Particle Physics - 2

1 The group of particles known as hadrons are composed of quarks. There are two sub-groups of hadrons: mesons and baryons.

a) What is the name of the property that defines a hadron? (1)

b) State the quark structure of a meson. (1)

c) State the quark structure of a baryon. (1)

d) The antiproton is the antiparticle of the proton. State **one** way that the proton and the antiproton are similar, and **one** way that they are different. (2)

e) What are the following values of an antiproton:

i) its charge (1)

ii) its baryon number (1)

iii) its quark structure? (1)

2 In the Standard Model of Matter, particles can be leptons, hadrons or exchange particles. Here is a list of particles:

electron proton neutron muon pion

a) From the list state the name of **one** lepton and **one** hadron. (2)

b) State one difference between leptons and hadrons. (1)

c) State the difference in structure between baryons and mesons. (1)

d) From the list state the name of **one** baryon and **one** meson. (2)

3 The table below shows some basic information about three hadrons.

Table 2.9

Sub-atomic particle	Quark structure	Baryon OR Meson	Relative charge	Baryon number	Strangeness
	$u\bar{d}$	meson		0	
	udd				0
Σ^+, sigma$^+$			+1		-1

a) Copy and complete the table. (3)

b) All of the sub-atomic particles shown in the table have a corresponding antiparticle. State one example of a baryon and its antibaryon **not** shown in the table and state their quark structures. (4)

c) The electron and the positron are an example of a lepton particle–antiparticle pair. State **one** property of positron that is the same as an electron, and **one** property that is different. (2)

4 Figure 2.21 shows two particles interacting. An offset line has been drawn to represent the exchange particle.

a) State the name of the interaction shown and give the name of the exchange particle drawn on the diagram. (2)

b) In this interaction, momentum and energy are conserved. Give the name of another quantity that is conserved. (1)

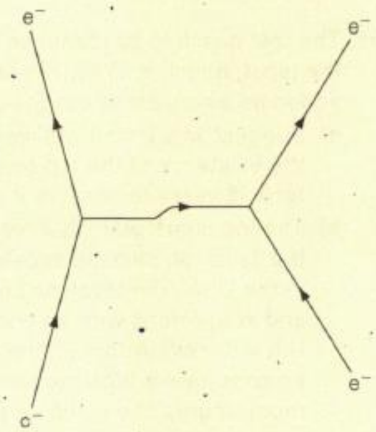

Figure 2.21 Feynman diagram showing two particles interacting.

Figure 2.22 shows another type of interaction. Another offset line has been drawn to represent the exchange particle.

c) Name the particles labelled A, B and C. (3)

d) State the name of this type of particle interaction. (1)

e) Momentum and energy are also conserved in this particle interaction. Name two other quantities that must be conserved for this interaction to occur and show how they are conserved. (4)

f) The Standard Model predicted the existence of the exchange particle involved in this interaction before it had been observed experimentally. Explain why it is important to test the prediction of a scientific model experimentally. (3)

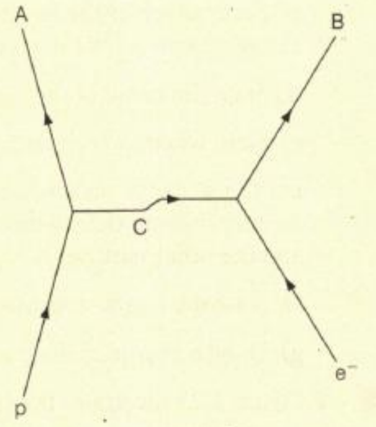

Figure 2.22 Another type of interaction.

5 The K^- kaon is a meson with strangeness −1. It can decay into a muon, μ^-, and a muon-antineutrino, $\bar{\nu}_\mu$, as shown in the equation below:

$$K^- \rightarrow \mu^- + \bar{\nu}_\mu$$

a) State and explain which particle interaction is responsible for this decay. (1)

b) Energy and momentum are conserved in this decay, as are **two** other quantities. State the name of these two quantities. (2)

c) State one property of a strange particle, such as the K^- kaon, that makes it different to a non-strange particle, such as a π^- pion. (1)

The K^+ kaon is also strange. It **could** decay via either of the following decay equations, however one of these decay equations is not possible:

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

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

d) State and explain which of these decay equations is not possible. (2)

The K^- kaon can also decay in the following way, producing a muon, a muon-neutrino and a third particle, X:

$$K^- \rightarrow X + \mu^- + \bar{\nu}_\mu$$

e) State which interaction is responsible for this decay. (1)

f) Particle X is identified as a pion. Explain why X must be a meson. (2)

g) State the charge on this particle. (1)

6 During β^- decay a neutron decays into a proton and an electron antineutrino.

a) Write an equation describing this decay. (1)

b) Using conservation laws, explain why an anti-electron-neutrino is produced rather than an electron-neutrino. (2)

c) Draw a Feynman diagram for this decay. (3)

β^+ decay involves the emission of positrons. $^{23}_{12}Mg$ is a positron emitter, decaying into a $^{23}_{11}Na$ nucleus, a positron and another particle, X.

d) State the name of the other particle, X. *(1)*

e) State whether each decay product is a baryon or a lepton. *(3)*

During β^+ decay, an up quark decays to a down quark and an exchange particle, which subsequently decays into the positron and the other particle, X.

f) State the quark structure of a neutron and a proton. *(2)*

g) Draw a Feynman diagram for this decay. *(3)*

7 Figure 2.23 illustrates the particle interaction known as electron capture.

a) During electron capture, charge, baryon number and lepton number are all conserved. Show how these three quantities are conserved. *(3)*

b) The isotope potassium-40, $^{40}_{19}K$, is an extremely unusual nuclide because it can decay by all three types of beta decay. It can decay via electron capture **or** positron emission **or** β^- emission. Write an equation summarising **each** decay. *(6)*

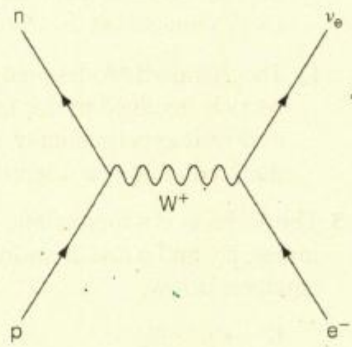

Figure 2.23 Feynman diagram showing electron capture.

8 The proton is an example of a hadron. The positron is an example of lepton.

a) State one similarity and one difference between protons and positrons. *(2)*

b) There are four forces that act between particles. Exchange particles can be used to explain these forces. Match the correct exchange particle to its force. *(3)*

Table 2.10

Force	Gravity	Strong	Weak	Electromagnetic
Exchange particle	Graviton	Photon	Gluon	$W^{\pm}$, Z

c) Describe how the force between a proton and a neutron varies with the separation distance between the two particles and quote suitable values for separation distance. *(3)*

d) Positrons and protons can interact via three of the above forces. Identify the force that cannot exist between the proton and the positron, and explain why they cannot interact in this way. *(2)*

9 Pions and muons are produced when high-energy cosmic rays interact with gases high up in the Earth's atmosphere. Write an account of how the Standard Model is used to classify pions and muons into particle groups. Your account should include the following:

- the names of the groups of particles that pions and muons belong to
- other examples of particles in these groups
- details of any properties that the particles have in common
- description of the ways that each particle can interact with other particles. *(6)*