Nuclear-practice-2-ShortA *[264 marks]*

This question is about radioactive decay.

In a particular nuclear medical imaging technique, carbon-11 $\left({}^{11}_{6}\mathrm{C}\right)$ is used. It is radioactive and decays through β^{+} decay to boron (B).

1a. Identify the numbers and the particle to complete the decay equation. *[2 marks]*

$${}^{11}_{6}\mathrm{C} \rightarrow {}^{\cdots\cdots}_{5}\mathrm{B} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^{+} + \cdots\cdots\cdots\cdot$$

1b. State the nature of the β^{+} particle. *[1 mark]*

The half-life of carbon-11 is 20.3 minutes.

1c. Outline a method for measuring the half-life of an isotope, such as the half-life of carbon-11. *[3 marks]*

1d. State the law of radioactive decay. *[1 mark]*

1e. Derive the relationship between the half-life $T_{\frac{1}{2}}$ and the decay constant λ , using the law of radioactive decay. *[2 marks]*

1f. Calculate the number of nuclei of carbon-11 that will produce an activity of $4.2 \times 10^{20}\ \mathrm{Bq}$. *[2 marks]*

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

Part 1 Nuclear reactions

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

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

2b. When particle X collides with a stationary nucleus of calcium-40 (Ca-40), *[6 marks]* a nucleus of potassium (K-40) and a proton are produced.

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

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.

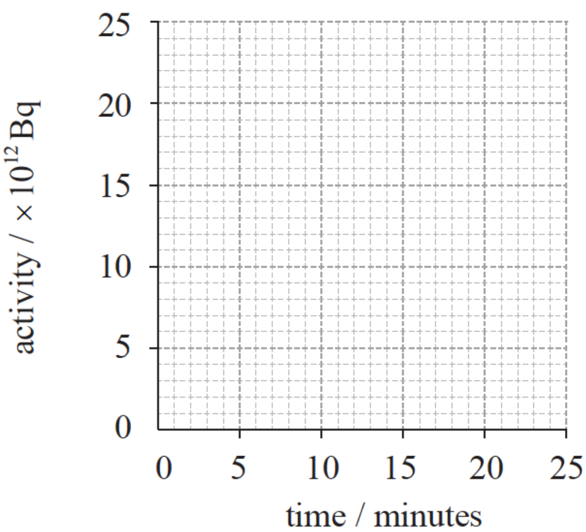
(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(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.

2c. Potassium-38 decays with a half-life of eight minutes. *[5 marks]*

(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.

Part 2 Thermal energy transfer

2d. (i) Define the *specific latent heat* of fusion of a substance. *[5 marks]*

(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.

2e. A piece of ice is placed into a beaker of water and melts completely. *[5 marks]*

The following data are available.

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

(i) Determine the final temperature of the water.

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

This question is about binding energy and mass defect.

3a. State what is meant by mass defect. *[1 mark]*

3b. (i) Data for this question is given below. *[6 marks]*

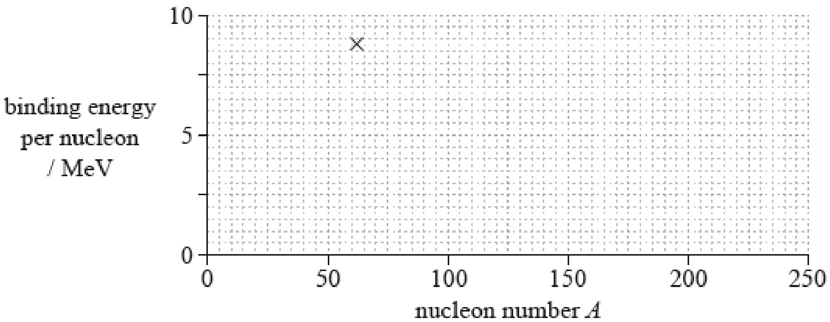
Binding energy per nucleon for deuterium $\left({}_{1}^{2}\mathrm{H}\right)$ is 1.1 MeV.

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

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

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

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

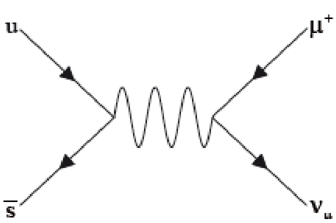


On the grid, sketch a graph to show how the average binding energy per nucleon varies with nucleon number *A*.

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

This question is about fundamental interactions.

The kaon $\left(\mathrm{K}^{+} = \mathrm{u}\bar{\mathrm{s}}\right)$ decays into an antimuon and a neutrino as shown by the Feynman diagram.



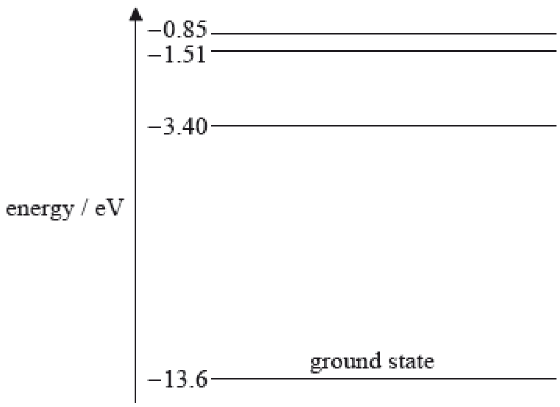
4a. Explain why the virtual particle in this Feynman diagram must be a weak interaction exchange particle. *[2 marks]*

4b. A student claims that the K^{+} is produced in neutron decays according to the reaction $\mathrm{n} \rightarrow \mathrm{K}^{+} + \mathrm{e}^{-}$. State **one** reason why this claim is false. *[1 mark]*

This question is about atomic spectra.

5a. Explain how atomic line spectra provide evidence for the existence of discrete electron energy levels in atoms. *[3 marks]*

The diagram shows some of the energy levels of a hydrogen atom.



5b. (i) Calculate the wavelength of the photon that will be emitted when an electron moves from the –3.40 eV energy level to the –13.6 eV energy level. *[5 marks]*

(ii) State and explain if it is possible for a hydrogen atom in the ground state to absorb a photon with an energy of 12.5 eV.

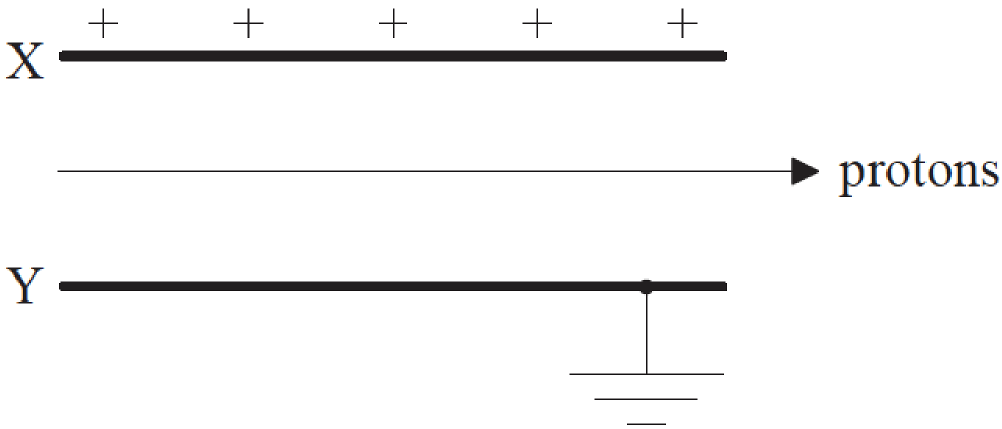
This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about change of phase.

Part 1 Electric fields and radioactive decay

6a. Define *electric field strength*. *[2 marks]*

6b. 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 marks]*

6c. Protons travelling with a speed of $3.9 \times 10^6 ms^{-1}$ enter the region between two charged parallel plates X and Y. Plate X is positively charged and plate Y is connected to earth. *[4 marks]*



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.

6d. 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 mark]*

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

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

6e. The following data are available for the reaction in (d). *[3 marks]*

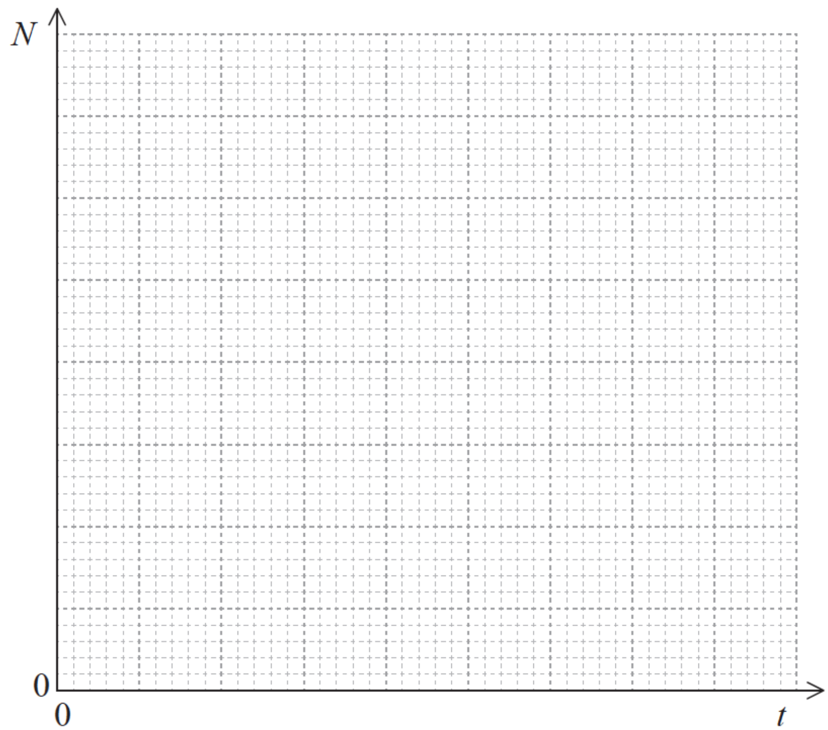
Rest mass of nitrogen-14 nucleus =14.0031 u
Rest mass of alpha particle =4.0026 u
Rest mass of X nucleus =16.9991 u
Rest mass of proton =1.0073 u

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.

6f. 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 marks]*

(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.



Part 2 Change of phase

6g. Water at constant pressure boils at constant temperature. Outline, in terms of the energy of the molecules, the reason for this. *[2 marks]*

6h. 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. The following data are available. *[4 marks]*

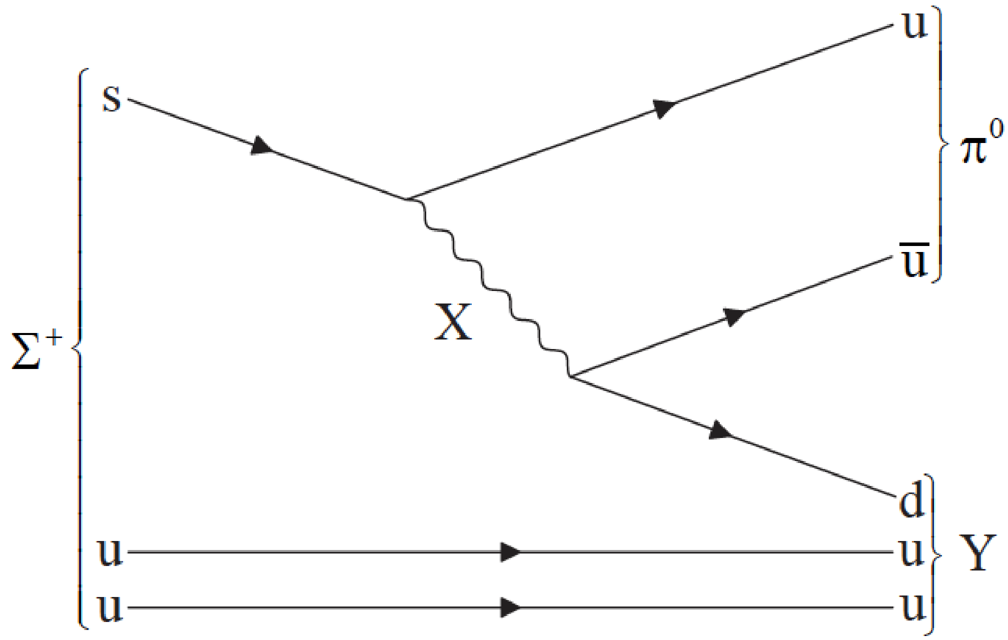
Initial mass of water in container = 0.300kg
Final mass of water in container = 0.312kg
Initial temperature of water in container = 15.2°C
Final temperature of water in container = 34.6°C
Specific heat capacity of water = 4.18×10^{3} $\text{J kg}^{-1}\text{K}^{-1}$

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

6i. Explain why, other than measurement or calculation error, the accepted value of *L* is greater than that given in (h). *[2 marks]*

This question is about particles.

7a. The Σ^+ particle can decay into a π^0 particle and another particle Y as shown in the Feynman diagram. *[4 marks]*



(i) Identify the exchange particle X.

(ii) Identify particle Y.

(iii) Outline the nature of the π^0.

7b. The π^0 particle can decay with the emission of two gamma rays, each one of which can subsequently produce an electron and a positron. *[3 marks]*

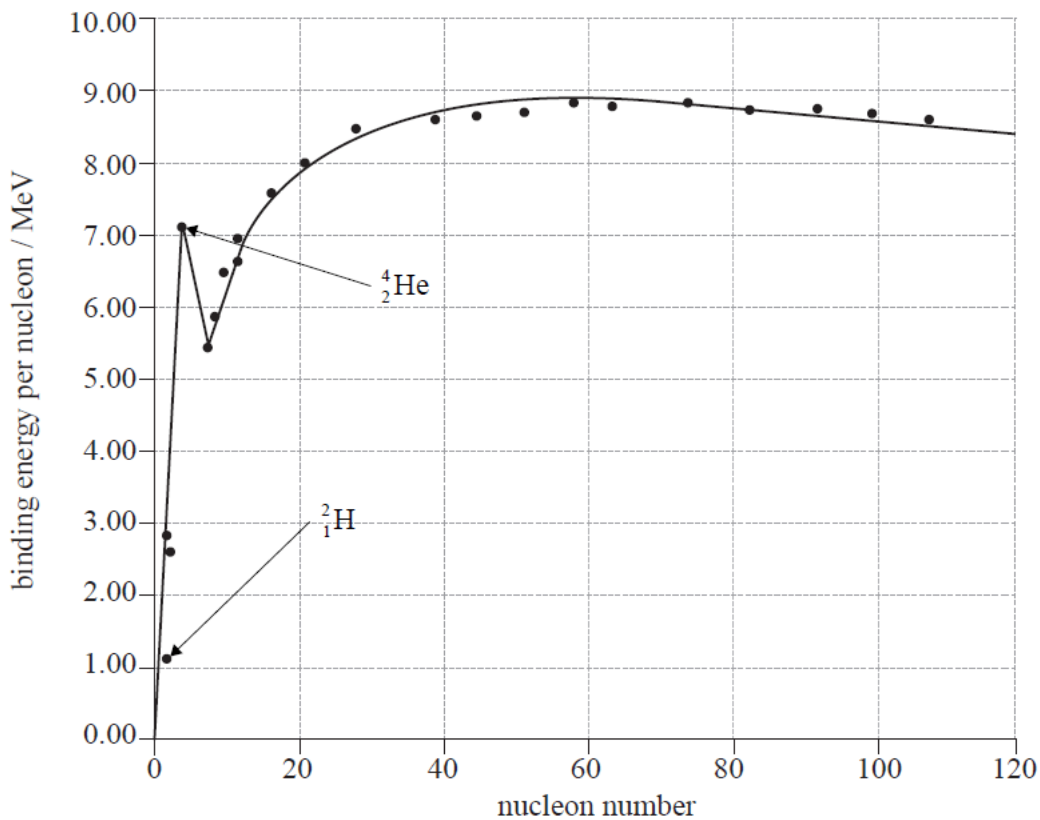
(i) State the process by which the electron and the positron are produced.

(ii) Sketch the Feynman diagram for the process in (c)(i).

7c. Discuss whether strangeness is conserved in the decay of the Σ^+ particle in (a). *[1 mark]*

Nuclear fusion

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



8a. (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.

8b. 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.

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

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

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

This question is in **two** parts. **Part 1** is about 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.*

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

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]*

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]*

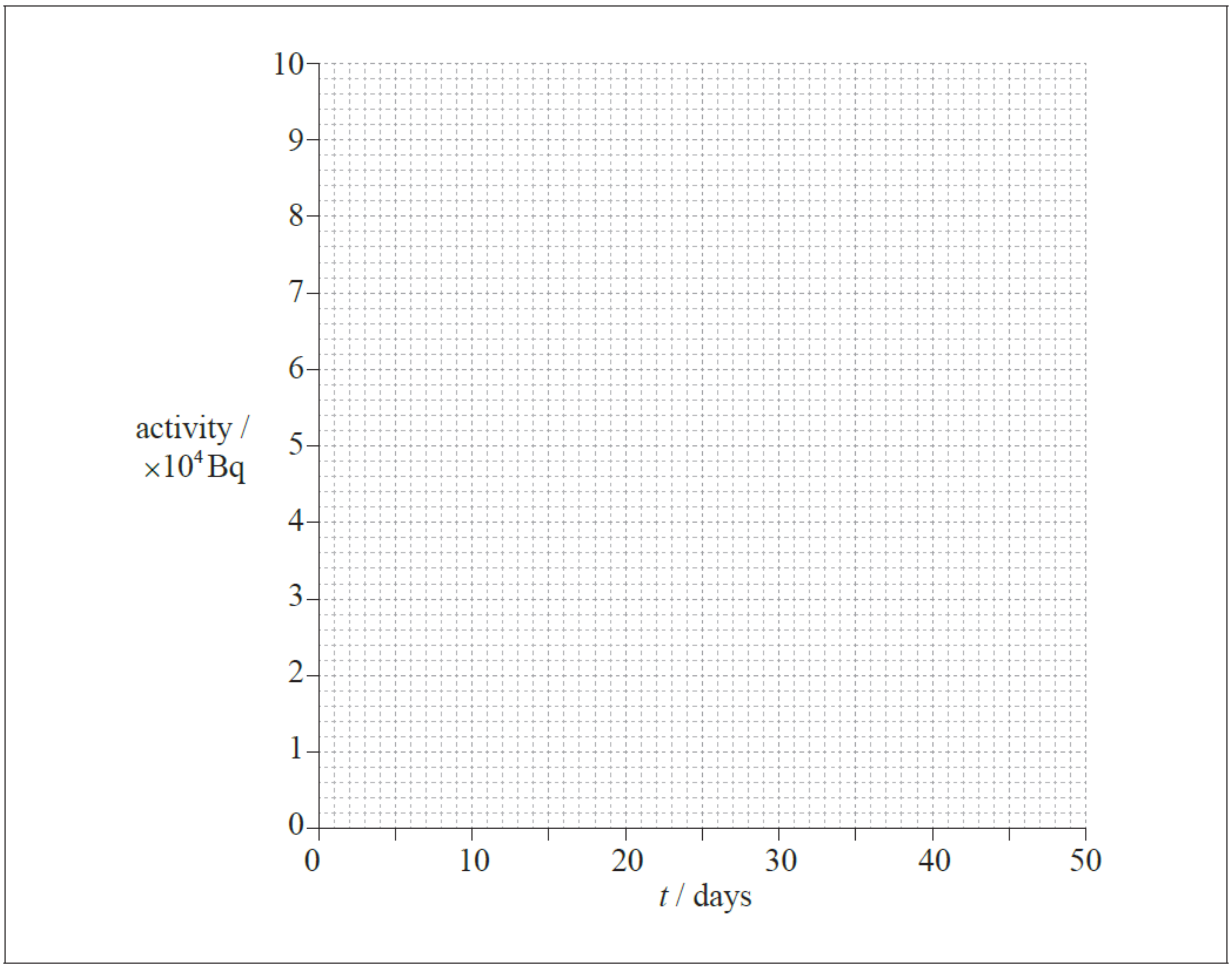
$$^{3}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + \mathrm{X} + \mathrm{Y}$$

X:

Y:

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]*

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.

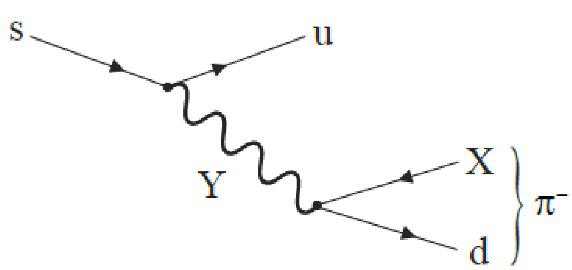
(ii) Determine the approximate mass of the boson in (b)(i).

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]*

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.

This question is about laser light.

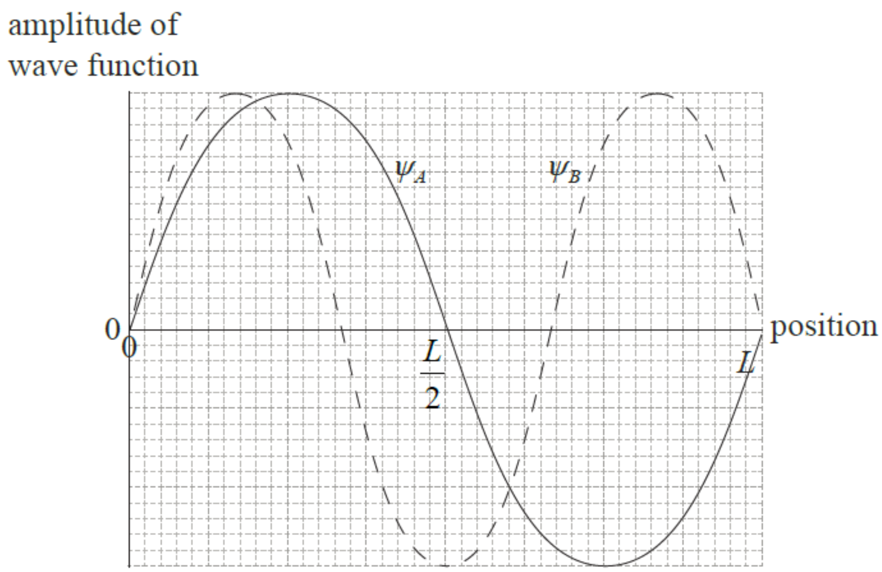
11c. The number of lines per millimetre in the diffraction grating in (b) is reduced. Describe the effects of this change on the fringe pattern in (b). *[2 marks]*

This question is about atomic energy levels.

12a. Explain how atomic spectra provide evidence for the quantization of energy in atoms. *[3 marks]*

12b. 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]*

12c. 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.

This question is about radioactive decay.

Sodium-22 undergoes β^+ decay.

13a. Identify the missing entries in the following nuclear reaction. *[3 marks]*

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

13b. Define *half-life*. *[1 mark]*

13c. Sodium-22 has a decay constant of 0.27 yr^{-1}. *[4 marks]*

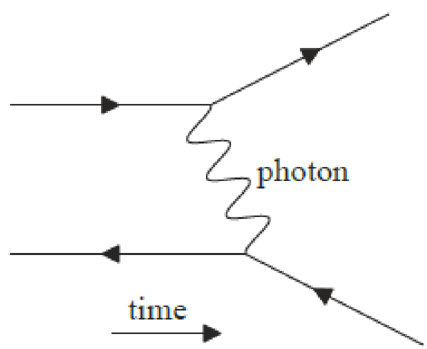
(i) Calculate, in years, the half-life of sodium-22.

(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.

This question is about quarks and interactions.

14a. Distinguish between the quark structure of a baryon and a meson. *[1 mark]*

14b. The Feynman diagram represents the electromagnetic scattering of an electron and a positron. *[3 marks]*



(i) Identify a positron on the diagram by labelling it with e^{+}.

(ii) State and explain the range of the interaction.

14c. The following reactions have never been observed. For each reaction state **one** conservation law that would be violated if the reactions were to occur. *[2 marks]*

$e^{+} + e^{+} \rightarrow p^{+} + p^{+}$
$e^{-} + v \rightarrow e^{+} + \bar{v}$

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).

15a. State the nuclear equation for this reaction. *[2 marks]*

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

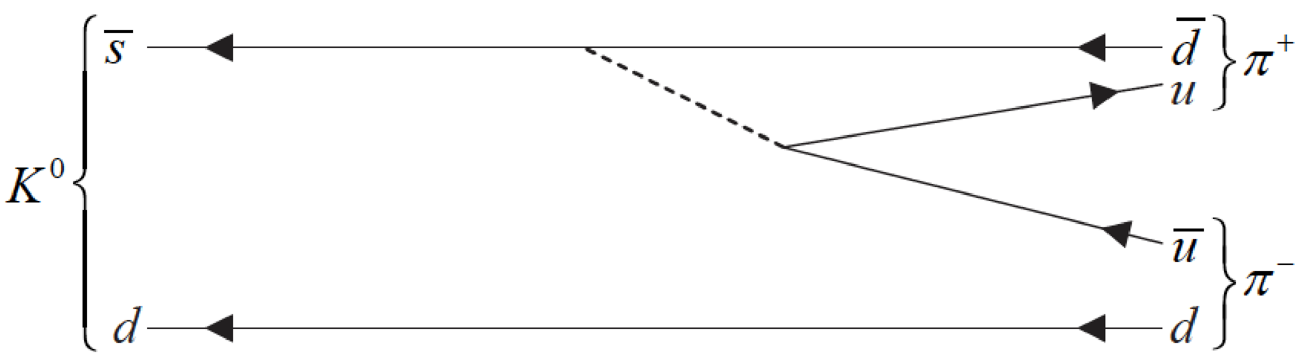
15b. Determine the fraction of caesium-137 that will have decayed after 120 years. *[2 marks]*

15c. 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]*

This question is about quarks.

16a. State the name of a particle that is its own antiparticle. *[1 mark]*

16b. 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.

This question is about radioactive decay.

17a. 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]*

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

17b. 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]*

17c. 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]*

Part 2 Radioactive decay

18a. Describe the phenomenon of natural radioactive decay. *[3 marks]*

18b. 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).

This question is about nuclear reactions.

19a. 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.

1. Nuclide:

   Isotope:

2.

(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.

19b. 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.

19c. 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

This question is about quarks and interactions.

20a. Outline how interactions in particle physics are understood in terms of exchange particles. *[2 marks]*

20b. Determine whether or not strangeness is conserved in this decay. *[2 marks]*

20c. 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 $\bar{\mathrm{d}}$ pair. *[2 marks]*

20d. The pion is unstable and decays through the weak interaction into a neutrino and an anti-muon. *[2 marks]*

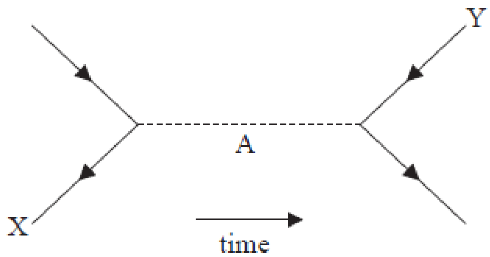
Draw a Feynman diagram for the decay of the pion, labelling all particles in the diagram.

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.

21a. Suggest why the kaon is classified as a boson. *[2 marks]*

21b. A kaon decays into an antimuon and a neutrino, $K^+ \rightarrow \mu^+ + \nu$. 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.

22a. 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.

22b. Tritium is a radioactive nuclide with a half-life of 4500 days. It decays to an isotope of helium. *[3 marks]*

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

This question is about electrons and the weak interaction.

23a. State *[2 marks]*

(i) what is meant by an elementary particle.

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

23b. 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.

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

Part 1 Nuclear reactor

24a. 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.

24b. Explain what would happen if the moderator of this reactor were to be removed. *[3 marks]*

24c. During its normal operation, the following set of reactions takes place in the reactor. *[3 marks]*

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

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

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

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

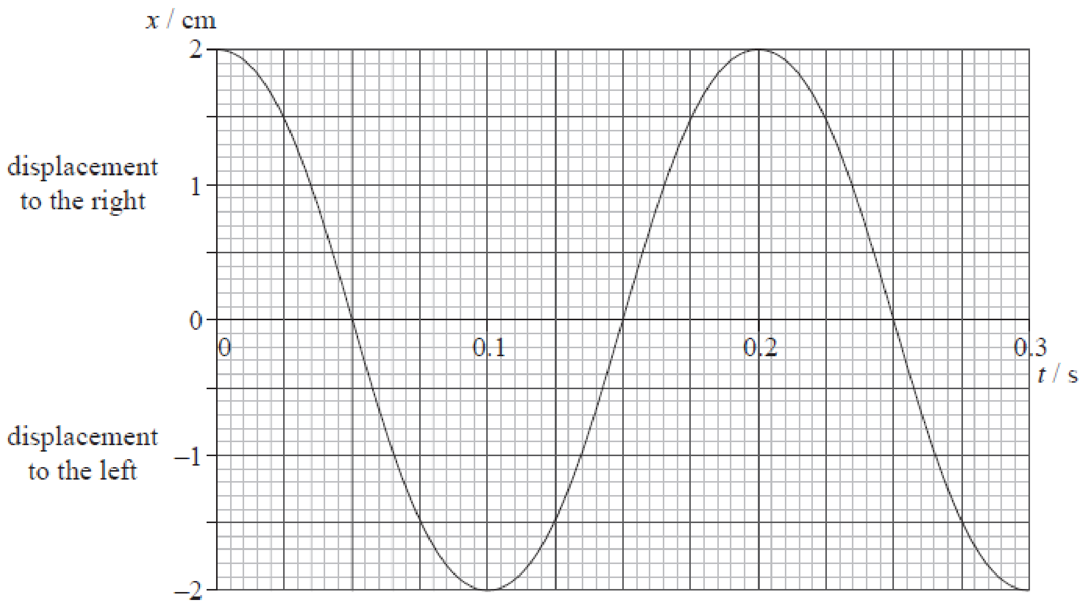
(ii) Comment on the international implications of the product of these reactions.

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



25a. For particle P, *[6 marks]*

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

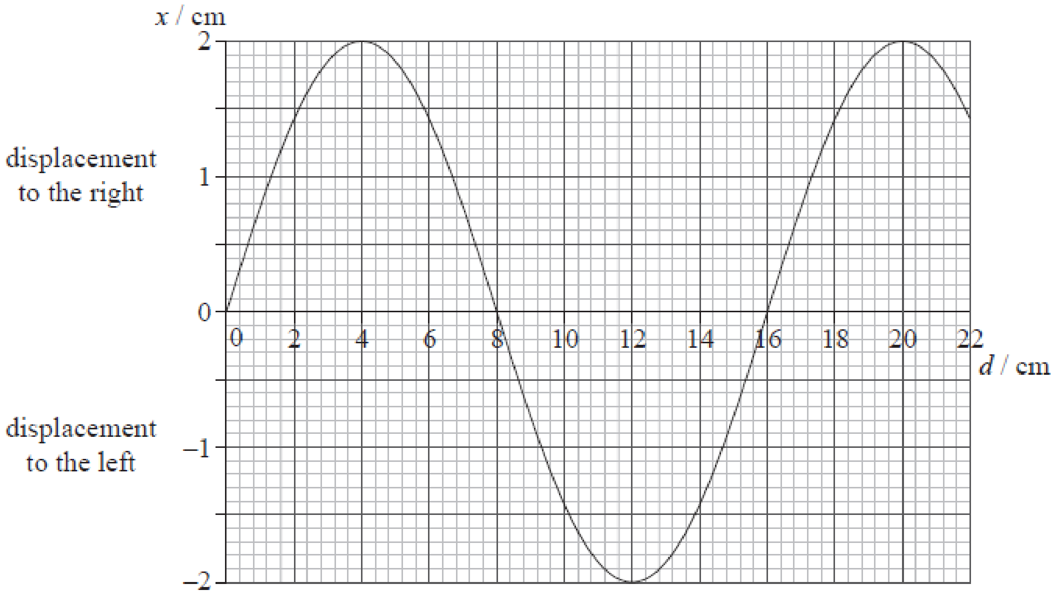
(ii) calculate the magnitude of its maximum acceleration.

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

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

25b. 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

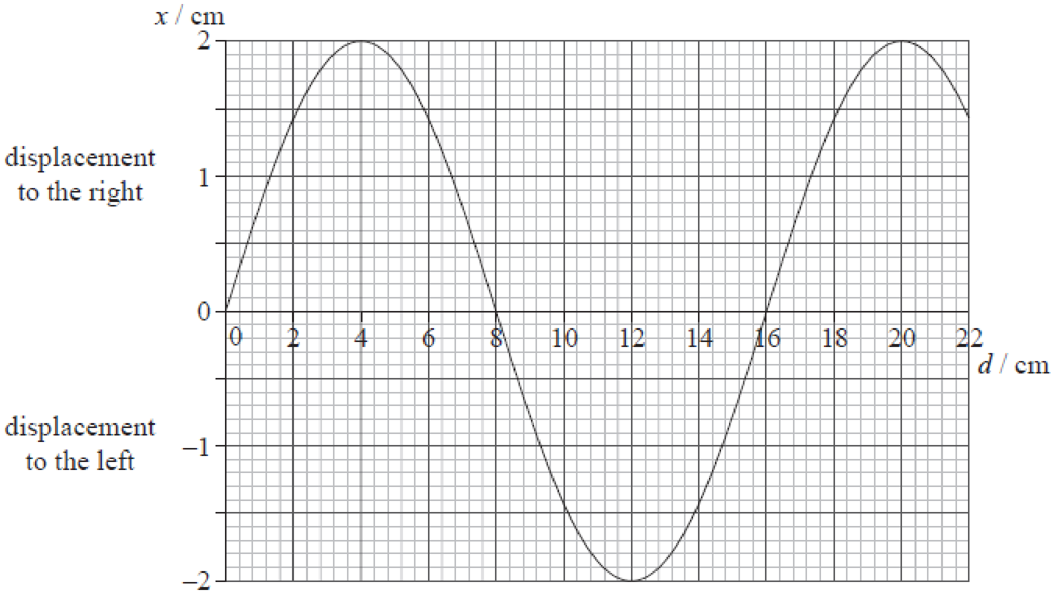


Determine for the longitudinal wave, using graph 1 and graph 2,

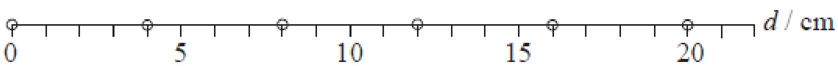
(i) the frequency.

(ii) the speed.

25c. **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.

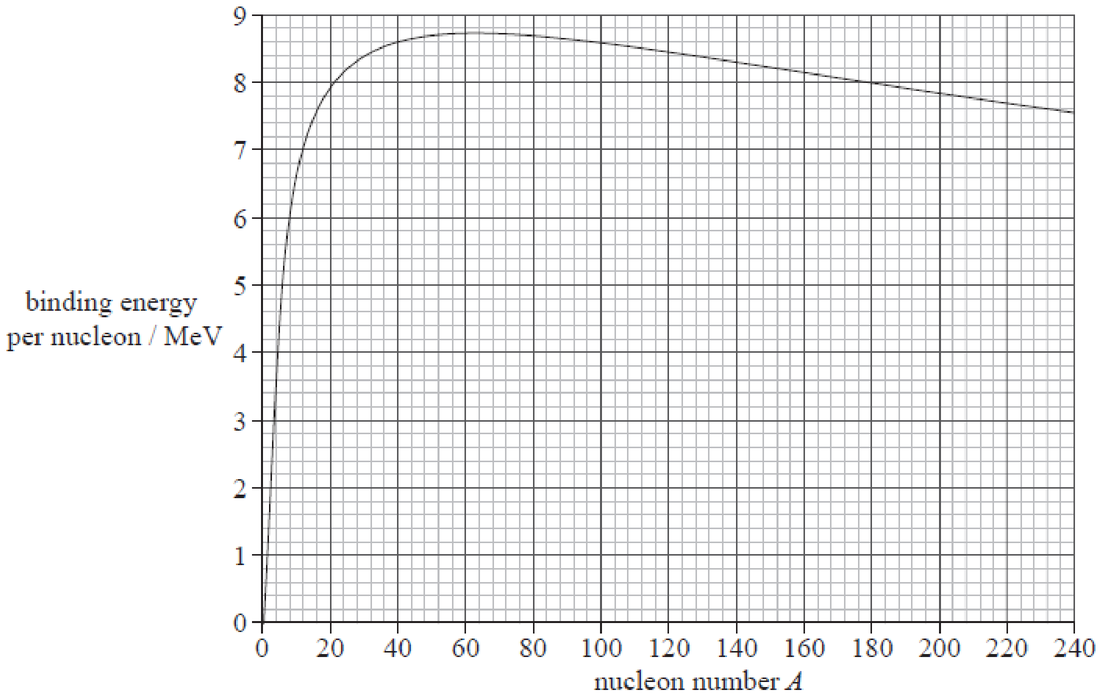
(ii) On the diagram above, label with the letter C a particle that is at the centre of a compression.

Part 2 Nuclear physics

26a. (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.

26b. 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.

26c. 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]*

Part 2 Unified atomic mass unit and a nuclear reaction

27a. Define the term *unified atomic mass unit*. *[1 mark]*

27b. The mass of a nucleus of rutherfordium-254 is 254.1001u. Calculate the mass in $\mathrm{GeVc^{-2}}$. *[1 mark]*

27c. In 1919, Rutherford produced the first artificial nuclear transmutation by bombarding nitrogen with α-particles. The reaction is represented by the following equation. *[4 marks]*

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

(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.)

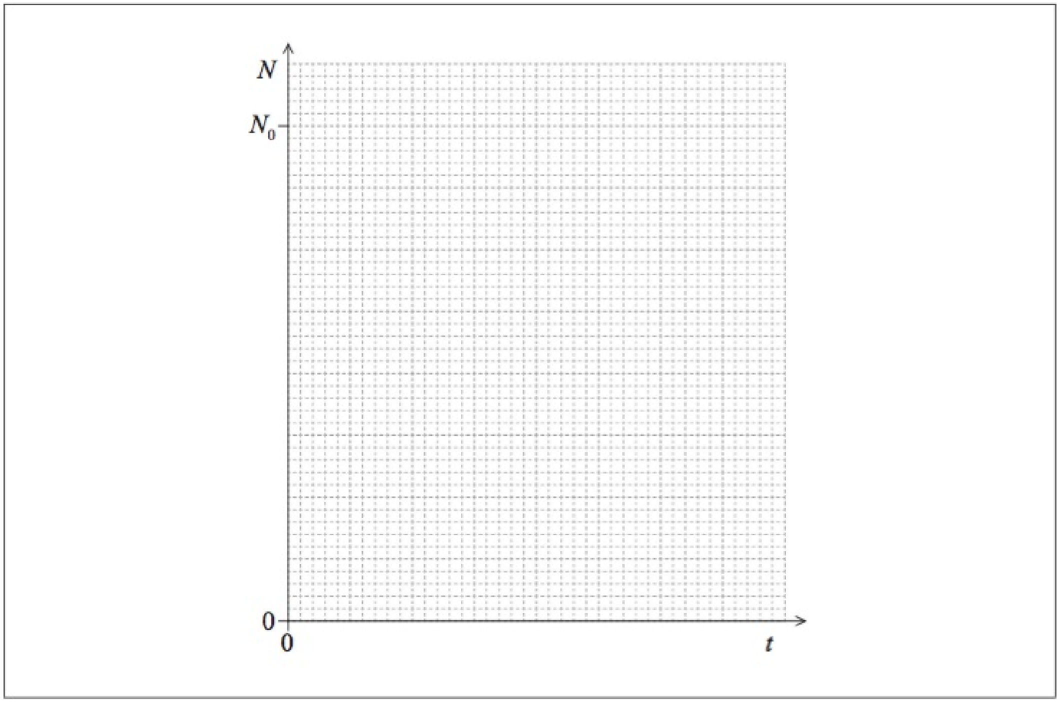
27d. The reaction in (c) produces oxygen (O-17). Other isotopes of oxygen include O-19 which is radioactive with a half-life of 30 s. *[2 marks]*

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

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

27e. 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]*

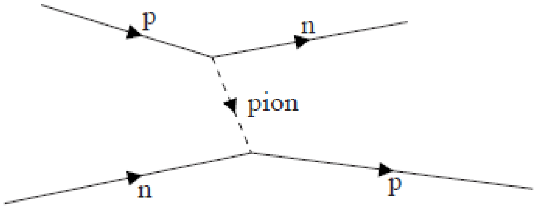
On the grid below, draw a graph to show the variation with time *t* of the number *N* of O-19 nuclei remaining in the sample. You should consider a time of *t*=0 to *t*=120s.



This question is about mesons.

28a. State what is meant by an exchange particle. *[1 mark]*

28b. A meson called the pion was detected in cosmic ray reactions in 1947 by Powell and Occhialini. The pion comes in three possible charge states: π^+ ,π^- and π^0. The Feynman diagram below represents a possible reaction in which a pion participates. *[2 marks]*



State and explain whether the meson produced is a π^+ ,π^- **or** a π^0.