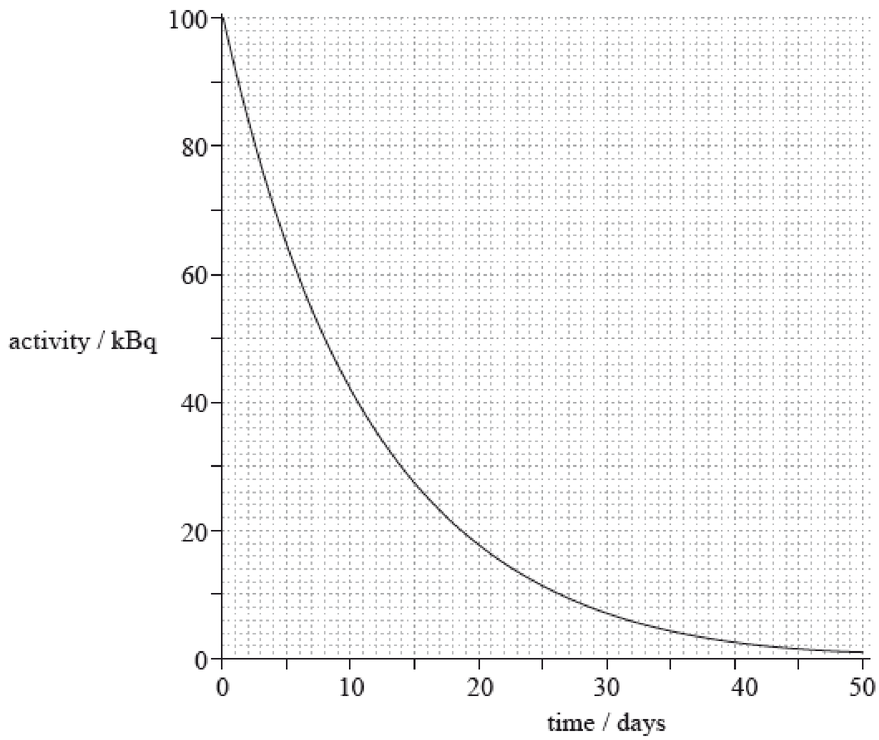
SL Paper 2

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]

$$ {}^{131}_{53}\text{I} \rightarrow {}^{131}_{\dots\dots}\text{Xe} + \beta^{-} + \dots\dots\dots\dots\dots $$

c.i. The I-131 can be used for a medical application but only when the activity lies within the range of $(20 \pm 10)\ \text{kBq}$. 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]

Markscheme

a. same number of protons / atoms of the same element;

different number of neutrons;

b. 54 <u>and</u> antineutrino/$\bar{\nu}$; *(both needed)*

c.i. range is 14 to 26 ***or*** 14 to 27;

12 ***or*** 13 days;

*Award **[2]** if marking points added to the graph.*

c.ii. starts at 50 kBq and approximately exponential decay curve;

half-life is $\sim 16 \text{ days}$ / line passes through $[16,\ 25]$ to within a small square;

Examiners report

a. A variety of good answers.

b. Many seemed unaware of the antineutrino.

c.i. Many candidates were able to determine the answer from the activity graph, but quite a few misunderstood what the question was asking for.

c.ii. This was done quite well, with most graphs starting at 50Bq and having the required half-life. However, too many candidates did not draw an acceptable exponentially shaped graph.

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]

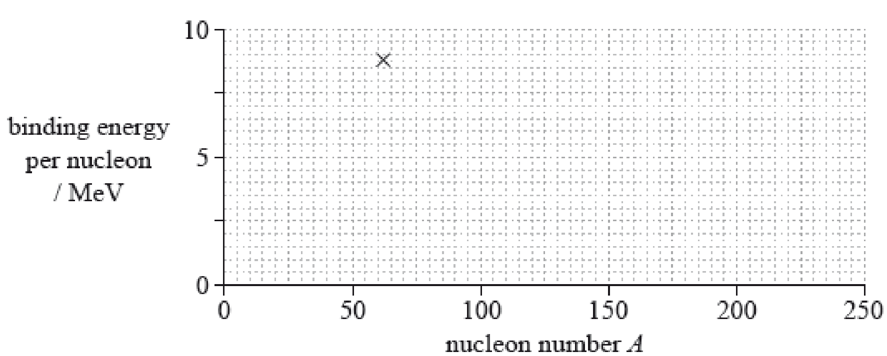
Binding energy per nucleon for deuterium $\left({}^{2}_{1}\text{H}\right)$ is 1.1 MeV.

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

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

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

(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).

Markscheme

a. difference between mass of a nucleus and the sum of mass of nucleons/ constituents/particles;

b. (i) binding energy of left-hand side $= 1.11 \times 2$ and binding energy of right-hand side $= 3 \times 2.6$; } *(both needed) (allow ECF)*

energy release $= 5.58$ (MeV); *(ignore sign)*

(ii) line goes through Ni point and nickel is the maximum ± 2 small squares horizontally; } *(allow Fe-56 as maximum – this is just outside the range allowed)*

line starts at 0, downward trend for *A* after 62, trend after nickel less steep than before;

Line must go through part of the X to award first marking point.

Line must not flatten out to award second marking point.

Allow smooth curve for low A.

Allow incorrect variations at low A.

(iii) nucleus produced in the reaction is higher up the curve than the reactants / *OWTTE*; } *(must see reference to graph)*

reference to binding energy/other valid reason results in energy release;

*Award **[0]** for a bald correct answer.*

*Award **[0]** for any discussion of fission.*

Examiners report

a. Most were able to define mass defect correctly but there were many small slips that denied the mark. Candidates should be encouraged to learn definitions or to understand the physics lying behind the definition sufficiently well to construct the definition from scratch. Candidates often compared atomic masses with the sum of the nucleons without commenting on the role of the electrons. Some definitions were in terms of energy. Others simply said that the mass of a nucleus is reduced when constructed from the individual nucleons, without answering the question.

b. (i) This relatively easy problem was not well done. There were many permutations of the numbers, and almost all were poorly explained. Completely correct solutions were rare and even these tended to have a poor level of explanation.

(ii) Candidates are required to be able to draw and annotate this plot. This question proved that very many do not appreciate the prominent features. There were mis-drawings on both sides of the maximum; the maximum itself was often misplaced by more than the specified tolerance (showing that candidates do not appreciate the minimum value of the binding energy per nucleon at the Fe-56 or Ni position). Other errors included inappropriate gradients on the right-hand side of the graph compared to the left and failures to begin the curve at the correct place.

(iii) Few candidates referred their knowledge to the graph and simply recalled – often correctly – some physics about the stability of the fusion product. However, this was rarely referred to the relative position of reactants and product on the graph.

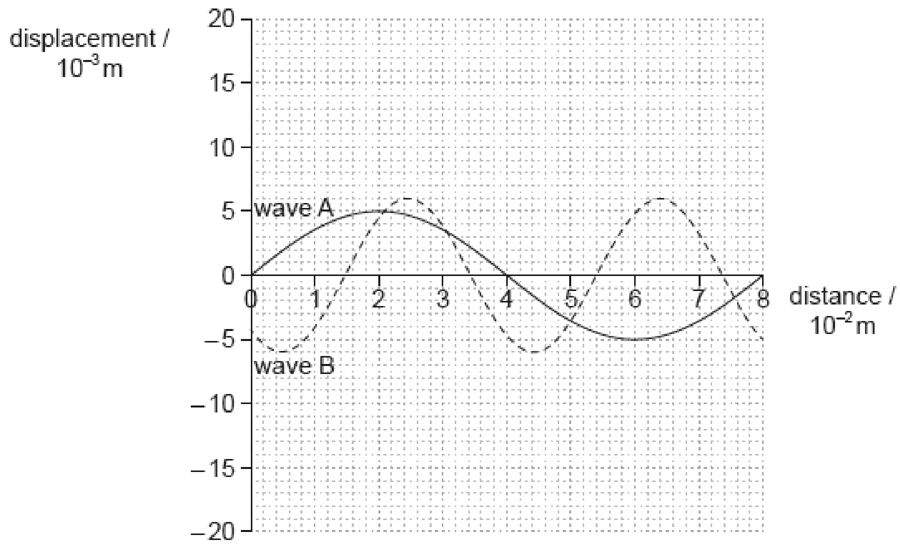
This question is in **two** parts. **Part 1** is about the nuclear model of the atom and radioactive decay. **Part 2** is about waves.

Part 1 Nuclear model of the atom and radioactive decay

The nuclide radium-226 $\left({}^{226}_{88}\mathrm{Ra}\right)$ 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]

Markscheme

a. most undeflected/pass straight through;

hence mostly empty space;

few deflected; *(allow "bent", "reflect", "bounce back" etc)* hence small dense nucleus;

positive / positively charged;

b. electron accelerated / mention of centripetal force;

should radiate EM waves/energy;

and spiral into the nucleus;

c.i. *nuclide*: nucleus characterized by specified number of protons and neutrons/its constituents;

isotope: nuclide with same number of protons / same element <u>and</u> different numbers of nucleons/neutrons;

c.ii. ${}^{222}_{86}\mathrm{Rn}$;

${}^{4}_{2}\mathrm{He}$ ***or*** ${}^{0}_{0}\gamma$;

top and bottom numbers balanced correctly;

c.iii 6 half-lives occurred;

9600 years;

*Award **[2]** for a bald correct answer.*

d. 5 mm ***or*** 5.0 mm; *units are required*

Allow other units, eg: 5/5.0 $\times$ 10^{-3} m.

e.i. wavelength $= 8.0\ \mathrm{cm}$ ***or*** 8 cm; *(accept clear substitution in MP2 for this mark)*

$v = (f\lambda =)\ 9 \times 8 = 72\ \mathrm{cm\,s^{-1}}$; *units are required*

*Award **[2]** for a bald correct answer.*

e.ii. wavelength $= 3.9\ (\mathrm{cm})$; *(accept answers in the range of 3.8 to 4.0 (cm))*

frequency $= \left(\frac{72}{3.9} =\right)\ 18$;

Hz ***or*** $\mathrm{s^{-1}}$;

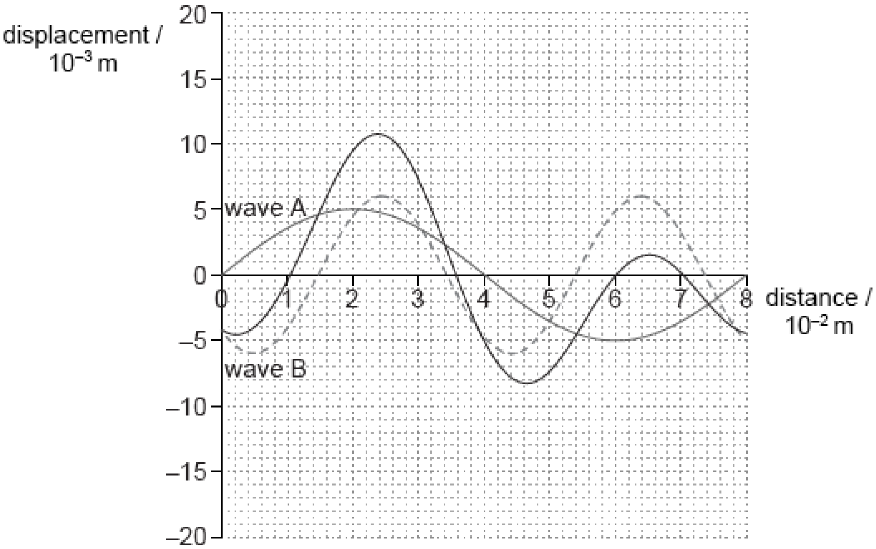
*Award **[3]** for a bald correct answer that includes unit.*

f.i. when two or more waves (of the same nature) meet/interfere / *OWTTE*;

the resultant displacement is the (vector) sum of their individual displacements; } *(do not allow constructive or destructive interference as answer to this point)*

Do not accept "amplitude" for "displacement" anywhere in answer.

f.ii.



start and end points correct (equal B) and crossing points on distance axis correct $(1, 3.6, 6, 7)$;

peaks and troughs at $(2.4, 11)$ $(4.6, -8)$ $(6.5, 1.5)$;

general shape correct as in example; } *(maximum and minimum must be alternating +/–)*

All tolerances ± 1 square.

Examiners report

a. This was generally well done, but too many candidates focused upon a description of the experiment rather than the evidence it provided.

b. Very poorly done.

c.i. The word nuclide refers to a nucleus with a specific number of protons and neutrons. Very few candidates understood this. They were, however, mostly able to show a clear understanding of what an isotope was.

c.ii. No problem for the majority of candidates.

c.iii. Most candidates were able to give the correct answer.

d. This was well done – an omission of the vital unit (so that the examiner can confirm the reading) was not too common.

e.i. This part was well done.

e.ii. This part was well done.

f.i. Many candidates described the meeting or interference of two waves, however, a considerable number went on to confuse amplitude with displacement in their answer and lost marks.

f.ii. This was a demanding drawing requiring candidates to show the complex superposition of two waves. Some candidates rose well to this challenge, took their time, and drew very good attempts. Many however produced rather half-hearted and rushed diagrams that lost one or more marks for lack of quality. Teachers would be advised to study the mark scheme as it gives a sensible route for the construction of the final answer.

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

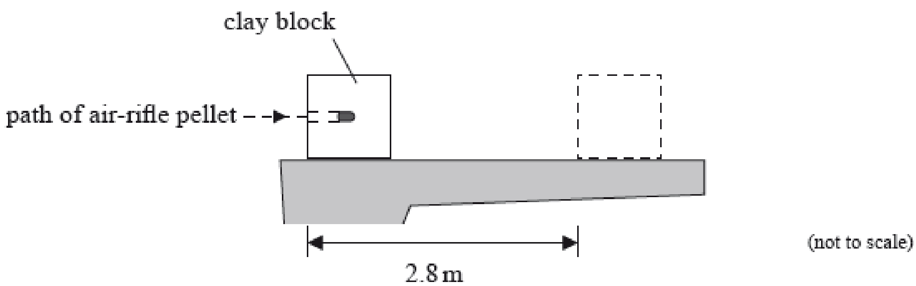
Part 1 Production of energy in nuclear fission

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.

Mass of air - rifle pellet	$= 2.0$ g
Mass of clay block	$= 56$ g
Velocity of impact of air - rifle pellet	$= 140\ \mathrm{m\,s^{-1}}$
Stopping distance of clay block	$= 2.8$ m

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.

Mass of neutron	$= 1.00867$ u
Mass of U - 235 nucleus	$= 234.99333$ u
Mass of Kr - 92 nucleus	$= 91.90645$ u
Mass of Ba - 141 nucleus	$= 140.88354$ u

(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 $4.8\ \mathrm{m\,s^{-1}}$. [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]

Markscheme

Part 1.a. (i) 3;

(ii) $\Delta m = 234.99333 - 91.90645 - 140.88354 - [2 \times 1.00867]$;

$= 0.186\ (\mathrm{u})$;

$\text{energy released} = 0.186 \times 931 = 173\ (\mathrm{MeV})$;

$173 \times 10^{6} \times 1.6 \times 10^{-19}$;

$(= 2.768) \approx 2.8 \times 10^{-11}\ (\mathrm{J})$

or

$\Delta m = 234.99333 - 91.90645 - 140.88354 - [2 \times 1.00867]$;

$= 0.186\ (\mathrm{u})$;

$\text{mass converted} = 0.186 \times 1.66 \times 10^{-27}\ (= 3.09 \times 10^{-28})$;

(use of $E = mc^2$) $\text{energy} = 3.09 \times 10^{-28} \times 9 \times 10^{-16}$;

$(= 2.77) \approx 2.8 \times 10^{-11}\ (\mathrm{J})$

*Award **[2 max]** if mass difference is incorrect.*

If candidate carries forward an incorrect value from (a)(i) [2 is common], treat this as ecf in (a)(ii).

*Award **[3 max]** if the candidate uses a value for x inconsistent with (a)(i).*

(iii) greater/higher energy;

Part 1.b. reduces neutron speed to (thermal) lower speeds;

so that chance of initiating fission is higher;

Accept "fast neutrons cannot cause fission" for 2nd marking point.

Part 1.c. 40% efficient so 40 (MW) required;

$\frac{40 \times 10^{6}}{2.8 \times 10^{-11}} = 1.43 \times 10^{18}$ per second;

number of fissions per day $= 1.23 \times 10^{23}$;

$\left(= \frac{1.23 \times 10^{23} \times 235}{6 \times 10^{23}}\right) = 48\ \text{g per day}$;

Part 2.a. the total momentum of a system is constant;

provided external force does not act;

or

the momentum of an isolated/closed system;

is constant;

*Award **[1]** for momentum before collision equals collision afterwards.*

Part 2.b. (i) initial momentum $= 2.0 \times 10^{-3} \times 140$;

final speed $\frac{2.0\times10^{-3}\times140}{5.6\times10^{-2}+2.0\times10^{-3}}$;

$= 4.8\ \mathrm{m\,s^{-1}}$

Watch for incorrect mass values in equation.

(ii) initial kinetic energy of pellet + clay block $= \frac{1}{2}mv^2$;

$0.5 \times 0.058 \times 4.8^2\ (= 0.67\ \mathrm{J})$;

$\text{force} = \frac{\text{work done}}{\text{distance travelled}}$;

$= 0.24\ \mathrm{N}$;

or

use of appropriate kinematic equation with consistent sign usage *e.g.* $a = \frac{u^2-v^2}{2s}$;

$a = \frac{4.8^2}{2\times2.8}$;

$F = \frac{0.058\times4.8^2}{2\times2.8}$;

$= 0.24\ \mathrm{N}$;

Part 2.c. kinetic energy of pellet is transferred to kinetic energy of clay block;

and internal energy of pellet and clay block;

clay block loses kinetic energy as thermal energy/heat;

Part 2.d. $v = \sqrt{2gs}$;

$= 4.1\ \mathrm{m\,s^{-1}}$;

Allow $g = 10\ \mathrm{m\,s^{-2}}$ answer 4.1 m s^{-2}

*Award **[2]** for bald correct answer.*

Examiners report

Part 1.a. (i) A common incorrect answer was 2.

(ii) Candidates were often able to carry this calculation through to a correct conclusion. It was a “show that” and a high level of explanation was required by examiners and was – in many cases – demonstrated.

(iii) Reponses here were mostly correct. However, the answer “It has a higher energy” was common. Candidates need to be reminded of the imprecision of such a statement. Is “It” the initiating neutron or the emitted neutron?

Part 1.b. Weaker candidates could not distinguish between the role of the moderator and that of the control rods.

Part 1.c. Many good calculations were seen but weaker candidates usually arrived at recognition that the required power from the reactor is 40 MW and could go no further.

Part 2.a. When the question is “State the principle of conservation of momentum.” an answer of “momentum is conserved” will attract no marks. The examiner needs to know what “conserved” means. Many omitted the statement that external forces do not act (or similar)

Part 2.b. (i) Careful examination of solutions showed that about one-third of candidate forgot to add the mass of the pellet to the final total mass of the block.

(ii) This two-stage calculation attracted the same error as part (i) and many power of ten errors through a failure to note the units of mass in the question.

Part 2 Descriptions of the energy transformations were incomplete and poorly described. There was a general failure to recognise that the pellet transfers its kinetic energy into a number of distinct forms. Candidates are too quick to ascribe energy loss to “friction” without indicating the seat of this energy loss.

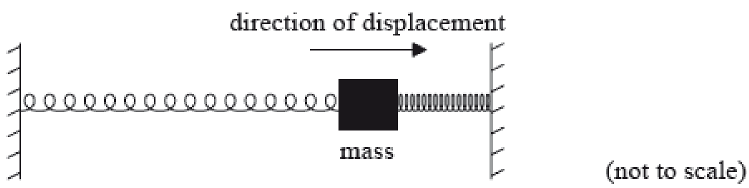
Part 2 Most candidates were able to complete this calculation or to get close to it. Some forgot to evaluate the square root having arrived at the speed squared.

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

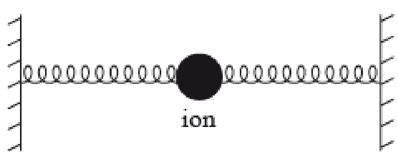
Part 1 Oscillation of a mass

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]

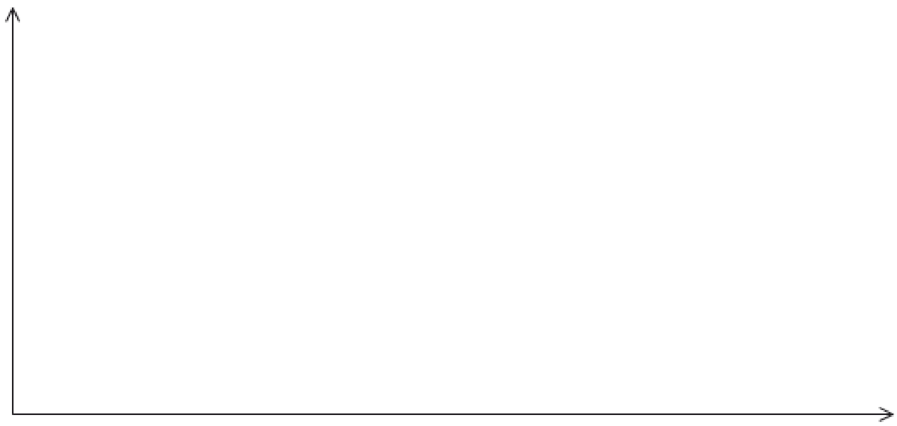
a.ii.Outline why the mass subsequently performs simple harmonic motion (SHM). [2]

a.iiiCalculate 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]

Markscheme

a.i. force of 1.8 N for each spring so total force is 3.6 N;

acceleration $= \frac{3.6}{0.8} = 4.5\ \mathrm{ms}^{-2}$; *(allow ECF from first marking point)*

to left/towards equilibrium position / negative sign seen in answer;

a.ii.force/acceleration is in opposite direction to displacement/towards equilibrium position;

and is proportional to displacement;

a.iii $\omega = \left(\sqrt{\left(\frac{a}{x}\right)} =\right) \sqrt{\frac{4.5}{60 \times 10^{-3}}}\ (= 8.66\ \mathrm{rad\,s^{-1}})$;

$T = 0.73\ \mathrm{s}$;

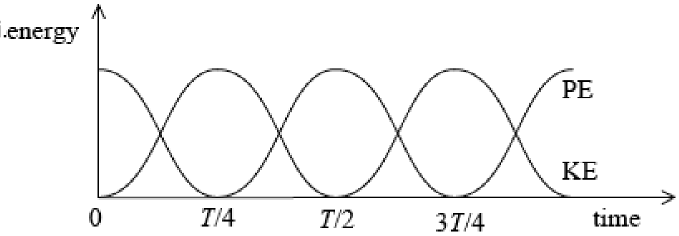
*Watch out for ECF from (a)(i) eg award **[2]** for $T = 1.0\ s$ for $a = 2.25\ \mathrm{m\,s^{-2}}$.*

b.i. $\omega = 2\pi \times 7 \times 10^{12} (= 4.4 \times 10^{13} Hz)$;

$5 \times 10^{-21}\ \mathrm{J}$;

Allow answers in the range of 4.8 to $4.9 \times 10^{-21}\ \mathrm{J}$ if 2 sig figs or more are used.

b.ii.



KE and PE curves labelled – very roughly $\cos^2$ and $\sin^2$ shapes; } *(allow reversal of curve labels)*

KE and PE curves in anti-phase and of equal amplitude;

at least one period shown;

either $E_{\max}$ marked correctly on energy axis, or T marked correctly on time axis;

c.i. 7.0×10^{12} Hz is equivalent to wavelength of 4.3×10^{-5} m;

d.i. number of fissions in one day $= 9.5 \times 10^{19} \times 24 \times 3600 \ (= 8.2 \times 10^{24})$;

mass of uranium atom $= 235 \times 1.661 \times 10^{-27} \ (= 3.9 \times 10^{-25} \text{ kg})$;

mass of uranium in one day $(= 8.2 \times 10^{24} \times 3.9 \times 10^{-25}) = 3.2 \text{ kg}$;

d.ii. energy per fission $= 200 \times 10^6 \times 1.6 \times 10^{-19} \ (= 3.2 \times 10^{-11} \text{ J})$;

power output $= (9.5 \times 10^{19} \times 3.2 \times 10^{-11} \times 0.32 =) \ 9.7 \times 10^8 \text{ W}$;

*Award **[1]** for an answer of* $6.1 \times 10^{27} \text{ eVs}^{-1}$.

e.i. neutrons have to be slowed down (before next fission);

because the probability of fission is (much) greater (with neutrons of thermal energy);

neutrons collide with/transfer energy to atoms/molecules (of the moderator);

e.ii. have high neutron capture cross-section/good at absorbing neutrons;

(remove neutrons from the reaction) thus controlling the rate of nuclear reaction;

Examiners report

a.i. This is a slightly different situation. Most candidates at SL did not use F and m to find acceleration. Very few added the force due to each spring and ECF was frequently applied.

a.ii. [N/A]

a.iii. [N/A]

b.i. [N/A]

b.ii. Care was needed in showing the constant and equal amplitudes. Many poor answers were seen.

c.i. [N/A]

d.i. [N/A]

d.ii. [N/A]

e.i. Mostly good answers although it was rare to find a candidate who stated that the probability of further fusion is increased with thermal neutrons.

e.ii. Too many answers lacked precision referring only to the use of control rods in avoiding an explosion or meltdown.

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

Markscheme

a. (i) *nuclide:*

(a species of atom that is characterized by) the constitution of its nucleus /the number of protons and neutrons in the nucleus OWTTE;

isotope:

nuclides with the same proton number but different nucleon/neutron numbers;

or

atoms of the same element that have different numbers of neutrons/neutron number;

(ii) alpha particle / helium nucleus / $^{4}_{2}\mathrm{He}$;

b. protons repel/break nucleus apart;

binding energy/strong force holds nucleus together;

neutron excess / n:p ratio is greater in lead therefore overall balance of forces is

more attractive / (magnitude of) binding energy per nucleon is greater in lead /

binding energy per nucleon more negative in lead than uranium;

c. Δm=235.04393–[143.922952+88.91763+2×1.00867];

=0.1860u; (*must see the u to award this mark*)

energy=0.1860×931.5=173.9 MeV;

(≈ 200 MeV)

Examiners report

a. (i) A good statement of the meaning of *nuclide* was rare. *Isotope* was much better understood and explained.

(ii) The majority identified the alpha particle as the other particle in the reaction. Common errors included the neutron, various forms of neutrino, and the previously unknown alpha photon.

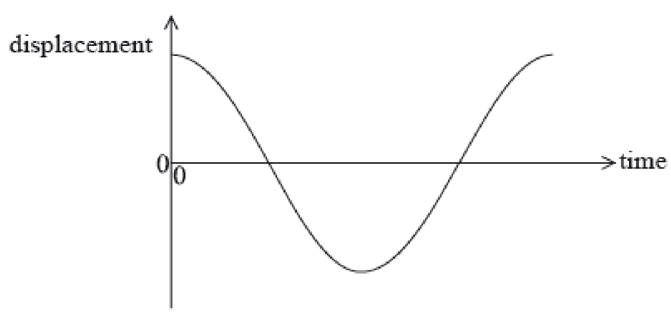
b. Candidates found it difficult to explain why U-235 is more unstable than a stable isotope of lead. It was rare to see clear statements of repulsive nature of the coulomb force and that it acts between protons whereas the strong nuclear force is attractive so that the balance of proton: neutron is changed in the more stable lead. Explanations in terms of binding energy per nucleon were also accepted. Explanations couched in terms of binding energy alone were usually incorrect.

c. **SL only** Calculations of the kinetic energy of the fission products in a nuclear reaction were carried through competently by many. Some however failed to show clearly the conversion from atomic mass units to electronvolts and lost some credit for this.

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

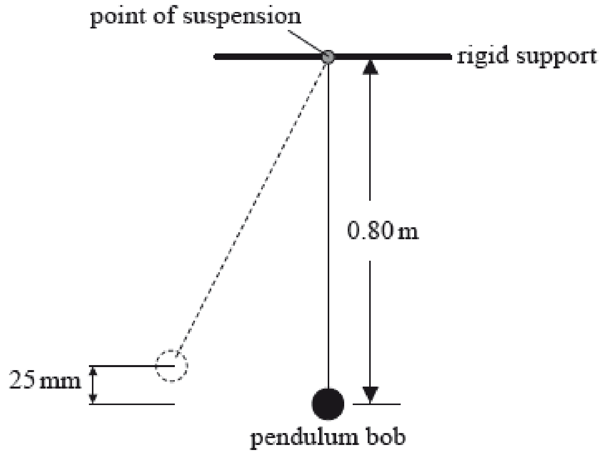
Part 1 Simple pendulum

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.

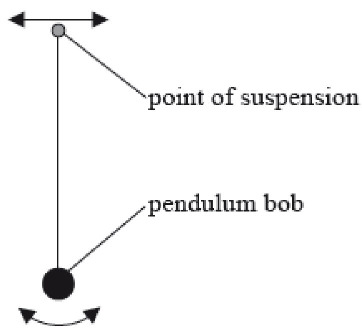


On the sketch graph above,

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 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]

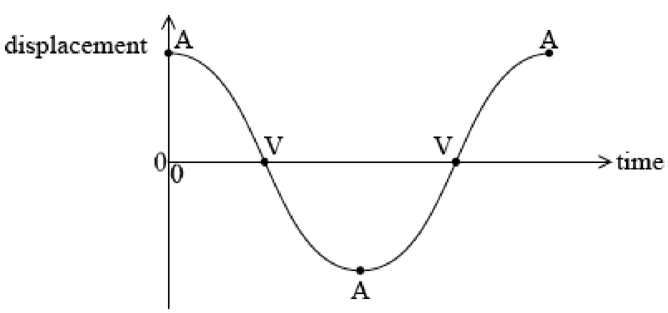
Part 2.b. (i) Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. [4]

(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.

Markscheme

Part 1.a. (i) one A correctly shown;

(ii) one V correctly shown;



Part 1.b. pendulum bob accelerates towards centre of circular path / *OWTTE*;

therefore force upwards;

that <u>adds</u> to tension produced by the weight;

Part 1.c. (i) evidence shown of equating kinetic energy and gravitational potential energy;

$v = \sqrt{(2 \times 9.8 \times 0.025)}$;

$= 0.70\ \mathrm{m\,s^{-1}}$

Allow g = 10 m s^{-2} answer 0.71 m s^{-2}.

(ii) centripetal acceleration $\left(= \frac{v^2}{r}\right)$ $\left[= \frac{0.7^2}{0.8}\right] = 0.61\ \left(\mathrm{m\,s^{-2}}\right)$;

net acceleration $= (9.81 + 0.61 =)\ 10.4\ \left(\mathrm{m\,s^{-2}}\right)$ ***or*** $T - mg = m \times 0.61$;

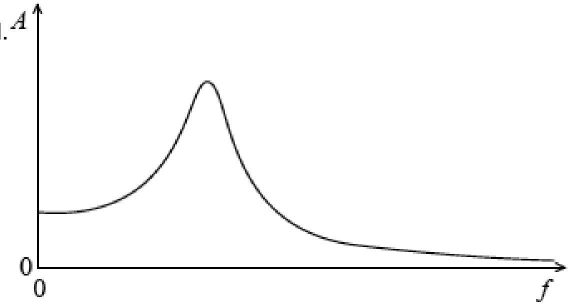
tension $= (ma =)\ 0.59\ \mathrm{N}$;

Allow g = 10 m s^{-2} answer 0.60 N.

*Award **[3]** for bald correct answer.*

Part1.d.

(i)



one maximum shown and curve broadly similar to example above;

amplitude falls on each side by lower amount on low driving frequency side;

(ii) resonance is where driving frequency equals/close to natural frequency;

the frequency at the maximum amplitude of the graph;

Part1.e. lower amplitude everywhere on graph;

with a much broader resonance peak;

maximum moves to left on graph;

*Award **[2]** for a sketch graph.*

Part2.a. most of the atom is empty space;

most of the mass/(protonic) charge of the atom is concentrated in the nucleus/nucleus is dense;

$$\left.\begin{array}{c}\text{nucleus is positively charged;}\\ \text{(most) alphas not close enough to nuclei to be deflected;}\\ \text{(very few) alphas (are) close enough to nuclei to be deflected;}\end{array}\right\} \begin{array}{c} These points can\\ be awarded to a\\ labelled diagram.\end{array}$$

To award the last two marking points for a diagram response the candidate must show that a non-deflected alpha is well away from a nucleus and a strongly deflected alpha is aimed very close or head-on.

Part2.b. (i) mention of Coulomb repulsion between protons;

mention of strong (nuclear) force (between nucleons);

overall balance must be correct (and more neutrons needed for this);

*Award **[0]** for a statement that neutron is negative.*

(ii) anti neutrino / $\bar{v}$;

Examiners report

Part1.a. Identifications of points A and V were mixed. About half the candidates received both marks here.

Part1.b. This was poorly done with many misapprehensions evident. The main problem was that candidates failed to associate the effect with the presence of a centripetal force and also unable to consider it in terms of the directions and additions of the various forces in the situation.

Part1.c. (i) This was well done by many. However a use of a *suvat* equation is not appropriate in this case as the acceleration is not uniform.

(ii) Candidates who kept a clear head were able to arrive at a correct answer even if they had failed in part (b)

Part 1.d. (i) Graphs were poor in general with few gaining both marks and many candidates unable to make any progress. Graphs often showed a decreasing amplitude against time despite the frequency label on the *x*-axis.

(ii) Few understood the meaning of the term “resonance” sufficiently to be able to describe it in terms of the graph.

Part 1.e. Again, few candidates referred their answer to the graph. Some were able to gain credit for discussing changes in amplitude.

Part 2.a. Candidates who rely on a diagram rather than a written description must ensure that their sketches give all the required information unambiguously. In this type of question it is also common to see candidates repeating part of the question itself back to the examiner; this will not gain credit. Candidates needed to distinguish between those alpha particles passing close to and those far away from a nucleus, and then to give the deduced properties of the nucleus from these observations. Descriptions were often illogical and repetitive.

Part 2.b. Most candidates could write with confidence about the repulsive nature of the proton-proton interaction and the attractive nature of the strong nuclear force. Few gave good accounts of the balance between these two forces or described the energy situation (a better way to answer). Weak candidates could not name the strong nuclear force adequately.

---

a. A nuclide of deuterium $\left({}_{1}^{2}\mathrm{H}\right)$ and a nuclide of tritium $\left({}_{1}^{3}\mathrm{H}\right)$ 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.

Markscheme

a. (i) number of fusions required per second $= \frac{2.5\times10^{8}}{2.8\times10^{-12}} \left(= 8.93\times10^{19}\right)$;

1 tritium nucleus has mass of 3 amu=$3.0\times1.67\times10^{-27}$(kg)(=$5.0\times10^{-27}$);

total tritium mass required = 4/4.4/4.5/4.48×10^{-7}(kgs^{-1});

*Award **[3]** for a bald correct answer.*

(ii) *Award any two appropriate problems e.g.*:
difficulty in maintaining high temperature for long periods;
difficulty in maintaining high density of plasma for long periods;
difficulty in enclosing plasma for long periods;
difficulty in controlled removal of heat from plasma;
difficulty in maintaining magnetic fields;

b. one-eight remains / 87.5 decayed;

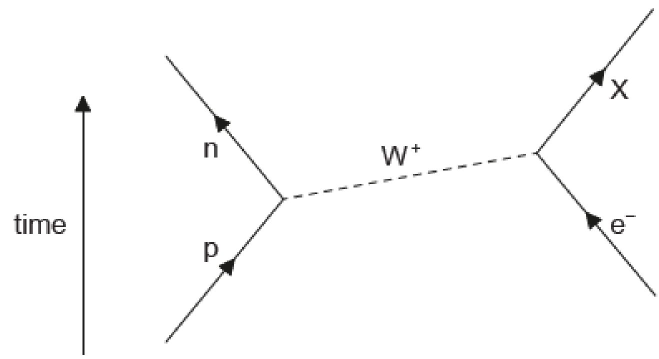
3 half lives;

13500 (days);

Examiners report

a. [N/A]
b. [N/A]

The Feynman diagram shows electron capture.



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

b. Distinguish between hadrons and leptons. [2]

Markscheme

a. it has a lepton number of 1 «as lepton number is conserved»

it has a charge of zero/is neutral «as charge is conserved»

OR

it has a baryon number of 0 «as baryon number is conserved»

Do not credit answers referring to energy

b. hadrons experience strong force

OR

leptons do not experience the strong force

hadrons made of quarks/not fundamental

OR

leptons are not made of quarks/are fundamental

hadrons decay «eventually» into protons

OR

leptons do not decay into protons

Accept leptons experience the weak force

Allow "interaction" for "force"

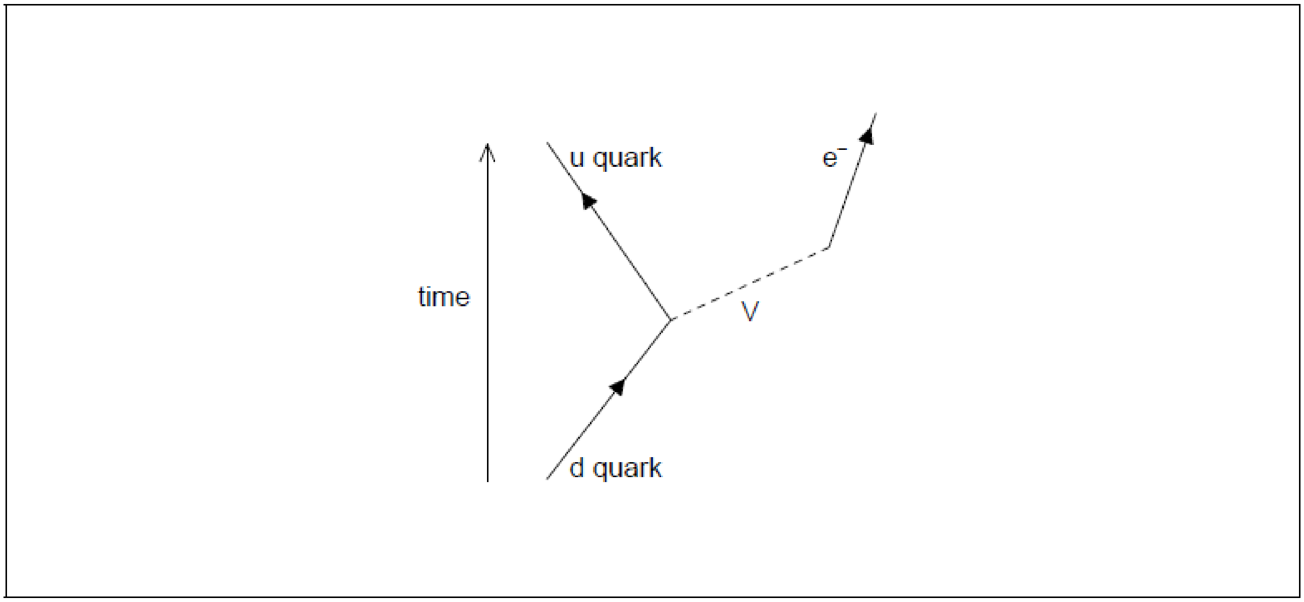
Examiners report

a. [N/A]
b. [N/A]

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]

Markscheme

a. «most of» the mass of the atom is confined within a very small volume/nucleus

«all» the positive charge is confined within a very small volume/nucleus

electrons orbit the nucleus «in circular orbits»

[2 marks]

b.i. the energy needed to separate the nucleons of a nucleus

OR

energy released when a nucleus is formed from its nucleons

*Allow neutrons **AND** protons for nucleons*

Don't allow constituent parts

[1 mark]

b.ii. $Q = 106 \times 8.550 - 106 \times 8.521 = 3.07$ «MeV»

«$Q \approx 3$ Me V»

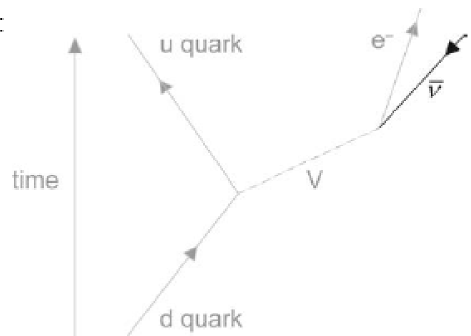
[1 mark]

c.i. line with arrow as shown labelled anti-neutrino/$\overline{\nu}$

Correct direction of the "arrow" is essential

The line drawn must be "upwards" from the vertex in the time direction i.e. above the horizontal

eg:



[1 mark]

c.ii. V = W⁻

[1 mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]

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.

Markscheme

b. power produced $\left(\frac{24}{0.32}\right)$=75MW;

energy produced in a year (75×10^6×365×24×60×60=)2.37×10^{15}J;

number of reactions required in one year $\left(\frac{2.37\times10^{15}}{3.2\times10^{-11}}\right) = 7.39 \times 10^{25}$;

mass used (7.39×10^{25}×235×1.66×10^{-27})≈29kg;

or

mass used $\left(\frac{7.39\times10^{25}}{6.02\times10^{23}} \times 235 \times 10^{-3}\right) = 29\text{kg};$

c. the neutrons would not be slowed down;

therefore they would not be/have less chance of being captured/induce fission;

so (much) less/no power would be produced;

d. (i) beta decay;

(ii) the reactions end up producing plutonium (from uranium 238);
(this isotope of) plutonium may be used to manufacture nuclear weapons / can be used as fuel in other reactors / plutonium is extremely toxic;

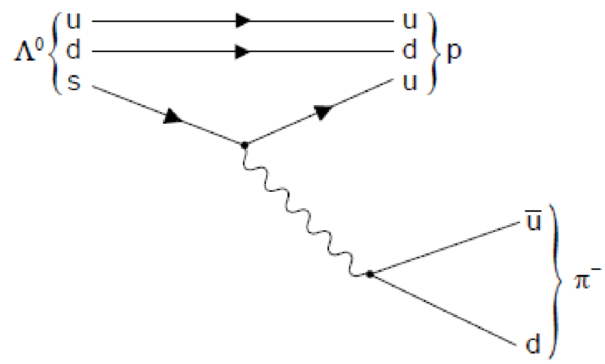
or

the products of the reactions are radioactive for long periods of time / *OWTTE*;
therefore posing storage/safety problems;

Examiners report

b. [N/A]
c. [N/A]
d. [N/A]

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]

Markscheme

a. *Meson:* quark-antiquark pair

Baryon: 3 quarks

b.i. ***Alternative 1***

strange quark changes «flavour» to an up quark

changes in quarks/strangeness happen only by the weak interaction

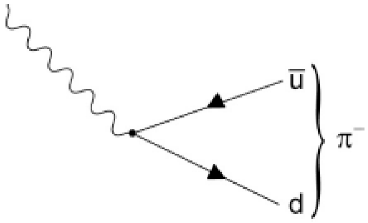
Alternative 2

Strangeness is not conserved in this decay «because the strange quark changes to an up quark»

Strangeness is not conserved during the weak interaction

Do not allow a bald answer of weak interaction.

b.ii. arrows drawn in the direction shown



*Both needed for **[1]** mark.*

b.iii. W^-

Do not allow W or W^+.

c. it lowers the cost to individual nations, as the costs are shared

international co-operation leads to international understanding ***OR*** historical example of co-operation ***OR*** co-operation always allows science to proceed

large quantities of data are produced that are more than one institution/research group can handle co-operation allows effective analysis

Any one.

Examiners report

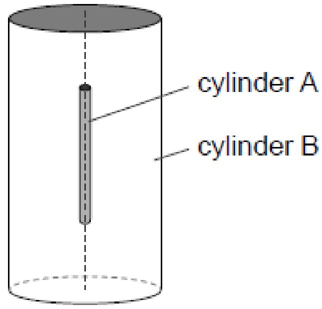
a. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]
c. [N/A]

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]

Markscheme

a. 222 ***AND*** 4

Both needed.

b. alpha particles highly ionizing

OR

alpha particles have a low penetration power

OR

thin glass increases probability of alpha crossing glass

OR

decreases probability of alpha striking atom/nucleus/molecule

c. conversion of temperature to 291 K

$p = 4.5 \times 10^{-9} \times 8.31 \times$ «$\frac{2.91}{1.3\times10^{-5}}$»

OR

$p = 2.7 \times 10^{15} \times 1.38 \times 10^{-23} \times$ «$\frac{2.91}{1.3\times10^{-5}}$»

0.83 or 0.84 «Pa»

d. electron/atom drops from high energy state/level to low state energy levels are discrete

wavelength/frequency of photon is related to energy change ***or*** quotes $E = hf$ ***or*** $E = \frac{hc}{\lambda}$

and is therefore also discrete

e. peer review guarantees the validity of the work

OR

means that readers have confidence in the validity of work

OWTTE

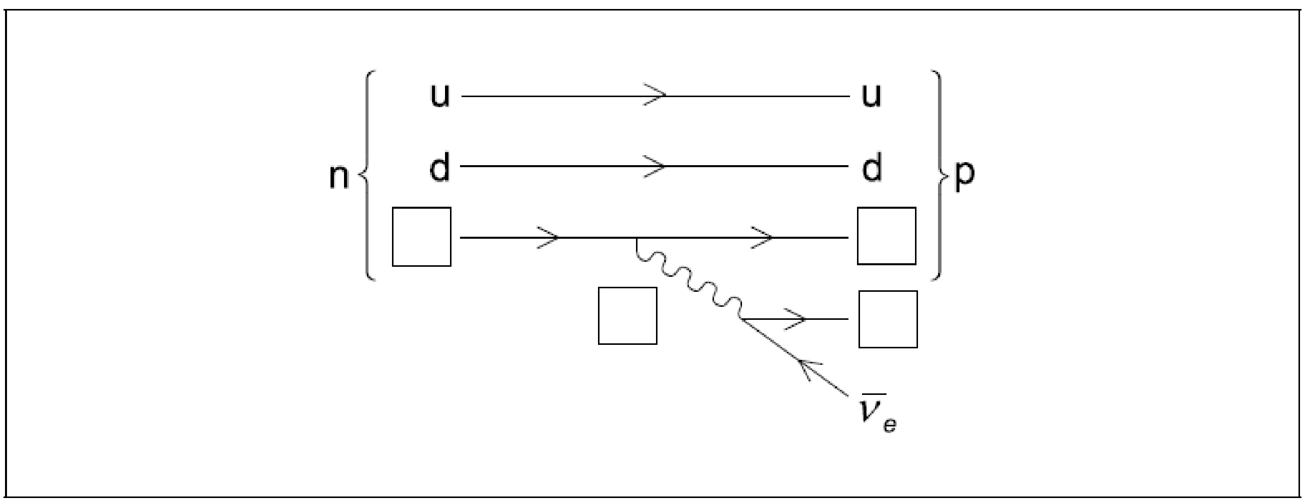
Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

---

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]



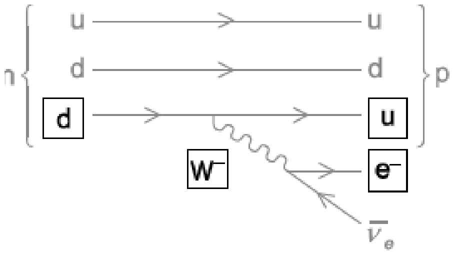
Label the diagram by inserting the **four** missing particle symbols.

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]

Markscheme

a. charge: –1«e» ***or*** negative ***or*** K^-

Negative signs required.

b. 

correct symbols for both missing quarks

exchange particle and electron labelled W ***or*** W^- and e ***or*** e^-
Do not allow W^+ or e^+ or β^+ Allow β or β^-

c. decay products include an electron that has mass

OR

products have energy that has a mass equivalent

OR

mass/mass defect/binding energy converted to mass/energy of decay products

«so»

mass C-14 > mass N-14
OR
mass of *n* > mass of *p*
OR
mass of *d* > mass of *u*

Accept reference to "lighter" and "heavier" in mass.
Do not accept implied comparison, eg "C-14 has greater mass". Comparison must be explicit as stated in scheme.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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]

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

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]

Markscheme

a. ${}^{137}_{56}\mathrm{Ba}$;

anti-neutrino / $\bar{v}$;

b. evidence of use of 4 half-lives;

so 0.938 ***or*** 93.8% ***or*** $\frac{15}{16}$ decays;

c. reference to a short-term effect e.g. skin reddening / burning;

reference to a long-term effect e.g. genetic damage / cancer;

reference to relative penetrative power of beta/ionizing power compared to alpha or gamma;

Examiners report

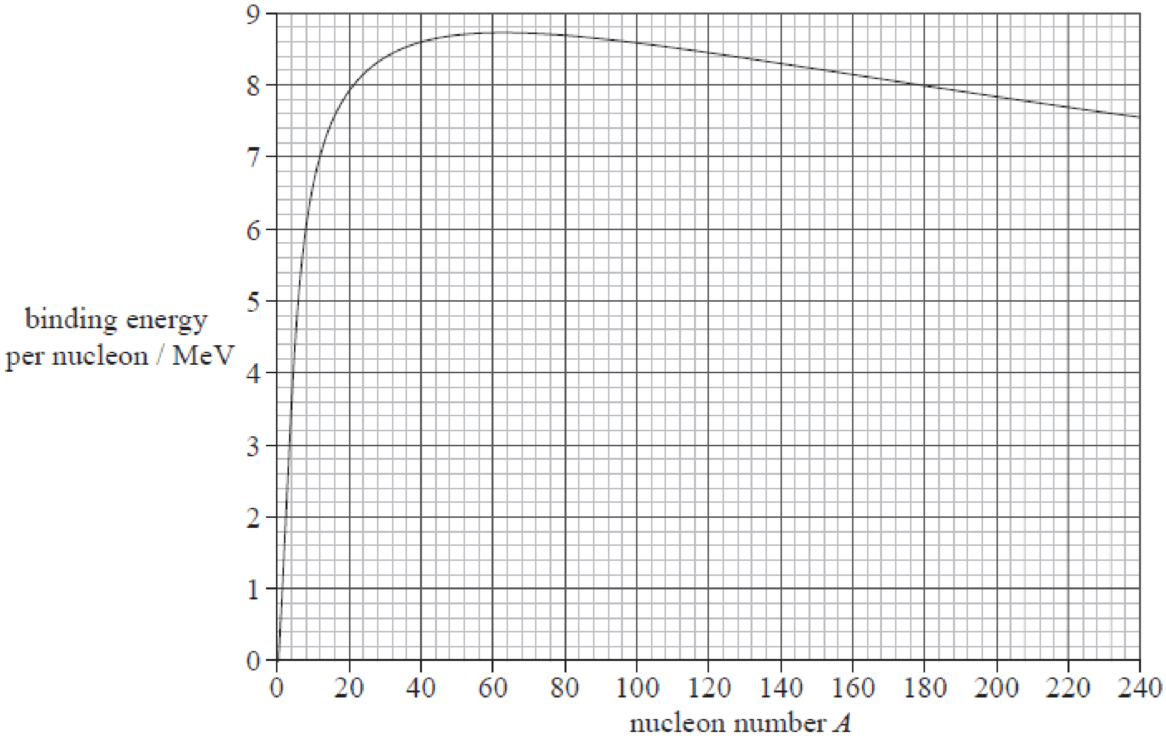
a. [N/A]
b. [N/A]
c. [N/A]

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

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

(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]

Markscheme

a. (i) the (minimum) energy required to completely separate the nucleons of a nucleus / the energy released when a nucleus is assembled;

(ii) mass defect is 94×1.007276+145×1.008665−238.990396=1.95u;
binding energy is 1.95×931.5=1816MeV;
binding energy per nucleon is $\frac{1816}{239}$ MeV;
=7.6MeV

b. (i) x=3;

(ii) binding energy of plutonium is 7.6×239=1816≈1800MeV
(known in (ii))
binding energy of products is 8.6×91+8.2×146=1980≈2000MeV;
energy released is (2000−1800)=200MeV;

c. the electric force is repulsive/tends to split the nucleus;

the electric force acts on protons, the strong nuclear force acts on nucleons;

the nuclear force is attractive/binds the nucleons;

but the electric force is long range whereas the nuclear force is short range;

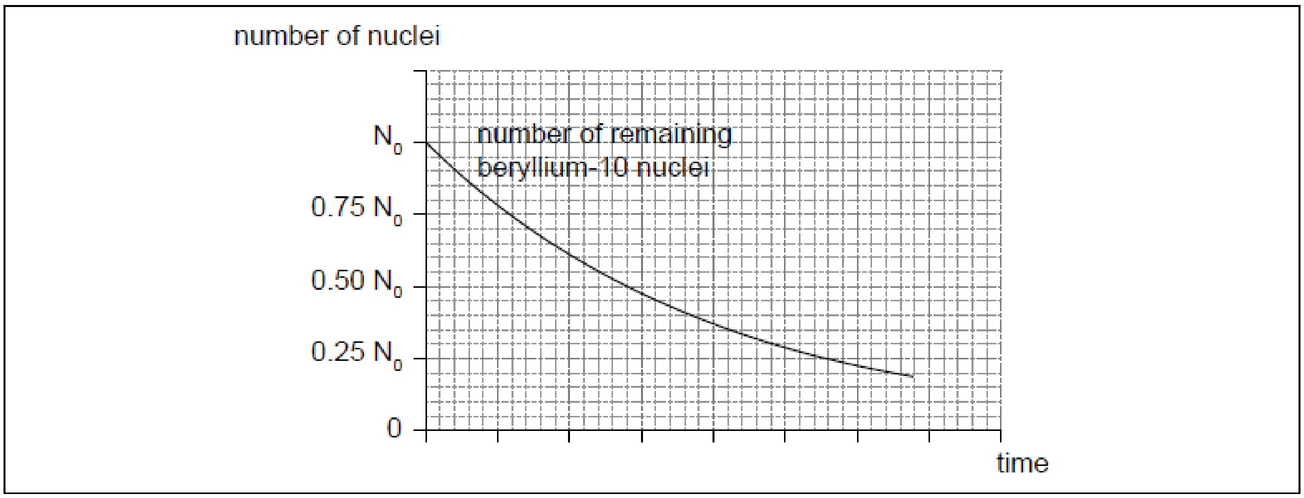
so adding more neutrons (compared to protons) contributes to binding and does not add to tendency to split the nucleus / a proton repels every other proton (in the nucleus) so extra neutrons are needed for binding;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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.iiiCalculate the peak wavelength in the intensity of the radiation emitted by the ice sample. [2]

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

Markscheme

a. ${}^{10}_{4}\mathrm{Be} \to {}^{10}_{5}\mathrm{B} + \beta + \overline{\mathrm{V}}_{\mathrm{e}}$

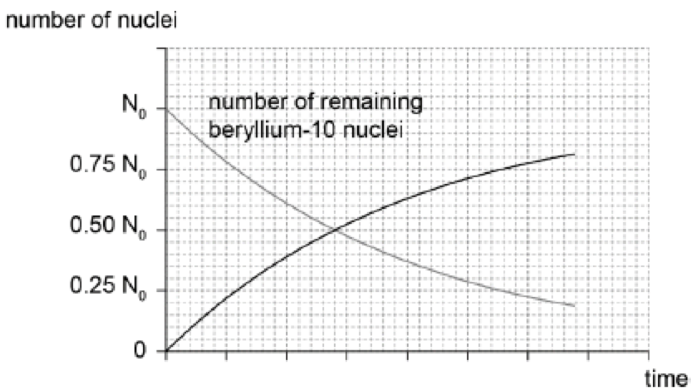
conservation of mass number ***AND*** charge ${}^{10}_{5}\mathrm{B}$, ${}^{10}_{4}\mathrm{Be}$

Correct identification of both missing values required for ***[1]****.*

[1 mark]

b.i.correct shape *ie* increasing from 0 to about 0.80 N_0

crosses given line at 0.50 N_0



[2 marks]

b.ii***ALTERNATIVE 1***

fraction of Be = $\frac{1}{8}$, 12.5%, or 0.125

therefore 3 half lives have elapsed

$t_{\frac{1}{2}} = \frac{4.3 \times 10^6}{3} = 1.43 \times 10^6$ «≈ 1.4×10^6» «y»

ALTERNATIVE 2

fraction of Be = $\frac{1}{8}$, 12.5%, or 0.125

$\frac{1}{8} = \mathrm{e}^{-\lambda}(4.3 \times 10^6)$ leading to $\lambda = 4.836 \times 10^{-7}$ «y»$^{-1}$

$\frac{\ln 2}{\lambda} = 1.43 \times 10^6$ «y»

Must see at least one extra sig fig in final answer.

[3 marks]

b.iii1.9×10^{11}

[1 mark]

c.i. emission of (infrared) electromagnetic/infrared energy/waves/radiation.

[1 mark]

c.ii. the (peak) wavelength of emitted em waves depends on temperature of emitter/reference to Wein's Law

so frequency/color depends on temperature

[2 marks]

c.iii $\lambda = \frac{2.90 \times 10^{-3}}{253}$

= 1.1×10^{-5} «m»

Allow ECF from MP1 (incorrect temperature).

[2 marks]

c.iv correct units for Intensity (allow *W, Nms^{-1} OR Js^{-1} in numerator)*

rearrangement into proper SI units = kgs^{-3}

Allow ECF for MP2 if final answer is in fundamental units.

[2 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]
c.iv. [N/A]

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).

Markscheme

a. emission of (alpha/beta/gamma) particles/photons/electromagnetic radiation;

nucleus becomes more (energetically) stable;

constant probability of decay (per unit time);

is random process;

activity/number of unstable nuclei in sample reduces by half over constant time intervals/exponentially;

not affected by temperature/environment / is spontaneous process;

b. (i) 93;

(ii) mass of products is less than mass of reactants / there is a mass defect;
mass is converted into energy (according to equation $E=mc^2$);

(iii) the (minimum) energy required to (completely) separate the nucleons in a nucleus / the energy released when a nucleus is assembled from its constituent nucleons;

(iv) calculation of binding energies as shown below;

americium-241 = 241×7.54=1817.14 MeV
neptunium-237 = 237×7.58 = 1796.46 MeV
helium-4 = 4×7.07 = 28.28 MeV

energy released is the difference of binding energies;
and so equals 7.60 MeV;

*Award **[2 max]** for an answer that multiplies by the number of neutrons or number of protons.*
Ignore any negative sign in answer.

Examiners report

a. [N/A]
b. [N/A]

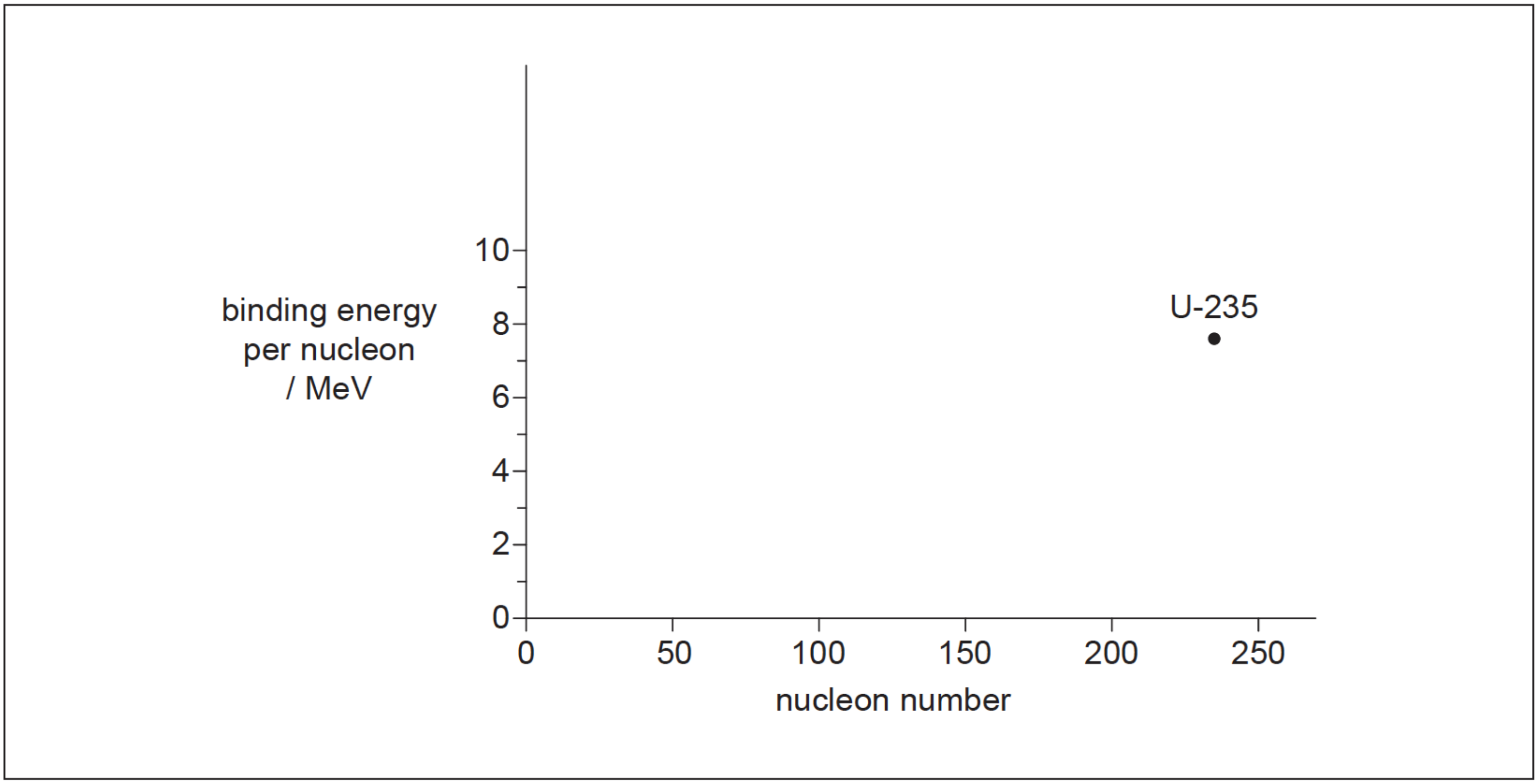
This question is in two parts. **Part 1** is about renewable energy. **Part 2** is about nuclear energy and radioactivity.

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 $8.5 ms^{-1}$ and the density of air is $1.3 kgm^{-3}$. 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.

Markscheme

a. (i) total wind power required $= \frac{750000}{0.3}$;

maximum wind power required per turbine, $P = \frac{750000}{5\times0.3}(= 500\text{kW})$;

$d = \left(\frac{8P}{\rho\pi v^3} =\right)^{\frac{1}{2}} 40(\text{m})$

*Award **[1 max]** for an answer of 48.9 (m) as it indicates 5 and 0.3 ignored.*
*Award **[2 max]** for 22 (m) as it indicates 0.3 ignored.*
*Award **[2 max]** for 89 (m) as it indicates 5 ignored.*

(ii) not all kinetic energy can be extracted from wind / losses in cables to community / turbine rotation may be cut off/"feathered" at high or low wind speeds;
Do not allow "wind speed varies" as question gives the average speed.

(iii) less kinetic energy available / wind speed less for turbines behind; turbulence/wake effect; *(do not allow "turbines stacked too close")*

(iv) *implications:* average wind speeds are greater / more space available;
limitations: installation/maintenance cost / difficulty of access / wave damage;
*Must see one each for **[2]**.*

b. (i) mass of coal per second (=0.0214 kg);

77.1 (kg);

or

energy saved per hour=0.75×3600 (=2700MJh^{-1}) ;

mass of coal saved $= \left(\frac{2700}{35} =\right) 77.1(\text{kg})$;

*Award **[2]** for a bald correct answer.*

(ii) *advantage:*
energy is free (apart from maintenance and start-up costs) / energy is renewable / sufficient for small community with predominance of wind / supplies energy to remote community / independent of national grid / any other reasonable advantage;
Answer must focus on wind farm not coal disadvantages.

disadvantage:
wind energy is variable/unpredictable / noise pollution / killing birds/bats / large open areas required / visual pollution / ecological issues / need to provide new infrastructure;

(iii) greenhouse gas molecules are excited by/absorbed by/resonate as a result of infrared radiations; { (must refer to infrared not "heat")
this radiation is re-emitted in all directions;
less greenhouse gas means less infrared/heat returned to Earth; { (consideration of return direction is essential for mark)
temperature falls (to reach new equilibrium);

c. energy released when a nucleus forms from constituent nucleons / (minimum) energy needed/work done to break a nucleus up into its constituent nucleons;

*Award **[0]** for energy to assemble nucleus.*

Do not allow "particles" or "components" for "nucleons".

Do not accept "energy that binds nucleons together" OWTTE.

d. *(*i) generally correct shape with maximum shown, trending down to U-235;

maximum shown somewhere between 40 and 70;

*Award **[0]** for straight line with positive gradient from origin.*

*Award **[1]** if maximum position correct but graph begins to rise or flatlines beyond or around U-235.*

(ii) identifies fission as occurring at high nucleon number / at right-hand side of graph;
fission means that large nucleus splits into two (or more) smaller nuclei/nuclei to left of fissioning nucleus (on graph);
(graph shows that) fission products have higher (average) binding energy per nucleon than U-235;
energy released related to difference between initial and final binding energy;
*Award **[2 max]** if no reference to graph.*

e. (i) ${}^{235}_{92}\mathrm{U} \to {}^{231}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$; *(allow He for α; treat charge indications as neutral)*

(ii) time taken for number of unstable nuclei/(radio)activity to halve;
Accept atom/isotope.
Do not accept mass/molecule/amount/substance.

(iii) three half-lives identified;
45 (mg);
*Award **[2]** for bald correct answer.*

Examiners report

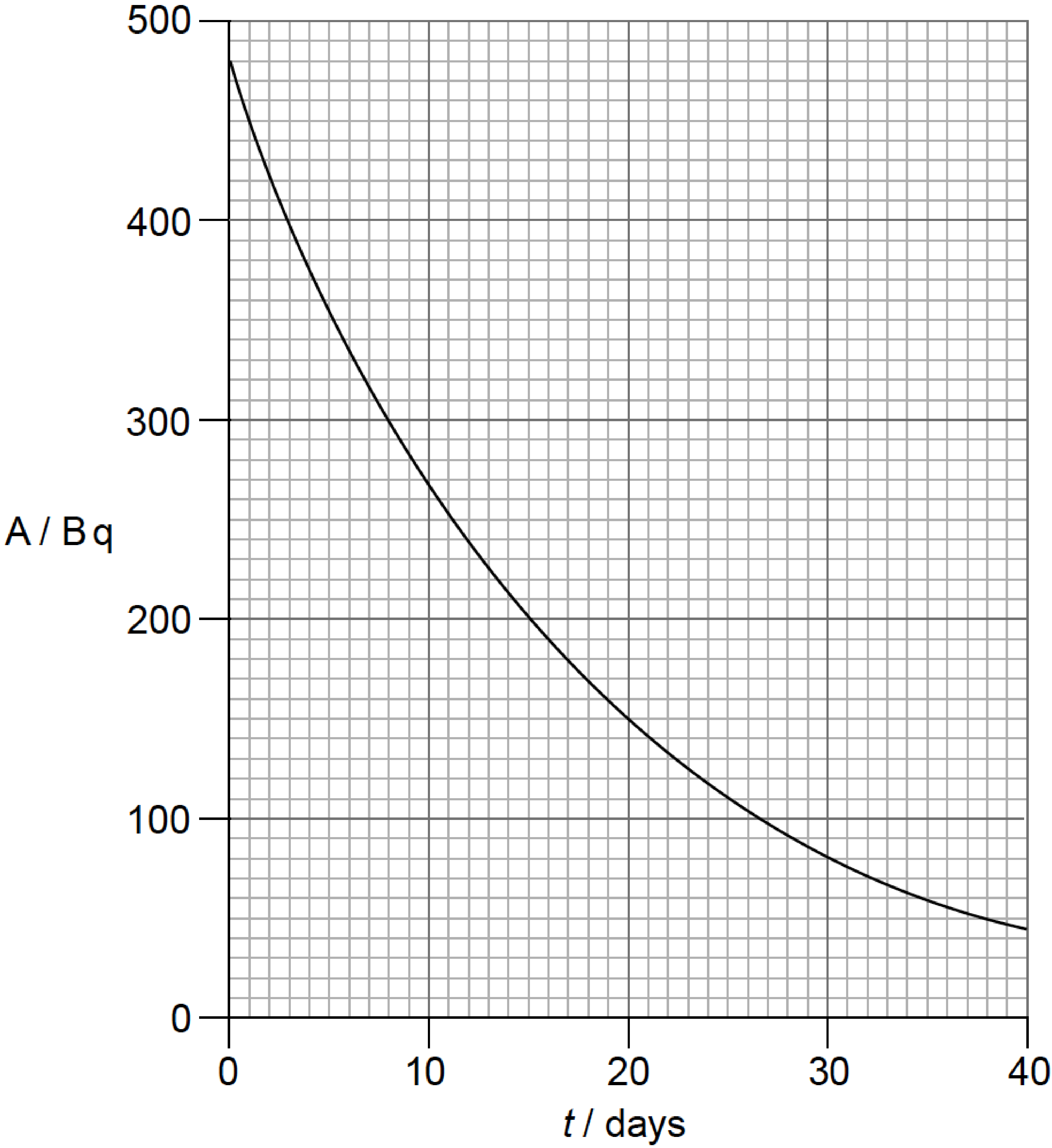
a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

---

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]

Markscheme

a. «energy/mass difference =» 8.450 – 8.398 «= 0.052 MeV»

Q = 1.7 ***or*** 1.66 ***or*** 1.664 MeV

OR

2.66×10^{-13} J

b. 11 – 12 days

c. quark theory is simpler ***OR*** Occam's razor example ***OR*** simple model explains complex observations

quotes experiment that led to quark theory, eg deep inelastic scattering **or** electron scattering

model incorporates strong/weak interactions/forces between protons and neutrons

model incorporates conservation rules

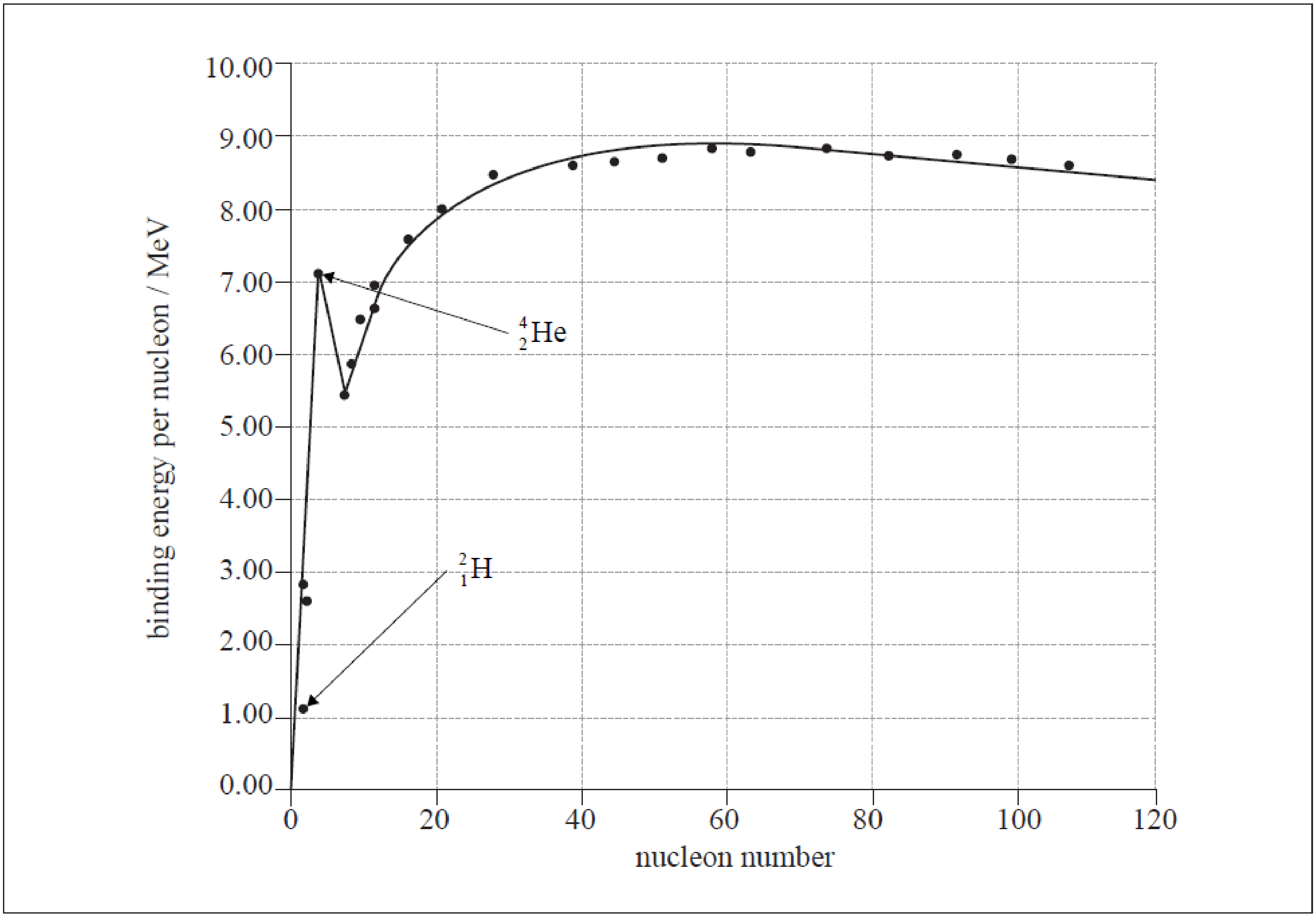
model explains differences between neutrons and protons ***OR*** explains decay of neutron to proton

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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 $^{2}_{1}H$ nuclei fuse to make a $^{4}_{2}He$ 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.

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{\dots}_{\dots}\dots\dots$$

$$^{3}_{1}H \rightarrow ^{3}_{\dots}He + ^{\dots}_{\dots}\dots\dots + ^{\dots}_{\dots}\dots\dots$$

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

Markscheme

a. (i) difference in total mass of individual nucleons and nucleus / energy needed to divide nucleus into component nucleons / energy liberated when nucleus formed from component individual nucleons;

nuclear binding energy is the energy equivalent of mass defect / reference to $E=mc^2$;

(ii) S marked near line between 50 and 70;

(iii) binding energy per nucleon read from graph as 1.1/1.2 and 7.1/7.2 (MeV);

both values multiplied by 4;

difference given between 23.6 and 24.4 (MeV);

3.8 x 10^{-12}(J) **or** 3.9 x 10^{-12} (J);

b. (i) ${}^{1}_{1}\mathrm{H}$ / ${}^{1}_{1}\mathrm{p}$;

${}^{2}_{3}\mathrm{He}$;

${}^{0}_{-1}\mathrm{e}$ / ${}^{0}_{-1}\beta$;

${}^{0}_{0}\bar{v}$; *(do not allow neutrino)*

(ii) recognition that fusion process is more likely (at high temperatures);

the (electric) force between nuclei is repulsive;

nuclei need ~ 10^{-15} m separations for strong force to act;

kinetic energy of nuclei increases with temperature;

(higher temperature) increases probability of nuclear collisions;

radioactive decay is unaffected by temperature;

*Award **[0]** for correct choice with no or wrong explanations.*

Examiners report

a. (i) The definition of either mass defect or nuclear binding energy was badly understood and there were many confused answers to this part. As in previous years the most common misunderstanding amounts to candidates believing that the nuclear binding energy is the energy that holds the nucleons together in the nucleus.

(ii) The majority of candidates labelled the most stable region within tolerance. A minority appear to have missed this part of the question and not answered it at all – candidates should be reminded to read the paper carefully and not to throw away marks by speed reading.

(iii) For a straightforward nuclear energy question this part was poorly answered. It was quite common to see candidates ignoring the fact that two deuterons were fusing to produce helium. As a 'show that' question, it is important that candidate do produce a final answer that is to more than the one digit approximation – many were satisfied by setting out the calculation and then immediately approximating to 4pJ without showing that this was the case. This will always lose a mark in such questions

b. (i) This part was quite well done by many candidates with the proton (in the first equation) and the electron or antineutrino (in the second equation) being the most common omissions or having mistakes in the proton or nucleon numbers.

(ii) Few candidates completed this well. Most did no more than to make a statement and it was uncommon for candidates to state that the beta decay is temperature independent. The best answers explained that the deuterium nuclei needed high kinetic energies to be able to approach each other and overcome the Coulombic repulsion and allow the strong nuclear force to come into play.

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

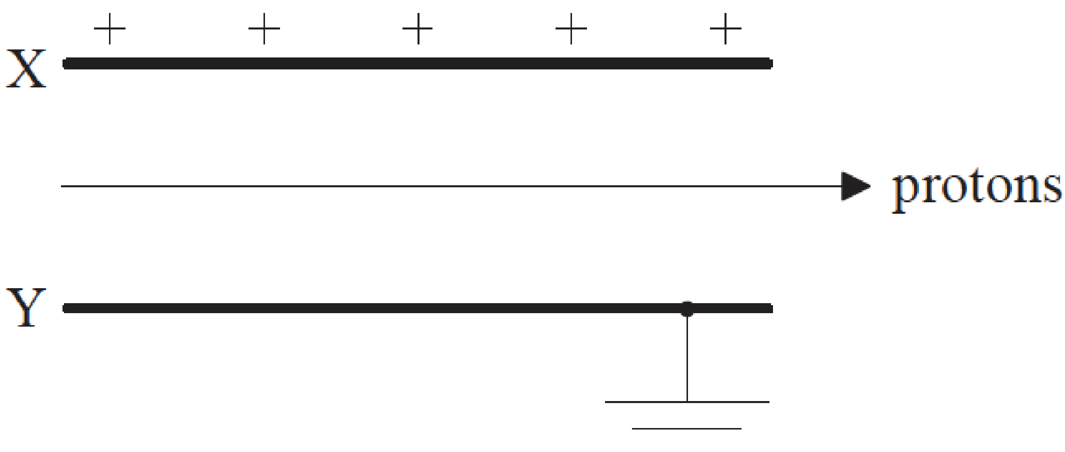
Part 1 Electric fields and radioactive decay

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]

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

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

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

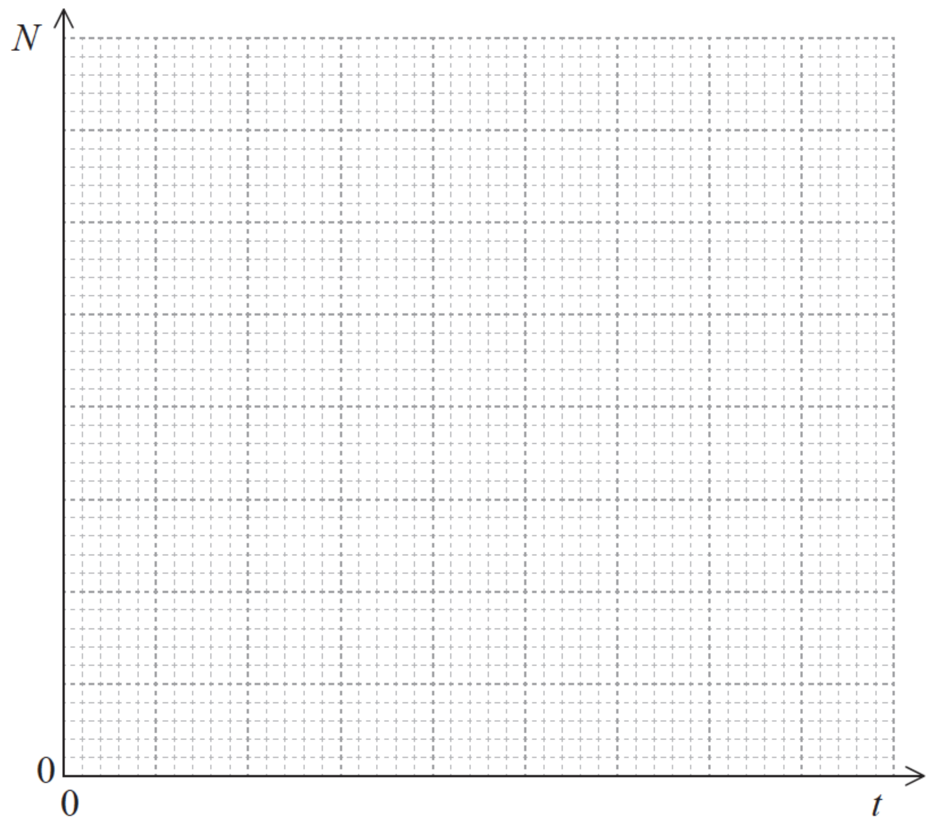
Rest mass of nitrogen-14 nucleus =14.0031 u
Rest mass of alpha particle =4.0026 u
Rest mass of X nucleus =16.9991 u
Rest mass of proton =1.0073 u

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 = $4.18 \times 10^3 Jkg^{-1}K^{-1}$

Show that the data give a value of about $1.8 \times 10^6 Jkg^{-1}$ 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]

Markscheme

a. the force exerted per unit charge;

on a positive small/test charge;

b. $E=\frac{ke}{r^2}=\frac{9\times10^{9}\times1.6\times10^{-19}}{10^{-30}}$;

$=1.4\times10^{21}\mathrm{NC}^{-1}$ ***or*** Vm^{-1};

c. (i) into the (plane of the) paper;

(ii) *Ee*=*Bev* ***or*** *E*=*Bv*;

=($2.3\times10^{-4}\times3.9\times10^{6}$=)900/897;

NC^{-1} ***or*** Vm^{-1};

d. *proton number*: 8

nucleon number: 17

(both needed)

e. 16.9991u+1.0073u-[14.0031u+4.0026u];

=-7.00×10^{-4};

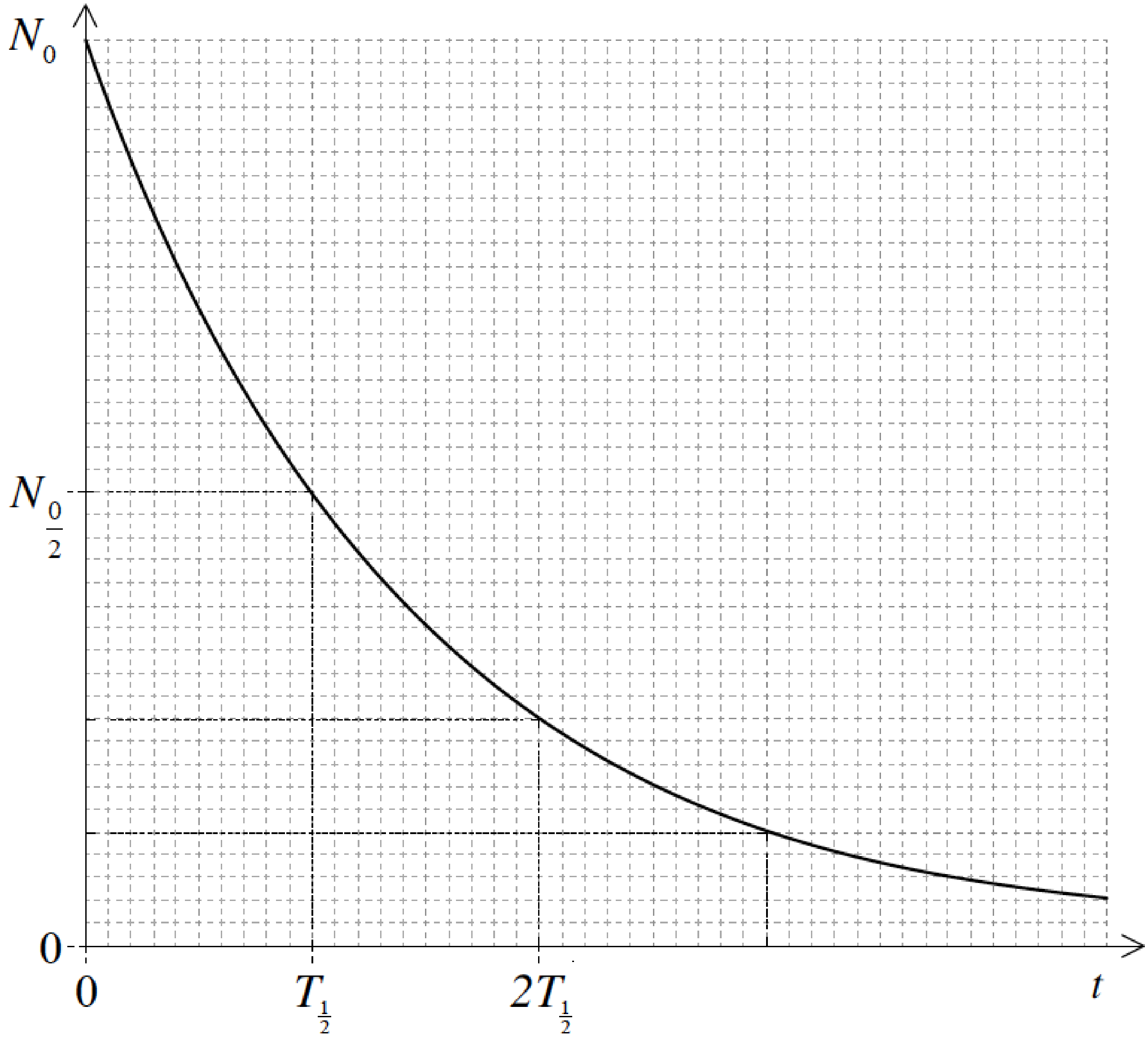
$7.000\times10^{-4}\times931.5$=0.6521MeV;

(~0.7MeV)

f. (i) *isotope:*

same proton number/element/number of protons ***and*** different number of neutrons/nucleon number/neutron number; } *(both needed)*

half-life:
time for the activity (of a radioactive sample) to fall by half its original value / time for half the radioactive/unstable nuclei/atoms (in a sample) to decay;

(ii) 

(approximately) exponential shape;
minimum of three half lives shown;
graph correct at $\left[T_{\frac{1}{2}}, \frac{N_0}{2}\right]$, $\left[2T_{\frac{1}{2}}, \frac{N_0}{4}\right]$, $\left[3T_{\frac{1}{2}}, \frac{N_0}{8}\right]$;

g. temperature is a measure of the (average) kinetic energy of the molecules;

at the boiling point, energy supplied (does not increase the kinetic energy) but (only) increases the potential energy of the molecules/goes into increasing the separation of the molecules/breaking one molecule from another / *OWTTE*;

h. (energy gained by cold water is) 0.300×4180×[34.6-15.2] / 24327;

(energy lost by cooling water is) 0.012×4180×[100-34.6] / 3280;

(energy lost by condensing steam is) 0.012*L*;

1.75×10^{6}(Jkg^{-1})/

$\frac{[\text{their energy gained by cold water} - \text{their energy lost by cooling water}]}{0.012}$;

Award **[4]** *for* 1.75×10^{6}*(Jkg*$^{-1}$*).*
Award **[2 max]** *for an answer that ignores cooling of condensed steam.*

i. some of the energy (of the condensing steam) is lost to the surroundings;

so less energy available to be absorbed by water / rise in temperature of the water would be greater if no energy lost;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]
g. [N/A]
h. [N/A]
i. [N/A]

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]

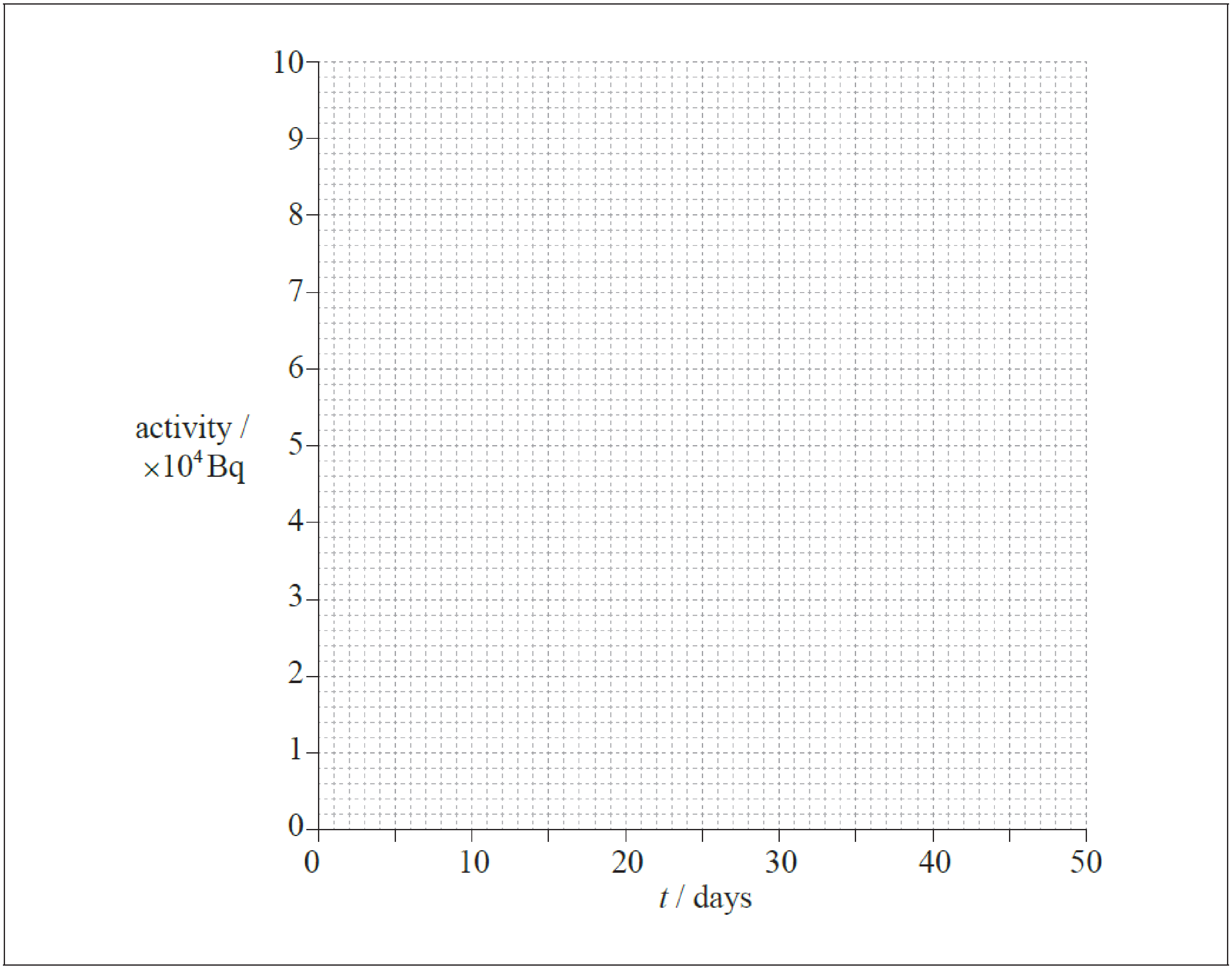
$$^{3}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + \mathrm{X} + \mathrm{Y}$$

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.

Markscheme

a. (i) nuclides/atom/element/nucleus/nuclei that have different nucleon/neutron numbers but same proton number/are same element / *OWTTE;*

(ii) the time taken for the activity (of a radioactive sample) to decrease by half / the time taken for half the (initial) number of radioactive nuclei/atoms/mass to decay; *("radioactive" must be seen in alternative answer)*

b. (i) 2;

(ii) (mass difference=)7.0160 – [3.0161+ 4.0026]= (–)2.7x 10^{-3}u;
(energy required=)(–)2.7x10^{-3}x931.5 ***or*** 2.5151(MeV) ;
(≈ 2.5 MeV)

Allow unit conversions via mass and mc^2 .
Must see either answer to 3+sf or subtraction or use of mc^2 to award 2nd mark.

c. 2.5MeV must be converted to mass (in the interaction) / otherwise the products would not be moving;

(to conserve momentum) final products must have total momentum equal to that of incoming neutron (so extra energy is required) / *OWTTE;*

d. product of mass and velocity; *(do not allow "speed")*

Accept symbols if defined correctly.

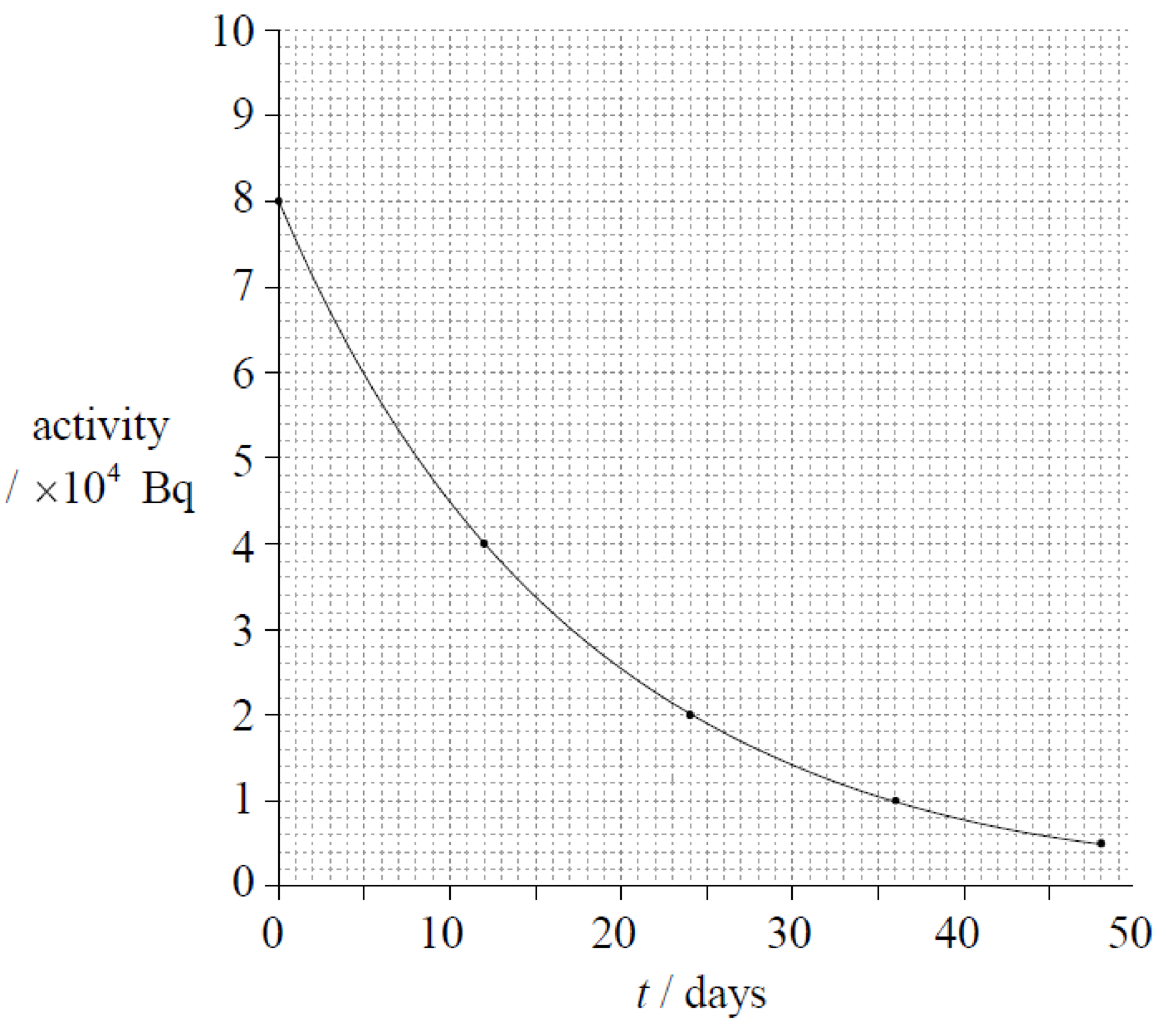
d. ${}^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \beta^{-} + \bar{v}$

β^- or ${}^{0}_{-1}\mathrm{e}$ **or** e^- **or** electron **or** beta particle;

$\bar{v}$ **or** ${}^{0}_{0}\bar{v}$ **or** antineutrino;

Allow answers in either order.

e. (i)



five correct data points;
smooth curve through data points;
Do not allow ECF if incorrect points are plotted leading to a non-smooth curve.
Award full credit for correct curve even if the data points are not visible.

(ii) 1.4×10^4 (Bq);
Allow correct reading from mis-drawn graph $\pm$ *0.1.*

(iii) number of atoms left=$\frac{1.2\times10^{11}\times1.4}{8}$ ***or*** uses proportion ***or*** uses ln$\left(\frac{N}{N_0}\right) = -\lambda t$; *(with correct values)*
2.1×10^{10};
Award ***[2]*** *for a bald correct answer.*

Examiners report

a. (i) Although many were able to give a correct statement of the meaning of the term isotope there were a disappointing number who could not. In general, candidates should attempt to give clearer, more succinct definitions.

(ii) Equally, definitions of radioactive half-life were often weak, incomplete and confused, referring to the amount or mass of the total (rarely initial) substance rather than its activity. These are straightforward definitions to memorize and candidates would be well advised to spend time on this routine task.

b. (i) The proton number was almost invariably correct.

(ii) All the basics of this question were understood, the calculation was not well completed by many. Candidates need to understand that to gain full credit in response to "show that" they must convince the examiner that all steps are shown. This is best done by taking the calculation through to at least one more significant figure than is quoted in the question and explaining each line of calculation in words. Even strong candidates are not as careful as they could be about this.

c. This was another question where the candidates needed to articulate a logical argument. It was extremely poorly done. It would seem that candidates are muddled between the concepts of energy and momentum. There were attempts to gain a mark but candidates did not consider in the first instance why the neutron energy has to be greater than 2.5 MeV. This should not have been beyond the more able SL candidate.

d. Most could define linear momentum correctly using the terms mass and velocity.

d. Failure to recognize that the antineutrino not the neutrino is produced marred this normally well-answered question.

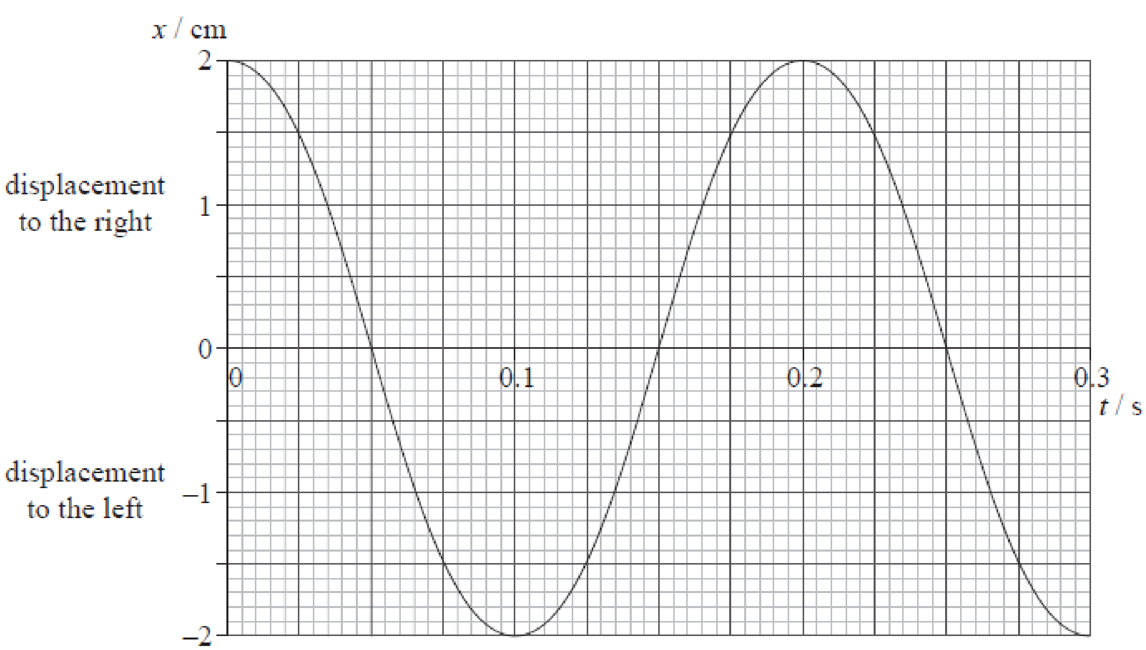
e. [N/A]

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.

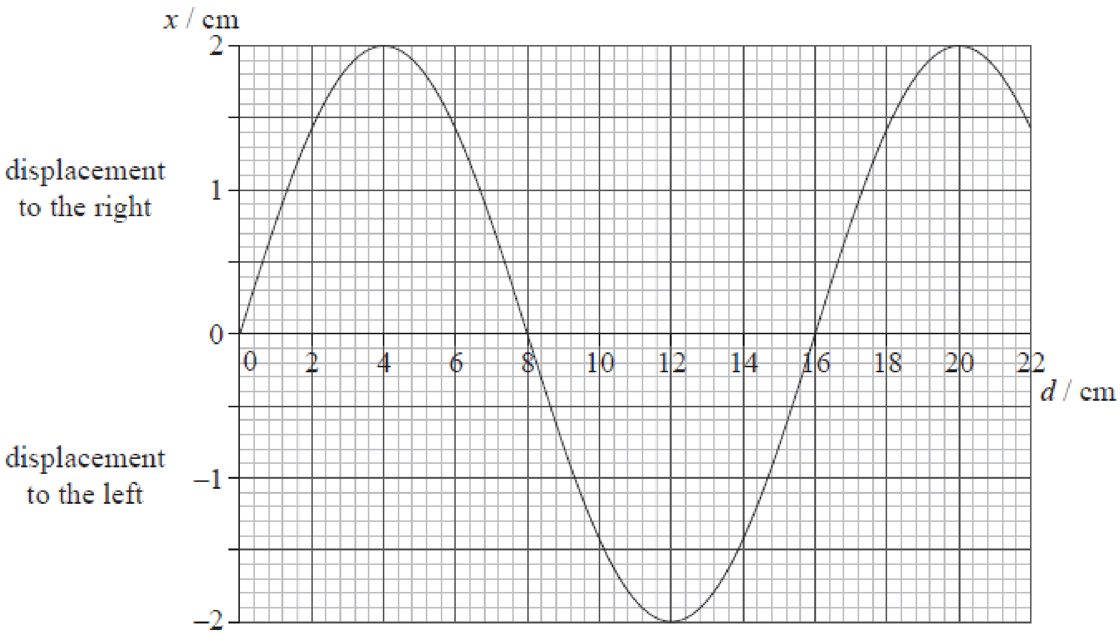
(ii) calculate the magnitude of its maximum acceleration.

(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

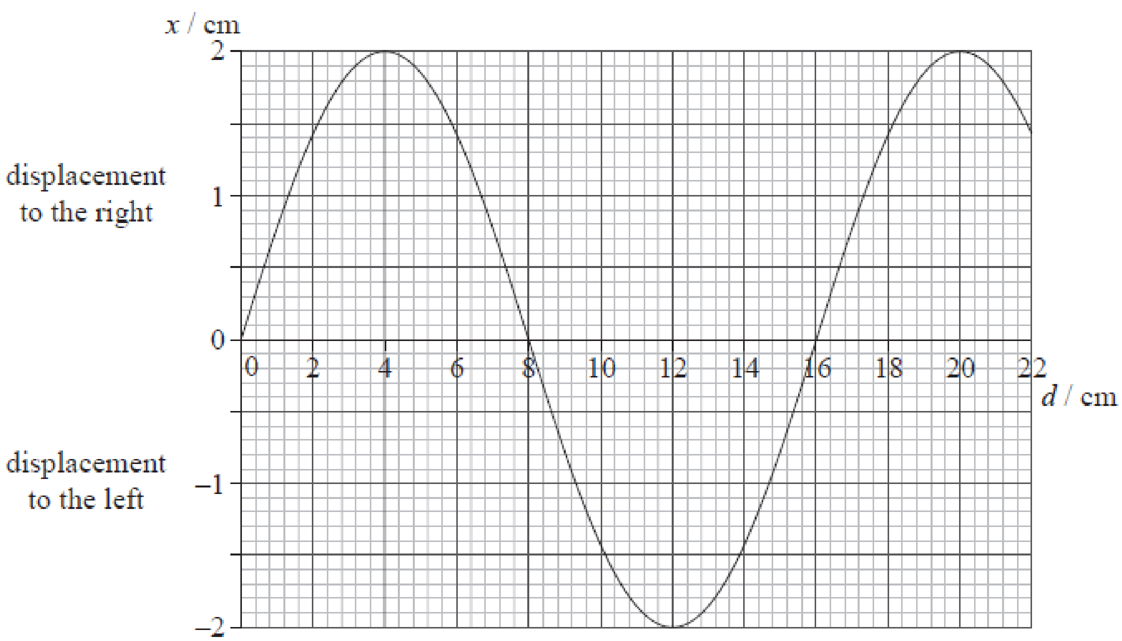


Determine for the longitudinal wave, using graph 1 and graph 2,

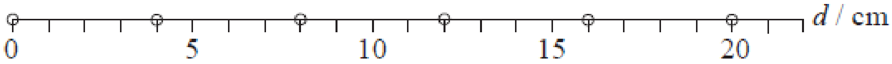
(i) the frequency.

(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.

Markscheme

a. (i) the amplitude is constant;

(ii) period is 0.20s;

$$a_{\max} = \left(\left[\frac{2\pi}{T}\right]^2 x_0 = 31.4^2 \times 2.0 \times 10^{-2}\right) = 19.7 \approx 20\text{ms}^{-2}$$

*Award **[2]** for correct bald answer and ignore any negative signs in answer.*

(iii) displacement at *t* = 0.12cm is (–)1.62cm;

$$v\left(= \frac{2\pi}{T}\sqrt{x_0 - x^2}\right) = 31.4\sqrt{\left(2.0 \times 10^{-2}\right)^2 - \left(1.62 \times 10^{-2}\right)^2} = 0.37\text{ms}^{-1};$$

Accept displacement in range 1.60 to 1.70 cm for an answer in range 0.33ms^{-1} to 0.38ms^{-1}.

or

$$v_0 = \frac{2\pi}{T}x_0 = 0.628\text{ms}^{-1};$$
$$|v| = \left(\left|-v_0 \sin\left[\frac{2\pi}{T}t\right]\right| \Rightarrow |v| = |-0.628\sin[31.4 \times 0.12]| = |0.37|\right) = 0.37\text{ms}^{-1};$$

or

drawing a tangent at 0.12s;
measurement of slope of tangent;
Accept answer in range 0.33ms^{-1} to 0.38ms^{-1} .

b. (i) use of $f = \frac{1}{T}$;

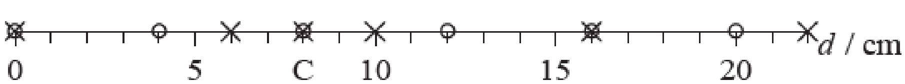
and so $f\left(= \frac{1}{0.20}\right) = 5.0\text{Hz};$

(ii) wavelength is 16cm;
and so speed is $v(=f\lambda=5.0\times0.16)=0.80\text{ms}^{-1}$;

c. (i) points at 0, 8 and 16 cm stay in the same place;

points at 4 and 20 cm move 2 cm to the right;

point at 12 cm moves 2 cm to the left;



(ii) the point at 8 cm;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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.)

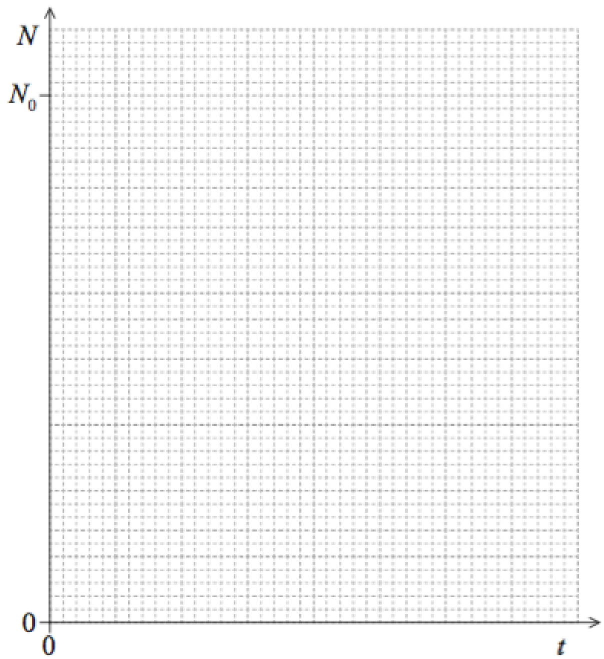
d. The reaction in (c) produces oxygen (O-17). Other isotopes of oxygen include O-19 which is radioactive with a half-life of 30 s. [2]

(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.



Markscheme

a. 1/12th mass of an atom of carbon-12/^{12}C ;

b. (254.1001×931.5 =)236.7(GeVc^{-2}); (*only accept answer in GeV c^{-2}*)

c. (i) proton / hydrogen nucleus / H$^+$ / $^1_1\mathrm{H}$ / $^1_1\mathrm{p}$;

(ii) Δm=(16.8383-[3.7428+13.0942]=)0.0013(GeVc^{-2});
energy required for reaction = 1.3 (MeV);
$^{17}_{8}\mathrm{O} + \mathrm{X} = (7.68 - 1.3 =)\, 6.4\, (6.38)\, \mathrm{MeV}$; *(allow correct answer in any valid energy unit)*

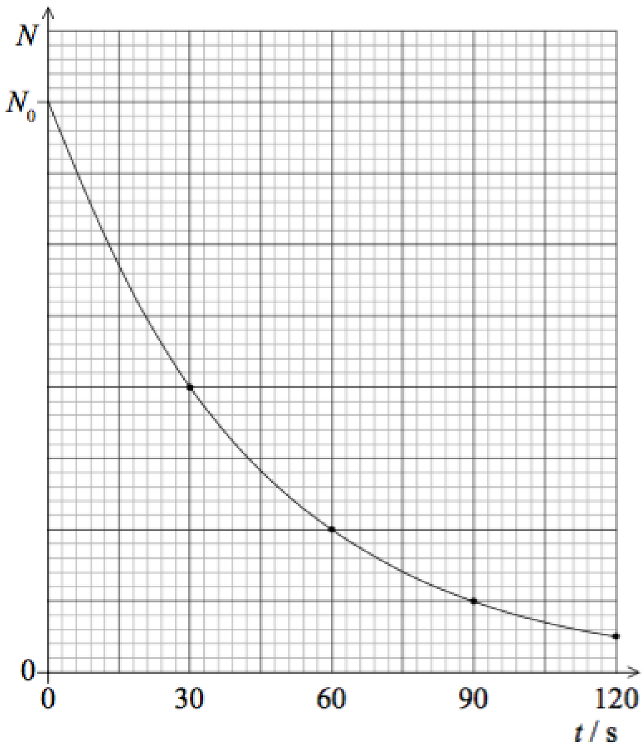
d. (i) (nuclei of same element with) same proton number, different number of neutrons / *OWTTE*;

(ii) the time for the activity of a sample to reduce by half / time for the number of the radioactive nuclei to halve from original value;

e. scale drawn on *t* axis; (*allow 10 grid squares ≡ 30 s or 40 s*)

smooth curve passes through $\frac{N_0}{2}$ at 30s, $\frac{N_0}{4}$ at 60s, $\frac{N_0}{8}$ at 90s, $\frac{N_0}{16}$ at 120s

(to within 1 square); *(points not necessary)*



Examiners report

a.
b.
c.
d.
e.

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.

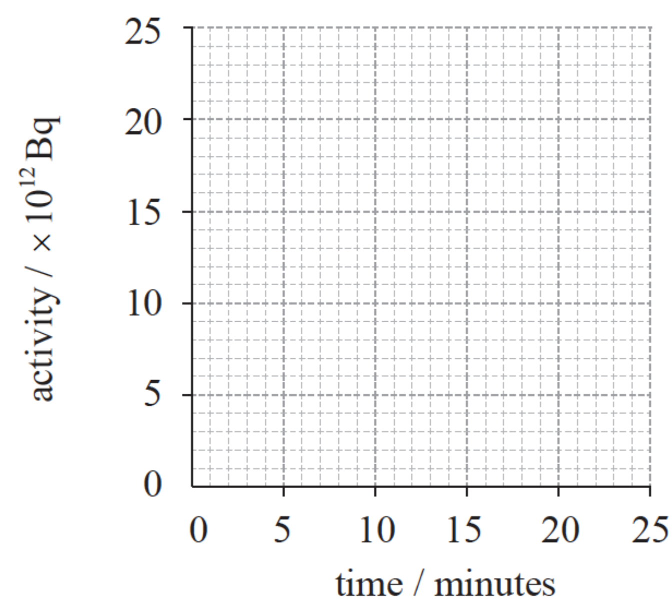
(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(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 = 3.3×10^5J 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).

Markscheme

a. one twelfth of the mass of a carbon-12 atom/ $^{12}_{6}\mathrm{C}$;

Do not allow nucleus.

$255.09\times931.5 = 237600(\mathrm{MeVc^{-2}})$;
*Award **[1]** for a bald correct answer.*

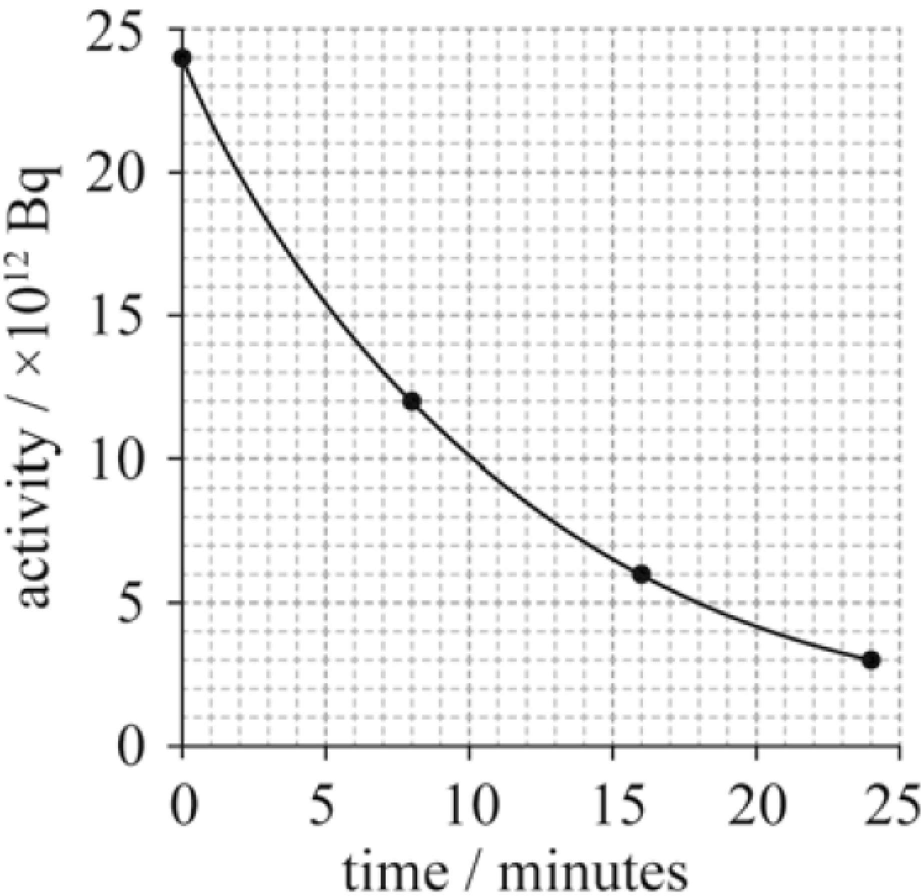
c. (i) neutron/$^{1}_{0}\mathrm{n}$;

(ii) the (rest) mass of the products is greater than that of the reactants;
energy must be given to supply this extra mass;

(iii) $\Delta m = [37216.560 + 938.272] - [37214.694 + 939.565] = 0.573\ (\mathrm{MeVc^{-2}})$;
energy required for reaction=0.573(MeV);
kinetic energy=(8.326-0.573=)7.753(MeV);
*Award **[3]** for a bald correct answer.*

d. (i) time for the activity of a sample to halve / time for half the radioactive nuclei to decay;

(ii) four data points (0, 24) (8, 12) (16, 6) (24, 3) correct;
smooth curve through points;



(iii) 2 hours (=120 minutes)=15 half-lives;

activity=$\frac{24\times10^{12}}{2^{15}} = 7.3 \times 10^8$ (Bq);

or

$\lambda = \frac{\ln 2}{8}$; $\left(A = A_0 e^{-\lambda t}\text{method}\right)$;

=7.3×10^8(Bq)

Award ***[2]*** *for a bald correct answer.*

e. (i) the energy (absorbed/released) when a unit mass/one kg;

of liquid freezes (to become solid) <u>at constant temperature</u> / of solid melts (to become liquid) <u>at constant temperature</u>;

(ii) potential energy changes during changes of state / bonds are weakened/broken during changes of state;

potential energy change is greater for vaporization than fusion / more <u>energy</u> is required to break bonds than to weaken them;

SLH vaporization is greater than SLH fusion;

Only award third marking point if first marking point or second marking point is awarded.

f. (i) use of $\Delta Q = mc\Delta T$ and *mL*;

$0.020 \times 3.3 \times 10^5 + 0.020 \times 4200 \times (T - 0) = 0.25 \times 4200 \times (80 - T)$;

T=68(°C);

Allow ***[3]*** *for a bald correct answer.*

Award ***[2]*** *for an answer of T=74°(C) (missed melted ice changing temperature).*

(ii) no energy given off to the surroundings/environment;

no energy absorbed by beaker;

no evaporation of water;

Examiners report

a. i) The definition of the unified atomic mass unit relates to the mass of the carbon 12 atom. Few candidates made this reference.

ii) Almost all were able to convert the mass unit into $MeVc^{-2}$.

c. i) This was well answered with the majority of candidates identifying the neutron.

ii) Few could relate the mass defect to the energy required to initiate the reaction.

iii) Many were able to calculate the mass defect but did not realize that in this reaction it is the energy needed to initiate the reaction. This is why the products have more combined mass than the reactants.

d. i) The definition of radioactive half-life was often poorly done with few appreciating that half the radioactive nuclei decay into a more stable form. Those that explained that the activity of the sample would halve were more successful.

ii) Almost all were able to draw the decay curve.

iii) This was well answered with responses split between those that successfully found the number of half-lives elapsed in 2 hours and going on to find the activity of the sample and those that took the decay constant route. At SL, most successfully found the number of half lives elapsed in 2 hours and were able to find the corresponding activity of the sample.

e. i) The majority related the latent heat to the energy required for a change of state but few successfully completed the definition by explaining that fusion is the change of state between a solid and liquid at constant temperature.

ii) This explanation was poorly done with few gaining full marks. Few could relate the change in potential energy during a change of state to fusion and vaporization.

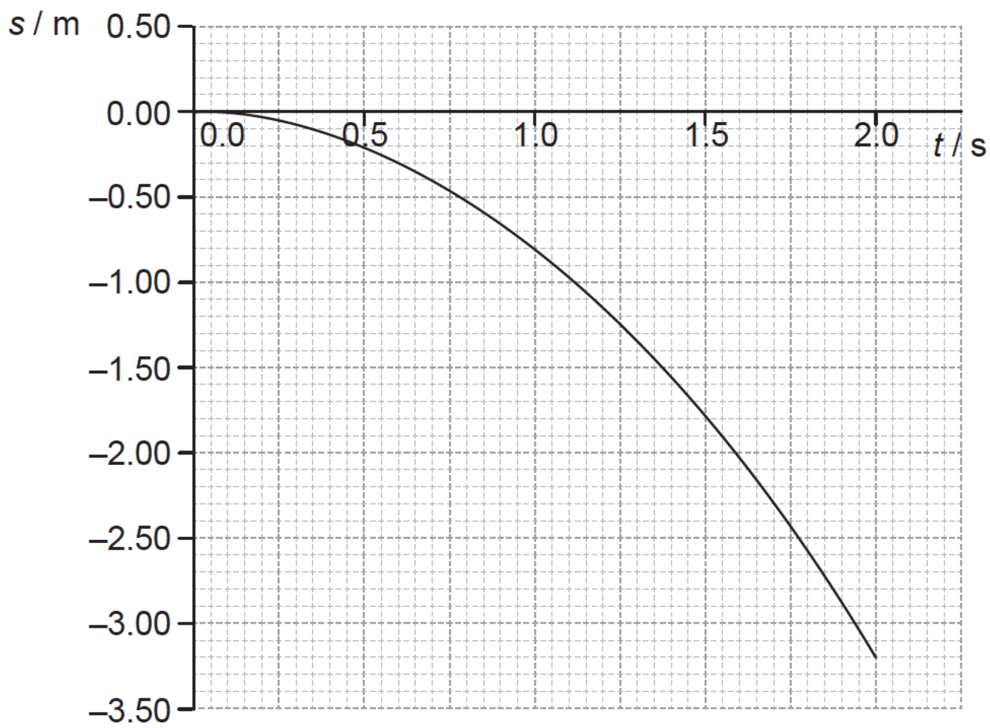
f. i) Of those candidates that established a relevant energy transfer equation, many did not include the heat gained by the ice once it had melted.

ii) Few could state two sources of energy loss that were not included in their energy equation.

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).

Markscheme

a. upwards (or away from the Moon) is taken as positive / downwards (or towards the Moon) is taken as negative / towards the Earth is positive;

b. (i) tangent drawn to curve at 0.80s;

correct calculation of gradient of tangent drawn;

–1.3 ±0.1m s^{-1} ***or*** 1.3 ±0.1m s^{-1} downwards;

or

correct coordinates used from the graph; substitution into a correct equation;

–1.3 ±0.1m s^{-1} ***or*** 1.3 ±0.1m s^{-1} downwards;

(ii) any correct method used;

correct reading from graph;

1.6 to 1.7 m s^{-2};

c. values for masses, distance and correct G substituted into Newton's law;

see subtraction (*ie r* value = $3.84 \times 10^{8} - 1.74 \times 10^{6} = 3.82 \times 10^{8}$ m);

F=5.4 to 5.5×10^{-4} N / *a*=2.7×10^{-3} m s^{-2};

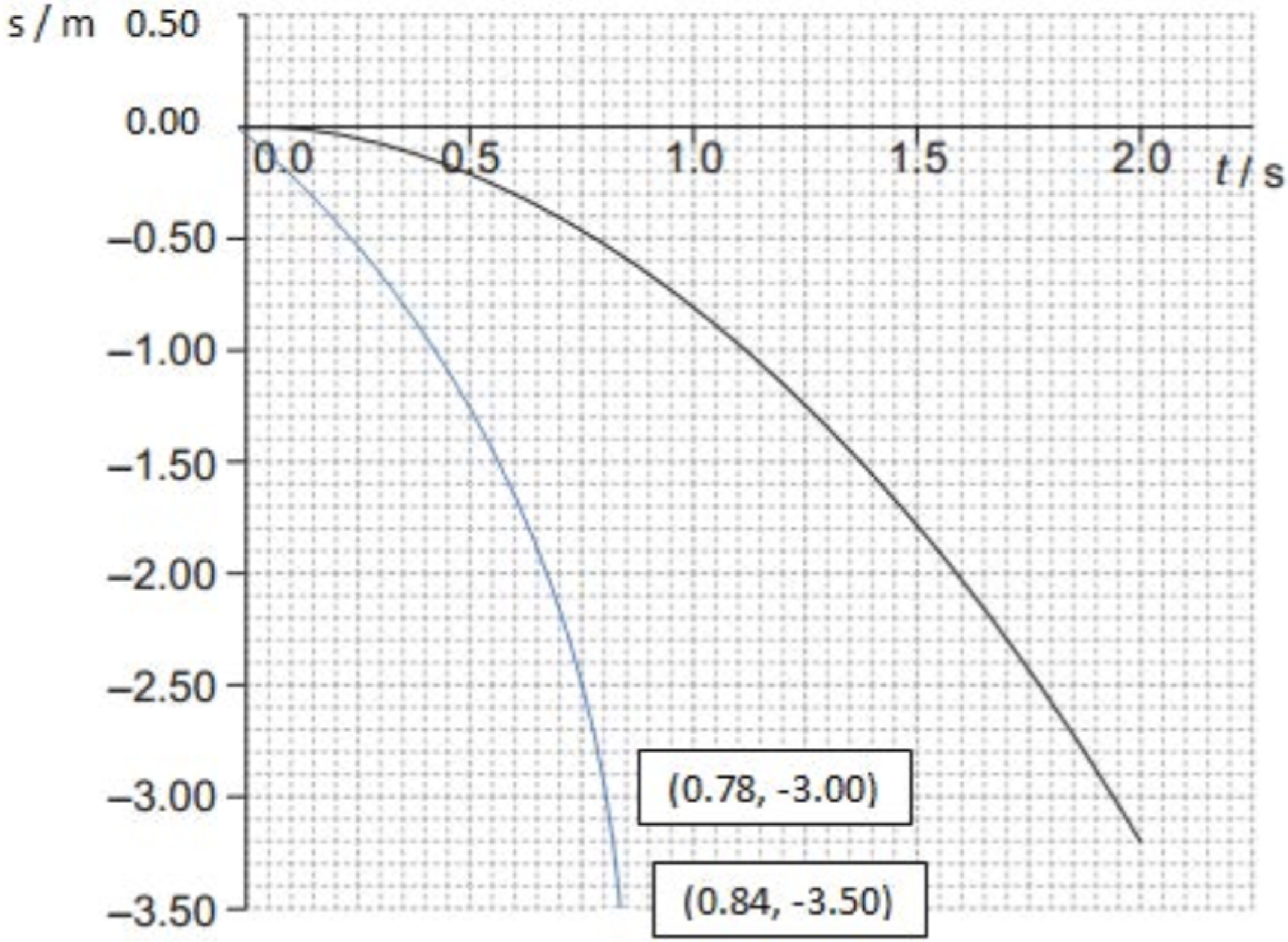
comment that it's insignificant compared with (0.2 × 1.63 =) 0.32 to 0.33 N / 1.63 m s^{-2};

d. 7.7 m s^{-1};

e. curve permanently below Moon curve;

smooth parabola; *(judge by eye)*

line passing through s = –3.00 m, t = 0.78 s ***or*** s = –3.50 m, t = 0.84 s (±1mm);



f. Ca-40 has 20 protons and 20 neutrons, Ca-47 has 20 protons and 27 neutrons / Ca-47 has 7 additional neutrons;

mention of strong/nuclear **and** coulomb/electrostatic/electromagnetic forces;

excess neutrons/too high a neutron-to-proton ration leads to the coulomb/electrostatic' electromagnetic force being greater than the strong/nuclear force (so the nucleus is unstable);

*Award **[1 max]** for an answer stating that Ca-47 has more neutrons so is bigger and less stable.*

g. six half-lives occurred;

$\left(\left(\frac{1}{2}\right)^6 =\right) 1.6\%$ remaining;

98.4 / 98% decayed;

h. (i)(electron) anti-neutrino / $\overline{v}$;

(ii) 46.95455 u – (46.95241 u + 0.00055 u) = 0.00159 u;

1.48 MeV;

(iii) does not account for energy of (anti) neutrino/gamma ray photons;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]
g. [N/A]
h. [N/A]