7.3 The Structure of Matter

Question Paper

Course	DP IB Physics
Section	7. Atomic, Nuclear & Particle Physics
Topic	7.3 The Structure of Matter
Difficulty	Medium

Time allowed: 80

Score: /66

Percentage: /100

Question 1a

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.

(a)
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

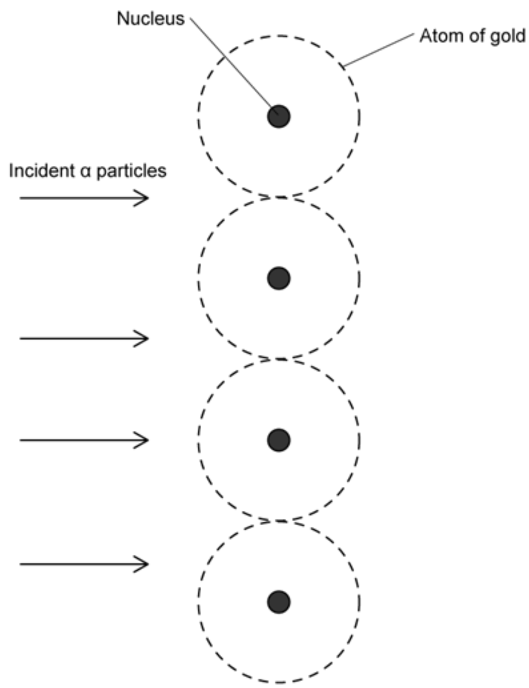
[1]

[3 marks]

Question 1b

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

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



[3 marks]

Question 1c

(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]

Question 1d

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.

(d)
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]

Question 2a

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.

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

[3 marks]

Question 2b

(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.

[4 marks]

Question 2c

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

(c)

(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]

[5 marks]

Question 2d

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.

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

[2 marks]

Question 3a

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

[4 marks]

Question 3b

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

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

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

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

[4 marks]

Question 3c

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

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

[3 marks]

Question 3d

(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]

Question 4a

The virtual photon mediates the electromagnetic force.

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

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

[2 marks]

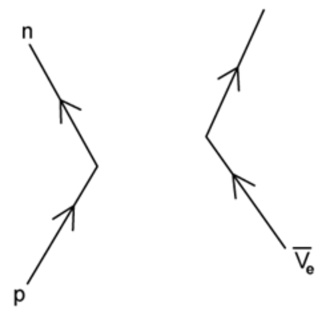
Question 4b

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

[3 marks]

Question 4c

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



(c) Complete the Feynman diagram.

[3 marks]

Question 4d

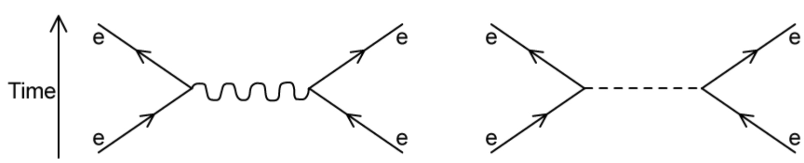
The neutron-neutrino interaction can be expressed in a similar way to the Feynman diagram in part (c).

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

[3 marks]

Question 5a

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



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

[1]

(ii)
Outline one difference between the two exchange particles

[1]

[2 marks]

Question 5b

b)

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

[2 marks]

Question 5c

(c)

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

[2 marks]

Question 5d

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.

(d)

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

[3 marks]