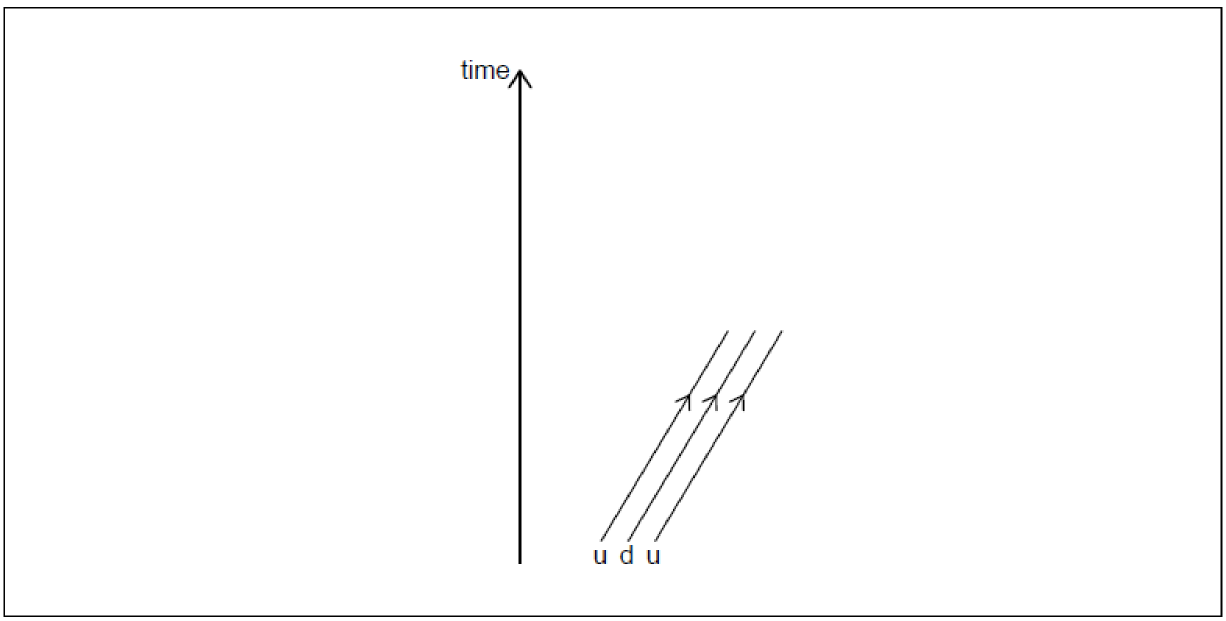
Nuclear-practice-1-ShortA *[192 marks]*

Silicon-30 $\left({}^{30}_{14}\mathrm{Si}\right)$ can be formed from phosphorus-30 $\left({}^{30}_{15}\mathrm{P}\right)$ by a process of beta-plus decay.

1a. Write down the nuclear equation that represents this reaction. *[2 marks]*

1b. Sketch the Feynman diagram that represents this reaction. The diagram has been started for you. *[3 marks]*



1c. Energy is transferred to a hadron in an attempt to separate its quarks. Describe the implications of quark confinement for this situation. *[2 marks]*

1d. The Standard Model was accepted by many scientists before the observation of the Higgs boson was made. *[1 mark]*

Outline why it is important to continue research into a topic once a scientific model has been accepted by the scientific community.

Deuterium, ${}^2_1\mathrm{H}$, undergoes fusion according to the following reaction.

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

2a. Identify particle X. *[1 mark]*

The following data are available for binding energies per nucleon.

$${}^2_1\mathrm{H} = 1.12\mathrm{MeV}$$

$${}^3_1\mathrm{H} = 2.78\mathrm{MeV}$$

2b. Determine, in MeV, the energy released. *[2 marks]*

2c. Suggest why, for the fusion reaction above to take place, the temperature of deuterium must be very high. *[2 marks]*

Particle Y is produced in the collision of a proton with a K- in the following reaction.

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

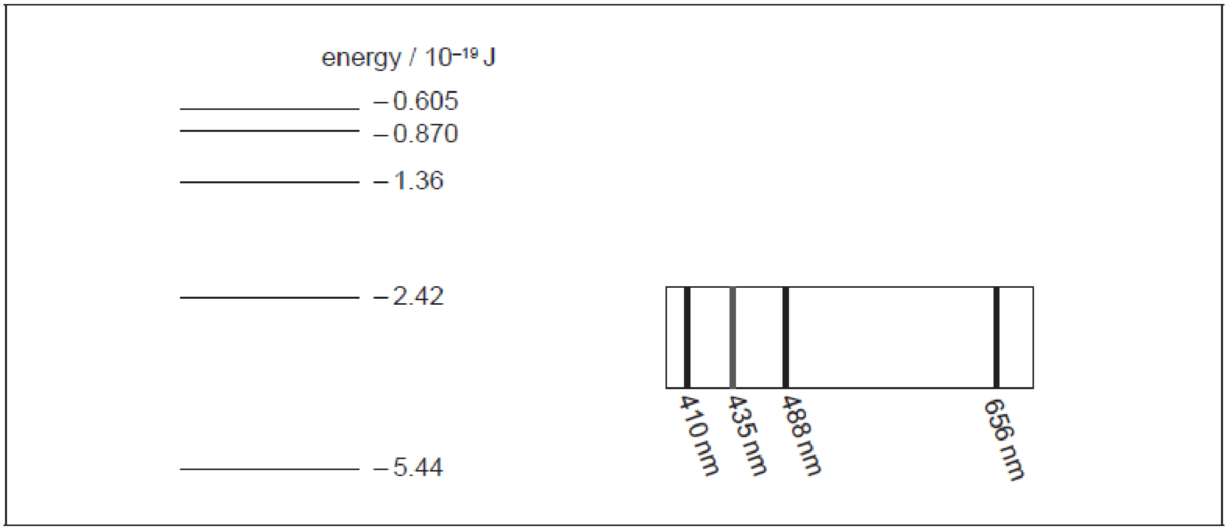
The quark content of some of the particles involved are

$$K^- = \bar{u}s \quad K^0 = d\bar{s}$$

2d. Identify, for particle Y, the charge. *[1 mark]*

2e. Identify, for particle Y, the strangeness. *[1 mark]*

The diagram shows the position of the principal lines in the visible spectrum of atomic hydrogen and some of the corresponding energy levels of the hydrogen atom.



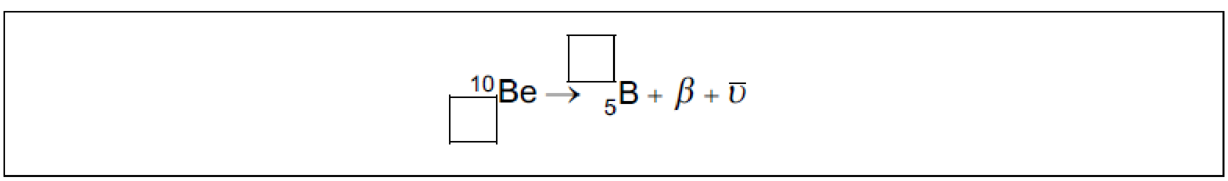
3a. Determine the energy of a photon of blue light (435nm) emitted in the hydrogen spectrum. *[3 marks]*

3b. Identify, with an arrow labelled B on the diagram, the transition in the hydrogen spectrum that gives rise to the photon with the energy in (a). *[1 mark]*

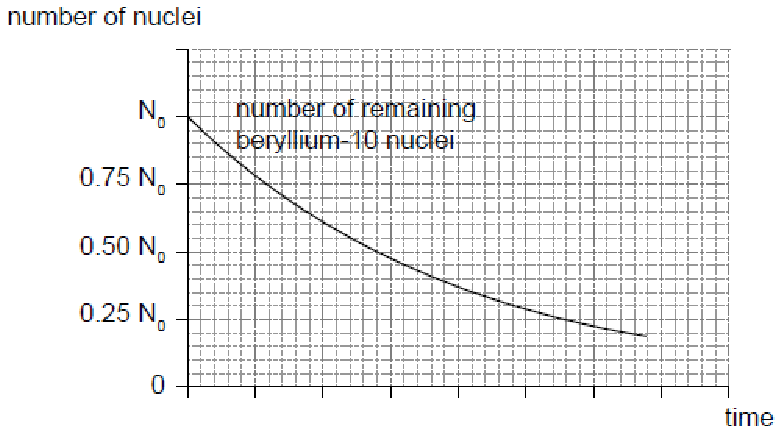
3c. Explain your answer to (b). *[2 marks]*

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

4a. Identify the missing information for this decay. *[1 mark]*



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.



4b. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. *[2 marks]*

4c. After 4.3×10^6 years, *[3 marks]*

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

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

4d. 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 mark]*

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

4e. State what is meant by thermal radiation. *[1 mark]*

4f. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. *[2 marks]*

4g. Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. *[2 marks]*

4h. Derive the units of intensity in terms of fundamental SI units. *[2 marks]*

5a. Rutherford constructed a model of the atom based on the results of the alpha particle scattering experiment. Describe this model. *[2 marks]*

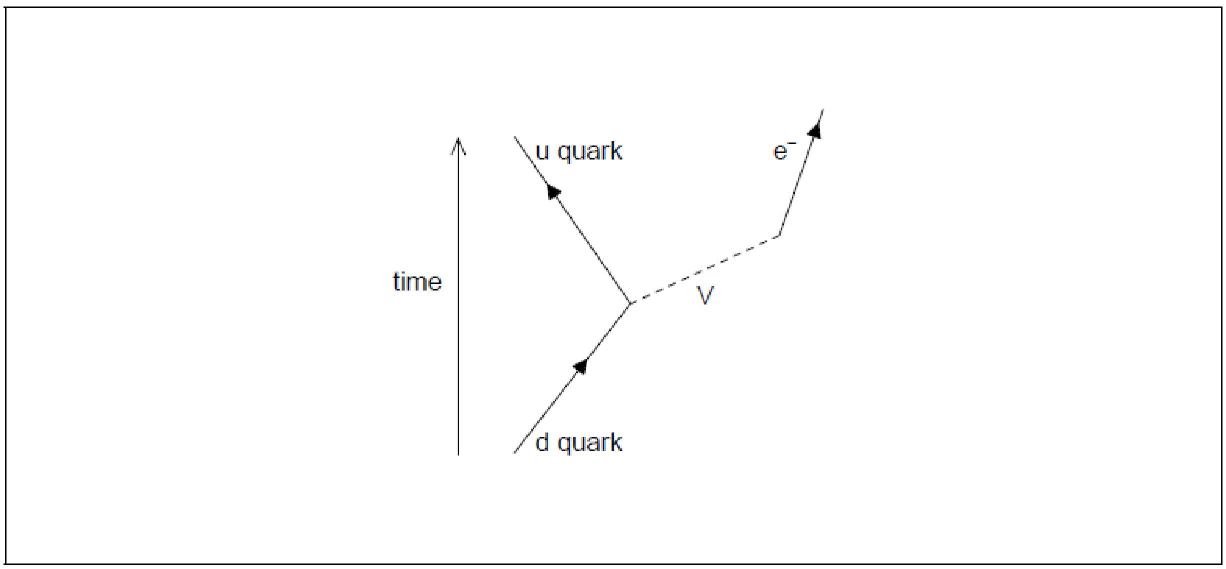
Rhodium-106 ($^{106}_{45}\mathrm{Rh}$) decays into palladium-106 ($^{106}_{46}\mathrm{Pd}$) by beta minus (β^-) decay.

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

5b. State what is meant by the binding energy of a nucleus. *[1 mark]*

5c. Show that the energy released in the β^- decay of rhodium is about 3 MeV. *[1 mark]*

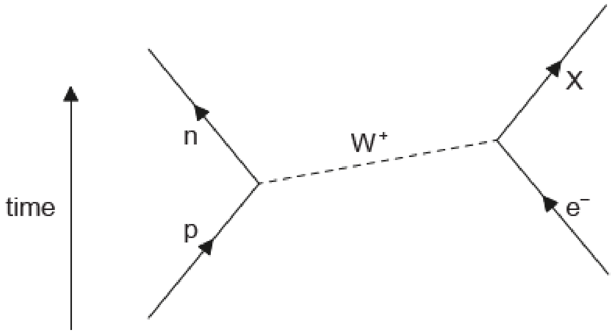
β^- decay is described by the following incomplete Feynman diagram.



5d. Draw a labelled arrow to complete the Feynman diagram. *[1 mark]*

5e. Identify particle V. *[1 mark]*

The Feynman diagram shows electron capture.



6a. Deduce that X must be an electron neutrino. *[2 marks]*

6b. Distinguish between hadrons and leptons. *[2 marks]*

7a. State the quark structures of a meson and a baryon. *[2 marks]*

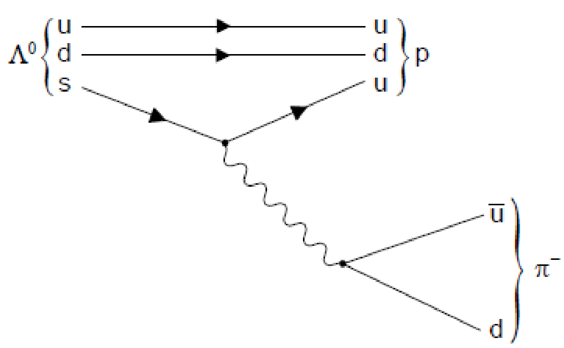
Meson: . . . .

. . . .

Baryon: . . . .

. . . .

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



7b. Explain which interaction is responsible for this decay. *[2 marks]*

7c. Draw arrow heads on the lines representing $\bar{u}$ and d in the π^-. *[1 mark]*

7d. Identify the exchange particle in this decay. *[1 mark]*

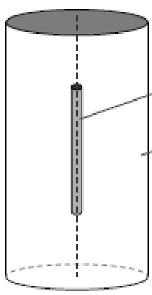
7e. Outline **one** benefit of international cooperation in the construction or use of high-energy particle accelerators. *[1 mark]*

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).

8a. Write down the missing values in the nuclear equation for this decay. *[1 mark]*

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

8b. 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 mark]*



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.

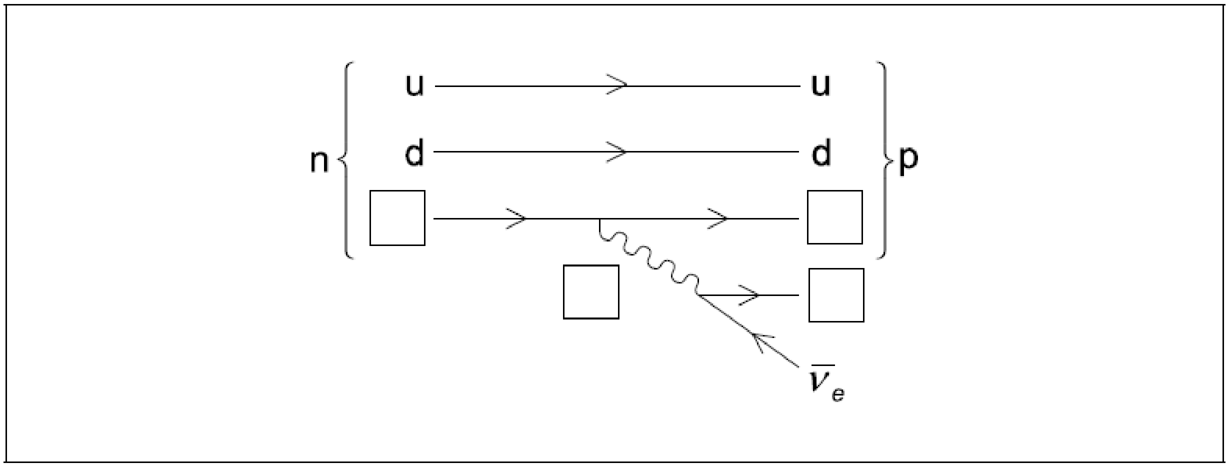
8c. Rutherford and Royds expected 2.7 x 10^{15} alpha particles to be emitted during the experiment. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3 x 10^{-5} m^3 and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B. *[3 marks]*

8d. 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 marks]*

8e. 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 mark]*

9a. A particular K meson has a quark structure ū s. State the charge on this meson. *[1 mark]*

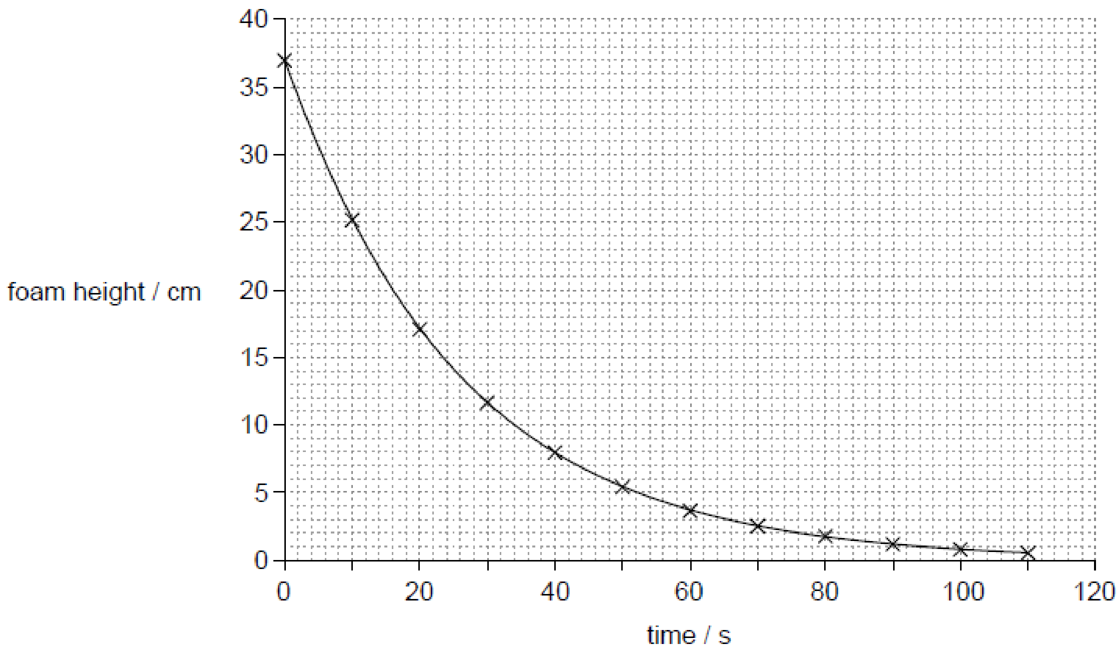
9b. The Feynman diagram shows the changes that occur during beta minus (β^-) decay. *[2 marks]*



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

9c. 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 marks]*

A student pours a canned carbonated drink into a cylindrical container after shaking the can violently before opening. A large volume of foam is produced that fills the container. The graph shows the variation of foam height with time.



10a. Determine the time taken for the foam to drop to *[2 marks]*

(i) half its initial height.

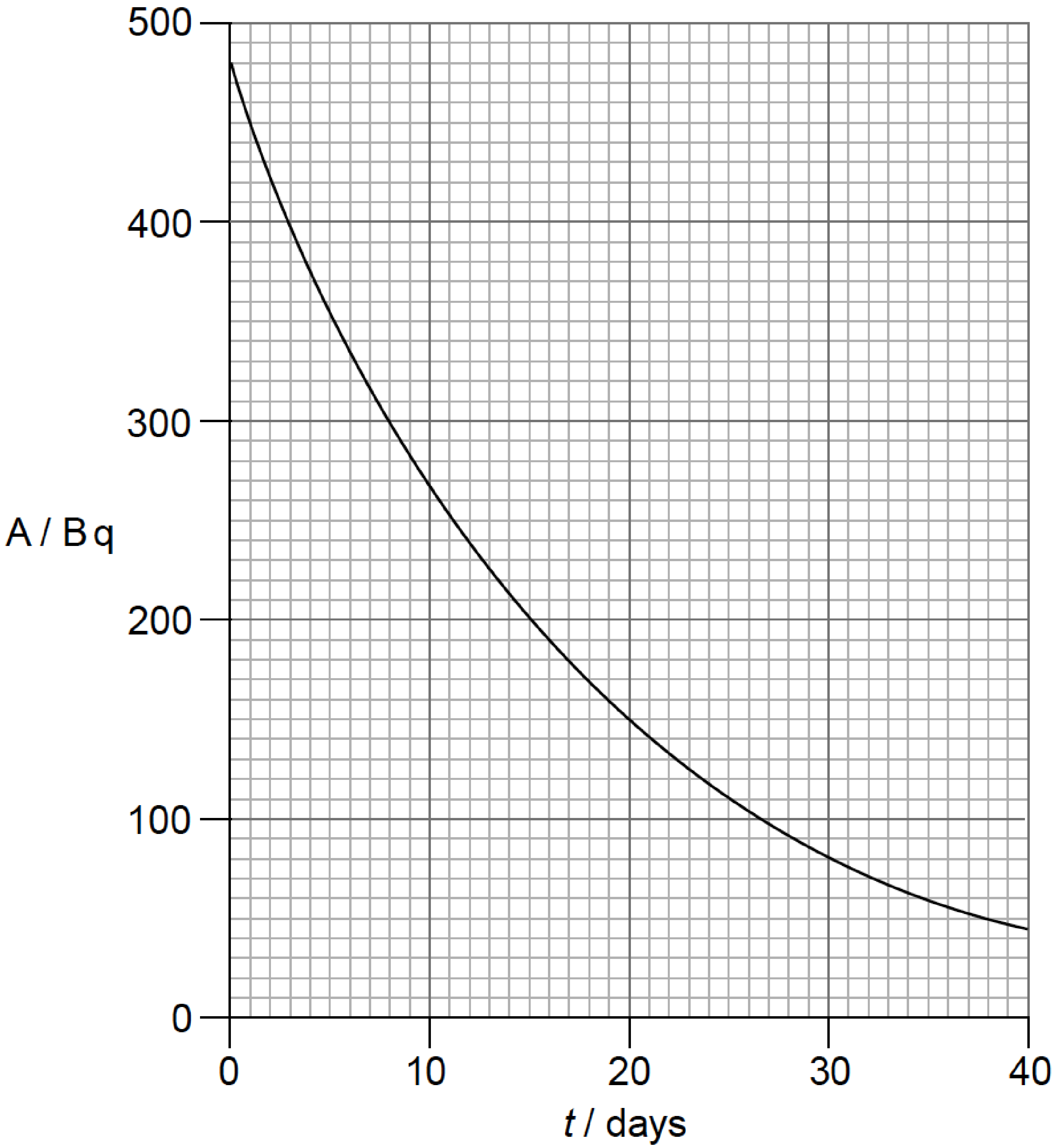
(ii) a quarter of its initial height.

10b. The change in foam height can be modelled using ideas from other areas of physics. Identify **one** other situation in physics that is modelled in a similar way. *[1 mark]*

11a. 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 marks]*

Determine the energy released in this decay.

11b. 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 mark]*



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

11c. Quarks were hypothesized long before their existence was experimentally verified. Discuss the reasons why physicists developed a theory that involved quarks. *[3 marks]*

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

12a. Outline how the evidence supplied by the Geiger–Marsden experiment supports the nuclear model of the atom. *[4 marks]*

12b. Outline why classical physics does not permit a model of an electron orbiting the nucleus. *[3 marks]*

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.

12c. State what is meant by the terms nuclide and isotope. *[2 marks]*

Nuclide:

Isotope:

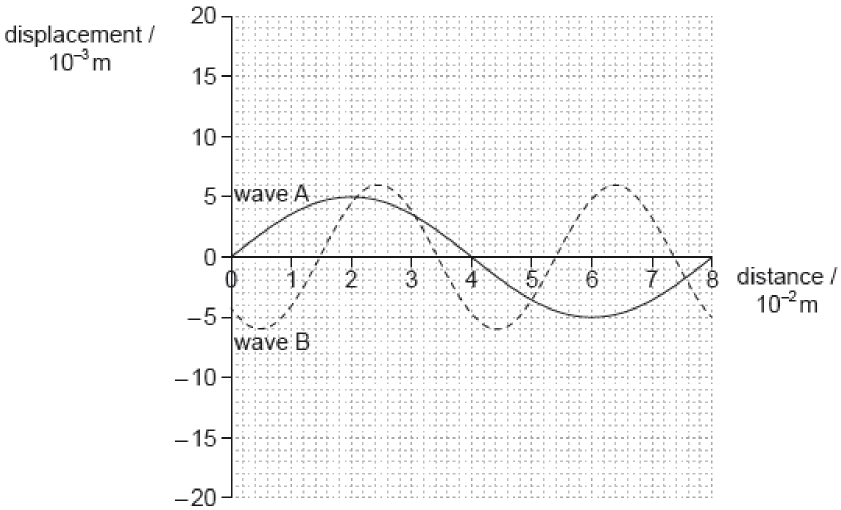
12d. Construct the nuclear equation for the decay of radium-226. *[3 marks]*

$${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{\dots\dots}_{\dots\dots}\mathrm{Rn} + {}^{\dots\dots}_{\dots\dots}\mathrm{He} + {}^{\dots\dots}_{\dots\dots}\gamma$$

12e. 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 marks]*

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.



12f. State the amplitude of wave A. *[1 mark]*

12g. Wave A has a frequency of 9.0 Hz. Calculate the velocity of wave A. *[2 marks]*

12h. Deduce the frequency of wave B. *[3 marks]*

12i. State what is meant by the principle of superposition of waves. *[2 marks]*

12j. On the graph opposite, sketch the wave that results from the superposition of wave A and wave B at that instant. *[3 marks]*

This question is about interactions and quarks.

13a. A lambda baryon Λ^0 is composed of the three quarks uds. Show that the charge is 0 and the strangeness is -1. *[2 marks]*

For the lambda baryon Λ^0, a student proposes a possible decay of Λ^0 as shown.

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

The quark content of the K^- meson is $\bar{\text{u}}\text{s}$.

13b. Discuss, with reference to strangeness and baryon number, why this proposal is feasible. *[4 marks]*

Strangeness:

Baryon number:

13c. Another interaction is *[1 mark]*

$$\Lambda^0 \rightarrow p + \pi^-$$

In this interaction strangeness is found **not** to be conserved. Deduce the nature of this interaction.

This question is about radioactive decay.

Meteorites contain a small proportion of radioactive aluminium-26 $\left({}^{26}_{13}\text{Al}\right)$ in the rock.

The amount of ${}^{26}_{13}\text{Al}$ is constant while the meteorite is in space due to bombardment with cosmic rays.

14a. Aluminium-26 decays into an isotope of magnesium (Mg) by β^+ decay. *[2 marks]*

$$ {}^{26}_{13}\text{Al} \rightarrow {}^{\text{X}}_{\text{Y}}\text{Mg} + \beta^+ + \text{Z}$$

Identify X, Y and Z in this nuclear decay process.

X:

Y:

Z:

14b. Explain why the beta particles emitted from the aluminium-26 have a continuous range of energies. *[2 marks]*

After reaching Earth, the number of radioactive decays per unit time in a meteorite sample begins to diminish with time. The half-life of aluminium-26 is 7.2×10^5 years.

14c. State what is meant by half-life. *[1 mark]*

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%.

15a. (i) Determine the diameter that will be required for the turbine blades to achieve the maximum power of 0.75 MW. *[8 marks]*

(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.

15b. 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 marks]*

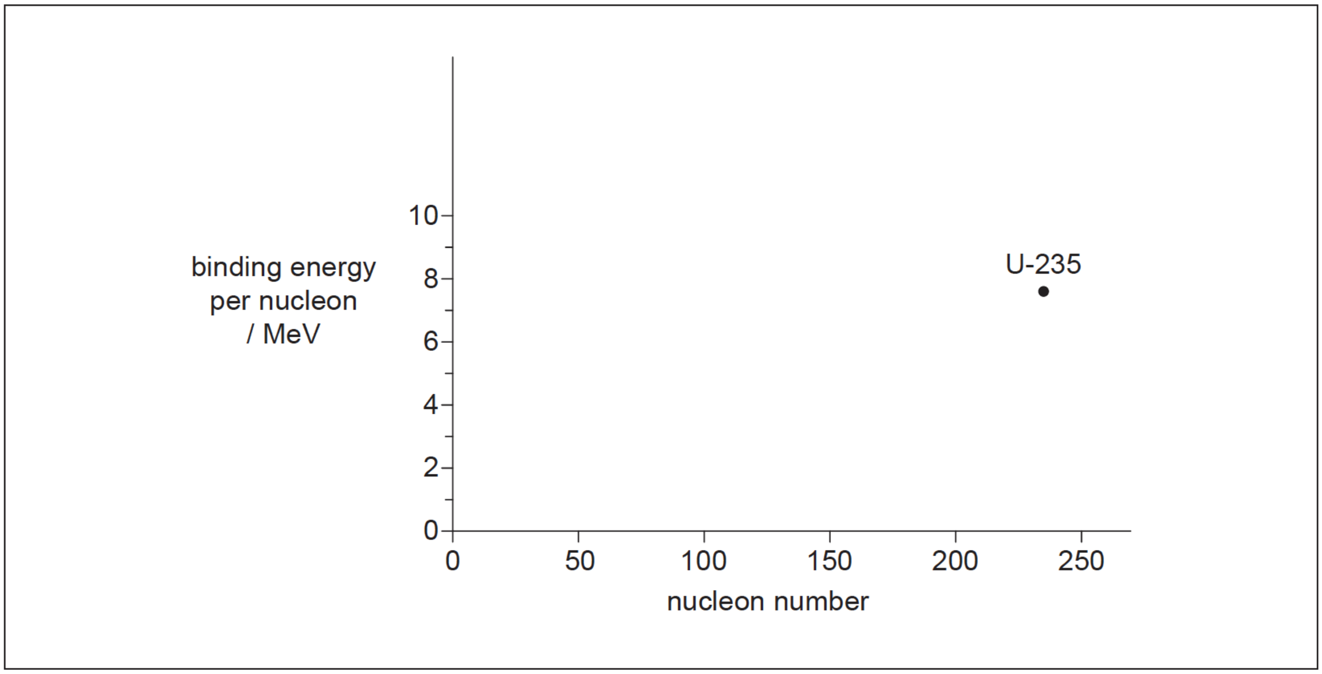
(i) The energy density of coal is $35 MJ kg^{-1}$. Estimate the minimum mass of coal that can be saved every hour when the wind farm is producing its full output.

(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.

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.



15c. State what is meant by the binding energy of a nucleus. *[1 mark]*

15d. (i) On the axes, sketch a graph showing the variation of nucleon number with the binding energy per nucleon. *[5 marks]*

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

15e. U-235 $\left({}^{235}_{92}\mathrm{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th). *[4 marks]*

(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.

This question is about quarks.

An interaction between an electron and a positron can lead to the production of hadrons via the reaction

$$e^- + e^+ \to u + \bar{u}$$

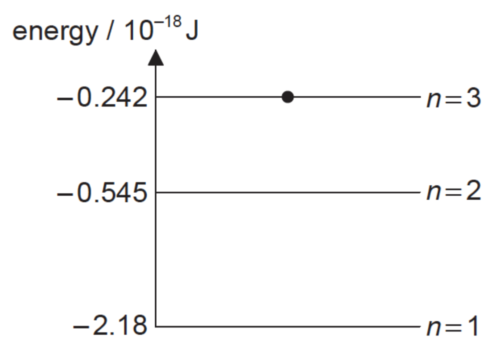
where u is an up quark. This process involves the electromagnetic interaction.

16a. Draw a Feynman diagram for this interaction. *[2 marks]*

16b. Outline, with reference to the strong interaction, why hadrons are produced in the reaction. *[2 marks]*

This question is about the hydrogen atom.

The diagram shows the three lowest energy levels of a hydrogen atom.



17a. An electron is excited to the *n*=3 energy level. On the diagram, draw arrows to show the possible electron transitions that can lead to the emission of a photon. *[2 marks]*

17b. Show that a photon of wavelength 656 nm can be emitted from a hydrogen atom. *[2 marks]*

This question is about radioactive decay.

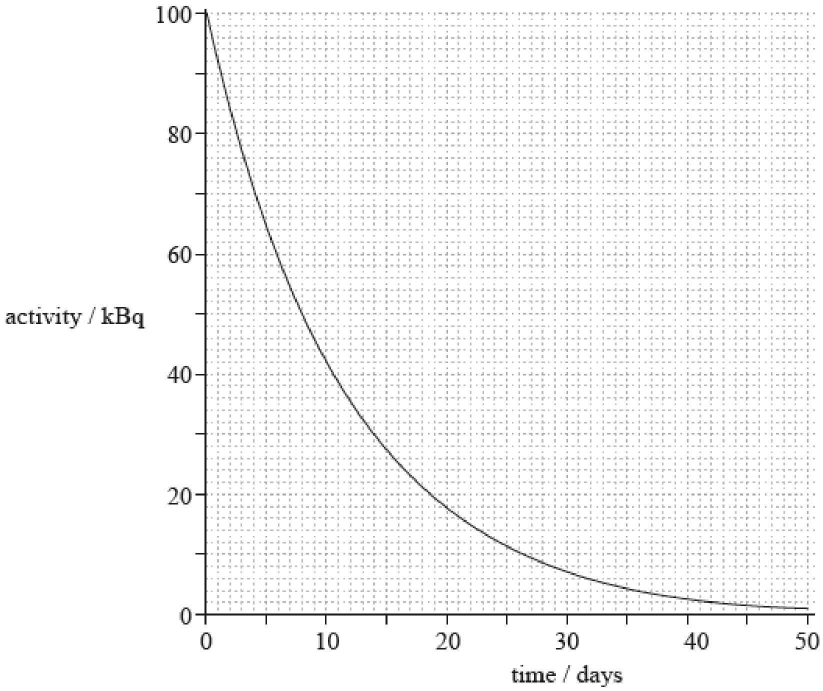
A nucleus of an iodine isotope, I-131, undergoes radioactive decay to form a nucleus of the nuclide xenon-131. Xe-131 is stable.

18a. Explain what is meant by an isotope. *[2 marks]*

18b. Identify the missing entries to complete the nuclear reaction for the decay of I-131. *[1 mark]*

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

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.



18c. The I-131 can be used for a medical application but only when the activity lies within the range of $(20 \pm 10)\ \mathrm{kBq}$. Determine an estimate for the time during which the iodine can be used. *[2 marks]*

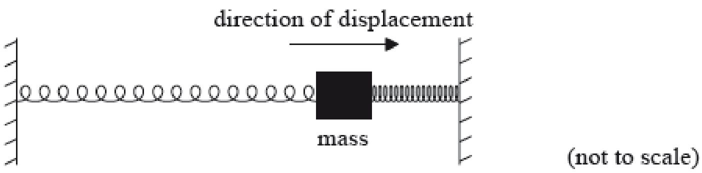
18d. A different isotope has half the initial activity and double the half-life of I-131. On the graph in (c), sketch the variation of activity with time for this isotope. *[2 marks]*

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.

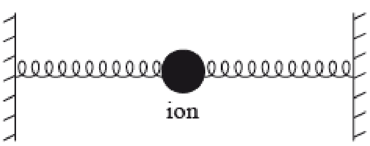


19a. Determine the acceleration of the mass at the moment of release. *[3 marks]*

19b. Outline why the mass subsequently performs simple harmonic motion (SHM). *[2 marks]*

19c. Calculate the period of oscillation of the mass. *[2 marks]*

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 $7 \times 10^{12}\ \mathrm{Hz}$ and the mass of the ion is $5 \times 10^{-26}\ \mathrm{kg}$. The amplitude of vibration of the ion is $1 \times 10^{-11}\ \mathrm{m}$.

19d. Estimate the maximum kinetic energy of the ion. *[2 marks]*

19e. 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 marks]*

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

19f. Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). *[1 mark]*

Part 2 Nuclear fission

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

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

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%.

19g. Determine the mass of U-235 that undergoes fission in the reactor every day. *[3 marks]*

19h. Calculate the power output of the nuclear power station. *[2 marks]*

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

19i. moderator. *[3 marks]*

19j. control rods. *[2 marks]*

This question is about fundamental interactions and elementary particles.

20a. Identify the type of fundamental interactions associated with the exchange particles in the table. *[2 marks]*

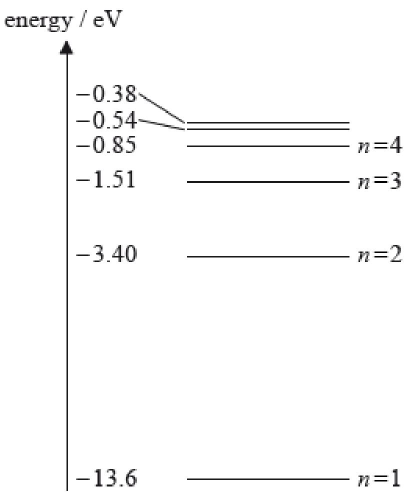
Exchange particle	Fundamental interaction
Photon	
Pi meson, π^+	

20b. State why π^+ mesons are **not** considered to be elementary particles. *[1 mark]*

This question is about atomic spectra and energy states.

21a. Outline how atomic absorption spectra provide evidence for the quantization of energy states in atoms. *[2 marks]*

21b. The diagram shows some atomic energy levels of hydrogen. *[1 mark]*



A photon of energy 2.86 eV is emitted from a hydrogen atom. Using the diagram, draw an arrow to indicate the electron transitions that results in the emission of this photon.

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).

22a. Identify the numbers and the particle to complete the decay equation. *[2 marks]*

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

22b. State the nature of the β^+ particle. *[1 mark]*

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

22c. Outline a method for measuring the half-life of an isotope, such as the half-life of carbon-11. *[3 marks]*

22d. State the law of radioactive decay. *[1 mark]*

22e. Derive the relationship between the half-life $T_{\frac{1}{2}}$ and the decay constant λ , using the law of radioactive decay. *[2 marks]*

22f. Calculate the number of nuclei of carbon-11 that will produce an activity of 4.2×10^{20} Bq. *[2 marks]*