defect. [1]

b. (i) Data for this question is given below. [6]

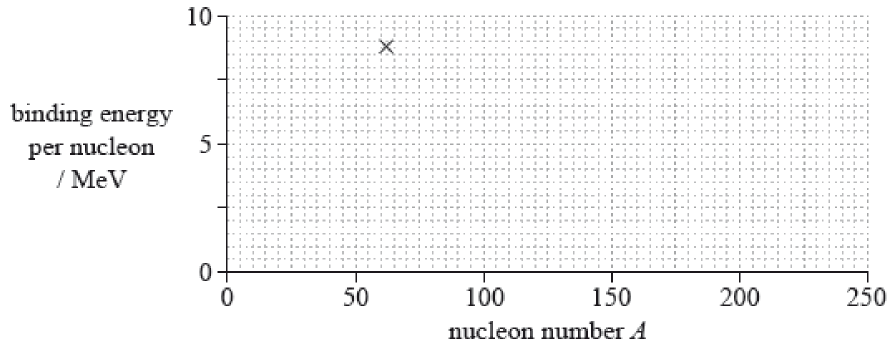
Binding energy per nucleon for deuterium $\left({}_{1}^{2}\mathrm{H}\right)$ is 1.1 MeV.

Binding energy per nucleon for helium-3 $\left({}_{2}^{3}\mathrm{He}\right)$ is 2.6 MeV.

Using the data, calculate the energy change in the following reaction.

$$ {}_{1}^{2}\mathrm{H} + {}_{1}^{1}\mathrm{H} \rightarrow {}_{2}^{3}\mathrm{He} + \gamma $$

(ii) The cross on the grid shows the binding energy per nucleon and nucleon number *A* of the nuclide nickel-62.



On the grid, sketch a graph to show how the average binding energy per nucleon varies with nucleon number *A*.

(iii) State and explain, with reference to your sketch graph, whether energy is released **or** absorbed in the reaction in (b)(i).

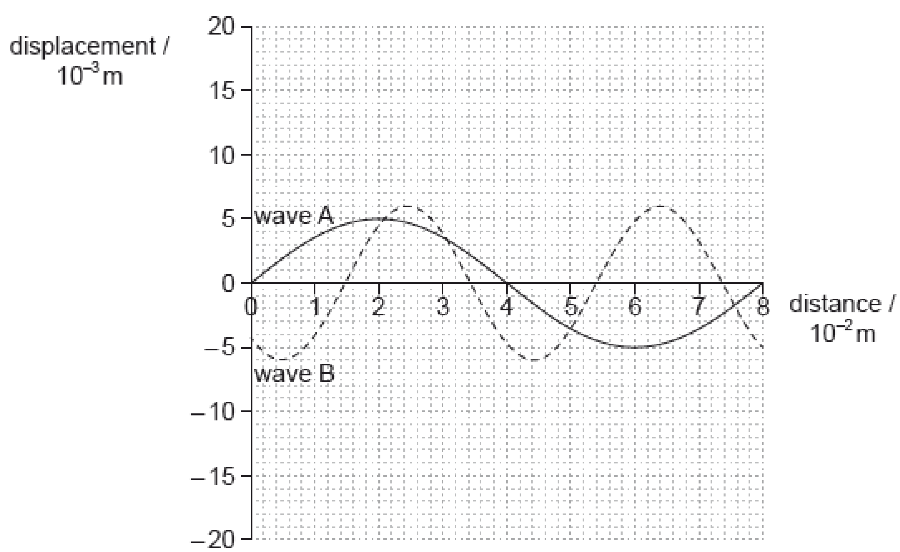
This question is in **two** parts. **Part 1** is about the nuclear model of the atom and radioactive decay. **Part 2** is about waves.

Part 1 Nuclear model of the atom and radioactive decay

The nuclide radium-226 $\left({}_{88}^{226}\mathrm{Ra}\right)$ decays into an isotope of radon (Rn) by the emission of an alpha particle and a gamma-ray photon.

Part 2 Waves

Two waves, A and B, are travelling in opposite directions in a tank of water. The graph shows the variation of displacement of the water surface with distance along the wave at a particular instant.



a. Outline how the evidence supplied by the Geiger–Marsden experiment supports the nuclear model of the atom. [4]

b. Outline why classical physics does not permit a model of an electron orbiting the nucleus. [3]

c.i. State what is meant by the terms nuclide and isotope. [2]

Nuclide:

Isotope:

c.ii. Construct the nuclear equation for the decay of radium-226. [3]

$$^{226}_{88}\text{Ra} \rightarrow {}^{\cdots}_{\cdots}\text{Rn} + {}^{\cdots}_{\cdots}\text{He} + {}^{\cdots}_{\cdots}\gamma$$

c.iii Radium-226 has a half-life of 1600 years. Determine the time, in years, it takes for the activity of radium-226 to fall to $\frac{1}{64}$ of its original activity. [2]

d. State the amplitude of wave A. [1]

e.i. Wave A has a frequency of 9.0 Hz. Calculate the velocity of wave A. [2]

e.ii. Deduce the frequency of wave B. [3]

f.i. State what is meant by the principle of superposition of waves. [2]

f.ii. On the graph opposite, sketch the wave that results from the superposition of wave A and wave B at that instant. [3]

This question is in **two** parts. **Part 1** is about the production of energy in nuclear fission. **Part 2** is about collisions.

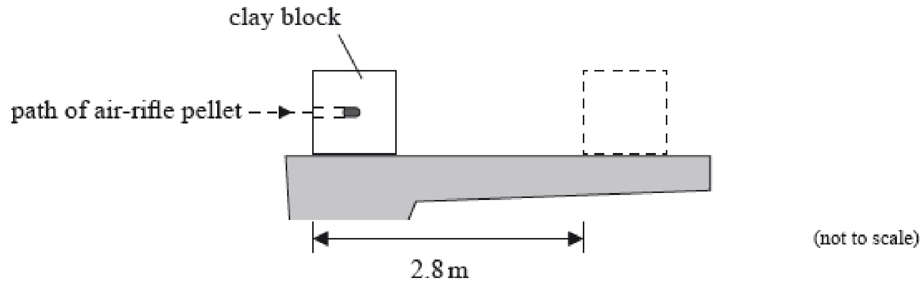
Part 1 Production of energy in nuclear fission

A possible fission reaction is

$$^{235}_{92}U +^{1}_{0} n \rightarrow^{92}_{36} Kr +^{141}_{56} Ba + x^{1}_{0}n.$$

Part 2 Collisions

In an experiment, an air-rifle pellet is fired into a block of modelling clay that rests on a table.



The air-rifle pellet remains inside the clay block after the impact.

As a result of the collision, the clay block slides along the table in a straight line and comes to rest. Further data relating to the experiment are given below.

$$\begin{aligned} &\text{Mass of air - rifle pellet} && = 2.0 \text{ g} \\ &\text{Mass of clay block} && = 56 \text{ g} \\ &\text{Velocity of impact of air - rifle pellet} && = 140 \text{ m s}^{-1} \\ &\text{Stopping distance of clay block} && = 2.8 \text{ m} \end{aligned}$$

Part 1.a. (i) State the value of x. [6]

(ii) Show that the energy released when one uranium nucleus undergoes fission in the reaction in (a) is about 2.8×10^{-11} J.

$$\begin{aligned} &\text{Mass of neutron} && = 1.00867 \text{ u} \\ &\text{Mass of U - 235 nucleus} && = 234.99333 \text{ u} \\ &\text{Mass of Kr - 92 nucleus} && = 91.90645 \text{ u} \\ &\text{Mass of Ba - 141 nucleus} && = 140.88354 \text{ u} \end{aligned}$$

(iii) State how the energy of the neutrons produced in the reaction in (a) is likely to compare with the energy of the neutron that initiated the reaction.

Part 1.b. Outline the role of the moderator. [2]

Part 1.c. A nuclear power plant that uses U-235 as fuel has a useful power output of 16 MW and an efficiency of 40%. Assuming that each fission of U-235 gives rise to 2.8×10^{-11} J of energy, determine the mass of U-235 fuel used per day. [4]

Part 2.a. State the principle of conservation of momentum. [2]

Part 2.b. (i) Show that the initial speed of the clay block after the air-rifle pellet strikes it is 4.8 m s^{-1}. [6]

(ii) Calculate the average frictional force that the surface of the table exerts on the clay block whilst the clay block is moving.

Part 2.c. Discuss the energy transformations that occur in the clay block and the air-rifle pellet from the moment the air-rifle pellet strikes the block until the clay block comes to rest. [3]

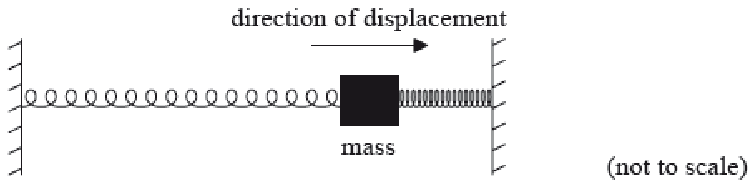
Part 2.d. The clay block is dropped from rest from the edge of the table and falls vertically to the ground. The table is 0.85 m above the ground. Calculate the speed with which the clay block strikes the ground. [2]

This question is in **two** parts. **Part 1** is about the oscillation of a mass. **Part 2** is about nuclear fission.

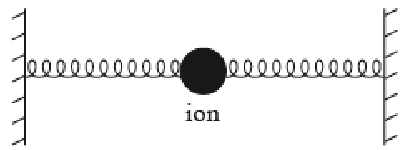
Part 1 Oscillation of a mass

A mass of 0.80 kg rests on a frictionless surface and is connected to two identical springs both of which are fixed at their other ends. A force of 0.030 N is required to extend or compress each spring by 1.0 mm. When the mass is at rest in the centre of the arrangement, the springs are not extended.

The mass is displaced to the right by 60 mm and released.



The motion of an ion in a crystal lattice can be modelled using the mass–spring arrangement. The inter-atomic forces may be modelled as forces due to springs as in the arrangement shown.



The frequency of vibration of a particular ion is 7×10^{12} Hz and the mass of the ion is 5×10^{-26} kg. The amplitude of vibration of the ion is 1×10^{-11} m.

Part 2 Nuclear fission

A reaction that takes place in the core of a particular nuclear reactor is as shown.

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{144}_{56}\text{Ba} + ^{89}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

In the nuclear reactor, 9.5×10^{19} fissions take place every second. Each fission gives rise to 200 MeV of energy that is available for conversion to electrical energy. The overall efficiency of the nuclear power station is 32%.

In addition to the U-235, the nuclear reactor contains a moderator and control rods. Explain the function of the

a.i. Determine the acceleration of the mass at the moment of release. [3]

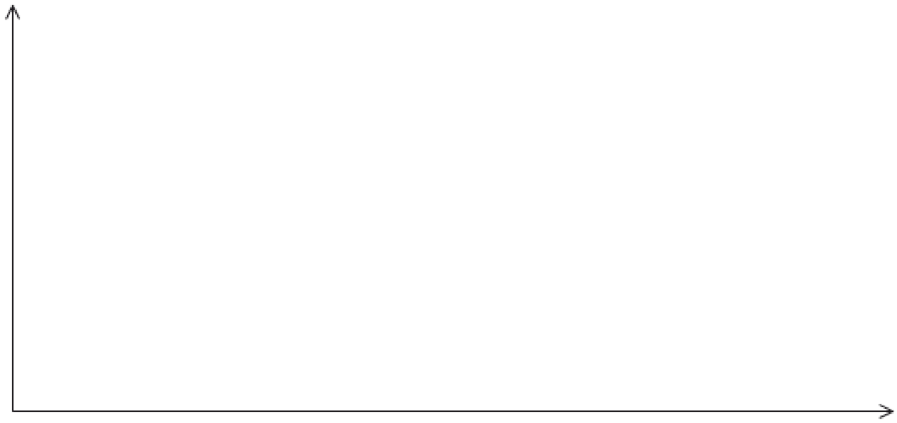
a.ii. Outline why the mass subsequently performs simple harmonic motion (SHM). [2]

a.iii Calculate the period of oscillation of the mass. [2]

b.i. Estimate the maximum kinetic energy of the ion. [2]

b.ii. On the axes, draw a graph to show the variation with time of the kinetic energy of mass and the elastic potential energy stored in the springs. [3]

You should add appropriate values to the axes, showing the variation over one period.



c.i. Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). [1]

d.i. Determine the mass of U-235 that undergoes fission in the reactor every day. [3]

d.ii. Calculate the power output of the nuclear power station. [2]

e.i. moderator. [3]

e.ii. control rods. [2]

This question is about nuclear reactions.

a. The nuclide U-235 is an isotope of uranium. A nucleus of U-235 undergoes radioactive decay to a nucleus of thorium-231 (Th-231). The proton number of uranium is 92. [3]

(i) State what is meant by the terms nuclide and isotope.

Nuclide:

Isotope:

(ii) One of the particles produced in the decay of a nucleus of U-235 is a gamma photon. State the name of another particle that is also produced.

b. The daughter nuclei of U-235 undergo radioactive decay until eventually a stable isotope of lead is reached. [3]

Explain why the nuclei of U-235 are unstable whereas the nuclei of the lead are stable.

c. Nuclei of U-235 bombarded with low energy neutrons can undergo nuclear fission. The nuclear reaction equation for a particular fission is shown below. [3]

$$^{1}_{0}\mathrm{n} + ^{235}_{92}\mathrm{U} \rightarrow ^{144}_{56}\mathrm{Ba} + ^{89}_{36}\mathrm{Kr} + 3^{1}_{0}\mathrm{n}$$

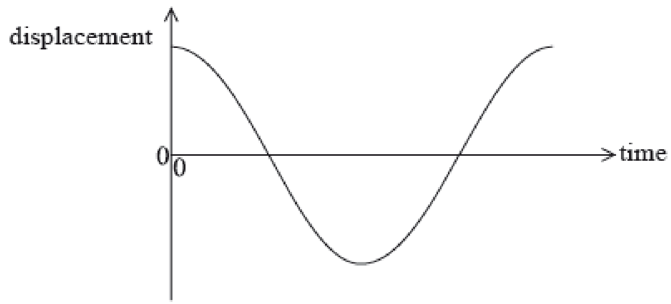
Show, using the following data, that the kinetic energy of the fission products is about 200 MeV.

Mass of nucleus of U-235 = 235.04393 u
Mass of nucleus of Ba-144 = 143.922952 u
Mass of nucleus of Kr-89 = 88.91763 u
Mass of neutron = 1.00867 u

This question is in **two** parts. **Part 1** is about a simple pendulum. **Part 2** is about the Rutherford model of the atom.

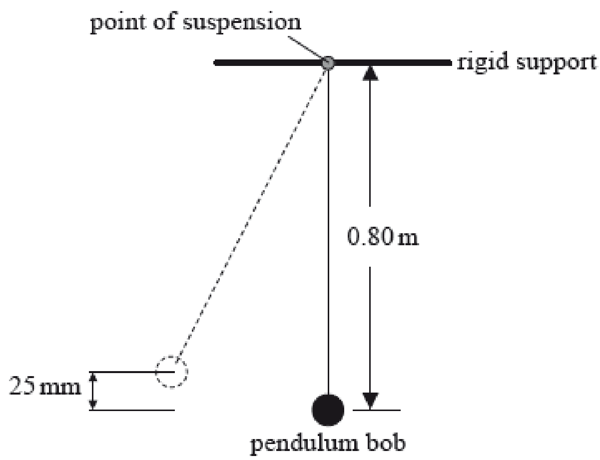
Part 1 Simple pendulum

A pendulum consists of a bob suspended by a light inextensible string from a rigid support. The pendulum bob is moved to one side and then released. The sketch graph shows how the displacement of the pendulum bob undergoing simple harmonic motion varies with time over one time period.

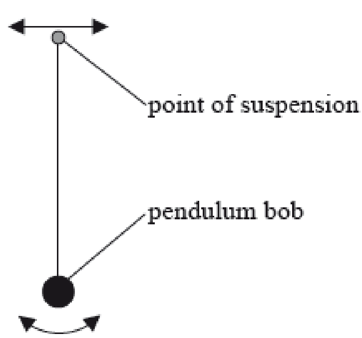


On the sketch graph above,

A pendulum bob is moved to one side until its centre is 25 mm above its rest position and then released.



The point of suspension of a pendulum bob is moved from side to side with a small amplitude and at a variable driving frequency f.



For each value of the driving frequency a steady constant amplitude A is reached. The oscillations of the pendulum bob are lightly damped.

Part 2 Rutherford model of the atom

The isotope gold-197 $\left({}^{197}_{79}Au\right)$ is stable but the isotope gold-199 $\left({}^{199}_{79}Au\right)$ is not.

Part 1.a. (i) label with the letter A a point at which the acceleration of the pendulum bob is a maximum. [2]

(ii) label with the letter V a point at which the speed of the pendulum bob is a maximum.

Part 1.b. Explain why the magnitude of the tension in the string at the midpoint of the oscillation is greater than the weight of the pendulum bob. [3]

Part 1.c. (i) Show that the speed of the pendulum bob at the midpoint of the oscillation is $0.70\ \mathrm{m\,s^{-1}}$. [5]

(ii) The mass of the pendulum bob is 0.057 kg. The centre of the pendulum bob is 0.80 m below the support. Calculate the magnitude of the tension in the string when the pendulum bob is vertically below the point of suspension.

Part 1.d. (i) On the axes below, sketch a graph to show the variation of A with f. [4]

(ii) Explain, with reference to the graph in (d)(i), what is meant by resonance.

Part 1.e. The pendulum bob is now immersed in water and the variable frequency driving force in (d) is again applied. Suggest the effect this immersion of the pendulum bob will have on the shape of your graph in (d)(i). [2]

Part 2.a. Most alpha particles used to bombard a thin gold foil pass through the foil without a significant change in direction. A few alpha particles are deviated from their original direction through angles greater than 90°. Use these observations to describe the Rutherford atomic model. [5]

Part 2.b. (i) Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. [4]

(ii) A nucleus of ${}^{199}_{79}\mathrm{Au}$ decays to a nucleus of ${}^{199}_{80}\mathrm{Hg}$ with the emission of an electron and another particle. State the name of this other particle.

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a. A nuclide of deuterium $\left({}^{2}_{1}\mathrm{H}\right)$ and a nuclide of tritium $\left({}^{3}_{1}\mathrm{H}\right)$ undergo nuclear fusion. [5]

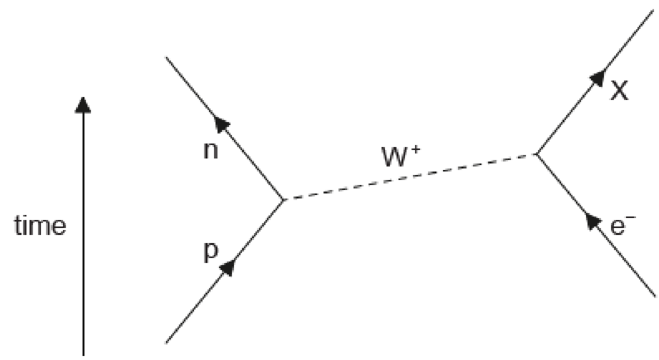
(i) Each fusion reaction releases 2.8×10^{-12}J of energy. Calculate the rate, in kg s^{-1}, at which tritium must be fused to produce a power output of 250 MW.

(ii) State **two** problems associated with sustaining this fusion reaction in order to produce energy on a commercial scale.

b. Tritium is a radioactive nuclide with a half-life of 4500 days. It decays to an isotope of helium. [3]

Determine the time at which 12.5% of the tritium remains undecayed.

The Feynman diagram shows electron capture.



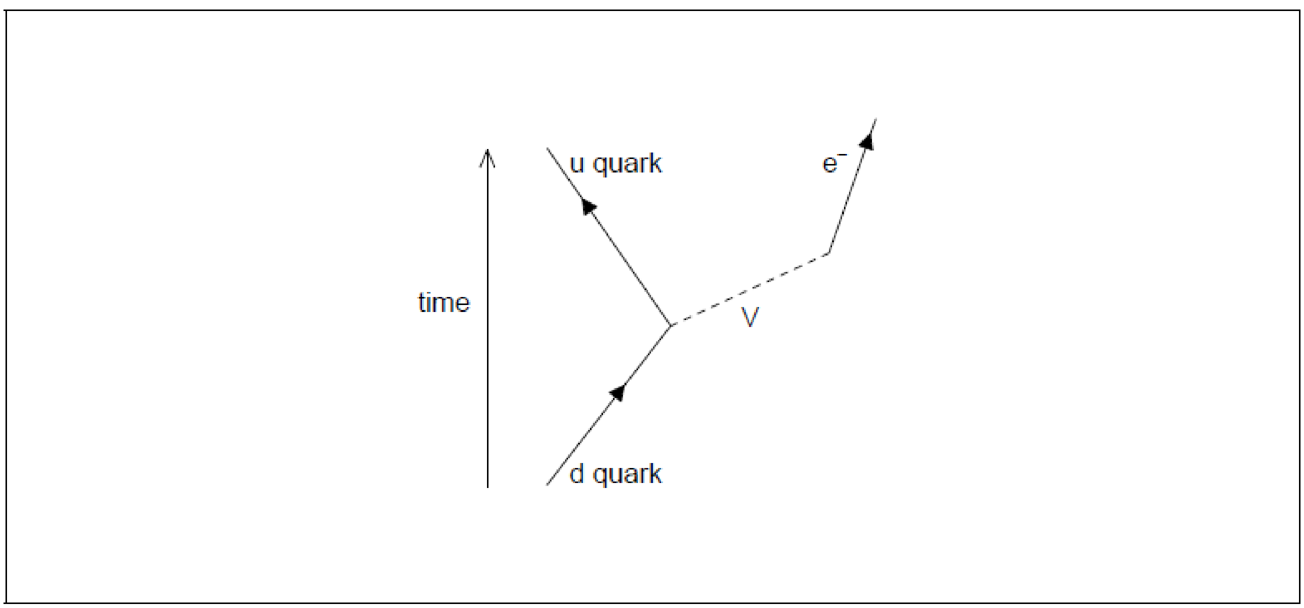
a. Deduce that X must be an electron neutrino. [2]

b. Distinguish between hadrons and leptons. [2]

Rhodium-106 ($^{106}_{45}\mathrm{Rh}$) decays into palladium-106 ($^{106}_{46}\mathrm{Pd}$) by beta minus (β^-) decay.

The binding energy per nucleon of rhodium is 8.521 MeV and that of palladium is 8.550 MeV.

β^- decay is described by the following incomplete Feynman diagram.



a. Rutherford constructed a model of the atom based on the results of the alpha particle scattering experiment. Describe this model. [2]

b.i. State what is meant by the binding energy of a nucleus. [1]

b.ii. Show that the energy released in the β^- decay of rhodium is about 3 MeV. [1]

c.i. Draw a labelled arrow to complete the Feynman diagram. [1]

c.ii. Identify particle V. [1]

This question is in **two** parts. **Part 1** is about a nuclear reactor. **Part 2** is about simple harmonic oscillations.

Part 1 Nuclear reactor

b. The reactor produces 24 MW of power. The efficiency of the reactor is 32 %. In the fission of one uranium-235 nucleus 3.2×10^{-11}J of energy is released. [4]

Determine the mass of uranium-235 that undergoes fission in one year in this reactor.

c. Explain what would happen if the moderator of this reactor were to be removed. [3]

d. During its normal operation, the following set of reactions takes place in the reactor. [3]

$^{1}_{0}\mathrm{n} + ^{238}_{92}\mathrm{U} \rightarrow ^{239}_{92}\mathrm{U}$ (I)

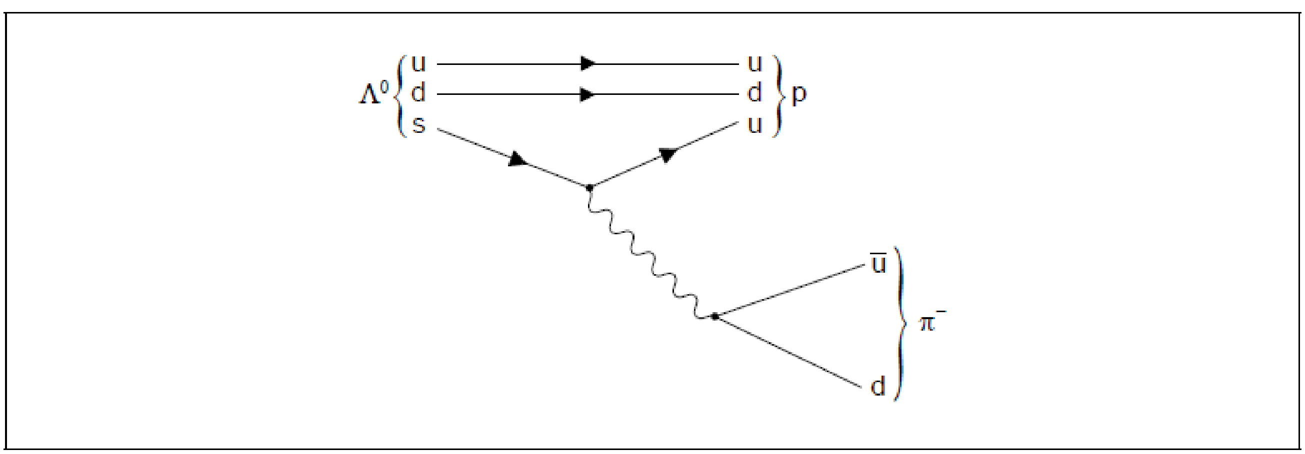
$^{239}_{92}\mathrm{U} \rightarrow ^{239}_{93}\mathrm{Np} + ^{0}_{-1}e + \bar{v}$ (II)

$^{239}_{93}\mathrm{Np} \rightarrow ^{239}_{94}\mathrm{Pu} + ^{0}_{-1}e + \bar{v}$ (III)

(i) State the name of the process represented by reaction (II).

(ii) Comment on the international implications of the product of these reactions.

A possible decay of a lambda particle (Λ^0) is shown by the Feynman diagram.



a. State the quark structures of a meson and a baryon. [2]

Meson: ....

....

Baryon: ....

....

b.i. Explain which interaction is responsible for this decay. [2]

b.ii. Draw arrow heads on the lines representing $\bar{u}$ and d in the π^{-}. [1]

b.iii. Identify the exchange particle in this decay. [1]

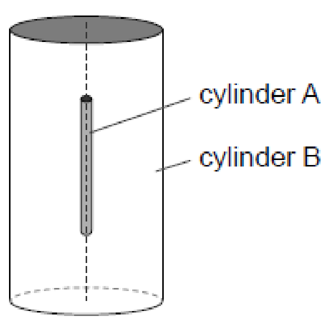
c. Outline **one** benefit of international cooperation in the construction or use of high-energy particle accelerators. [1]

The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 ($^{226}_{86}\mathrm{Ra}$) decays by alpha emission to form a nuclide known as radon (Rn).

a. Write down the missing values in the nuclear equation for this decay. [1]

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{\cdots\cdots}_{86}\mathrm{Rn} + {}^{\cdots\cdots}_{2}\alpha$$

b. Rutherford and Royds put some pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B. [1]



At the start of the experiment all the air was removed from cylinder B. The alpha particles combined with electrons as they moved through the wall of cylinder A to form helium gas in cylinder B.

The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin.

c. Rutherford and Royds expected 2.7×10^{15} alpha particles to be emitted during the experiment. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3×10^{-5} m^3 and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B. [3]

d. Rutherford and Royds identified the helium gas in cylinder B by observing its emission spectrum. Outline, with reference to atomic energy levels, how an emission spectrum is formed. [3]

e. The work was first reported in a peer-reviewed scientific journal. Outline why Rutherford and Royds chose to publish their work in this way. [1]

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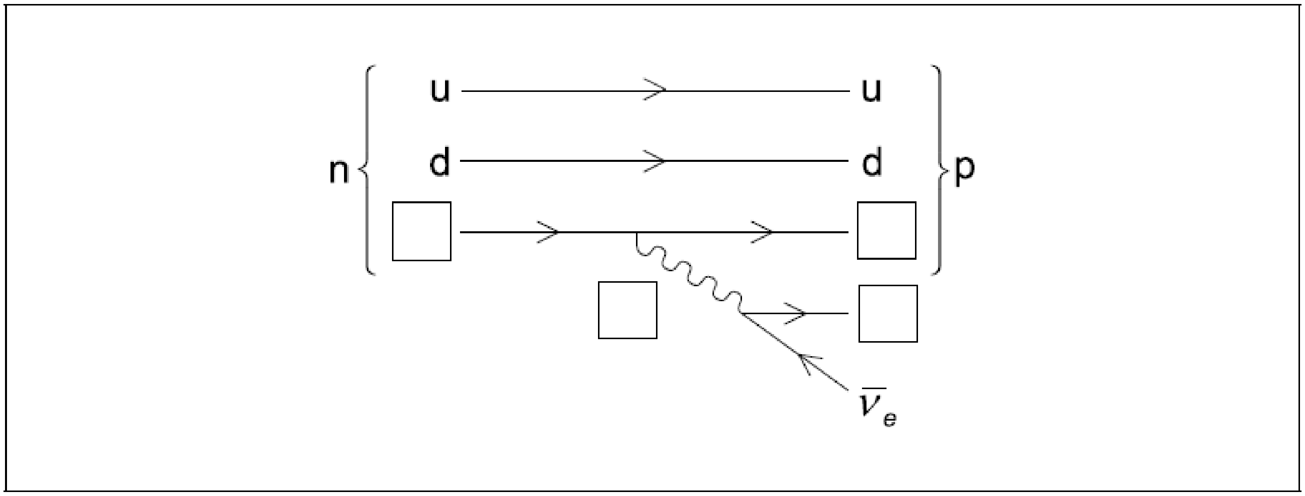
a. A particular K meson has a quark structure $\bar{u}s$. State the charge on this meson. [1]

b. The Feynman diagram shows the changes that occur during beta minus (β^-) decay. [2]



Label the diagram by inserting the **four** missing particle symbols.

c. Carbon-14 (C-14) is a radioactive isotope which undergoes beta minus (β^-) decay to the stable isotope nitrogen-14 (N-14). Energy is released during this decay. Explain why the mass of a C-14 nucleus and the mass of a N-14 nucleus are slightly different even though they have the same nucleon number. [2]

This question is about radioactivity.

Caesium-137 $\left({}^{137}_{55}\text{Cs}\right)$ is a radioactive waste product with a half-life of 30 years that is formed during the fission of uranium. Caesium-137 decays by the emission of a beta-minus (β^-) particle to form a nuclide of barium (Ba).

a. State the nuclear equation for this reaction. [2]

$${}^{137}_{55}\text{Cs} \rightarrow {}^{\dots\dots}_{\dots\dots}\text{Ba} + {}^{0}_{-1}\beta^{-} + \dots\dots\dots$$

b. Determine the fraction of caesium-137 that will have decayed after 120 years. [2]

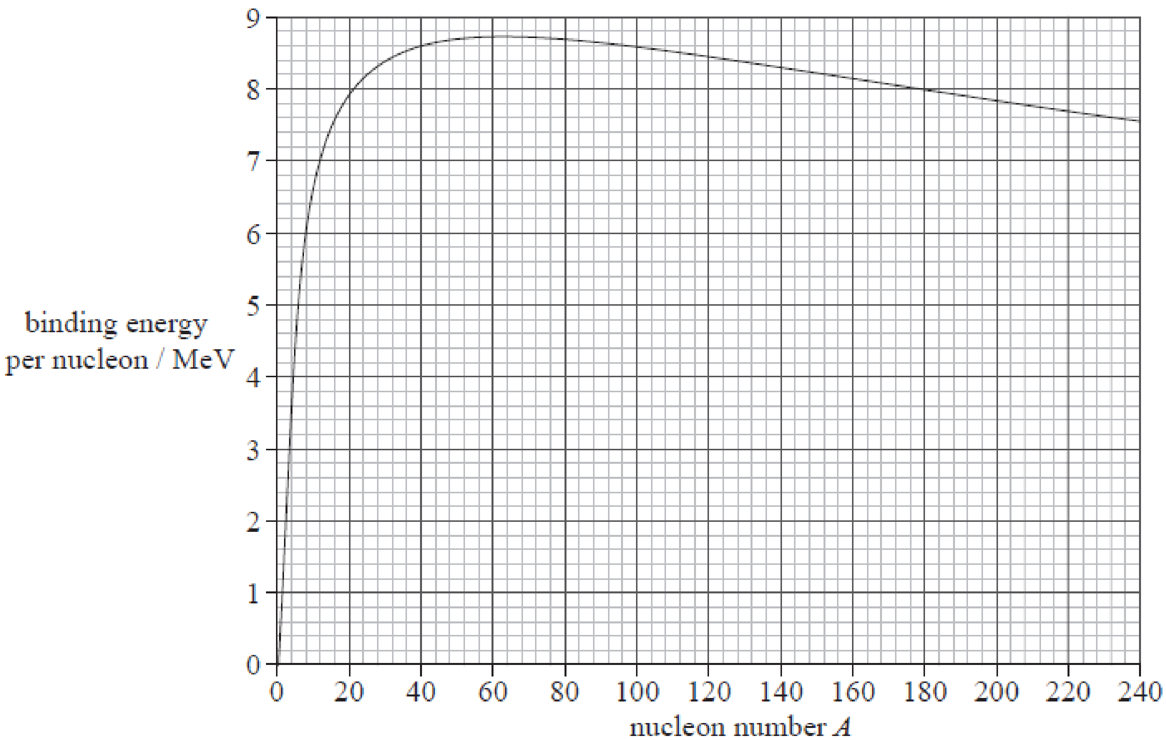
c. Explain, with reference to the biological effects of ionizing radiation, why it is important that humans should be shielded from the radiation emitted by caesium-137. [2]

Part 2 Nuclear physics

a. (i) Define *binding energy* of a nucleus. [4]

(ii) The mass of a nucleus of plutonium $\left({}^{239}_{94}\mathrm{Pu}\right)$ is 238.990396 u. Deduce that the binding energy per nucleon for plutonium is 7.6 MeV.

b. The graph shows the variation with nucleon number *A* of the binding energy per nucleon. [3]



Plutonium $\left({}^{239}_{94}\mathrm{Pu}\right)$ undergoes nuclear fission according to the reaction given below.

$${}^{239}_{94}\mathrm{Pu} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{91}_{38}\mathrm{Sr} + {}^{146}_{56}\mathrm{Ba} + x{}^{1}_{0}\mathrm{n}$$

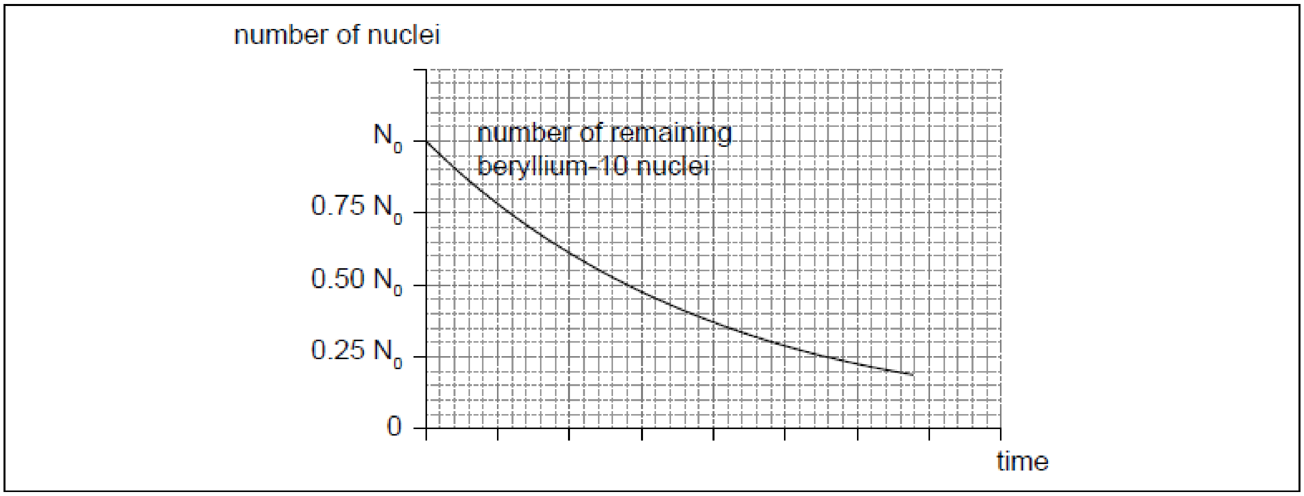
(i) Calculate the number *x* of neutrons produced.

(ii) Use the graph to estimate the energy released in this reaction.

c. Stable nuclei with a mass number greater than about 20, contain more neutrons than protons. By reference to the properties of the nuclear force and of the electrostatic force, suggest an explanation for this observation. [4]

The radioactive nuclide beryllium-10 (Be-10) undergoes beta minus (*β*–) decay to form a stable boron (B) nuclide.

The initial number of nuclei in a pure sample of beryllium-10 is N_0. The graph shows how the number of remaining **beryllium** nuclei in the sample varies with time.



An ice sample is moved to a laboratory for analysis. The temperature of the sample is –20 °C.

a. Identify the missing information for this decay. [1]

$$^{10}_{\square}\text{Be} \rightarrow {}^{\square}_{5}\text{B} + \beta + \overline{\upsilon}$$

b.i. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. [2]

b.ii After 4.3×10^6 years, [3]

$$\frac{\text{number of produced boron nuclei}}{\text{number of remaining beryllium nuclei}} = 7.$$

Show that the half-life of beryllium-10 is 1.4×10^6 years.

b.iii Beryllium-10 is used to investigate ice samples from Antarctica. A sample of ice initially contains 7.6×10^{11} atoms of beryllium-10. State the number of remaining beryllium-10 nuclei in the sample after 2.8×10^6 years. [1]

c.i. State what is meant by thermal radiation. [1]

c.ii. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. [2]

c.iii Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. [2]

c.iv Derive the units of intensity in terms of fundamental SI units. [2]

Part 2 Radioactive decay

a. Describe the phenomenon of natural radioactive decay. [3]

b. A nucleus of americium-241 (Am-241) decays into a nucleus of neptunium-237 (Np-237) in the following reaction. [7]

$$^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{X}\mathrm{Np} + {}^{4}_{2}\alpha$$

(i) State the value of *X*.

(ii) Explain in terms of mass why energy is released in the reaction in (b).

(iii) Define *binding energy* of a nucleus.

(iv) The following data are available.

Nuclide	Binding energy per nucleon / MeV
americium-241	7.54
neptunium-237	7.58
helium-4	7.07

Determine the energy released in the reaction in (b).

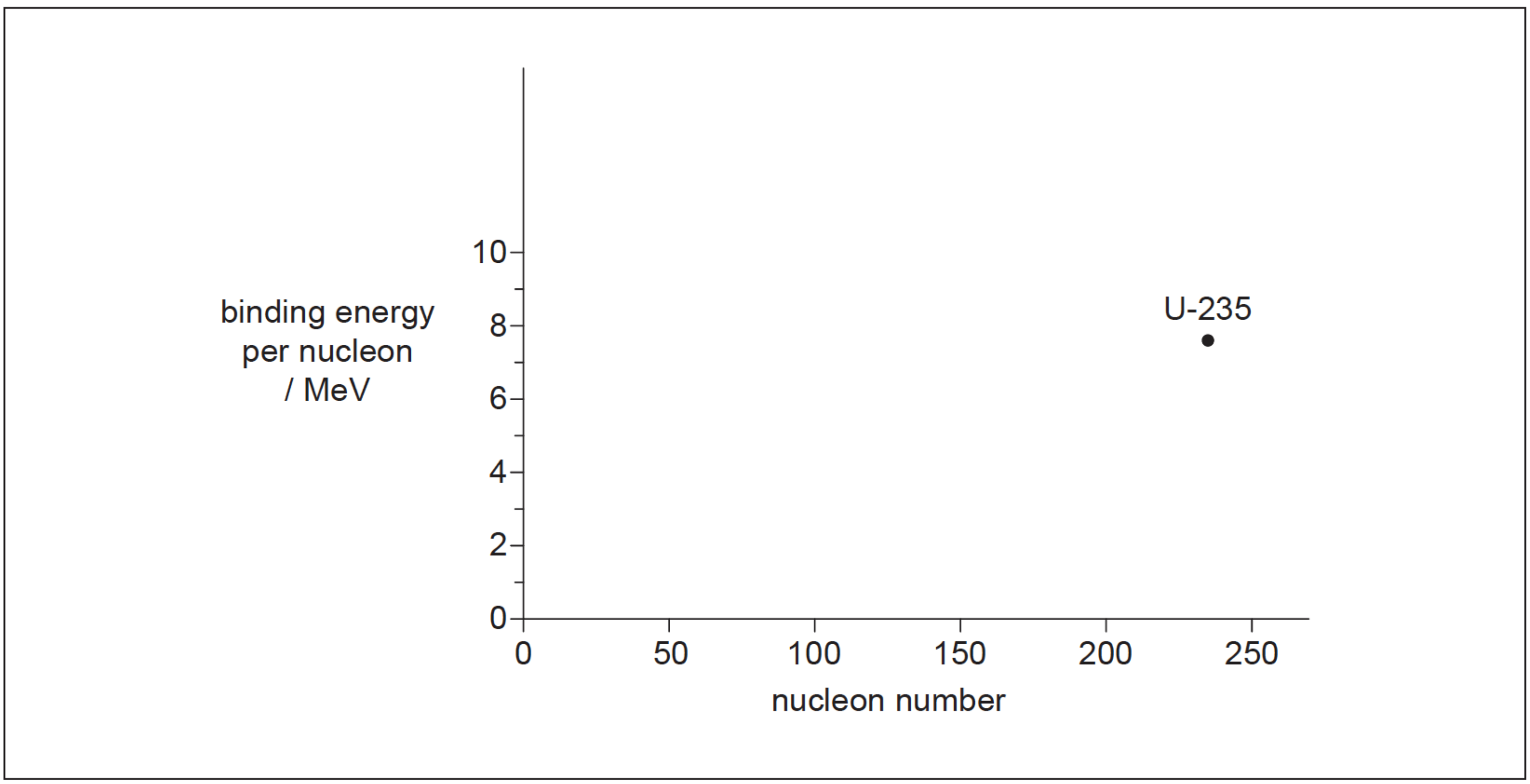
This question is in two parts. **Part 1** is about renewable energy. **Part 2** is about nuclear energy and radioactivity.

Part 1 Renewable energy

A small coastal community decides to use a wind farm consisting of five identical wind turbines to generate part of its energy. At the proposed site, the average wind speed is 8.5ms^{-1} and the density of air is 1.3kgm^{-3}. The maximum power required from the wind farm is 0.75 MW. Each turbine has an efficiency of 30%.

Part 2 Nuclear energy and radioactivity

The graph shows the variation of binding energy per nucleon with nucleon number. The position for uranium-235 (U-235) is shown.



a. (i) Determine the diameter that will be required for the turbine blades to achieve the maximum power of 0.75 MW. [8]

(ii) State **one** reason why, in practice, a diameter larger than your answer to (a)(i) is required.

(iii) Outline why the individual turbines should not be placed close to each other.

(iv) Some members of the community propose that the wind farm should be located at sea rather than on land. Evaluate this proposal.

b. Currently, a nearby coal-fired power station generates energy for the community. Less coal will be burnt at the power station if the wind farm is constructed. [7]

(i) The energy density of coal is 35 MJ kg^{-1}. Estimate the minimum mass of coal that can be saved every hour when the wind farm is producing its full output.

(ii) One advantage of the reduction in coal consumption is that less carbon dioxide will be released into the atmosphere. State **one** other advantage and **one** disadvantage of constructing the wind farm.

(iii) Suggest the likely effect on the Earth's temperature of a reduction in the concentration of atmospheric greenhouse gases.

c. State what is meant by the binding energy of a nucleus. [1]

d. (i) On the axes, sketch a graph showing the variation of nucleon number with the binding energy per nucleon. [5]

(ii) Explain, with reference to your graph, why energy is released during fission of U-235.

e. U-235 $\left({}^{235}_{92}\mathrm{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th). [4]

(i) State the nuclear equation for this decay.

(ii) Define the term *radioactive half-life*.

(iii) A sample of rock contains a mass of 5.6 mg of U-235 at the present day. The half-life of U-235 is 7.0×10^{8} years. Calculate the initial mass of the U-235 if the rock sample was formed 2.1×10^{9} years ago.

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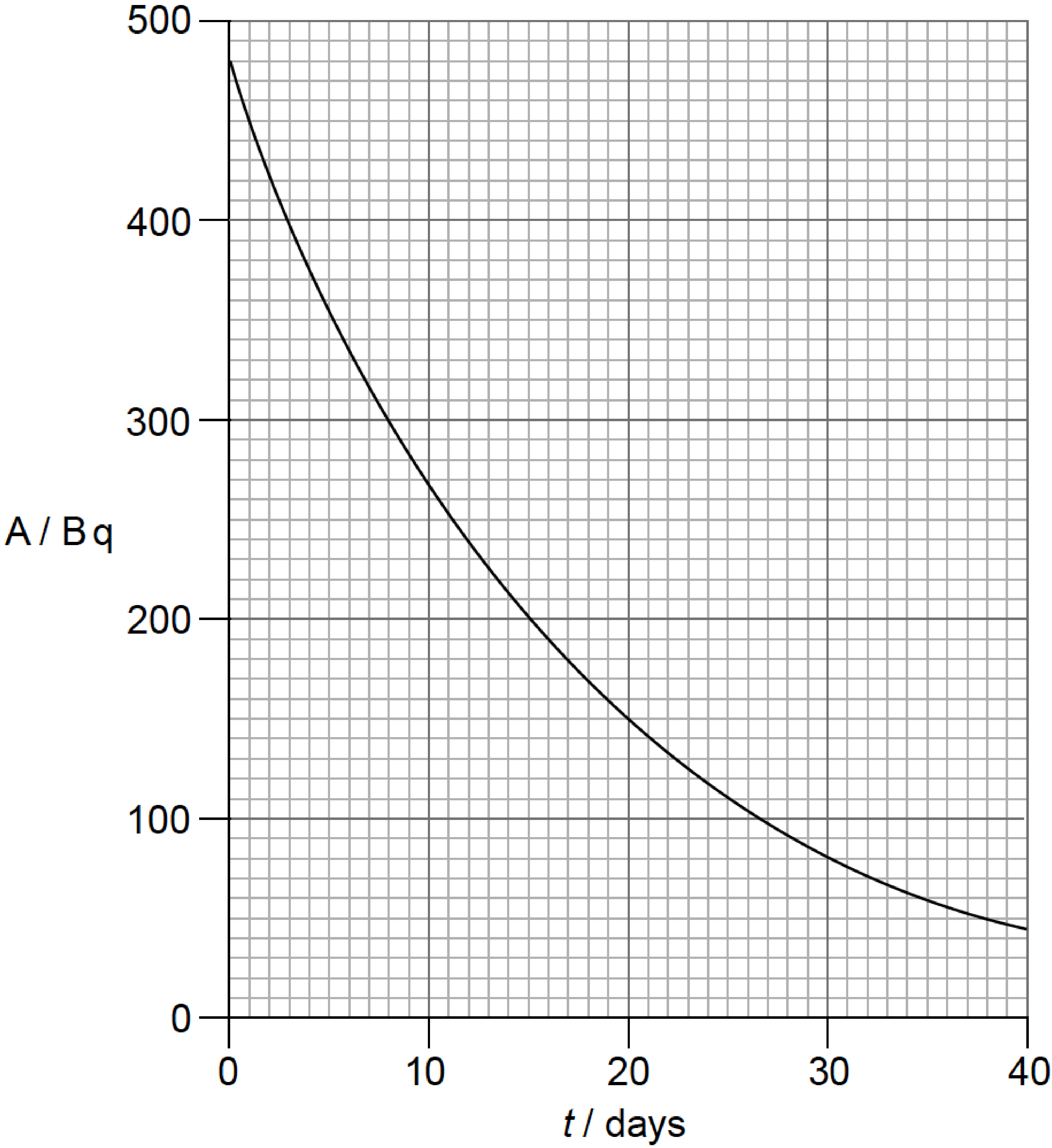
a. A nucleus of phosphorus-32 $\left({}^{32}_{15}\mathrm{P}\right)$ decays by beta minus (β^{-}) decay into a nucleus of sulfur-32 $\left({}^{32}_{16}\mathrm{S}\right)$. The binding energy per nucleon of ${}^{32}_{15}\mathrm{P}$ is 8.398 MeV and for ${}^{32}_{16}\mathrm{S}$ it is 8.450 MeV. [2]

Determine the energy released in this decay.

b. The graph shows the variation with time *t* of the activity A of a sample containing phosphorus-32 $\left({}^{32}_{15}\mathrm{P}\right)$. [1]

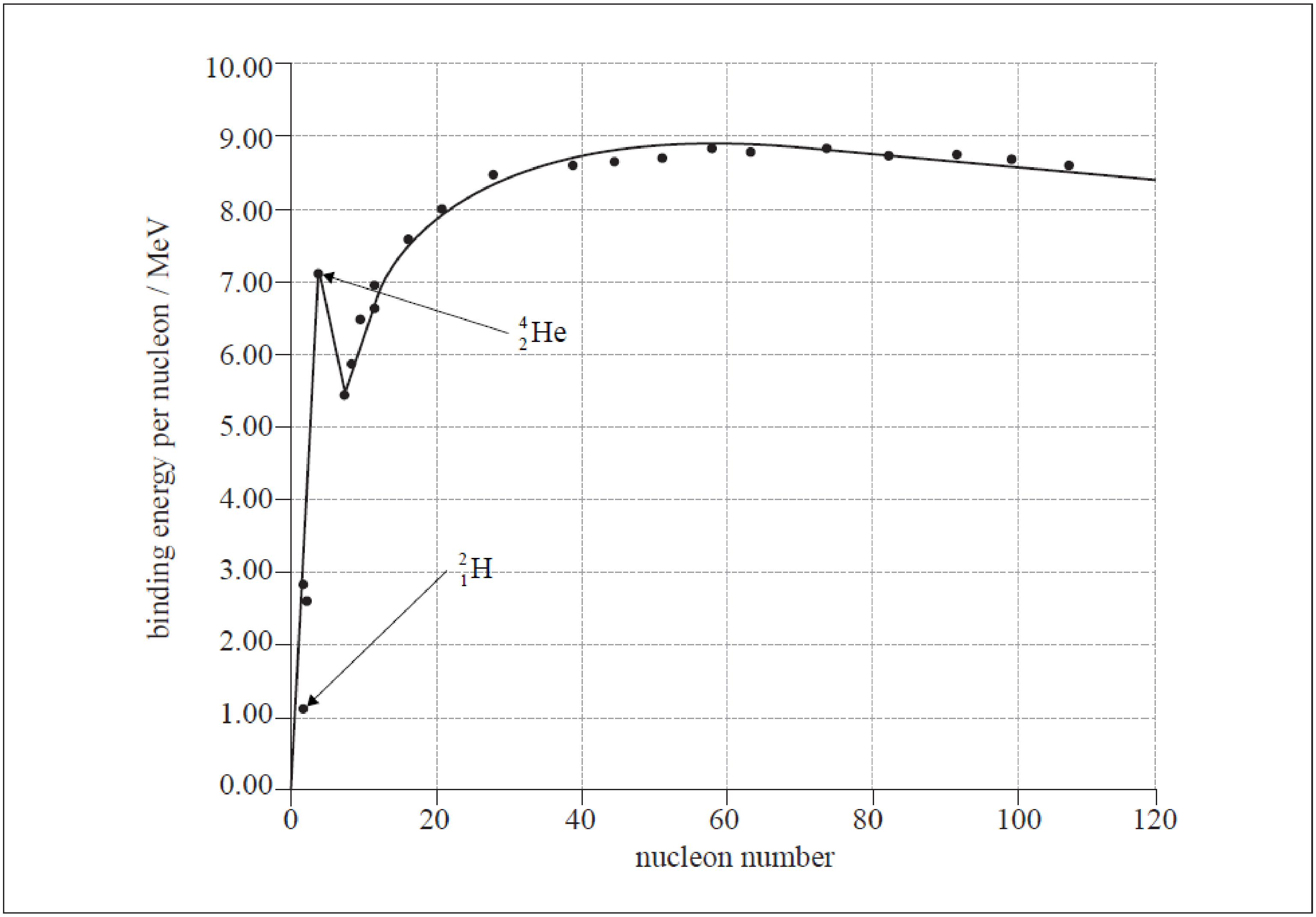


Determine the half-life of ${}^{32}_{15}\mathrm{P}$.

c. Quarks were hypothesized long before their existence was experimentally verified. Discuss the reasons why physicists developed a theory that involved quarks. [3]

Nuclear fusion

The diagram shows the variation of nuclear binding energy per nucleon with nucleon number for some of the lighter nuclides.



a. (i) Outline, with reference to mass defect, what is meant by the term nuclear binding energy. [7]

(ii) Label, with the letter **S**, the region on the graph where nuclei are most stable.

(iii) Show that the energy released when two $^{2}_{1}\text{H}$ nuclei fuse to make a $^{4}_{2}\text{He}$ nucleus is approximately 4pJ.

b. In one nuclear reaction two deuterons (hydrogen-2) fuse to form tritium (hydrogen-3) and another particle. The tritium undergoes β^{-} decay to form an isotope of helium. [7]

(i) Identify the missing particles to complete the equations.

$$^{2}_{1}\text{H} + ^{2}_{1}\text{H} \rightarrow ^{3}_{1}\text{H} + ^{\cdots}_{\cdots}\ldots\ldots$$

$$^{3}_{1}\text{H} \rightarrow ^{3}_{\cdots}\text{He} + ^{\cdots}_{\cdots}\ldots\ldots + ^{\cdots}_{\cdots}\ldots\ldots$$

(ii) Explain which of these reactions is more likely to occur at high temperatures.

This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about change of phase.

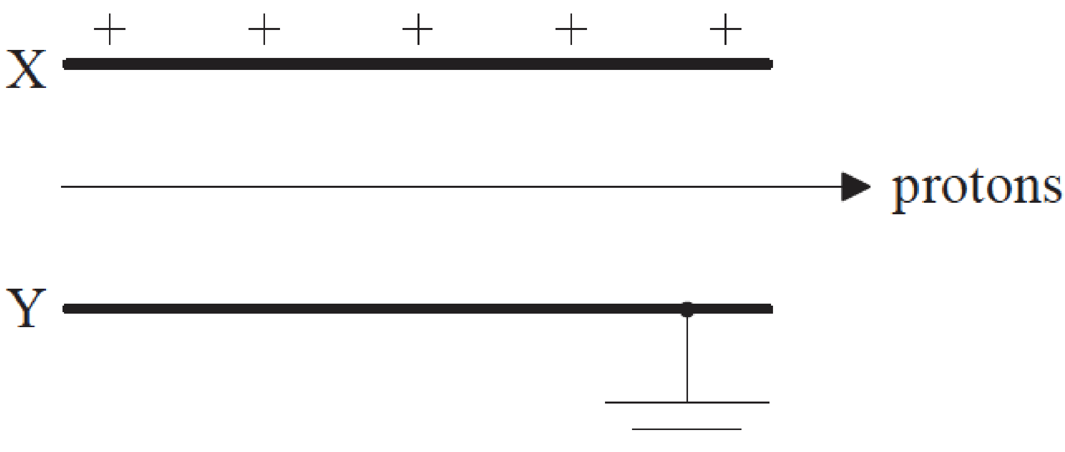
Part 1 Electric fields and radioactive decay

Part 2 Change of phase

a. Define *electric field strength*. [2]

b. A simple model of the proton is that of a sphere of radius 1.0×10^{-15}m with charge concentrated at the centre of the sphere. Estimate the magnitude of the field strength at the surface of the proton. [2]

c. Protons travelling with a speed of $3.9\times10^{6}\text{ms}^{-1}$ enter the region between two charged parallel plates X and Y. Plate X is positively charged and plate Y is connected to earth. [4]



A uniform magnetic field also exists in the region between the plates. The direction of the field is such that the protons pass between the plates without deflection.

(i) State the direction of the magnetic field.

(ii) The magnitude of the magnetic field strength is 2.3×10^{-4}T. Determine the magnitude of the electric field strength between the plates, stating an appropriate unit for your answer.

d. Protons can be produced by the bombardment of nitrogen-14 nuclei with alpha particles. The nuclear reaction equation for this process is given below. [1]

$$^{14}_{7}\text{N} + {}^{4}_{2}\text{He} \rightarrow \text{X} + {}^{1}_{1}\text{H}$$

Identify the proton number and nucleon number for the nucleus X.

e. The following data are available for the reaction in (d). [3]

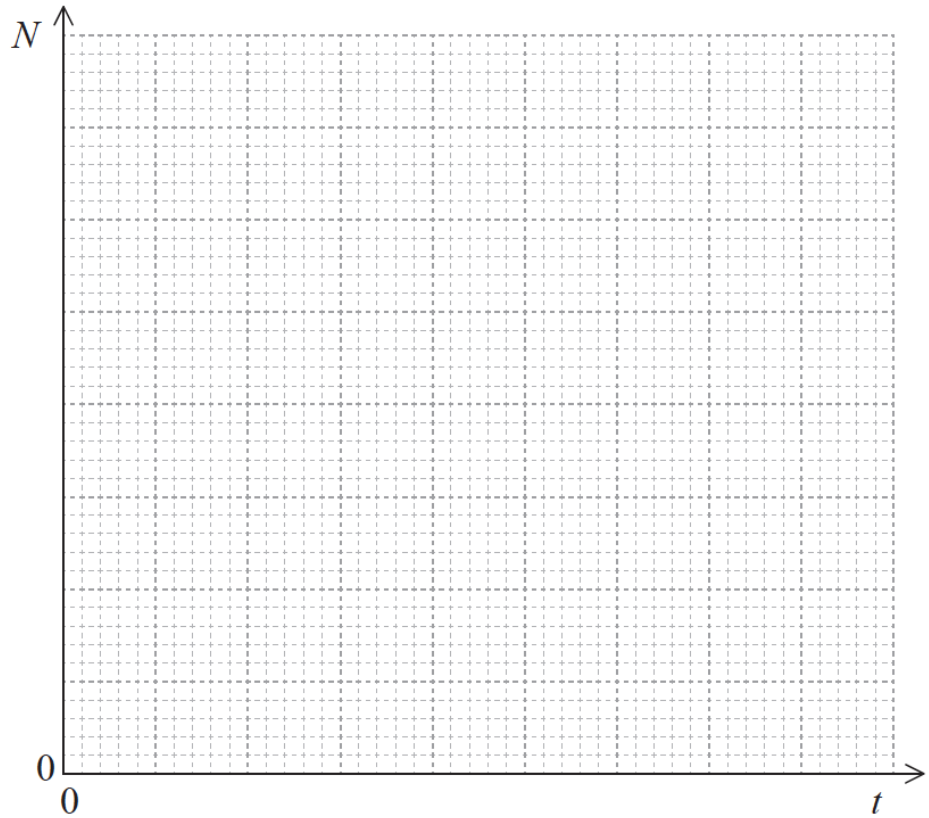
Rest mass of nitrogen-14 nucleus =14.0031 u
Rest mass of alpha particle =4.0026 u
Rest mass of X nucleus =16.9991 u
Rest mass of proton =1.0073 u

Show that the minimum kinetic energy that the alpha particle must have in order for the reaction to take place is about 0.7 Me V.

f. A nucleus of another isotope of the element X in (d) decays with a half-life $T_{\frac{1}{2}}$ to a nucleus of an isotope of fluorine-19 (F-19). [5]

(i) Define the terms *isotope* and *half-life*.

(ii) Using the axes below, sketch a graph to show how the number of atoms *N* in a sample of X varies with time *t*, from *t*=0 to $t = 3T_{\frac{1}{2}}$. There are N_0 atoms in the sample at *t*=0.



g. Water at constant pressure boils at constant temperature. Outline, in terms of the energy of the molecules, the reason for this. [2]

h. In an experiment to measure the specific latent heat of vaporization of water, steam at 100°C was passed into water in an insulated container. [4]

The following data are available.

Initial mass of water in container = 0.300kg
Final mass of water in container = 0.312kg
Initial temperature of water in container = 15.2°C
Final temperature of water in container = 34.6°C
Specific heat capacity of water = 4.18×10^{3}Jkg^{-1}K^{-1}

Show that the data give a value of about 1.8×10^{6}Jkg^{-1} for the specific latent heat of vaporization *L* of water.

i. Explain why, other than measurement or calculation error, the accepted value of *L* is greater than that given in (h). [2]

This question is in **two** parts. **Part 1** is about nuclear reactions and radioactive decay. **Part 2** is about thermal concepts.

Part 1 Nuclear reactions and radioactive decay

Part 2 Momentum

a. The isotope tritium (hydrogen-3) has a radioactive half-life of 12 days. [2]

(i) State what is meant by the term isotope.

(ii) Define *radioactive half-life.*

b. Tritium may be produced by bombarding a nucleus of the isotope lithium-7 with a high-energy neutron. The reaction equation for this interaction is [3]

$$^{7}_{3}\mathrm{Li} + ^{1}_{0}\mathrm{n} \rightarrow ^{3}_{1}\mathrm{H} + ^{4}_{Z}\mathrm{X} + ^{1}_{0}\mathrm{n}$$

(i) Identify the proton number *Z* of X.

(ii) Use the following data to show that the minimum energy that a neutron must have to initiate the reaction in (b)(i) is about 2.5 MeV.

Rest mass of lithium-7 nucleus	= 7.0160 u
Rest mass of tritium nucleus	= 3.0161 u
Rest mass of X nucleus	= 4.0026 u

c. Assuming that the lithium-7 nucleus in (b) is at rest, suggest why, in terms of conservation of momentum, the neutron initiating the reaction must have an energy greater than 2.5 MeV. [2]

d. Define *linear momentum.* [1]

d. A nucleus of tritium decays to a nucleus of helium-3. Identify the particles X and Y in the nuclear reaction equation for this decay. [2]

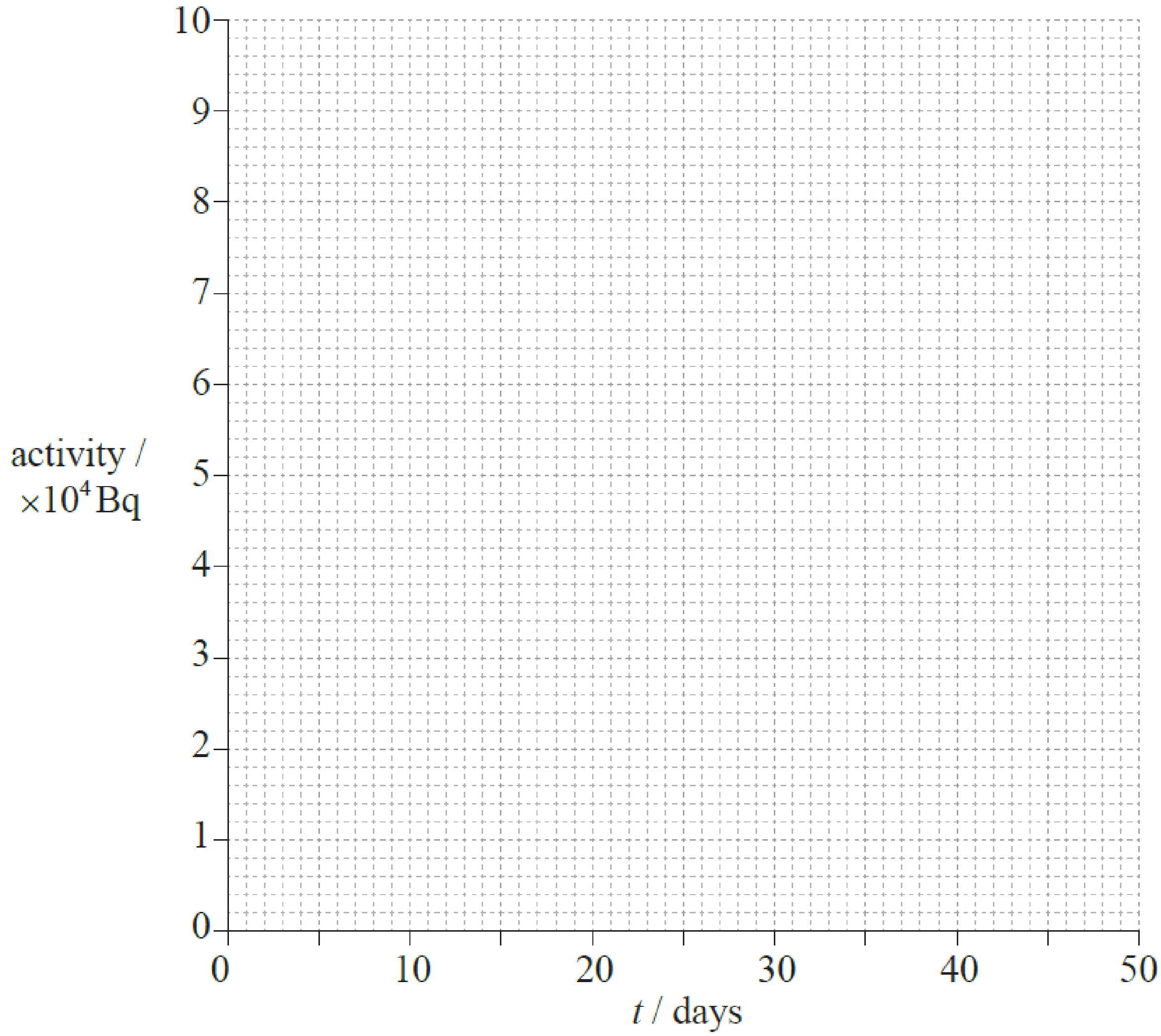
$$^{3}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + \mathrm{X} + \mathrm{Y}$$

X:

Y:

e. A sample of tritium has an activity of 8.0×10^{4} Bq at time t=0. The half-life of tritium is 12 days. [5]

(i) Using the axes below, construct a graph to show how the activity of the sample varies with time from t=0 to t=48 days.



(ii) Use the graph to determine the activity of the sample after 30 days.

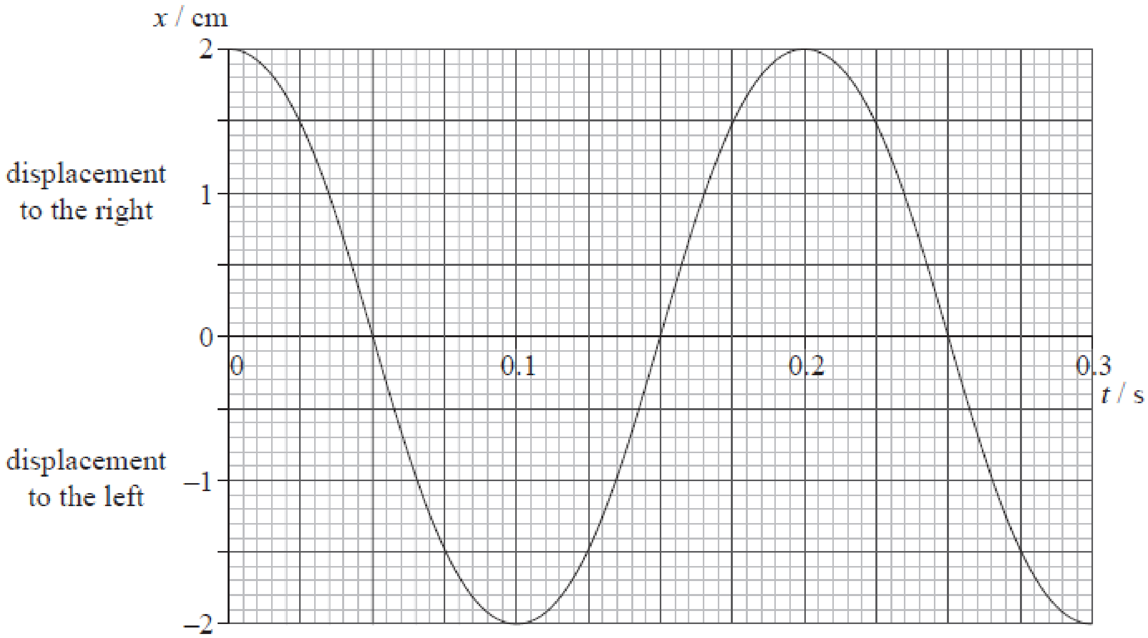
(iii) The activity of a radioactive sample is proportional to the number of atoms in the sample. The sample of tritium initially consists of 1.2×10^{11} tritium atoms. Determine, using your answer to (e)(ii) the number of tritium atoms remaining after 30 days.

Part 2 Simple harmonic oscillations

A longitudinal wave travels through a medium from left to right.

Graph 1 shows the variation with time t of the displacement x of a particle P in the medium.

Graph 1



a. For particle P, [6]

(i) state how graph 1 shows that its oscillations are not damped.

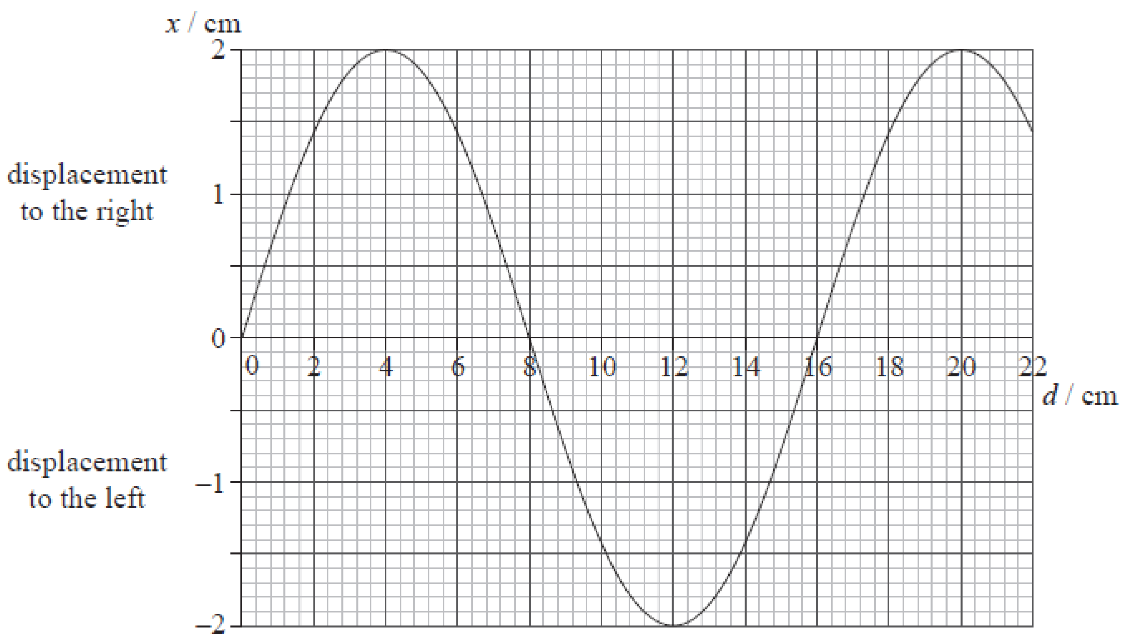
(ii) calculate the magnitude of its maximum acceleration.

(iii) calculate its speed at t=0.12 s.

(iv) state its direction of motion at t=0.12 s.

b. Graph 2 shows the variation with position d of the displacement x of particles in the medium at a particular instant of time. [4]

Graph 2

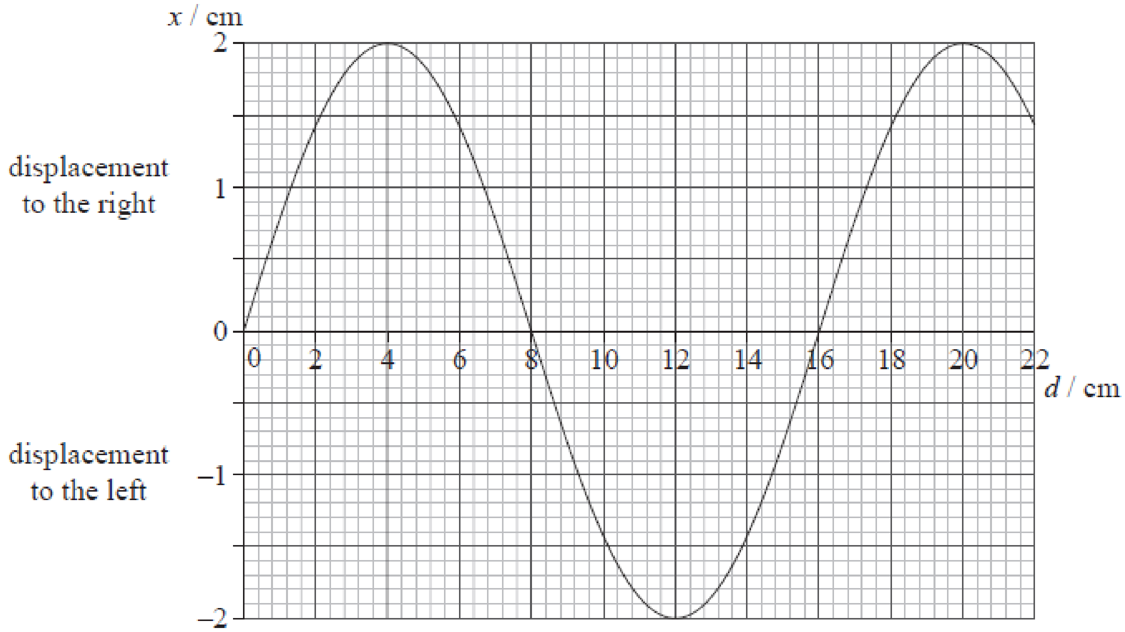


Determine for the longitudinal wave, using graph 1 and graph 2,

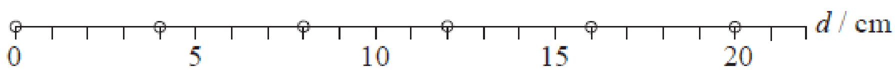
(i) the frequency.

(ii) the speed.

c. **Graph 2** – reproduced to assist with answering (c)(i). [4]



(c) The diagram shows the equilibrium positions of six particles in the medium.



(i) On the diagram above, draw crosses to indicate the positions of these six particles at the instant of time when the displacement is given by graph 2.

(ii) On the diagram above, label with the letter C a particle that is at the centre of a compression.

Part 2 Unified atomic mass unit and a nuclear reaction

a. Define the term *unified atomic mass unit*. [1]

b. The mass of a nucleus of rutherfordium-254 is 254.1001u. Calculate the mass in $GeVc^{-2}$. [1]

c. In 1919, Rutherford produced the first artificial nuclear transmutation by bombarding nitrogen with α-particles. The reaction is represented by the following equation. [4]

$$\alpha + {}^{14}_{7}\mathrm{N} \rightarrow {}^{17}_{8}\mathrm{O} + \mathrm{X}$$

(i) Identify **X**.

(ii) The following data are available for the reaction.

Rest mass of α = 3.7428 $GeVc^{-2}$
Rest mass of ${}^{14}_{7}\mathrm{N}$ = 13.0942 $GeVc^{-2}$
Rest mass of ${}^{17}_{8}\mathrm{O} + \mathrm{X}$ = 16.8383 $GeVc^{-2}$

The initial kinetic energy of the α-particle is 7.68 MeV. Determine the sum of the kinetic energies of the oxygen nucleus and **X**. (Assume that the nitrogen nucleus is stationary.)

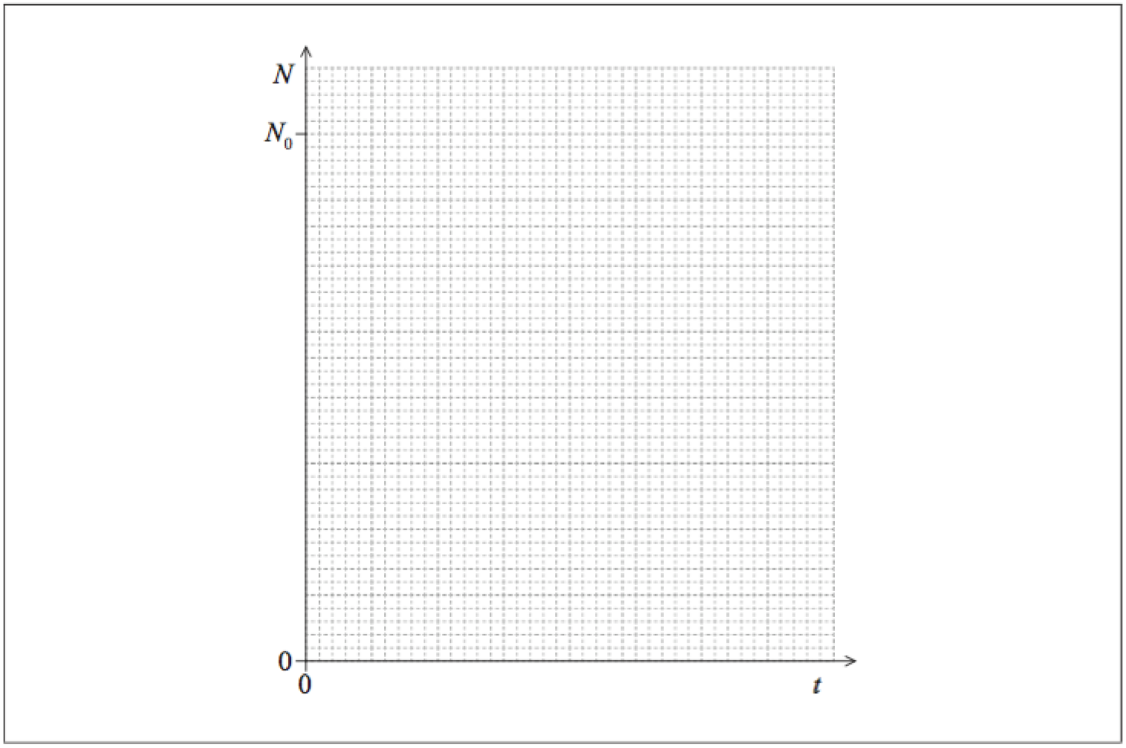
d. The reaction in (c) produces oxygen (O-17). Other isotopes of oxygen include O-19 which is radioactive with a half-life of 30 s. [2]

(i) State what is meant by the term isotopes.

(i) Define the term *radioactive half-life*.

e. A nucleus of the isotope O-19 decays to a stable nucleus of fluorine. The half-life of O-19 is 30 s. At time *t*=0, a sample of O-19 contains a large number N_0 nuclei of O-19. [2]

On the grid below, draw a graph to show the variation with time *t* of the number *N* of O-19 nuclei remaining in the sample. You should consider a time of *t*=0 to *t*=120s.



This question is in **two** parts. **Part 1** is about nuclear reactions. **Part 2** is about thermal energy transfer.

Part 1 Nuclear reactions

Part 2 Thermal energy transfer

a. (i) Define the term *unified atomic mass unit.* [2]

(ii) The mass of a nucleus of einsteinium-255 is 255.09 u. Calculate the mass in $MeVc^{-2}$.

c. When particle X collides with a stationary nucleus of calcium-40 (Ca-40), a nucleus of potassium (K-40) and a proton are produced. [6]

$$^{40}_{20}\mathrm{Ca} + \mathrm{X} \rightarrow {}^{40}_{19}\mathrm{K} + {}^{1}_{1}\mathrm{p}$$

The following data are available for the reaction.

Particle	Rest mass / MeV c^{-2}
calcium-40	37 214.694
X	939.565
potassium-40	37 216.560
proton	938.272

(i) Identify particle X.

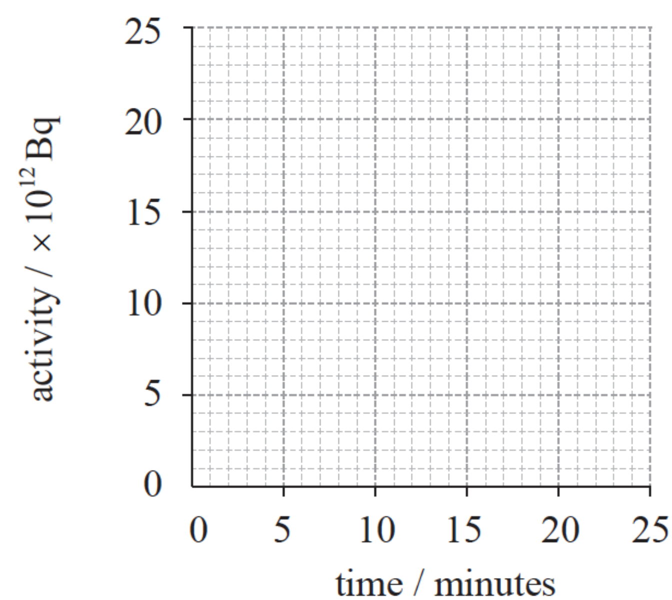
(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(iii) Before the reaction occurs, particle X has kinetic energy 8.326 MeV. Determine the total combined kinetic energy of the potassium nucleus and the proton.

d. Potassium-38 decays with a half-life of eight minutes. [5]

(i) Define the term *radioactive half-life*.

(ii) A sample of potassium-38 has an initial activity of 24×10^{12}Bq. On the axes below, draw a graph to show the variation with time of the activity of the sample.



(iii) Determine the activity of the sample after 2 hours.

e. (i) Define the *specific latent heat* of fusion of a substance. [5]

(ii) Explain, in terms of the molecular model of matter, the relative magnitudes of the specific latent heat of vaporization of water and the specific latent heat of fusion of water.

f. A piece of ice is placed into a beaker of water and melts completely. [5]

The following data are available.

Initial mass of ice = 0.020 kg
Initial mass of water = 0.25 kg
Initial temperature of ice = 0°C
Initial temperature of water = 80°C
Specific latent heat of fusion of ice = 3.3×10^5 J kg^{-1}
Specific heat capacity of water = 4200 J kg^{-1}K^{-1}

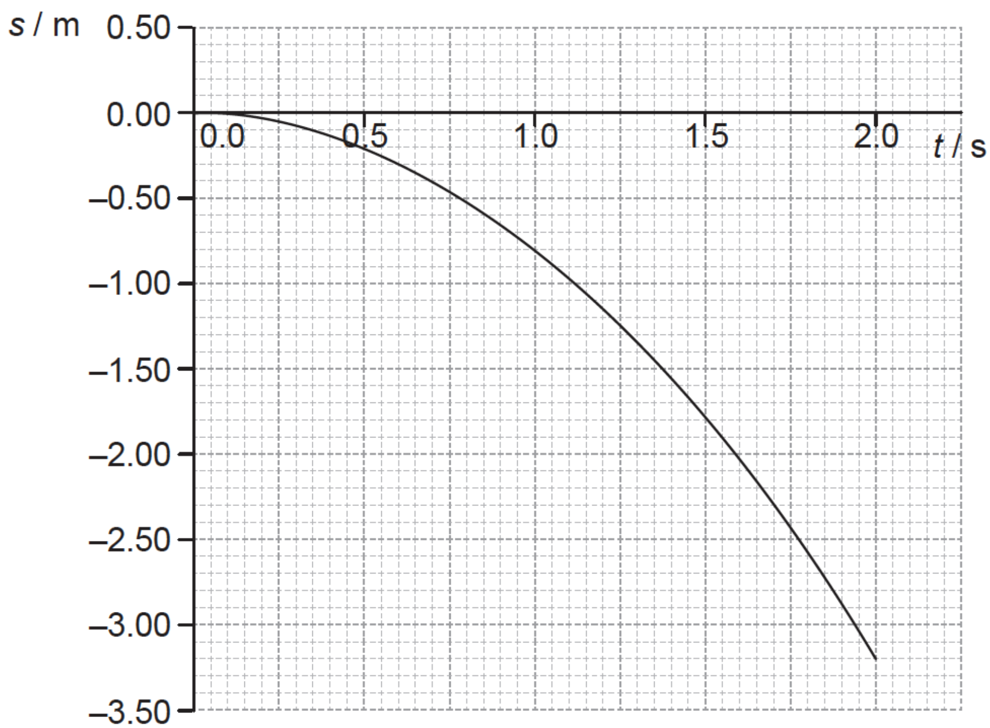
(i) Determine the final temperature of the water.

(ii) State **two** assumptions that you made in your answer to part (f)(i).

This question is in **two** parts. **Part 1** is about kinematics and gravitation. **Part 2** is about radioactivity.

Part 1 Kinematics and gravitation

A ball is released near the surface of the Moon at time *t*=0. The point of release is on a straight line between the centre of Earth and the centre of the Moon. The graph below shows the variation with time *t* of the displacement s of the ball from the point of release.



Part 2 Radioactivity

Two isotopes of calcium are calcium-40 $\left({}^{40}_{20}\mathrm{Ca}\right)$ and calcium-47 $\left({}^{47}_{20}\mathrm{Ca}\right)$. Calcium-40 is stable and calcium-47 is radioactive with a half-life of 4.5 days.

a. State the significance of the negative values of *s*. [1]

b. Use the graph to [6]

(i) estimate the velocity of the ball at $t = 0.80$ s.

(ii) calculate a value for the acceleration of free fall close to the surface of the Moon.

c. The following data are available. [4]

Mass of the ball = 0.20 kg

Mean radius of the Moon = 1.74×10^6 m

Mean orbital radius of the Moon about the centre of Earth = 3.84×10^8 m

Mass of Earth = 5.97×10^{24} kg

Show that Earth has no significant effect on the acceleration of the ball.

d. Calculate the speed of an identical ball when it falls 3.0 m from rest close to the surface of Earth. Ignore air resistance. [1]

e. Sketch, on the graph, the variation with time *t* of the displacement *s* from the point of release of the ball when the ball is dropped close to the surface of Earth. (For this sketch take the direction towards the Earth as being negative.) [3]

f. Explain, in terms of the number of nucleons and the forces between them, why calcium-40 is stable and calcium-47 is radioactive. [3]

g. Calculate the percentage of a sample of calcium-47 that decays in 27 days. [3]

h. The nuclear equation for the decay of calcium-47 into scandium-47 $\left({}^{47}_{21}\mathrm{Sc}\right)$ is given by [4]

$${}^{47}_{20}\mathrm{Ca} \rightarrow {}^{47}_{21}\mathrm{Sc} + {}^{0}_{-1}\mathrm{e} + \mathrm{X}$$

(i) Identify X.

(ii) The following data are available.

Mass of calcium-47 nucleus = 46.95455 u
Mass of scandium-47 nucleus = 46.95241 u

Using the data, determine the maximum kinetic energy, in MeV, of the products in the decay of calcium-47.

(iii) State why the kinetic energy will be less than your value in (h)(ii).