SL Paper 3

This question is about leptons and mesons.

Leptons are a class of elementary particles and each lepton has its own antiparticle. State what is meant by an

Unlike leptons, the π^+ meson is not an elementary particle. State the

a. (i) elementary particle. [2]

(ii) antiparticle of a lepton.

b. The electron is a lepton and its antiparticle is the positron. The following reaction can take place between an electron and positron. [3]

$$e^- + e^+ \rightarrow \gamma + \gamma$$

Sketch the Feynman diagram for this reaction and identify on your diagram any virtual particles.

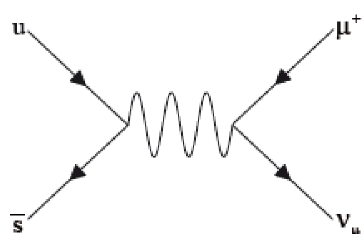
c. (i) quark structure of the π^+ meson. [2]

(ii) reason why the following reaction does not occur.

$$p^+ + p^+ \rightarrow p^+ + \pi^+$$

This question is about fundamental interactions.

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



b.i. Explain why the virtual particle in this Feynman diagram must be a weak interaction exchange particle. [2]

c. 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]

This question is about interactions and quarks.

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 ūs.

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

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

Strangeness:

Baryon number:

b.ii Another interaction is [1]

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

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 $\left({}^{26}_{13}\mathrm{Al}\right)$ in the rock.

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

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.

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

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

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

X:

Y:

Z:

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

c.i. State what is meant by half-life. [1]

c.ii. A meteorite which has just fallen to Earth has an activity of 36.8 Bq. A second meteorite of the same mass, which arrived some time ago, has an activity of 11.2 Bq. Determine, in years, the time since the second meteorite arrived on Earth. [3]

This question is about fundamental interactions and elementary particles.

The Feynman diagram represents the decay of a π^+ meson into an anti-muon and a muon neutrino.

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

Exchange particle	Fundamental interaction
Photon	
Pi meson, π^+	

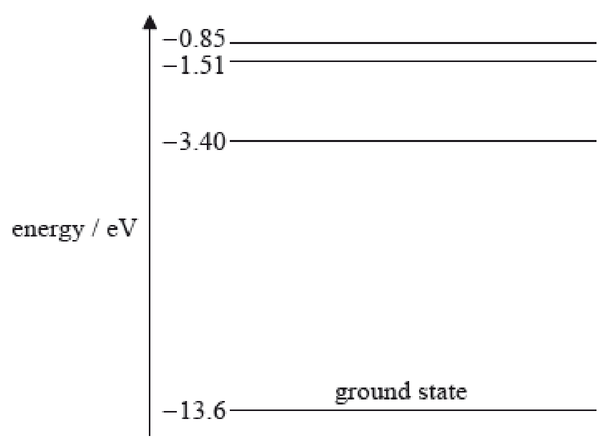
a.ii. State why π^+ mesons are **not** considered to be elementary particles. [1]

b.i. Identify the exchange particle associated with this decay. [1]

b.ii. Deduce that this decay conserves baryon number. [2]

This question is about atomic spectra.

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



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

b. (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]

(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 about radioactive decay.

Sodium-22 undergoes β^{+} decay.

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

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

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

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

(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 the spectrum of atomic hydrogen.

Calculate the difference in energy in eV between the energy levels in the hydrogen atom that give rise to the red line in the spectrum.

This question is about radioactive decay.

The half-life of Au-189 is 8.84 minutes. A freshly prepared sample of the isotope has an activity of 124Bq.

a. A nucleus of a radioactive isotope of gold (Au-189) emits a neutrino in the decay to a nucleus of an isotope of platinum (Pt). [2]

In the nuclear reaction equation below, state the name of the particle X and identify the nucleon number A and proton number Z of the nucleus of the isotope of platinum.

$$^{189}_{79}Au \rightarrow {}^{A}_{Z}\,Pt + X + v$$

X:

A:

Z:

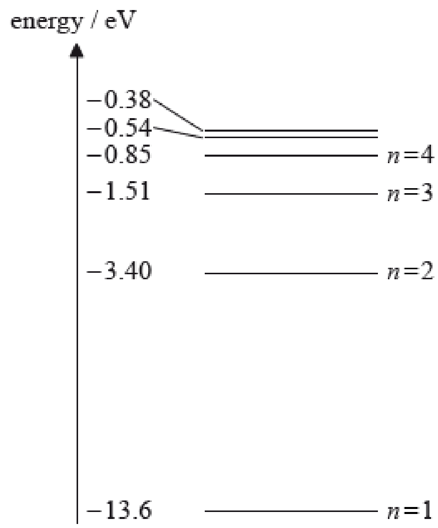
b. (i) Calculate the decay constant of Au-189. [3]

(ii) Determine the activity of the sample after 12.0 min.

This question is about atomic spectra and energy states.

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

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



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 strangeness.

The following particle interaction is proposed.

$$p + \pi^- \to K^- + \pi^+$$

In this interaction, charge is conserved.

State, in terms of baryon and strangeness conservation, whether the interaction is possible.

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).

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

a.i. Identify the numbers and the particle to complete the decay equation. [2]

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

a.ii. State the nature of the β^+ particle. [1]

b.i. Outline a method for measuring the half-life of an isotope, such as the half-life of carbon-11. [3]

b.ii. State the law of radioactive decay. [1]

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

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

This question is about electrons and the weak interaction.

a. State [2]

(i) what is meant by an elementary particle.

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

c. 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]

(i) State the name of the exchange particle.

(ii) The weak interaction has a range of the order of 10^{-18}m. Determine, in $\mathrm{GeVc^{-2}}$, 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 about elementary particles.

This quark is said to be an elementary particle.

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

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

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

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

This question is about radioactive decay.

a. 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]

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

b. 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. [3]

Determine the age of the rock.

c. 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]

This question is about atomic energy levels.

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

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

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

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

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

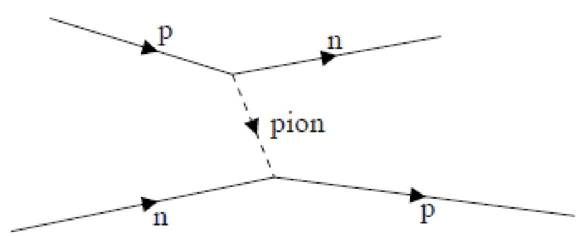
where *n* is a positive integer.

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.

This question is about mesons.

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

c. 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]



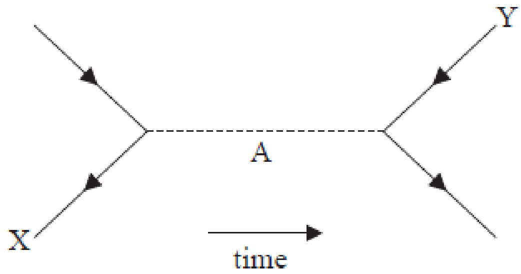
State and explain whether the meson produced is a π^+, π^- **or** a π^0.

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.

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

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



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

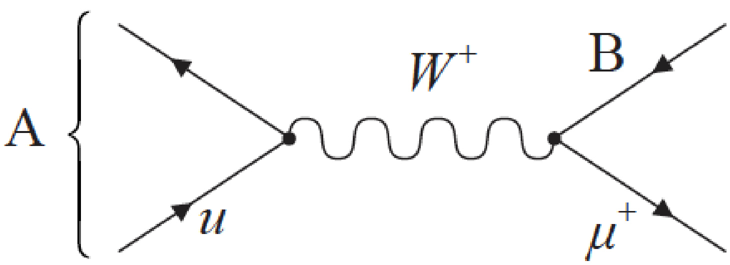
(ii) Explain how it can be deduced that this decay takes place through the weak interaction.

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

This question is about quarks.

The quark content of a π^+ meson includes an up quark.

The Feynman diagram represents the decay of a π^+ meson.



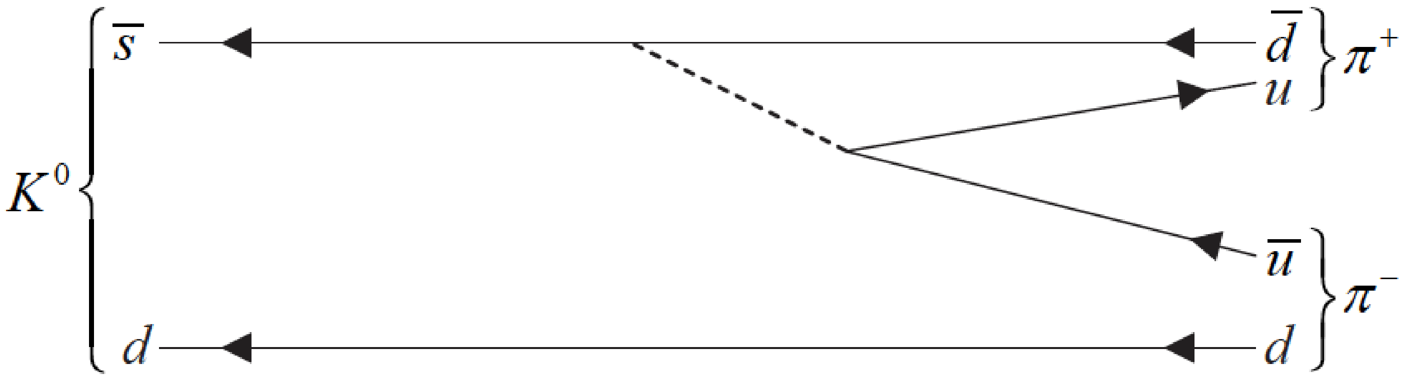
a. Identify the particles labelled A and B. [2]

b. State, with reference to their properties, **two** differences between a photon and a W boson. [2]

This question is about quarks.

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

b. 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]



(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.

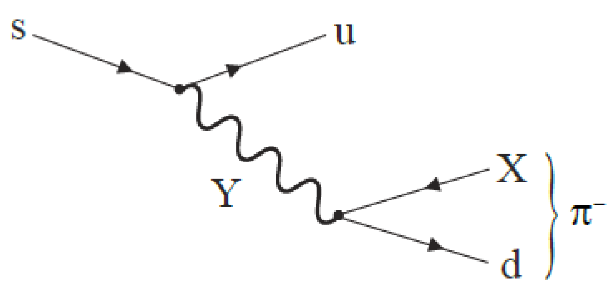
This question is about the Ω^- particle.

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

This question is about laser light.

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

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



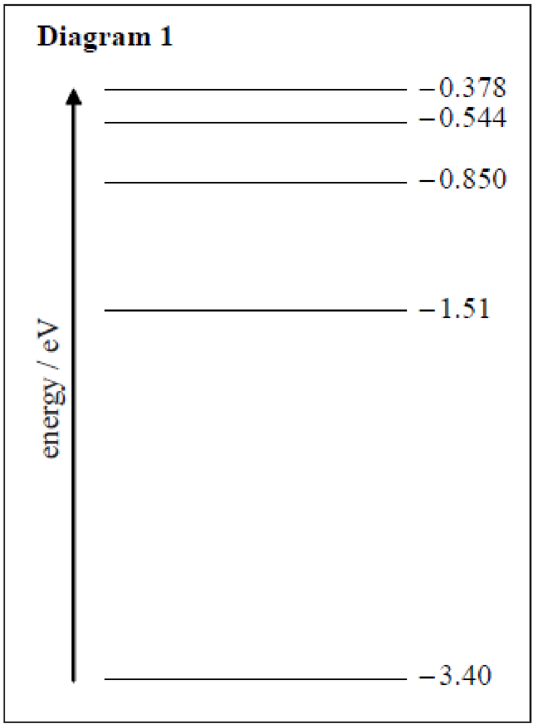
(i) Identify X.

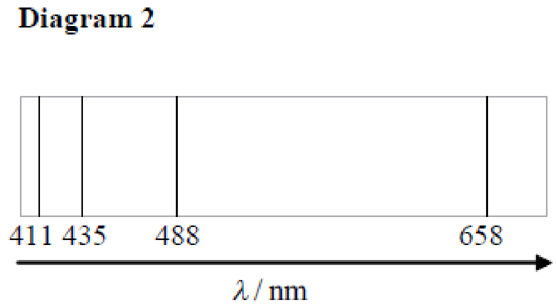
(ii) Identify Y.

c. 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]

This question is about atomic spectra.

Diagram 1 shows some of the energy levels of the hydrogen atom. Diagram 2 is a representation of part of the emission spectrum of atomic hydrogen. The lines shown represent transitions involving the – 3.40 eV level.





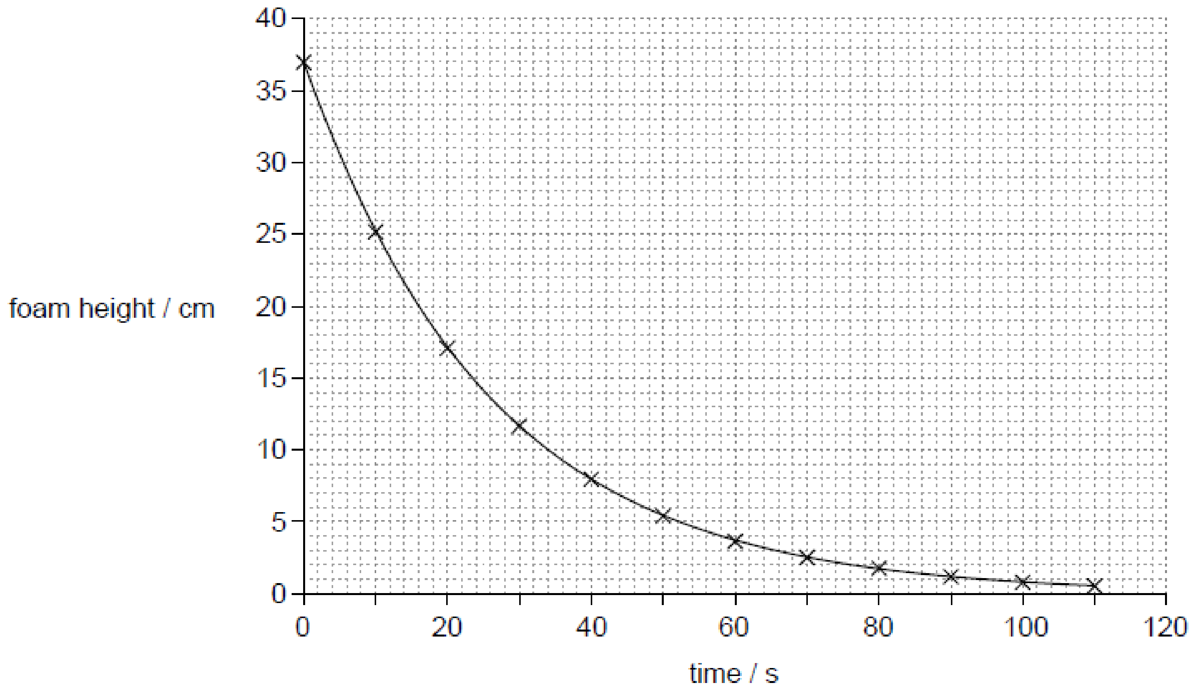
a. Deduce that the energy of a photon of wavelength 658 nm is 1.89 eV. [3]

b. (i) On **diagram 1**, draw an arrow to show the electron transition between energy levels that gives rise to the emission of a photon of wavelength 658 nm. Label this arrow with the letter A. [2]

(ii) On **diagram 1**, draw arrows to show the electron transitions between energy levels that give rise to the emission of photons of wavelengths 488 nm, 435 nm and 411 nm. Label these arrows with the letters B, C and D.

c. Explain why the lines in the emission spectrum of atomic hydrogen, shown in **diagram 2**, become closer together as the wavelength of the emitted photons decreases. [3]

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.



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

(i) half its initial height.

(ii) a quarter of its initial height.

b. 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]

This question is about quarks and interactions.

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

c. Determine whether or not strangeness is conserved in this decay. [2]

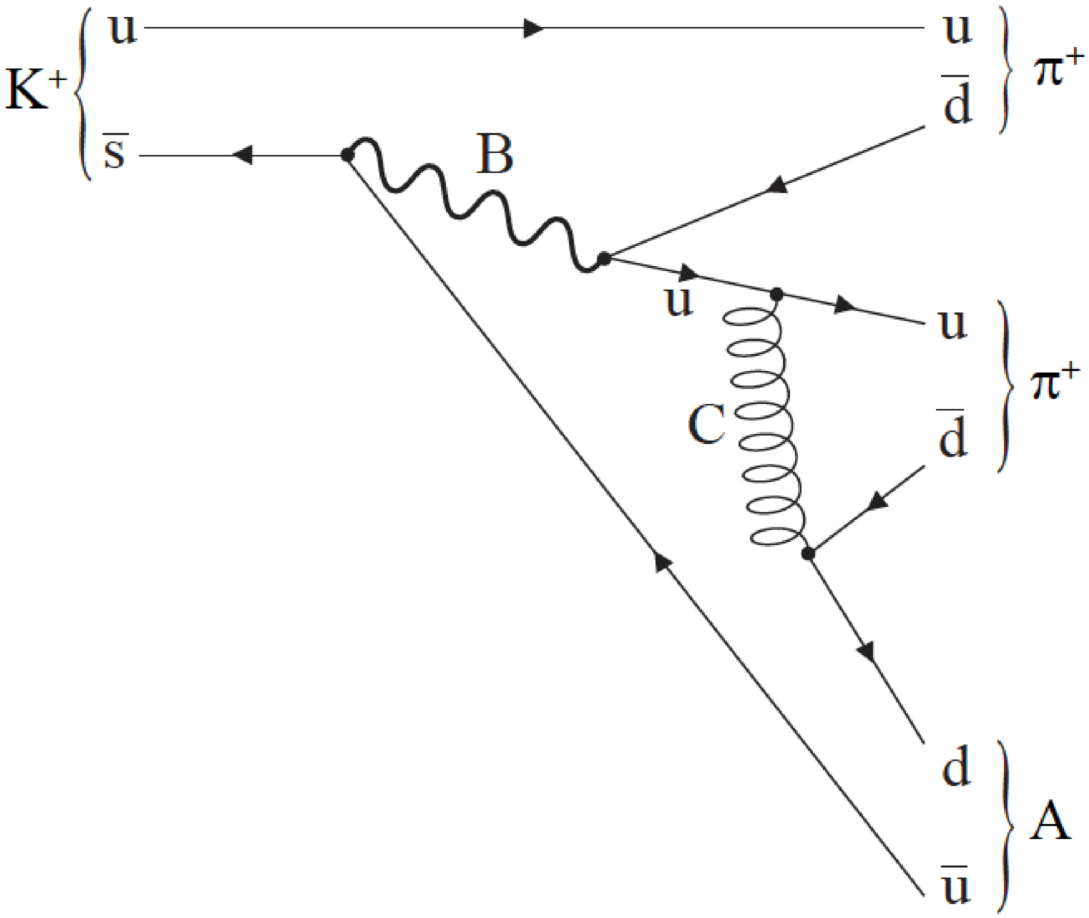
d. The total energy of the particle represented by the dotted line is 1.2 GeV more than what is allowed by energy conservation. Determine the time interval from the emission of the particle from the s quark to its conversion into the d $\bar{\mathrm{d}}$ pair. [2]

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

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

This question is about fundamental interactions.

The Feynman diagram shows the decay of a K^+ meson into three other particles.



a. Identify particle A. [1]

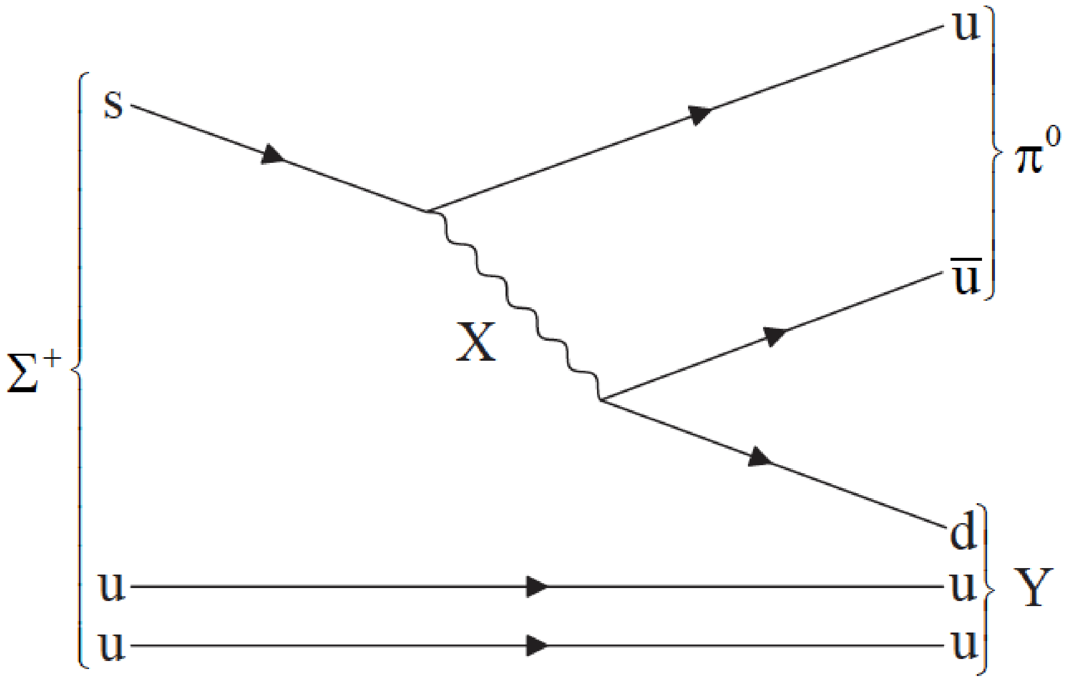
b. (i) Identify the interaction whose exchange particle is represented by B. [2]

(ii) Identify the exchange particle labelled C.

c. Outline how the concept of strangeness applies to the decay of a K^+ meson shown in this Feynman diagram. [2]

This question is about particles.

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



(i) Identify the exchange particle X.

(ii) Identify particle Y.

(iii) Outline the nature of the π^0.

c. 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]

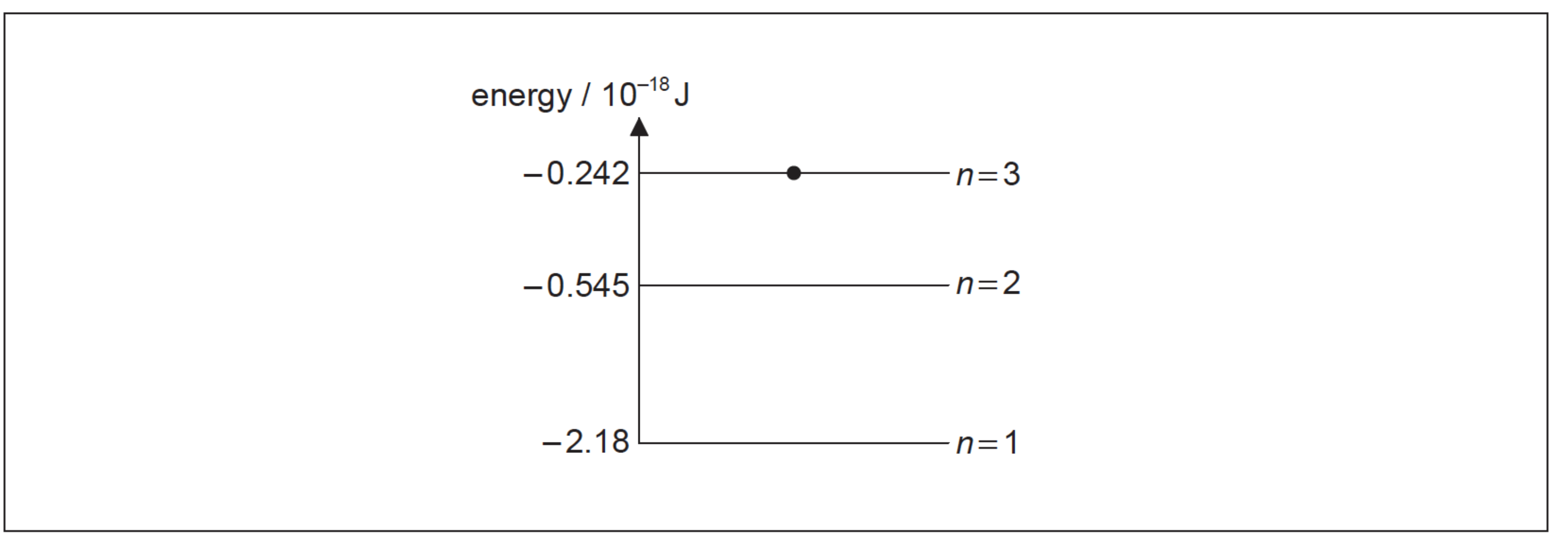
(i) State the process by which the electron and the positron are produced.

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

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

This question is about the hydrogen atom.

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



a. 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]

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

This question is about quarks.

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

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

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

a. Draw a Feynman diagram for this interaction. [2]

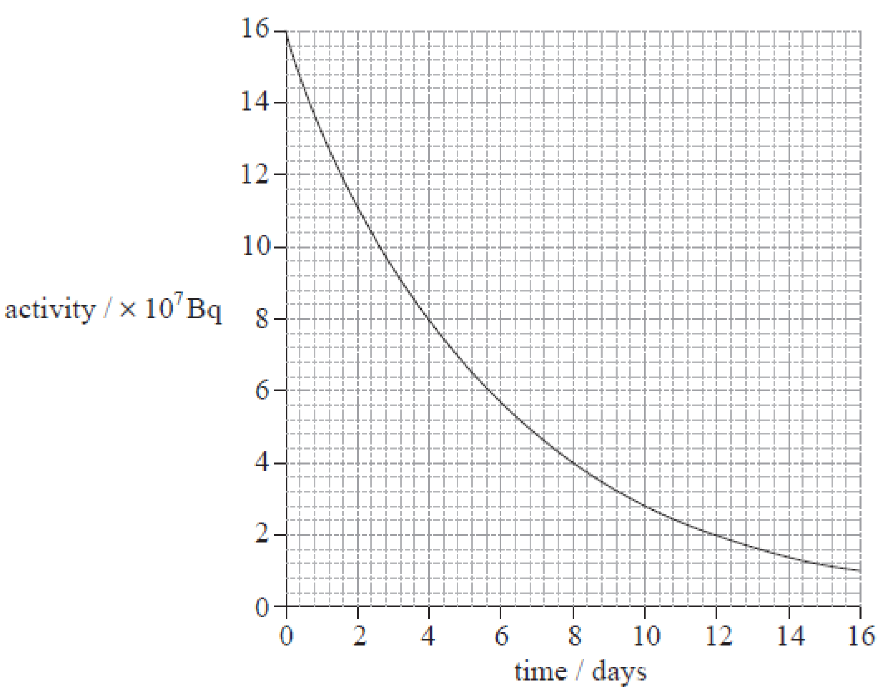
b. Outline, with reference to the strong interaction, why hadrons are produced in the reaction. [2]

This question is about radioactive decay.

Iodine-124 (I-124) is an unstable radioisotope with proton number 53. It undergoes beta plus decay to form an isotope of tellurium (Te).

a. State the reaction for the decay of the I-124 nuclide. [2]

b. The graph below shows how the activity of a sample of iodine-124 changes with time. [6]



(i) State the half-life of iodine-124.

(ii) Calculate the activity of the sample at 21 days.

(iii) A sample of an unknown radioisotope has a half-life twice that of iodine-124 and the same initial activity as the sample of iodine-124. On the axes opposite, draw a graph to show how the activity of the sample would change with time. Label this graph X.

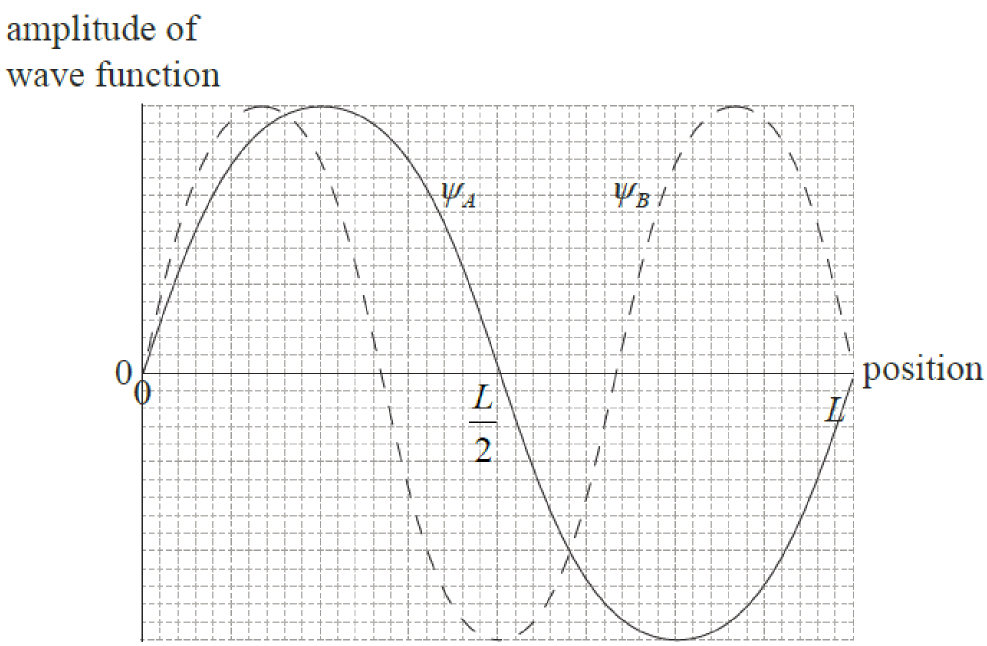
(iv) A second sample of iodine-124 has half the initial activity as the original sample of iodine-124. On the axes opposite, draw a graph to show how the activity of this sample would change with time. Label this graph Y.

This question is about atomic energy levels.

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

b. 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]

c. 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]



(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.
