IB · DP · Physics

3 hours 15 questions

Structured Questions

7.3 The Structure of Matter

7.3.1 Discovery of the Nucleus / 7.3.2 Quarks & Leptons / 7.3.3 Hadrons, Baryons & Mesons / 7.3.4 Particle Conservation Laws / 7.3.5 Fundamental Forces / 7.3.6 Feynman Diagrams & Confinement / 7.3.7 The Standard Model of Particle Physics

Easy (5 questions)	/66
Medium (5 questions)	/66
Hard (5 questions)	/51
Total Marks	**/183**

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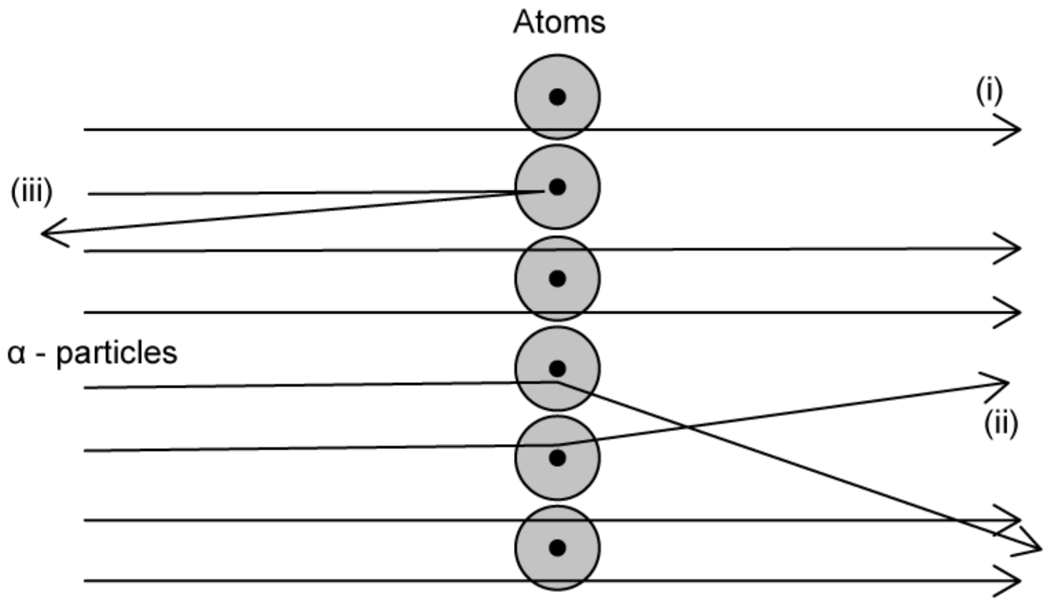
Easy Questions

1 (a) The Rutherford-Geiger-Marsden Experiment provided evidence for the structure of the atom. The set up consisted of alpha particles being fired at a thin gold foil, with a detector to detect deflected particles.

The diagram shows some of the potential paths taken by the alpha particles.



Draw lines to connect the correct statements for each path of the alpha particle.

(i)	The majority of α-particles went straight through the gold foil	This suggested the nucleus is extremely small and where the mass and charge of the atom is concentrated
(ii)	Some α-particles deflected through small angles of <10°	This suggested the atom is mainly empty space
(iii)	Only a small number of α-particles deflected straight back at angles of >90°	This suggested there is a positive nucleus at the centre (since two positive charges would repel)

(3 marks)

(b) Since Rutherford's discovery, further discoveries about the nature of matter have been made.

Complete the following sentences with appropriate words or phrases:

The nucleus is made of ________ and ________, and these themselves are made of the fundamental particles known as ________. Any particle made of these is known as a ________. Another example of a fundamental particle is the ________.

(5 marks)

(c) One type of hadron is the K+ meson, which has a strangeness of +1.

(i) State the quark composition of a meson

[1]

(ii) State the baryon number of a K+ meson

[1]

(iii) Show that the quark composition of a K+ meson is $u\bar{s}$

[4]

(6 marks)

(d) Electrons are an example of another type of fundamental particle called a lepton.

(i) State the charge on a muon.

[1]

(ii) State the mass of the electron neutrino.

[1]

(iii) State the fundamental force which leptons do not interact with, but quarks do.

[1]

(3 marks)

2 (a) The following particles are available:

$$p \quad \overline{n} \quad \mu^+ \quad e^+ \quad \gamma$$

Identify all examples of:

(i) Hadrons.

[1]

(ii) Leptons.

[1]

(iii) Antiparticles.

[1]

(iv) Charged particles.

[1]

(v) Exchange particles.

[1]

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(5 marks)

(b) Quarks can combine to give various baryons and mesons. The proton and neutron are the baryons which subsequently make up the nucleus.

State the quark composition of:

(i) A proton.

[1]

(ii) A neutron.

[1]

....

(2 marks)

(c) The proton has a charge of +1*e*.

Explain why the proton has this charge by referring to the charge of its constituent quarks.

(2 marks)

(d) Protons and neutrons are both examples of baryons. An electron is an example of a lepton

Complete the table below with the correct charge, baryon and lepton numbers for each particle.

	Charge	Baryon number	Lepton number
Proton, p	+1	1	
Anti-Neutron, $\overline{n}$			0
Pion minus, π^-	−1		0
Photon, γ	0	0	
Up quark, u	$+\frac{2}{3}$		0
Electron, e		0	

(6 marks)

3 (a) The four fundamental forces are mediated through exchange particles.

Define the phrase 'exchange particle'.

(2 marks)

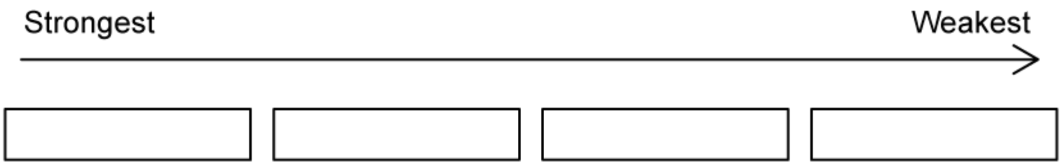
(b) Draw lines to match the force with the correct exchange particle:

Fundamental force
Electromagnetic
Strong
Weak
Gravitational

Exchange particle
Pion/gluon
Graviton (theoretical)
W^-, W^+, Z^0
Photon (virtual)

(4 marks)

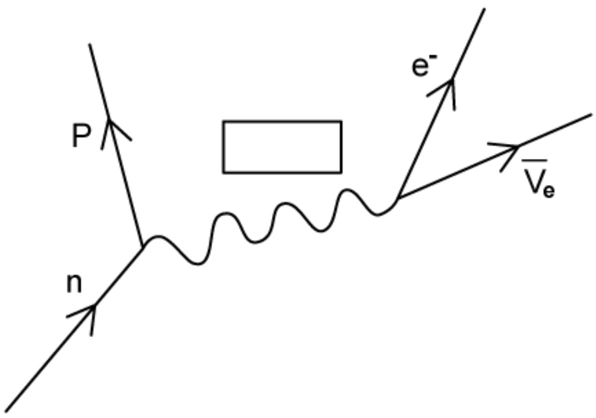
(c) Arrange the four fundamental forces in the boxes below the arrow in order of strongest to weakest.



(3 marks)

(d) Feynman diagrams represent particle interactions in the form of a diagram.

The following is a Feynman diagram showing beta−minus decay, with the exchange particle missing.



Label the correct exchange particle on the diagram.

(1 mark)

4 (a) State what is meant by the standard model of particle physics.

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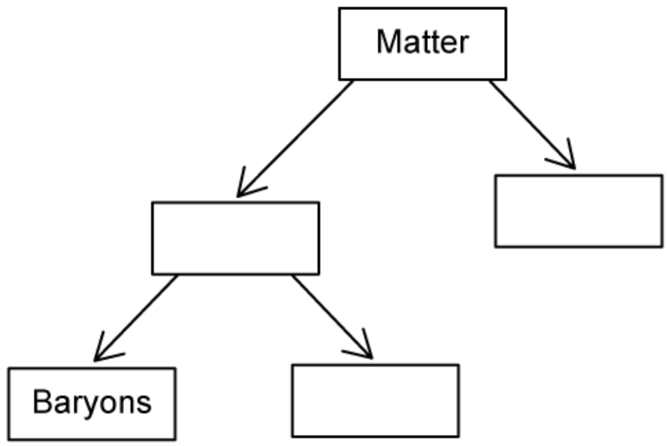
(2 marks)

(b) The standard model describes the fundamental particles that make up other sub-atomic particles.

One method of representing the standard model is as shown in the diagram below.



Complete the missing information in the boxes in the diagram.

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(3 marks)

(c) Another more detailed way of showing the standard model is shown below, where the different fundamental particles are arranged on cards:

u up	c charm	t top	g graviton	H Higgs boson
d down	s strange	b bottom	γ photon	
e electron	μ muon	τ tau	Z Z boson	
ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

By writing a letter in the correct box, identify:

(i) Quarks, with the letter **Q**

[1]

(ii) Leptons, with the letter **L**

[1]

(iii) Gauge bosons, with the letter **B**

[1]

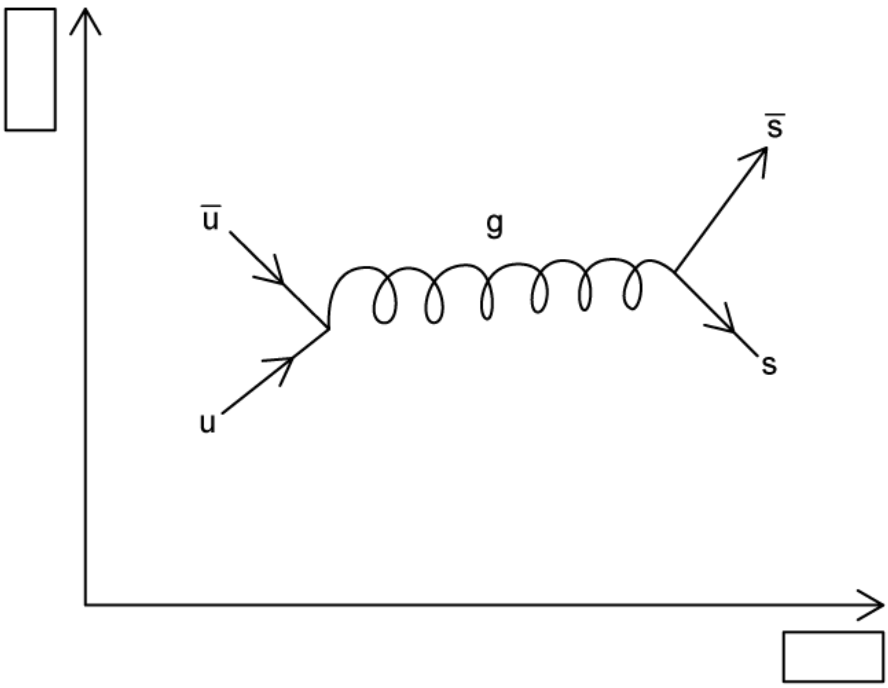
(3 marks)

(d) The final particle on the standard model diagram in part (b) is the Higgs boson. It was predicted in 1964 and confirmed in 2012.

State what the Higgs boson is responsible for.

(1 mark)

5 (a) The following Feynman diagram shows a particle interaction.



Label the axes of the Feynman diagram.

(2 marks)

(b) State:

(i) The exchange particle in the interaction shown in part (a).

[1]

(ii) The fundamental force represented by this exchange particle.

[1]

(2 marks)

(c) The Feynman diagram in part (a) represents part of the particle interaction

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

The composition of each particle in terms of quarks is:

- $\pi^- = d\,\bar{u}$
- $p = uud$
- $K^0 = d\,\bar{s}$
- $\Lambda^0 = uds$

(i) Identify the two particles in this interaction which contain a strange or anti-strange quark .

[2]

(ii) By considering the strangeness of each of the particles, show that strangeness is conserved in this interaction.

[3]

(iii) State the interaction which does not conserve strangeness.

[1]

(6 marks)

(d) Quarks can only exist within hadrons, this is known as quark confinement.

Complete the gaps in the sentences below to describe confinement:

There are two types of hadron, ________ and ________. Quarks cannot be ________ but must be in pairs or triplets. Quarks are kept in place by ________. If an attempt is made to separate quarks, more ________ are produced using the energy required to separate them.

(5 marks)

Medium Questions

1 (a) Rutherford used the scattering of α particles to provide evidence for the structure of the atom. The apparatus includes a narrow beam of α particles fired at a very thin sheet of gold foil inside a vacuum chamber.

Explain why it is essential to use:(i)a vacuum in the chamber

[1]

(ii) a very thin sheet of gold foil

[1]

(iii) a narrow beam of alpha particles

[1]

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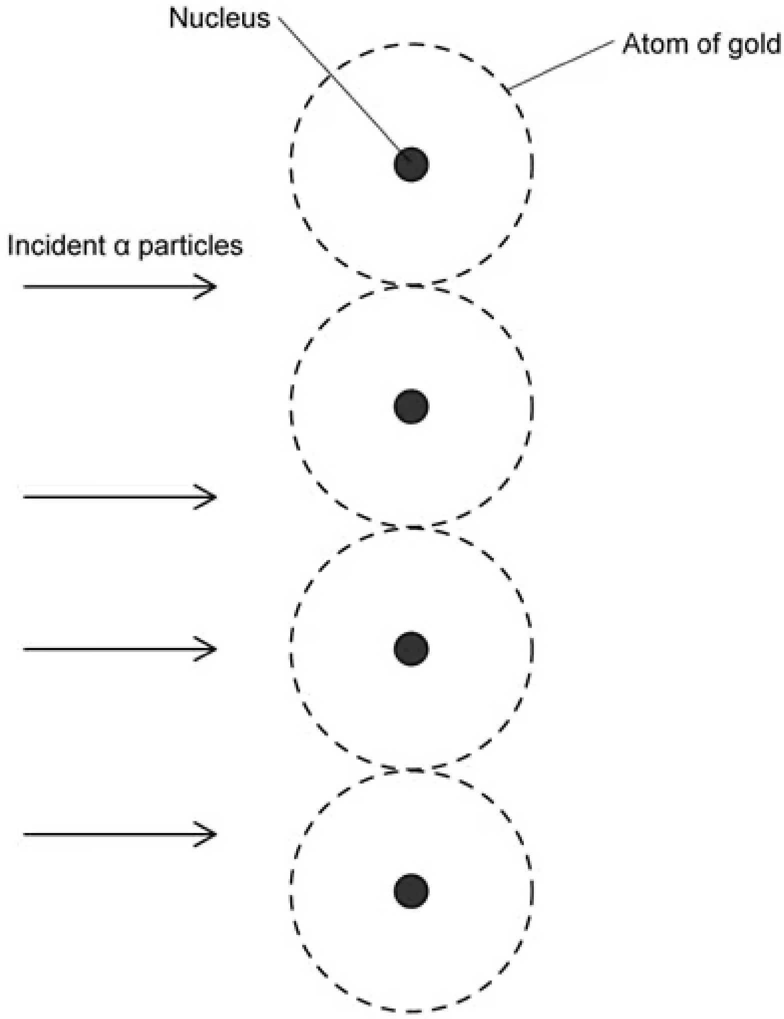
(3 marks)

(b) The diagram shows α particles incident on a layer of atoms in a gold foil.

On the diagram, draw and complete the paths followed by **each** of the α particles shown.



(3 marks)

(c) Outline the results of the scattering experiment by explaining:

(i) the main observations of the scattering experiment

[2]

(ii) the significance of each observation

[3]

(5 marks)

(d) The Thomson model of the atom preceded Rutherford's model. In the Thomson model, the atom was imagined as a sphere of positive charge of diameter 10^{-10} m containing electrons moving within the sphere.

Thomson's model could explain some of the results of the Rutherford experiment, but not all.

Explain

(i) why, at small deflections, Rutherford's experiment can be explained by Thomson's model but not at large deflections

[3]

(ii) why Rutherford's model of the atom can account for the results at both small and large deflections

[3]

(6 marks)

2 (a) Electron capture is one of the ways a nucleus attains stability.

In this process, a proton in the nucleus 'captures' an inner-shell electron. While the mass number is unchanged, the atomic number decreases by 1, and a highly energetic particle is released.

Deduce the type of interaction responsible for this process and explain your reasoning.

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(3 marks)

(b) By writing an appropriate equation for this process and applying the laws of particle physics, identify the highly energetic particle emitted in this process.

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(4 marks)

(c) At the quark level, only some are directly involved in this process. Those which are not are sometimes called 'spectator quarks'.

(i) Use your equation to sketch a suitable Feynman diagram for this process.

[3]

(ii) Sketch another Feynman diagram in terms of the quarks directly involved in electron capture. Do not include spectator quarks.

[2]

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(5 marks)

(d) A similar process known as muon capture is being investigated for use in the disposal of highly radioactive waste. A highly energetic muon beam causes muons to be captured by protons in the nuclei of the radioactive isotopes in order to convert them into more stable isotopes.

Write the equation and sketch a Feynman diagram for this process.

(2 marks)

3 (a) Compare and contrast the properties of baryons and mesons.

(4 marks)

(b) Σ^0 is a baryon with a quark structure of uds.

A proposed particle interaction involving the Σ^0 baryon is:

$$p + e^+ \rightarrow e^- + \Sigma^0 + K^+$$

Use the principles of conservation of charge, baryon number, lepton number and strangeness to determine whether this decay is possible.

(4 marks)

(c) Σ^0 is part of a family of baryons called Sigma baryons. They are all strange particles.

Determine the quark combination of the Σ^+ baryon. Clearly show your working

(3 marks)

(d) Determine the charge, baryon number, lepton number and strangeness of a particle with the quark combination dds.

Clearly explain your reasoning for each.

(4 marks)

4 (a) The virtual photon mediates the electromagnetic force.

It is called a 'virtual' photon because it is not detectable in a laboratory.

Sketch a Feynman diagram to show electrostatic repulsion between two electrons.

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(2 marks)

(b) Explain why virtual photons cannot be detected in a laboratory but are nonetheless required by particle physics.

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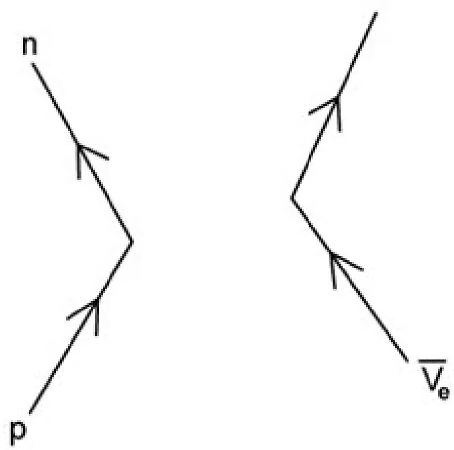
(3 marks)

(c) The unfinished Feynman diagram shows the interaction between a proton and an anti-neutrino.



Complete the Feynman diagram.

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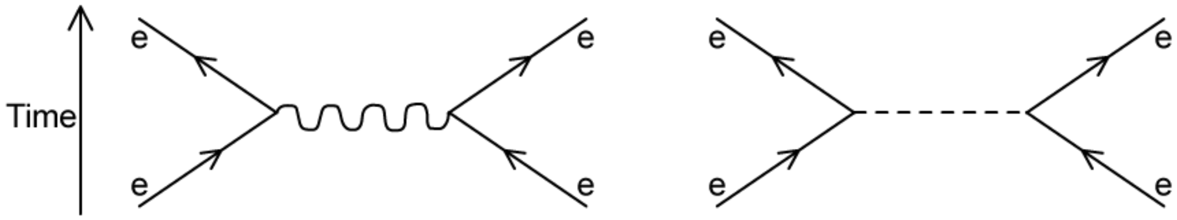
(3 marks)

(d) The neutron-neutrino interaction can be expressed in a similar way to the Feynman diagram in part (c).

Describe the changes to the Feynman diagram in part (c) that would show the neutron-neutrino interaction.

(3 marks)

5 (a) The Feynmann diagrams show two electroweak interactions between electrons. One of the exchange particles is a photon.



(i) Identify the other exchange particle which isn't a photon

[1]

(ii) Outline one difference between the two exchange particles

[1]

(2 marks)

(b) Outline how interactions in particle physics are understood in terms of exchange particles.

(2 marks)

(c) Describe the significance of the Higgs Boson in the standard model of quarks and leptons.

(2 marks)

(d) The discovery of the Higgs Boson marked a huge accomplishment for particle physicists.

It was first hypothesised by Peter Higgs and his team in 1964 and then discovered by a large collaborative effort at the CERN particle physics laboratory much later in 2012.

Explain what is meant by the term 'hypothesised' and suggest why it took over forty years to discover the Higgs Boson.

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(3 marks)

Hard Questions

1 (a) Particle X has a strangeness of –1 and decays to produce a proton and a pion.

$$X \rightarrow p + \pi^-$$

Deduce the quark structure of particle X.

(3 marks)

(b) A strange quark decays in the following way

$$s \rightarrow u + Y + d$$

Deduce particle Y.

(3 marks)

(c) Hence, draw a Feynman diagram at the quark level for the decay of particle X.

(3 marks)

2 (a) Explain why the discovery of the Higgs Boson was of crucial significance.

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(3 marks)

(b) Draw a Feynman diagram for the interaction

$$e^- + e^+ \rightarrow d + \overline{d}$$

Assume that the time axis is from left to right.

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(3 marks)

(c) Explain why multiple hadrons have been produced in this reaction.

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(3 marks)

3 (a) A young student of physics reads up about particles and anti-particles.

In their physics lesson, they excitedly tell their teacher how they learned that a proton has an anti-particle called an anti-proton, and the neutron has an anti-particle called an anti-neutron.

They go on to say that, since the neutron is neutrally charged, it is its own anti-particle.

Identify the student's misconception and explain why they are incorrect.

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(3 marks)

(b) Suggest another particle which is an example of being its own anti-particle and explain your reasoning.

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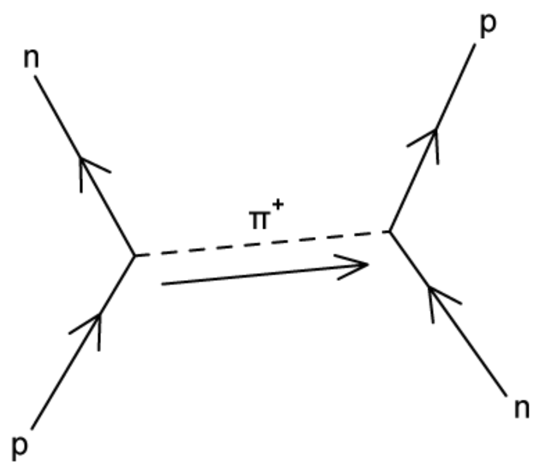
(2 marks)

(c) Interactions between protons and neutrons can temporarily violate conservation laws.



One such interaction is shown.

(i) Identify the type of interaction shown.

[1]

(ii) By referencing the properties of the exchange particle, explain how it temporarily violates conservation laws.

[2]

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(3 marks)

4 (a) The baryon decuplet is a vision tool used by particle physicists to classify groups of particles called baryons.

Discuss the properties of baryons.

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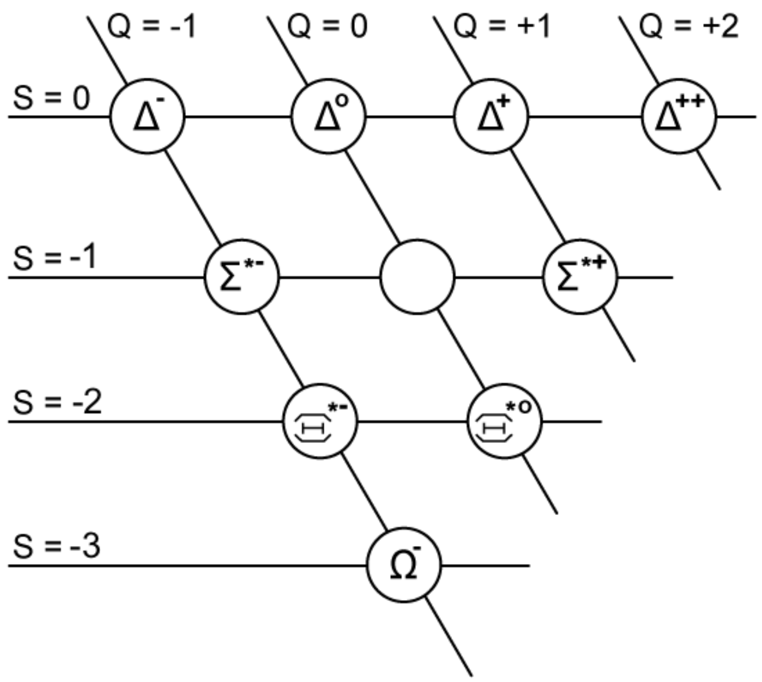
(4 marks)

(b) In the baryon decuplet, strangeness S is plotted on the horizontal axes and charge Q is plotted on the diagonal axe. Some information is missing.



Deduce the quark composition of the Ω^- baryon, using each axis to justify your answer.

....

....

(3 marks)

(c) Deduce the quark composition and an appropriate symbol for the missing baryon.

(4 marks)

5 (a) i) State two particles that are their own antiparticle.

[2]

ii) Explain why K^0 is not its own antiparticle.

[1]

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(3 marks)

(b) The K^0 meson decays into two pions and has a strangeness of 1. State the decay equation at the quark level for the K^0 meson.

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(3 marks)

(c) Heavier quarks can decay into lighter quarks by exchanging a virtual particle that meditates the type of interaction. This particle can then decay into a quark and its equivalent anti–quark.

Draw a Feynman diagram for the decay of the K^0 meson at the quark level. Clearly label the K^0 meson and the two pions.

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(4 marks)

(d) Muons decay via the same interaction as the K^0 meson into leptons. One such decay is

$$\mu^- \rightarrow e^- + \overline{\nu}_e + \_\_\_\_$$

(i) Complete the missing particle in the decay.

[1]

(ii) Draw the Feynman diagram for the decay of a negative muon, (μ^-). Clearly label the time axis.

[3]

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(4 marks)