1)

(a) *Hadrons* are a group of particles composed of quarks. Hadrons can either be baryons or mesons.

(a) (i) What property defines a hadron?

.....

(1 mark)

(a) (ii) What is the quark structure of a baryon?

.....

(1 mark)

(a) (iii) What is the quark structure of a meson?

.....

(1 mark)

(b) State **one** similarity and **one** difference between a particle and its antiparticle.

similarity .....

.....

difference .....

.....

(2 marks)

(c) Complete the table below which lists properties of the antiproton.

	charge / C	**baryon number**	**quark structure**
antiproton			

(2 marks)

(d) The K^- is an example of a meson with strangeness –1. The K^- decays in the following way:

$$K^- \rightarrow \mu^- + \overline{\nu_u}$$

(d) (i) State, with a reason, what interaction is responsible for this decay.

.....

.....

.....

.....

(2 marks)

(d) (ii) State **two** properties, other than energy and momentum, that are conserved in this decay.

.....

.....

.....

.....

(2 marks)

2)

Sub-atomic particles can either be hadrons or leptons.

(a) (i) State **one difference** between these two groups of particles.

.....

(1 mark)

(a) (ii) Give an example of a non-strange hadron and an example of a lepton.

hadron .....

lepton .....

(2 marks)

(a) (iii) Hadrons can be further divided into two groups. Name these two groups **and** state a difference between them.

.....

.....

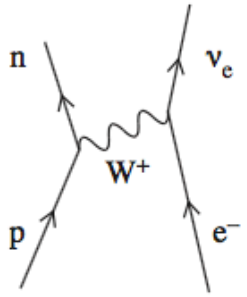
.....

.....

(3 marks)

(b) The Feynman Diagram in **Figure 1** represents an interaction known as electron capture.

Figure 1



(b) State a conservation law obeyed in this interaction. Show how the property mentioned in the law is conserved.

.....

.....

.....

.....

.....

(2 marks)

3)

Under certain circumstances, a photon moving through a material can interact with the nucleus of an atom of the material to produce an electron and a positron.

(i) What is the name of this process?

.....

(1 mark)

(ii) Give one reason why the photon could not produce a single electron instead of an electron and a positron.

.....

.....

.....

.....

(2 marks)

(iii) Make use of the Data and Formulae booklet to show that the minimum energy of the photon required for this process is 1.02 MeV.

(1 mark)

(iv) Photons whose wavelength exceeds a certain value will not cause this process. Calculate the maximum wavelength for the process to occur stating your answer to an appropriate number of significant figures.

answer = ... m

(4 marks)

(v) Explain what will happen to the positron produced by the interaction.

.....

.....

.....

.....

(2 marks)

4)

(a) The table gives information about some fundamental particles.

Complete the table by filling in the missing information.

particle	quark structure	charge	strangeness	baryon number
	uud		0	
Sigma $^{+}$	uus	+ 1		
	$u\bar{d}$		0	0

(7 marks)

(b) Each of the particles in the table has an antiparticle.

(b) (i) Give **one** example of a baryon particle **and** its corresponding antiparticle.

particle .....

antiparticle .....

(1 mark)

(b) (ii) State the quark structure of an antibaryon.

.....

(1 mark)

(b) (iii) Give **one** property of an antiparticle that is the same for its corresponding particle and **one** property that is different.

Same .....

.....

Different .....

.....

(2 marks)

5)

(a) Pair production can occur when a photon interacts with matter. Explain the process of pair production.

.....

.....

.....

.....

(2 marks)

(b) Explain why pair production cannot take place if the frequency of the photon is below a certain value.

.....

.....

.....

.....

.....

.....

(3 marks)

(c) Energy and momentum are conserved during pair production. State **two** other quantities that must also be conserved.

.....

.....

(2 marks)

6)

Under certain circumstances it is possible for a photon to be converted into an electron and a positron.

(a) State what this process is called.

.....

(1 mark)

(b) A photon must have a minimum energy in order to create an electron and a positron.

Calculate the minimum energy of the photon in joules. Give your answer to an appropriate number of significant figures.

minimum energy = ... J

(3 marks)

(c) A photon of slightly higher energy than that calculated in part (b) is converted into an electron and a positron.

State what happens to the excess energy.

.....

.....

(1 mark)

(d) Describe what is likely to happen to the positron shortly after its creation.

.....

.....

.....

.....

(2 marks)

7)

(a) (i) State how many quarks there are in a baryon.

.....

(1 mark)

(a) (ii) Hadrons fall into two groups, baryons being one of them.

State the name that is given to the other group of hadrons.

.....

(1 mark)

(a) (iii) Give **two** properties of hadrons that distinguish them from leptons.

property 1 .....

.....

property 2 .....

.....

(2 marks)

(b) The forces between particles can be explained in terms of exchange particles.

Complete the following table by identifying an exchange particle involved in the interaction.

interaction	**exchange particle**
electromagnetic	.....
weak	.....

(2 marks)

(c) The following equation shows electron capture.

$$p + e^- \rightarrow n + \nu_e$$

(c) (i) Draw a Feynman diagram that represents this interaction.

(3 marks)

(c) (ii) Explain why, when electron capture occurs, a neutrino rather than an antineutrino is produced.

.....

.....

.....

(1 mark)

8)

(a) The Σ^+ particle is a baryon with strangeness -1.

(a) (i) How many quarks does the Σ^+ particle contain?

.....

.....

answer.....

(1 mark)

(a) (ii) How many of the quarks are strange?

.....

.....

answer.....

(1 mark)

(b) The Σ^+ decays in the following reaction

$$\Sigma^+ \rightarrow \pi^+ + n$$

(b) (i) State **two** quantities that are conserved in this reaction.

.....

.....

(2 marks)

(b) (ii) State a quantity that is not conserved in this reaction.

.....

(1 mark)

(b) (iii) What interaction is responsible for this reaction?

.....

(1 mark)

(b) (iv) Into what particle will the neutron formed in this reaction eventually decay?

.....

(1 mark)

9)

(a) (i) Name two baryons.

.....

(2 marks)

(a) (ii) State the quark structure of the pion π^+.

.....

(1 mark)

(b) (i) The K^+ kaon is a strange particle. Give **one** characteristic of a strange particle that makes it different from a particle that is not strange.

.....

.....

(1 mark)

(b) (ii) One of the following equations represent a possible decay of the K^+ kaon.

$$K^+ \rightarrow \pi^+ + \pi^0$$

$$K^+ \rightarrow \mu^+ + \overline{\nu}_\mu$$

State, with a reason, which one of these decays is not possible.

.....

.....

(2 marks)

(c) Another strange particle, X, decays in the following way:

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

(c) (i) State what interaction is involved in this decay.

.....

(1 mark)

(c) (ii) Show that X must be a neutral particle.

.....

.....

(1 mark)

(c) (iii) Deduce whether X is a meson, baryon or lepton, explaining how you arrive at your answer.

.....

.....

.....

.....

(2 marks)

(c) (iv) Which particle in this interaction is the most stable?

.....

(1 mark)

10)

(a) The K^- meson has strangeness –1.

(a) (i) State the quark composition of a meson.

.....

(1 mark)

(a) (ii) State the baryon number of the K^- meson.

.....

(1 mark)

(a) (iii) What is the quark composition of the K^- meson?

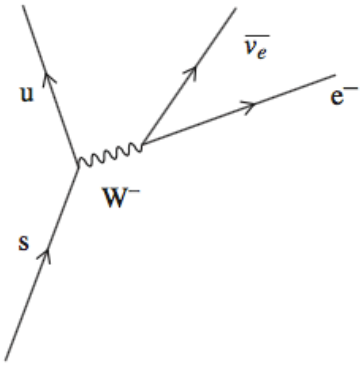
.....

.....

(1 mark)

(b) **Figure 1** shows a Feynman diagram for a possible decay of the strange quark.

Figure 1



(b) (i) Which interaction is responsible for this decay?

.....

(1 mark)

(b) (ii) Energy and momentum are conserved when the W^- particle is produced. State **two** other quantities that are also conserved and **one** that is not.

conserved .....

conserved .....

not conserved .....

(3 marks)

(b) (iii) Complete this equation for the decay of a K^- meson.

$K^- \rightarrow$ ..... + ... + ...

(2 marks)

11)

(a) Protons can interact with electrons by gravity and by two other fundamental interactions. In the following table identify these interactions and name the exchange particle involved.

interaction	exchange particle

(2 marks)

(b) State the quark composition of a proton.

.....

(1 mark)

(c) A change in quark identity is involved in *electron capture*.

(c) (i) Explain what is meant by electron capture.

.....

.....

.....

.....

.....

.....

(3 marks)

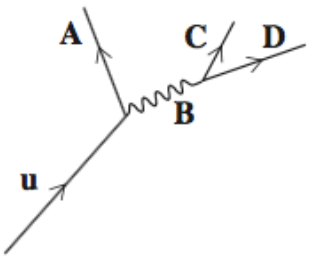
(c) (ii) In the space below draw a Feynman diagram representing electron capture.

(3 marks)

12)

A positron is emitted from a nucleus when a proton changes to a neutron in the nucleus. The Feynman diagram for the quark interaction is shown in **Figure 1**.

Figure 1



(a) Identify the particles labelled **A**, **B**, **C** and **D** in the diagram.

A .....

B .....

C .....

D .....

(3 marks)

(b) (i) State the interaction responsible for this process.

.....

(1 mark)

(b) (ii) State which letter in **Figure 1** represents an exchange particle.

.....

(1 mark)

(b) (iii) State **one** difference between this exchange particle and a photon.

.....

(1 mark)

(c) Energy and momentum have to be conserved in this process. State **two** other quantities that need to be conserved and show that they are conserved in the process.

quantity 1 .....

.....

.....

quantity 2 .....

.....

.....

(4 marks)

13)

(a) The positive kaon, K^+, has a strangeness of $+1$.

(a) (i) What is the quark structure of the K^+?

[1 mark]

.....

(a) (ii) What is the baryon number of the K^+?

[1 mark]

.....

(a) (iii) What is the antiparticle of the K^+?

[1 mark]

.....

(b) The K^+ may decay into a neutrino and an antimuon in the following way.

$$K^+ \rightarrow \nu_\mu + \mu^+$$

(b) (i) Complete **Table 1** using ticks and crosses as indicated in the first row.

[3 marks]

Table 1

Classification	K^+	ν_μ	μ^+
lepton	×	✓	✓
charged particle			
hadron			
meson			

(b) (ii) In this decay, charge, energy and momentum are conserved.
Give another quantity that is conserved in this decay and one that is not conserved.

[2 marks]

Conserved .....

Not conserved .....

(c) Another possible decay of the K^+ is shown in the following equation,

$$K^+ \rightarrow \pi^+ + X$$

(c) (i) Identify X by ticking **one** box from the following list.

[1 mark]

electron	
muon	
negative pion	
neutral pion	
neutrino	
neutron	
positron	

(c) (ii) Give **one** reason for your choice in part (c)(i).

[1 mark]

.....

.....

.....

.....

14)

The equation shows an interaction between a proton and a negative kaon that results in the formation of particle, X.

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

(a) (i) State and explain whether X is a charged particle.

[2 marks]

.....

.....

(a) (ii) State and explain whether X is a lepton, baryon or meson.

[2 marks]

.....

.....

(a) (iii) State the quark structure of the K^-, K^+ and the K^0.

[3 marks]

K^-.....

K^+ .....

K^0.....

(a) (iv) Strangeness is conserved in the interaction.

Determine, explaining your answer, the quark structure of X.

[3 marks]

.....

.....

.....

.....

15)

(a) Hadrons and leptons are two groups of particles.
Write an account of how particles are placed into one or other of these two groups.
Your account should include the following:

- how the type of interaction is used to classify the particles
- examples of each type of particle
- details of any similarities between the two groups
- details of how **one** group may be further sub-divided.

The quality of your written communication will be assessed in your answer.

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(6 marks)

(b) Every type of particle has a corresponding antiparticle.

(b) (i) Give **one** example of a particle and its corresponding antiparticle.

particle .....

antiparticle .....

(1 mark)

(b) (ii) State **one** difference between this particle and its antiparticle.

.....

.....

(1 mark)

16)

(a) Baryons, mesons and leptons are affected by particle interactions.

Write an account of these interactions. Your account should:

- include the names of the interactions
- identify the groups of particles that are affected by the interaction
- identify the exchange particles involved in the interaction
- give examples of **two** of the interactions you mention.

The quality of your written communication will be assessed in your answer.

[6 marks]

.....

.....

.....

.....

.....

.....

(b) Draw a labelled Feynman diagram that represents a particle interaction.

[3 marks]