'up', 'down' and 'strange' quarks, and are denoted by the symbols u, d and s, respectively. The properties of these three quarks are shown in Table 1.

Table 1 *Quark properties*

	quarks			antiquarks		
	up u	down d	strange s	up $\bar{u}$	down $\bar{d}$	strange $\bar{s}$
charge Q	$+\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{2}{3}$	$+\frac{1}{3}$	$+\frac{1}{3}$
strangeness S	0	0	–1	0	0	+1

Quark combinations

The rules for combining quarks to form baryons and mesons are astonishingly simple:

Mesons are hadrons, each consisting of a quark and an antiquark. Figure 2 shows all nine different quark–antiquark combinations and the meson in each case. Notice that:

- A π^0 meson can be any quark-corresponding antiquark combination.
- Each pair of charged mesons is a particle–antiparticle pair.
- There are two uncharged K mesons, the K^0 meson and the $\bar{K}^0$ meson.
- The antiparticle of any meson is a quark–antiquark pair and therefore another meson.

Baryons and **antibaryons** are hadrons that consist of three quarks for a baryon or three antiquarks for an antibaryon.

- A proton is the uud combination.
- A neutron is the udd combination.
- An antiproton is the $\bar{u}\bar{u}\bar{d}$ combination.

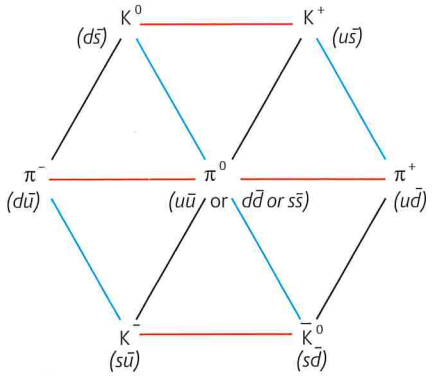
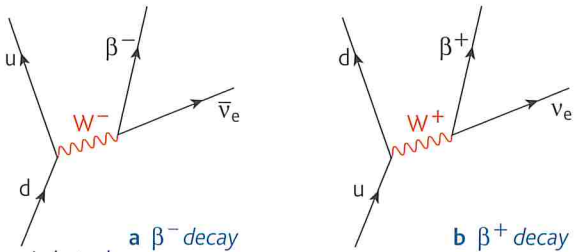


Figure 2 *Quark combinations for the mesons*

Quarks and beta decay

In β^- decay, a neutron in a neutron-rich nucleus changes into a proton, releasing an electron and an electron antineutrino. In quark terms, a down quark changes to an up quark. The Feynman diagram for this change is shown in Figure 3a).

In β^+ decay, a proton in a proton-rich nucleus changes into a neutron, releasing a positron and an electron neutrino. In quark terms, an up quark changes to a down quark. The Feynman diagram for this change is shown in Figure 3b).



a β^- *decay* **b** β^+ *decay*

Figure 3 *Quark changes in beta decay*

Study tip

You do not need to remember the quark composition of any other baryons but you may be asked to work out the charge or strangeness of any baryon or antibaryon from its quark composition.

The proton is the only stable baryon. A free neutron decays into a proton, releasing an electron and an electron antineutrino, as in β^- decay.

Summary questions

1 **a** How does the quark composition of a meson compare with the quark composition of a baryon?

b State the quark composition of **i** a proton, **ii** a neutron.

2 Determine the quark composition of each of the following hadrons, given its strangeness.

a a π^0 meson ($S = 0$)

b an antiproton ($S = 0$)

c a K^- meson ($S = -1$)

d a Σ^0 baryon ($S = -1$)

3 In β^+ decay, a positron and an electron neutrino are emitted when a proton in the nucleus changes into a neutron.

a In terms of quarks, draw a Feynman diagram to represent this change.

b Describe the changes that are represented in the diagram.

4 **a** A Σ^- particle has a strangeness of –1. Show that it is composed of a strange quark and two down quarks.

b A K^+ meson is composed of a strange antiquark and an up quark. A Σ^- baryon is composed of a strange quark and two down quarks. They can be created in the reaction shown below:

$\pi^- + p \longrightarrow K^+ + \Sigma^-$

Describe this reaction in terms of quark and antiquarks.