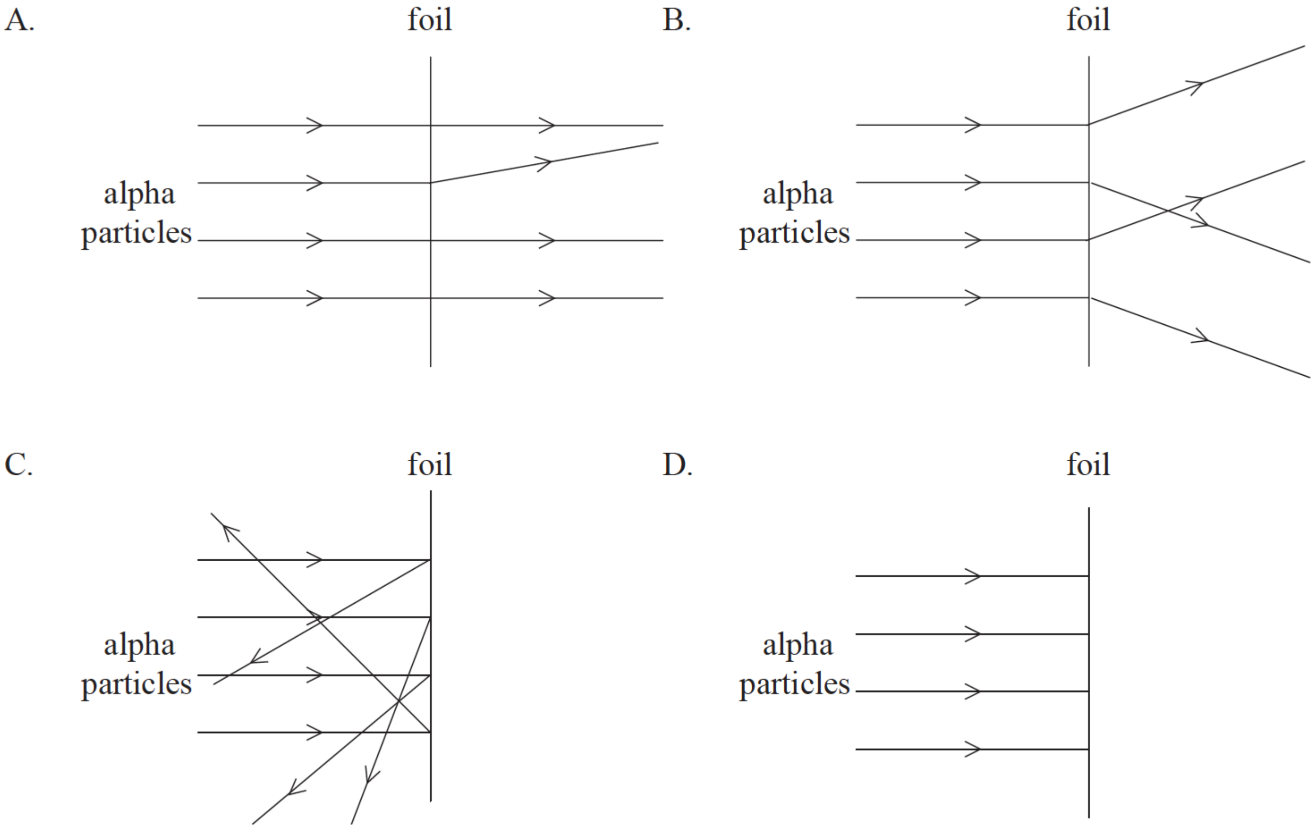
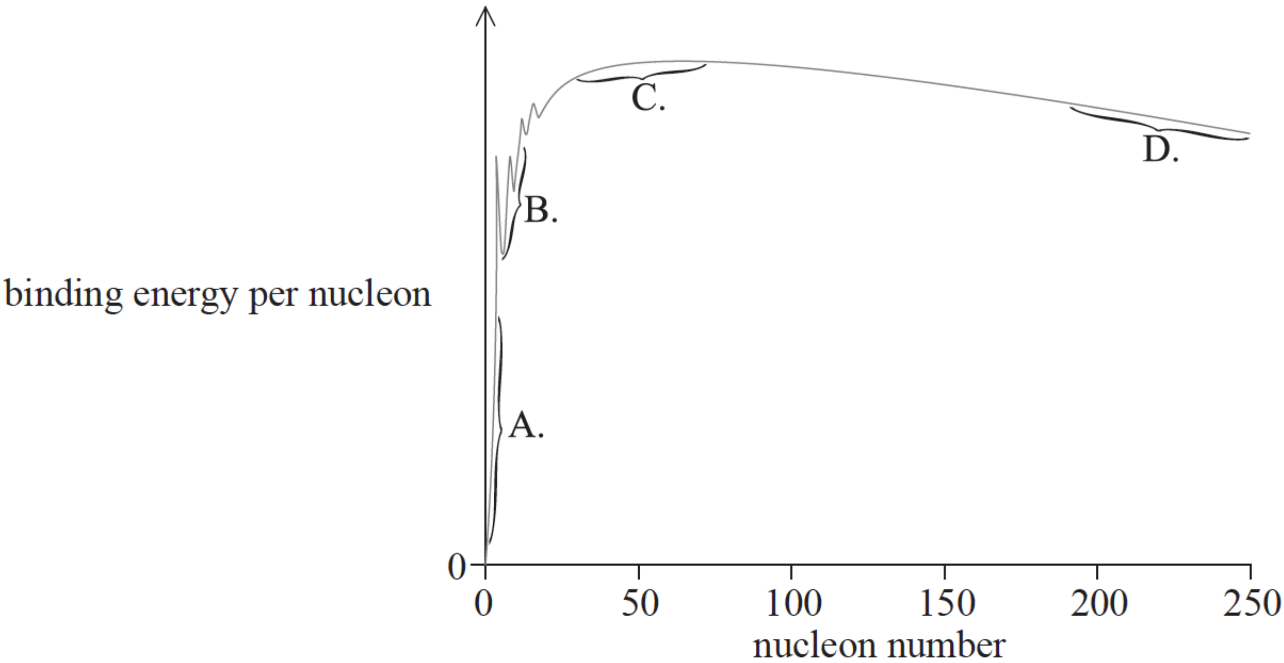
T7-1 *[255 marks]*

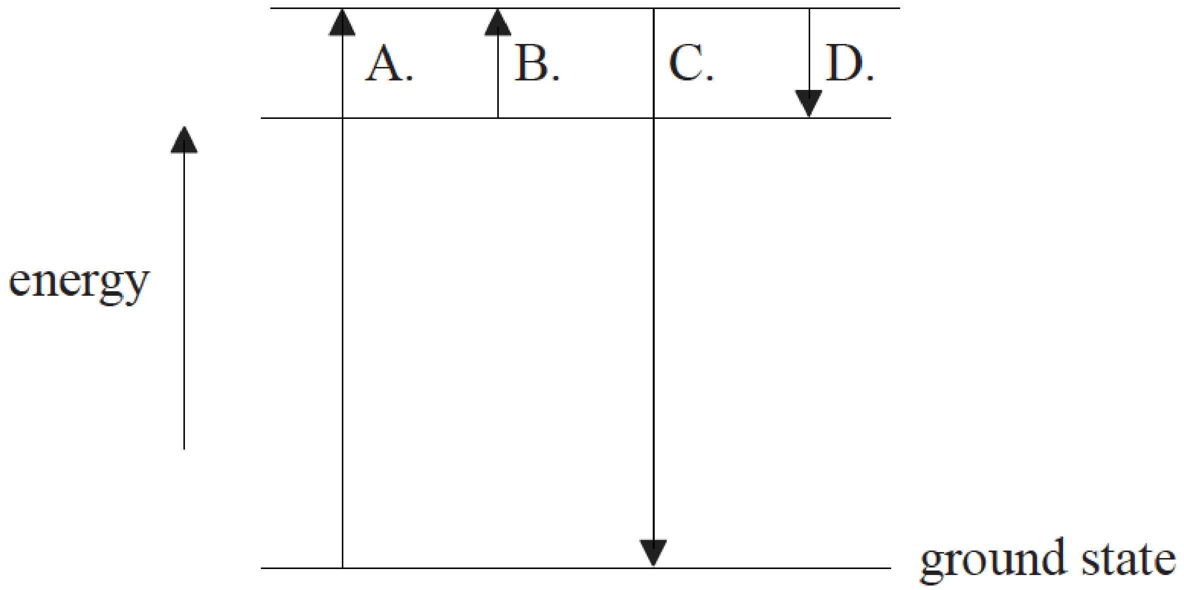
1. In the Geiger–Marsden experiment alpha particles were directed at a thin gold foil. Which of the following shows how the majority of the alpha particles behaved after reaching the foil? *[1 mark]*



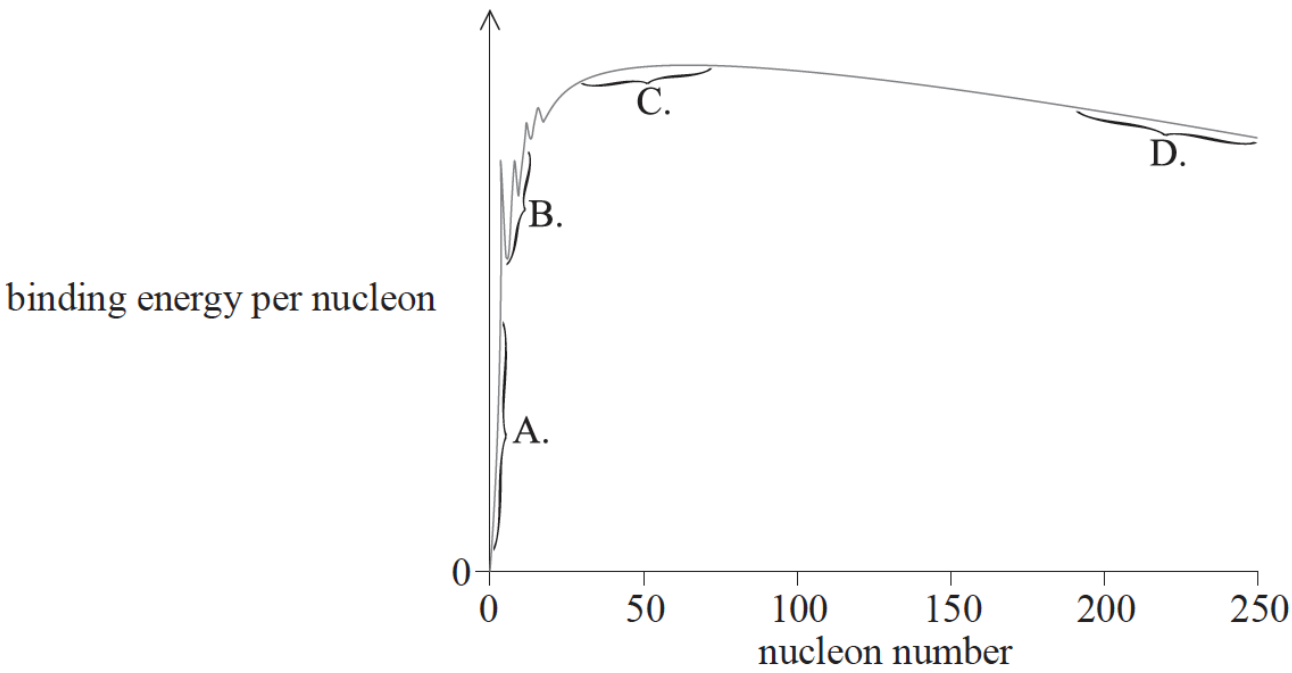
2. The graph shows the relationship between binding energy per nucleon and nucleon number. In which region are nuclei most stable? *[1 mark]*



3. The diagram shows three electron energy levels of an atom. Which transition results in the emission of a photon of the longest wavelength? *[1 mark]*



4. The graph shows the relationship between binding energy per nucleon and nucleon number. In which region are nuclei most stable? *[1 mark]*

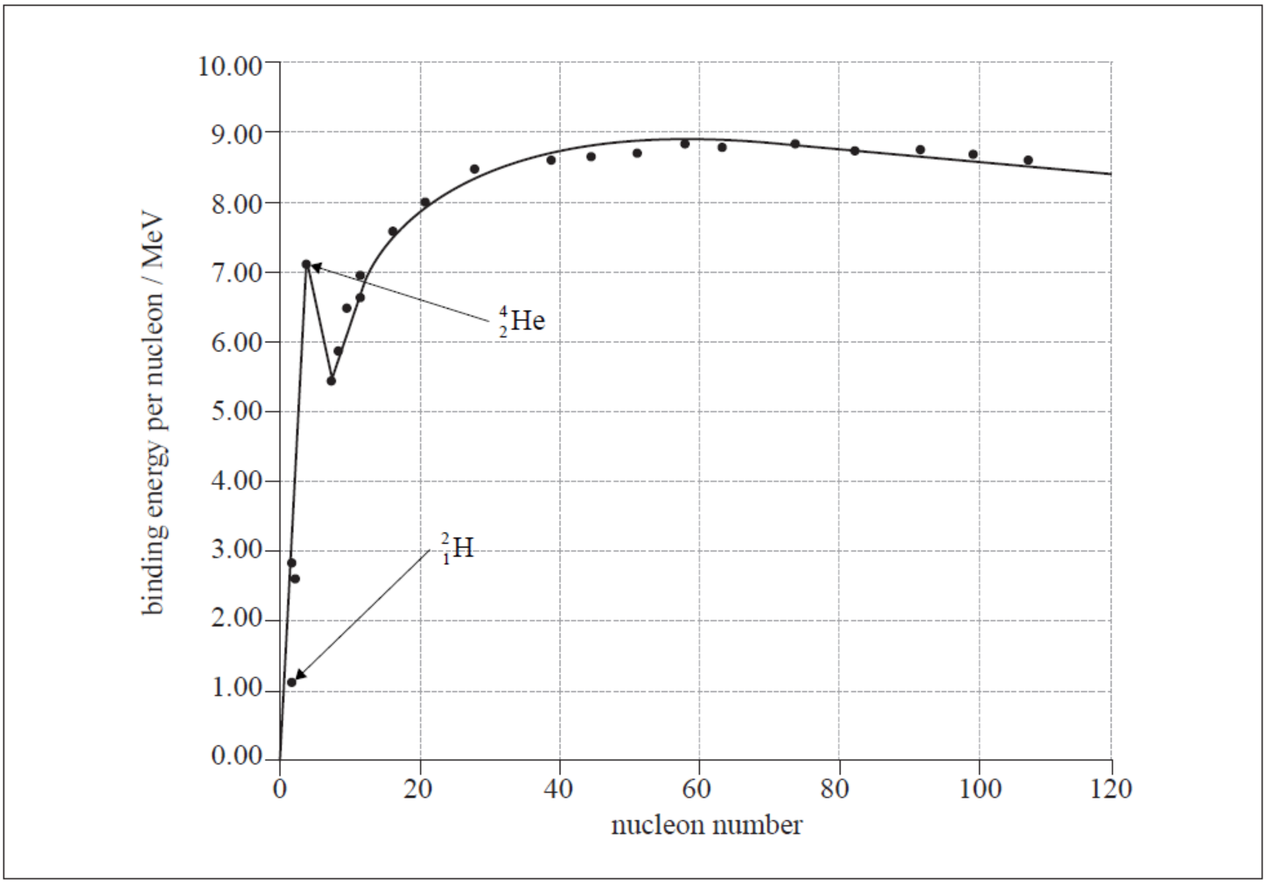


5. Which of the following would decrease the initial activity of a sample of plutonium? *[1 mark]*

A. Placing the sample in a lead container
B. Placing the sample in a dark room
C. Decreasing the mass of the sample
D. Decreasing the temperature of the sample

Nuclear fusion

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



6a. (i) Outline, with reference to mass defect, what is meant by the term nuclear binding energy. *[7 marks]*

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

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

6b. 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 marks]*

(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.

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This question is about atomic energy levels.

7a. Explain how atomic spectra provide evidence for the quantization of energy in atoms. *[3 marks]*

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7b. Outline how the de Broglie hypothesis explains the existence of a **discrete** set of wavefunctions for electrons confined in a box of length *L*. *[3 marks]*

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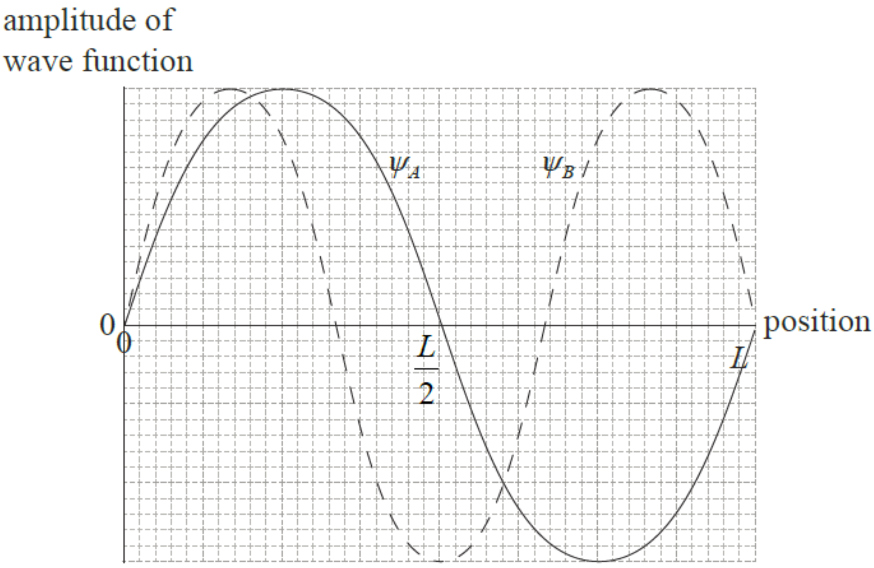
7c. The diagram below shows the shape of two allowed wavefunctions ψ_A and ψ_B for an electron confined in a one-dimensional box of length L. *[6 marks]*



(i) With reference to the de Broglie hypothesis, suggest which wavefunction corresponds to the larger electron energy.

(ii) Predict and explain which wavefunction indicates a larger probability of finding the electron near the position $\frac{L}{2}$ in the box.

(iii) On the graph in (c) on page 7, sketch a possible wavefunction for the **lowest** energy state of the electron.

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This question is about radioactive decay.

Sodium-22 undergoes β^+ decay.

8a. Identify the missing entries in the following nuclear reaction. *[3 marks]*

$$^{22}_{11}\mathrm{Na} \rightarrow {}^{22}_{\dots}\mathrm{Ne} + {}^{0}_{\dots}e + {}^{0}_{0}\dots$$

8b. Define *half-life*. *[1 mark]*

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8c. Sodium-22 has a decay constant of 0.27 yr^{-1}. *[4 marks]*

(i) Calculate, in years, the half-life of sodium-22.

(ii) A sample of sodium-22 has initially 5.0×10^{23} atoms. Calculate the number of sodium-22 atoms remaining in the sample after 5.0 years.

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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

9a. The isotope tritium (hydrogen-3) has a radioactive half-life of 12 days. *[2 marks]*

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

(ii) Define *radioactive half-life.*

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9b. 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 marks]*

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

(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

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9c. 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 marks]*

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9d. 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 marks]*

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

X:

Y:

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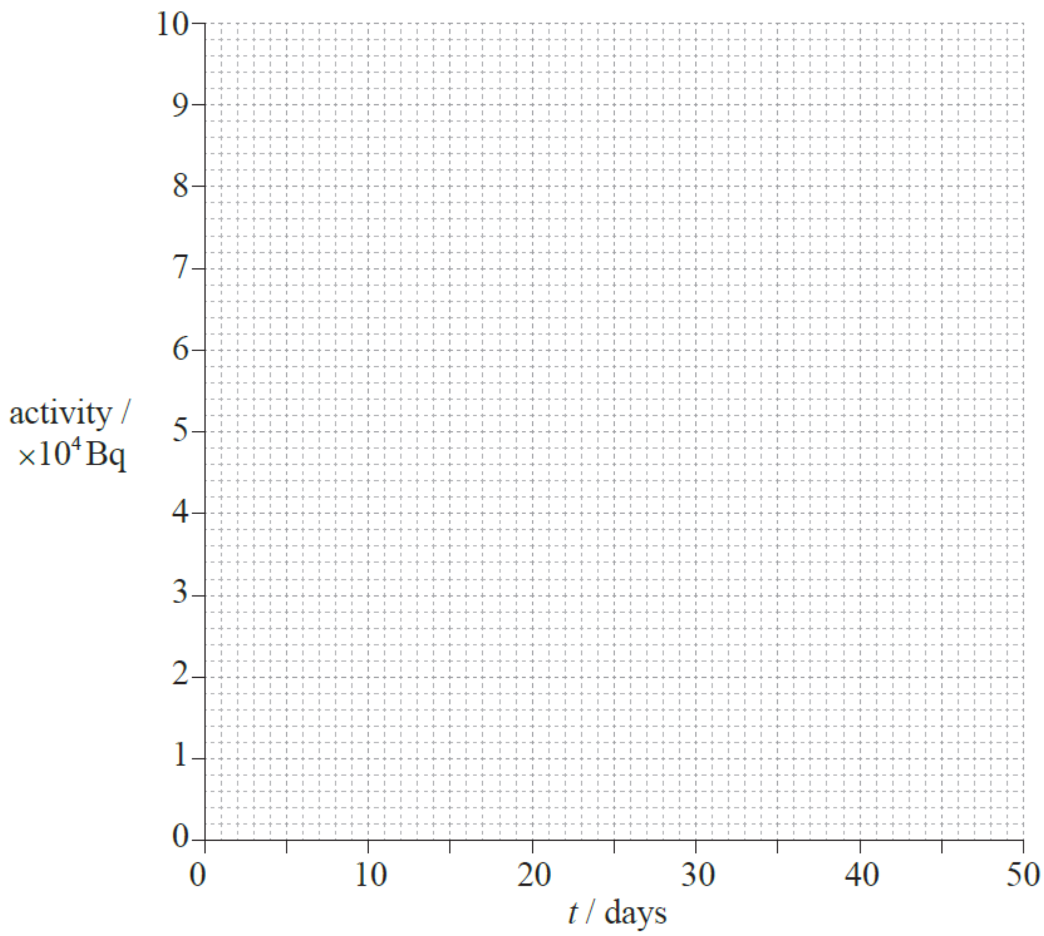
9e. A sample of tritium has an activity of 8.0×10^4 Bq at time t=0. The half-life of tritium is 12 days. *[5 marks]*

(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.

This question is about elementary particles.

This quark is said to be an elementary particle.

10a. State what is meant by the term elementary particle. *[1 mark]*

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10b. The strong interaction between two nucleons has a range of about 10^{-15} m. *[3 marks]*

(i) Identify the boson that mediates the strong interaction.

(ii) Determine the approximate mass of the boson in (b)(i).

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This question is about the Ω^- particle.

The Ω^- particle is a baryon which contains only strange quarks.

11a. Deduce the strangeness of the Ω^- particle. *[1 mark]*

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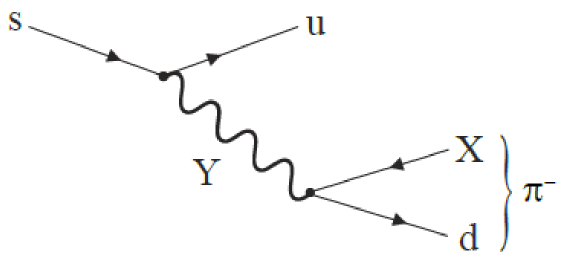
11b. The Feynman diagram shows a quark change that gives rise to a possible decay of the Ω^- particle. *[2 marks]*



(i) Identify X.

(ii) Identify Y.

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This question is about laser light.

11c. The number of lines per millimetre in the diffraction grating in (b) is reduced. Describe the effects of this change on the fringe pattern in (b). *[2 marks]*

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12. Which particle is acted on by both the strong nuclear force and the Coulomb force? *[1 mark]*

A. Antineutrino
B. Electron
C. Neutron
D. Proton

13. A nucleus of californium (Cf) contains 98 protons and 154 neutrons. Which of the following correctly identifies this nucleus of californium? *[1 mark]*

A. $^{98}_{252}\mathrm{Cf}$

B. $^{154}_{98}\mathrm{Cf}$

C. $^{252}_{98}\mathrm{Cf}$

D. $^{350}_{154}\mathrm{Cf}$

This question is about elementary particles.

The quark is said to be an elementary particle.

14. (i) State what is meant by the term elementary particle. *[2 marks]*

(ii) Identify another elementary particle other than the quark.

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This question is about hadrons.

15. The interaction in (a) can also occur via the weak interaction with neutral current mediation producing an up and anti-up quark pair. *[2 marks]*

Draw a labelled Feynman diagram for this interaction. Time on your diagram should go from left to right.

This question is about particle production.

16. In a particular experiment, moving kaon mesons collide with stationary protons. The following reaction takes place *[3 marks]*

$$p + K^- \rightarrow K^0 + K^+ + X$$

where X is an unknown particle. This process involves the strong interaction. The quark structure of the kaons is $K^- = \bar{u}s$, $K^0 = d\bar{s}$, and $K^+ = \bar{u}s$.

(i) State the strangeness of the unknown particle X.

(ii) Particle X is a hadron. State and explain whether X is a meson **or** a baryon.

This question is about radioactivity.

Caesium-137 $\left({}^{137}_{55}\mathrm{Cs}\right)$ 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).

17a. State the nuclear equation for this reaction. *[2 marks]*

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

17b. Determine the fraction of caesium-137 that will have decayed after 120 years. *[2 marks]*

17c. 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 marks]*

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This question is about atomic energy levels.

18a. Outline a laboratory procedure for producing and observing the atomic absorption spectrum of a gas. *[3 marks]*

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18b. (i) Describe the appearance of an atomic absorption spectrum. *[4 marks]*

(ii) Explain why the spectrum in (a) provides evidence for quantization of energy in atoms.

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18c. The principal energy levels of the hydrogen atom in electronvolt (eV) are given by *[3 marks]*

$$E_n = \frac{13.6}{n^2}$$

where n is a positive integer.

Determine the wavelength of the absorption line that corresponds to an electron transition from the energy level given by n=1 to the level given by n=3.

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This question is about radioactive decay.

19a. A nuclide of the isotope potassium-40 $\left({}^{40}_{19}\mathrm{K}\right)$ decays into a stable nuclide of the isotope argon-40 $\left({}^{40}_{18}\mathrm{Ar}\right)$. Identify the particles X and Y in the nuclear equation below. *[2 marks]*

$$ {}^{40}_{19}\mathrm{K} \rightarrow {}^{40}_{18}\mathrm{Ar} + \mathrm{X} + \mathrm{Y} $$

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19b. The half-life of potassium-40 is 1.3×10^{9}yr. In a particular rock sample it is found that 85 % of the original potassium-40 nuclei have decayed. Determine the age of the rock. *[3 marks]*

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19c. State the quantities that need to be measured in order to determine the half-life of a long-lived isotope such as potassium-40. *[2 marks]*

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20. The nuclear reaction equation for the decay of a nucleus of thorium-231 (Th-231) to a nucleus of protactinium-231 (Pa-231) is shown below. *[1 mark]*

$$^{231}_{90}\mathrm{Th} \rightarrow ^{231}_{91}\mathrm{Pa} + \beta^{-} + x$$

The particle *x* is a/an

A. proton.
B. antineutrino.
C. neutron.
D. electron.

21. The half-life of a particular radioactive isotope is 8 days. The initial activity of a pure sample of the isotope is *A*. *[1 mark]*

Which of the following is the time taken for the activity of the isotope to change by $\frac{7}{8}A$?

A. 7 days
B. 24 days
C. 32 days
D. 56 days

22. When compared with beta particles and gamma-ray photons, alpha particles have the greatest *[1 mark]*

A. mass.

B. penetrating power.

C. range in air.

D. speed.

23. Which statement correctly describes the process of nuclear fusion? *[1 mark]*

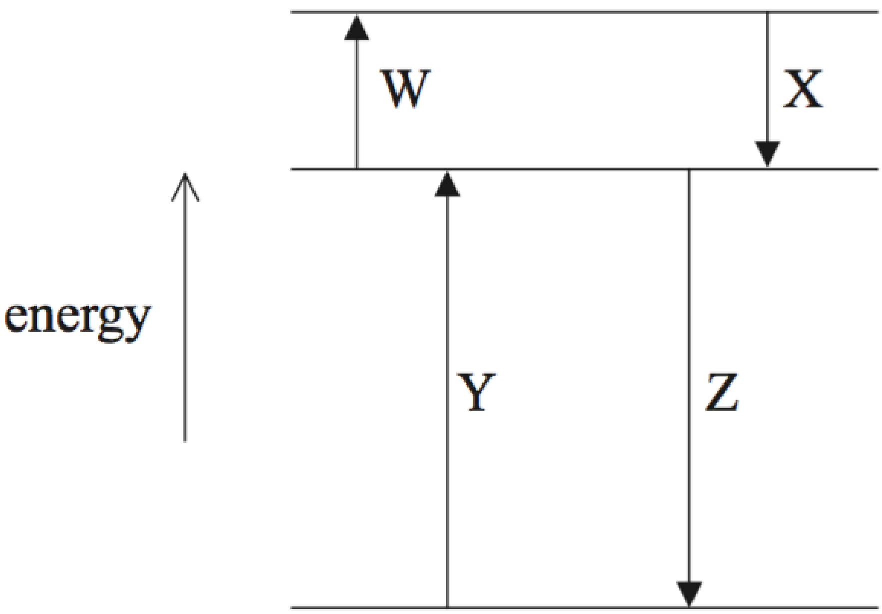
A. The joining together of two small atoms to create a larger atom.

B. The splitting up of a large atom to create two smaller atoms.

C. The joining together of two small nuclei to create a larger nucleus.

D. The splitting up of a large nucleus to create two smaller nuclei.

24. The diagram shows three energy levels of the hydrogen atom and some of the associated electron transitions between the levels. *[1 mark]*



Which labelled electron transition gives rise to the photon with the greatest wavelength and which gives rise to the photon with the smallest wavelength?

	Greatest wavelength	Smallest wavelength
A.	X	W
B.	Y	Z
C.	X	Z
D.	Y	W

25. Which of the following is a correct list of particles upon which the strong nuclear force may act? *[1 mark]*

A. protons and neutrons
B. protons and electrons
C. neutrons and electrons
D. protons, neutrons and electrons

This question is about nuclear reactions.

26a. 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 marks]*

(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.

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26b. The daughter nuclei of U-235 undergo radioactive decay until eventually a stable isotope of lead is reached. *[3 marks]*

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

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26c. 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 marks]*

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

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

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27. All isotopes of uranium must have the same *[1 mark]*

A. chemical properties.
B. mass.
C. half-life.
D. decay constant.

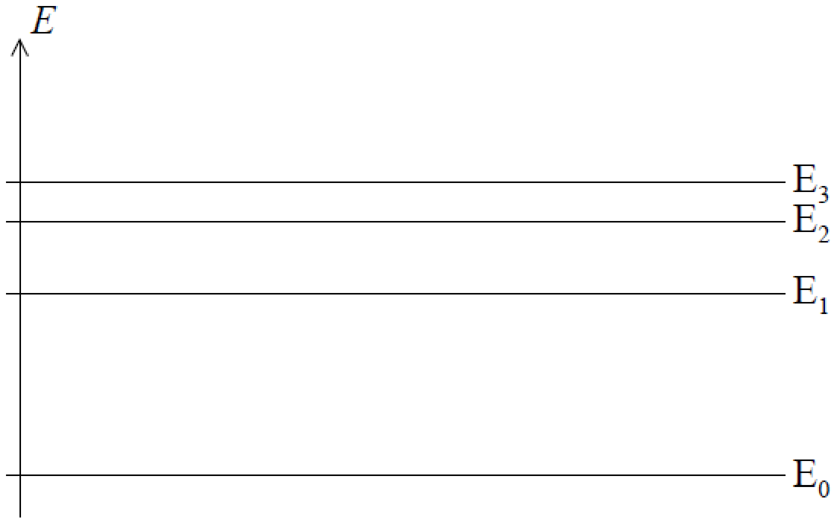
28. A unit in which mass defect can be measured is *[1 mark]*

A. MeV.
B. MeV c^{-1}.
C. MeV c^{-2}.
D. MeV per nucleon.

29. When compared with beta particles and gamma-ray photons, alpha particles have the greatest *[1 mark]*

A. mass.
B. penetrating power.
C. range in air.
D. speed.

30. The lowest four energy levels of a particular atom are represented in the energy level diagram below. *[1 mark]*



Planck's constant is *h*. What is the highest frequency in the atom's emission spectrum that is associated with these levels?

A. $\frac{E_3}{h}$

B. $\frac{E_0}{h}$

C. $\frac{E_3 - E_0}{h}$

D. $\frac{E_3 - E_2}{h}$

31. Evidence for the existence of isotopes can come from analysis of *[1 mark]*

A. the closest approach distance from charged particle scattering experiments.
B. the discrete energies of alpha particles from a given nuclide.
C. the range of energies of beta particles from a given nuclide.
D. the paths taken by ions in a Bainbridge mass spectrometer.

Part 2 Radioactive decay

32a. Describe the phenomenon of natural radioactive decay. *[3 marks]*

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32b. A nucleus of americium-241 (Am-241) decays into a nucleus of neptunium-237 (Np-237) in the following reaction. *[7 marks]*

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

(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).

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Part 3 Atomic energy levels

33a. Outline how atomic emission spectra provide evidence for the quantization of energy in atoms. *[2 marks]*

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33b. Consider an electron confined in a one-dimensional “box” of length *L*. The de Broglie waves associated with the electron are standing waves with wavelengths given by $\frac{2L}{n}$, where *n*=1, 2, 3, … *[3 marks]*

Show that the energy E_n of the electron is given by

$$En = \frac{n^2h^2}{8m_eL^2}$$

where *h* is Planck’s constant and m_e is the mass of the electron.

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33c. An electron is confined in a “box” of length $L = 1.0\times10^{-10}$m in the $n=1$ energy level. Its position as measured from one end of the box is $(0.5\pm0.5)\times10^{-10}$m. Determine *[4 marks]*

(i) the momentum of the electron.

(ii) the uncertainty in the momentum.

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This question is about quarks and interactions.

34a. Outline how interactions in particle physics are understood in terms of exchange particles. *[2 marks]*

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34b. Determine whether or not strangeness is conserved in this decay. *[2 marks]*

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34c. The total energy of the particle represented by the dotted line is 1.2 GeV more than what is allowed by energy conservation. Determine the time interval from the emission of the particle from the s quark to its conversion into the $d\,\bar{d}$ pair. *[2 marks]*

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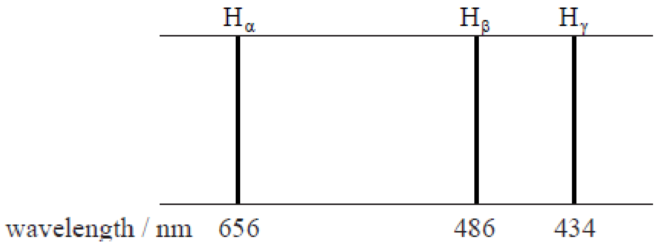
34d. The pion is unstable and decays through the weak interaction into a neutrino and an anti-muon. *[2 marks]*

Draw a Feynman diagram for the decay of the pion, labelling all particles in the diagram.

Part 2 Energy levels of the hydrogen atom

35. The diagram represents the three principal spectral lines in the visible region of the spectrum of atomic hydrogen. *[5 marks]*



The electron in the hydrogen atom can only occupy certain allowed energy levels.

(i) Outline how the spectral lines provide evidence for the existence of these energy levels.

(ii) Determine the difference in energy between the **two** levels from which electron transitions give rise to the H_α and H_γ spectral lines respectively.

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This question is about the decay of a kaon.

A kaon (K^+) is a meson consisting of an up quark and an anti-strange quark.

36a. Suggest why the kaon is classified as a boson. *[2 marks]*

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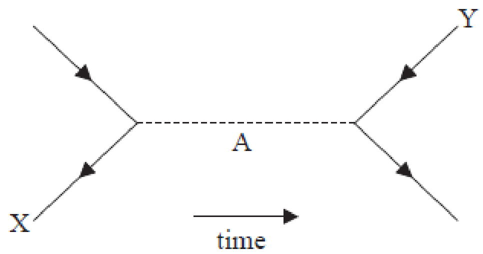
36b. A kaon decays into an antimuon and a neutrino, $K^+ \rightarrow \mu^+ + v$. The Feynman diagram for the decay is shown below. *[6 marks]*



(i) State the **two** particles labelled X and Y.

(ii) Explain how it can be deduced that this decay takes place through the weak interaction.

(iii) State the name and sign of the electric charge of the particle labelled A.

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This question is about quarks.

37a. State the name of a particle that is its own antiparticle. *[1 mark]*

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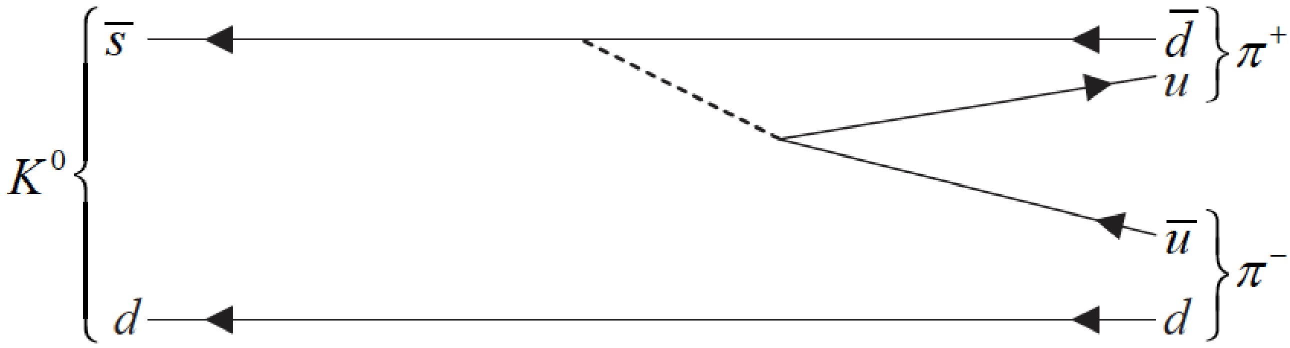
37b. The meson K^0 consists of a d quark and an anti s quark. The K^0 decays into two pions as shown in the Feynman diagram. *[3 marks]*



(i) State a reason why the kaon K^0 cannot be its own antiparticle.

(ii) Explain how it may be deduced that this decay is a weak interaction process.

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This question is about quarks.

38a. State the name of a particle that is its own antiparticle. *[1 mark]*

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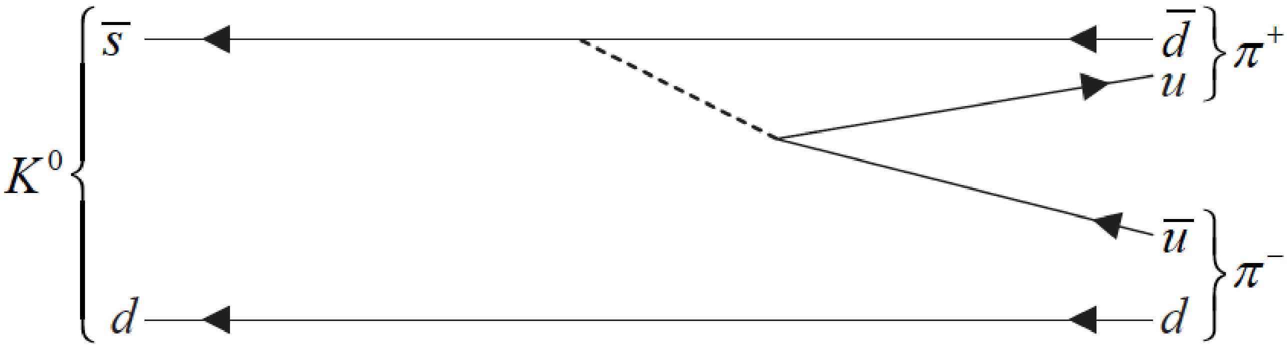
38b. The meson K^0 consists of a d quark and an anti s quark. The K^0 decays into two pions as shown in the Feynman diagram. *[6 marks]*



(i) State a reason why the kaon K^0 cannot be its own antiparticle.

(ii) Explain how it may be deduced that this decay is a weak interaction process.

(iii) State the name of the particle denoted by the dotted line in the diagram.

(iv) The mass of the particle in (b)(iii) is approximately 1.6×10^{-25}kg. Determine the range of the weak interaction.

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This question is about deep inelastic scattering.

39a. A student states that “the strong nuclear force is the strongest of the four fundamental interactions”. Explain why this statement is not correct. *[2 marks]*

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39b. Describe how deep inelastic scattering experiments support your answer to (a). *[2 marks]*

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39c. State **two** other conclusions that may be reached from deep inelastic scattering experiments. *[2 marks]*

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40. The half-life of a radioactive nuclide is 20s. What fraction of the original sample will have decayed in one minute? *[1 mark]*

A. $\frac{1}{8}$

B. $\frac{1}{4}$

C. $\frac{1}{2}$

D. $\frac{7}{8}$

41. Which of the following gives evidence to support the existence of atomic energy levels? *[1 mark]*

A. Alpha particle scattering
B. Absorption spectra
C. The existence of isotopes
D. Beta decay

42. The nuclear equation below is an example of the transmutation of mercury into gold. *[1 mark]*

$$^{2}_{1}\mathrm{H} + ^{199}_{80}\mathrm{Hg} \rightarrow ^{197}_{79}\mathrm{Au} + \mathrm{X}$$

The particle **X** is a

A. gamma-ray photon.

B. helium nucleus.

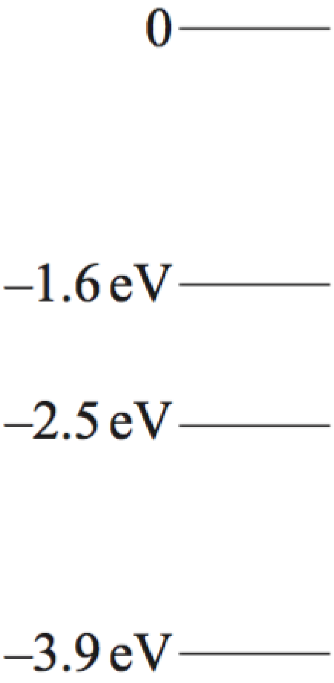
C. proton.

D. neutron.

43. In a fission reaction, the total mass and the total binding energy before the reaction are M_i and E_i respectively, where the binding energy is defined as a positive quantity. After the reaction the total mass is M_f and the total binding energy is E_f . Which of the following correctly compares the total masses and the total binding energies? *[1 mark]*

	Total mass	Total binding energy
A.	$M_f > M_i$	$E_f < E_i$
B.	$M_f > M_i$	$E_f > E_i$
C.	$M_f < M_i$	$E_f < E_i$
D.	$M_f < M_i$	$E_f > E_i$

44. The diagram below shows some of the energy levels available to an electron in a caesium atom. *[1 mark]*



Photons of energy 0.9eV pass through a sample of low pressure caesium vapour. Which of the following gives the energy transition of the electron when a photon is absorbed?

A. From -3.9eV to 0

B. From -2.5eV to -1.6eV

C. From -1.6eV to -2.5eV

D. From 0 to -3.9eV

Part 2 Unified atomic mass unit and a nuclear reaction

45a. Define the term *unified atomic mass unit*. *[1 mark]*

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45b. The mass of a nucleus of rutherfordium-254 is 254.1001u. Calculate the mass in $GeVc^{-2}$. *[1 mark]*

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45c. In 1919, Rutherford produced the first artificial nuclear transmutation by bombarding nitrogen with α-particles. *[4 marks]*
The reaction is represented by the following equation.

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

(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.)

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45d. 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 marks]*

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

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

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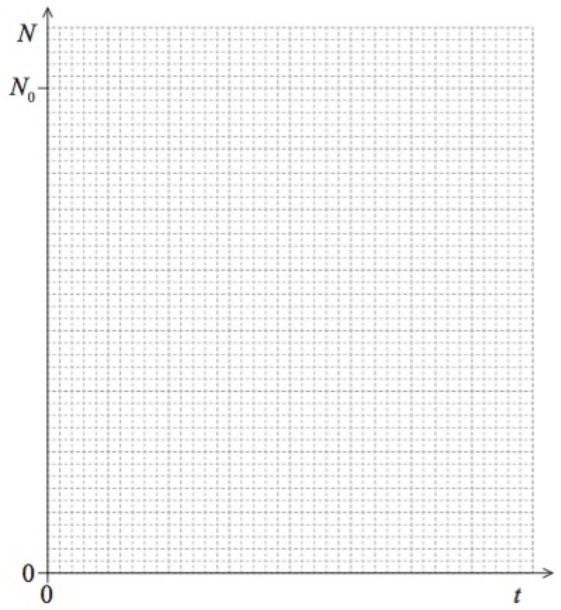
45e. A nucleus of the isotope O-19 decays to a stable nucleus of fluorine. The half-life of O-19 is 30 s. At time t=0, a sample of O-19 contains a large number N_0 nuclei of O-19. *[2 marks]*

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.



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

(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.

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This question is about nuclear processes.

47a. Describe what is meant by *[4 marks]*

(i) radioactive decay.

(ii) nuclear fusion.

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47b. Tritium is a radioactive nuclide with a half-life of 4500 days. It decays to an isotope of helium. *[3 marks]*

Determine the time taken for 90% of a sample of tritium to decay.

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47c. A nuclide of deuterium $\left({}_1^2\mathrm{H}\right)$ and a nuclide of tritium $\left({}_1^3\mathrm{H}\right)$ undergo nuclear fusion. The reaction equation for this process is *[1 mark]*

$${}_1^2\mathrm{H}+{}_1^3\mathrm{H} \rightarrow {}_2^4\mathrm{He} + \mathrm{X}$$

Identify X.

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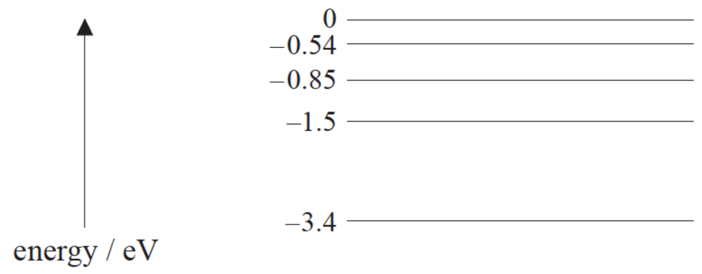
Part 2 Atomic spectra

The diagram shows some of the principal energy levels of atomic hydrogen.



The emission line spectrum of atomic hydrogen contains a blue line of wavelength 490nm.

48. (i) Calculate, in eV, the energy of a photon of wavelength 490 nm. *[4 marks]*

(ii) On the diagram above, identify with an arrow, the electron transition that gives rise to the emission line of wavelength 490 nm.

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This question is about electrons and the weak interaction.

49a. State *[2 marks]*

(i) what is meant by an elementary particle.

(ii) to which class of elementary particles the electron belongs.

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49b. An electron is one of the particles produced in the decay of a free neutron into a proton. An exchange particle is also involved in the decay. *[6 marks]*

(i) State the name of the exchange particle.

(ii) The weak interaction has a range of the order of 10^{-18}m. Determine, in $GeVc^{-2}$, the order of magnitude of the mass of the exchange particle.

(iii) It is suggested that the exchange particle in the weak interaction arises from the decay of one type of quark into another. With reference to the quark structure of nucleons, state the reason for this suggestion.

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This question is about the standard model.

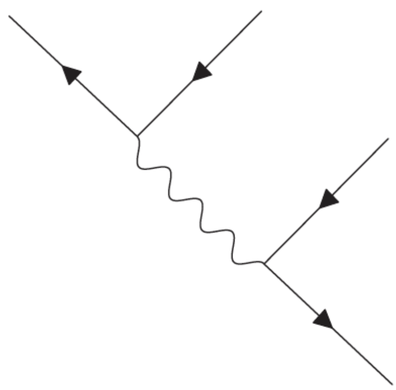
50. Muons can decay via the weak interaction into electrons and neutrinos. One such decay is *[6 marks]*

$$\mu^+ \rightarrow e^+ + v_e + \bar{v}_\mu$$

(i) Using the table provided, show that in this decay, lepton number L, electron lepton number L_e and muon lepton number L_μ are all conserved.

	μ^+	e^+	v_e	$\bar{v}_\mu$
L				
L_e				
L_μ				

(ii) Label the Feynman diagram below for the decay of a positive muon (μ^+).



51. Which of the following gives the correct number of protons and neutrons in a nucleus of carbon-14 $\left({}^{14}_{6}\mathrm{C}\right)$. *[1 mark]*

	Protons	Neutrons
A.	8	6
B.	6	8
C.	14	6
D.	6	14

52. A freshly prepared sample contains 4.0 µg of iodine-131. After 24 days, 0.5µg of iodine-131 remain. The best estimate of the half-life of iodine-131 is *[1 mark]*

A. 8 days.
B. 12 days.
C. 24 days.
D. 72 days.

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

Part 1 Nuclear reactor

53a. 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 marks]*

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

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53b. Explain what would happen if the moderator of this reactor were to be removed. *[3 marks]*

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53c. During its normal operation, the following set of reactions takes place in the reactor. *[3 marks]*

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

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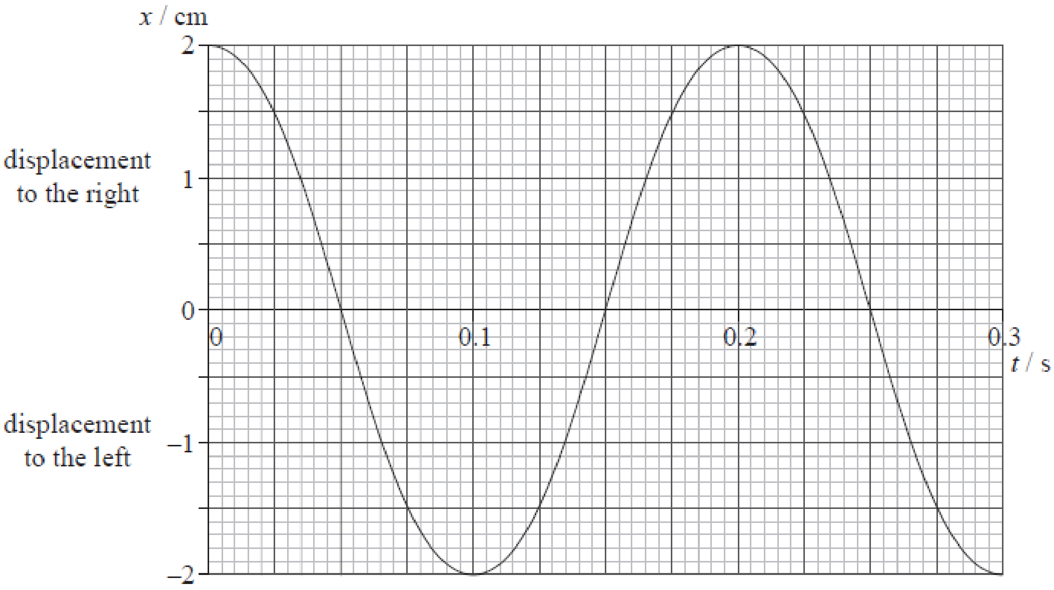
Part 2 Simple harmonic oscillations

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



54a. For particle P, *[6 marks]*

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

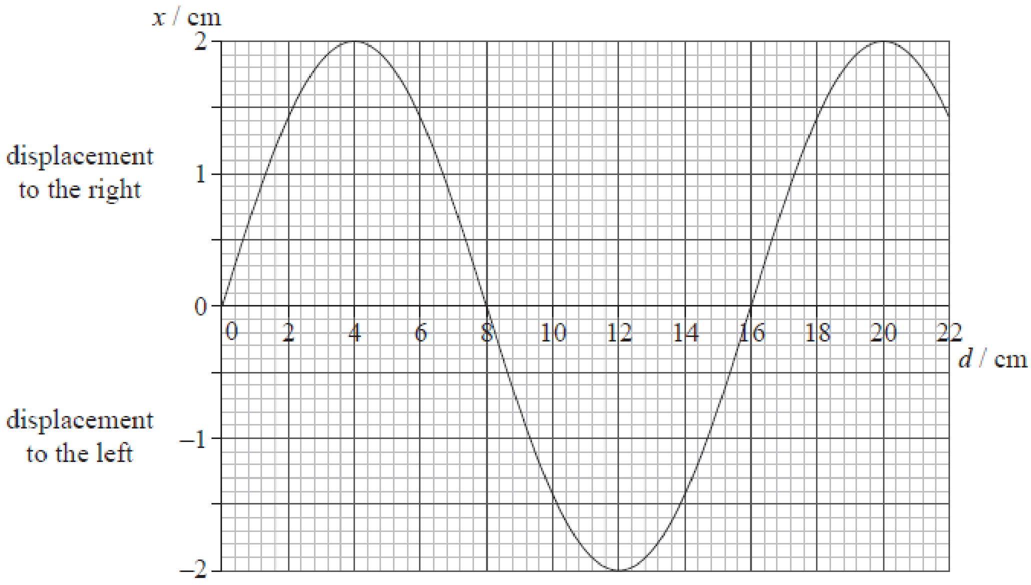
(ii) calculate the magnitude of its maximum acceleration.

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

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

54b. Graph 2 shows the variation with position *d* of the displacement *x* of particles in the medium at a particular instant of time. *[4 marks]*

Graph 2



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

(i) the frequency.

(ii) the speed.

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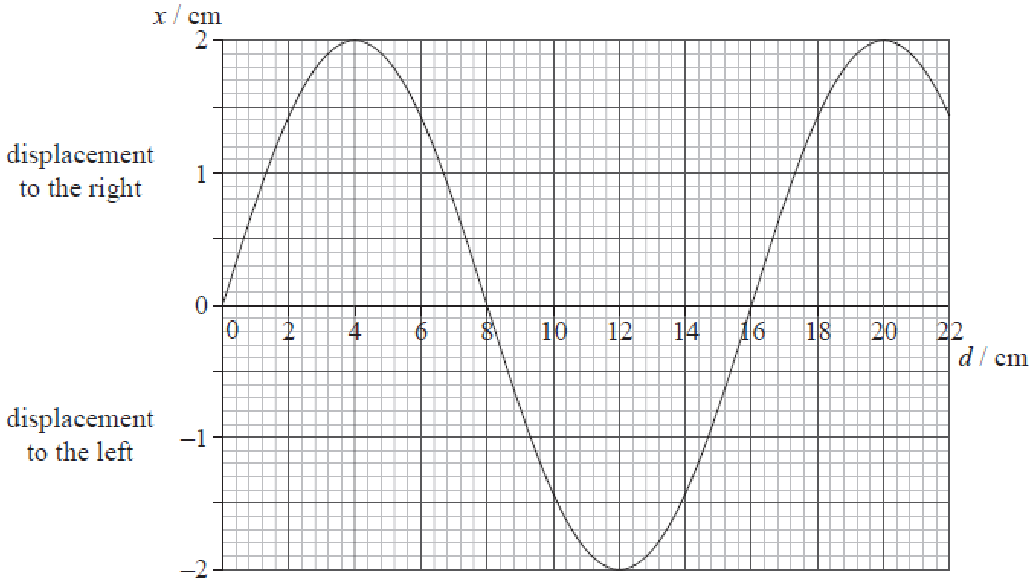
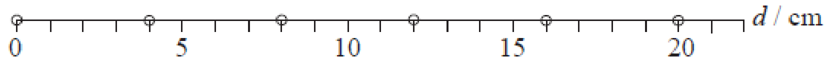
54c. **Graph 2** – reproduced to assist with answering (c)(i). *[4 marks]*



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



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

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

Part 2 Nuclear physics

55a. (i) Define *binding energy* of a nucleus. *[4 marks]*

(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.

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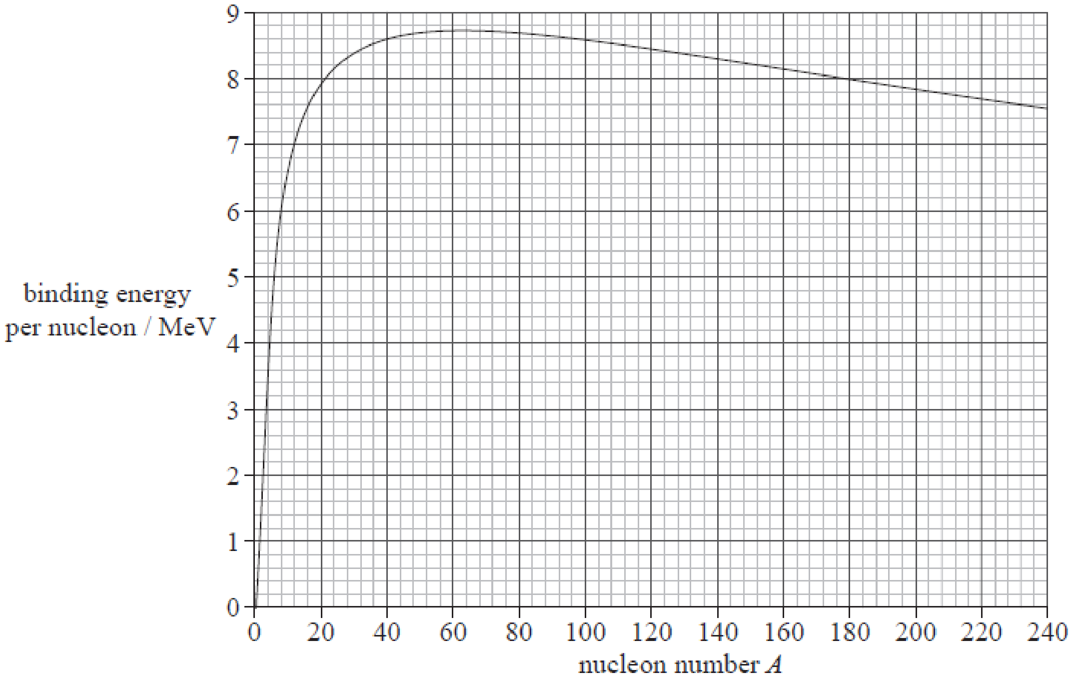
55b. The graph shows the variation with nucleon number *A* of the binding energy per nucleon. *[3 marks]*



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

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

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

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

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55c. 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 marks]*

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56. A proton decays to a neutron. The other products of the decay are a *[1 mark]*

A. positron and neutrino.
B. positron and antineutrino.
C. electron and neutrino.
D. electron and antineutrino.