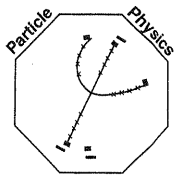

Quarks

The questions on this sheet are about quarks, the relationship between their properties and those of the hadrons that they make up, and the ways they can be affected by the strong and weak interactions.

To answer the questions, you will need to use the tables of particle properties on this sheet and on Student Sheet 4.2. Table 1 has spaces for further information about quarks that you will be able to fill in later. By answering the questions, you will complete Table 2, which can be combined with the table from Sheet 4.2. and kept for reference. You will not be expected to memorize information about individual particles from any of these tables.

Answers and notes are given on a separate page: together with the questions, these summarize some key points about quarks and hadrons.

Section A The quark content of hadrons

Q1 (a) Using Table 1, find the overall charge Q, baryon number B and strangeness S of the hadrons that have the following constituents.

(i) uss

(ii) $u\bar{d}$

(b) Use your answers to part (a) to fill in two of the spaces in the 'quark content' column of Table 2.

Q2 Use information in Tables 1 and 2 to help you to fill in the remaining spaces in the 'quark content' column of Table 2.

Section B Quarks and conservation laws in strong reactions

Questions 3 and 4 illustrate a law that applies to *all* strong reactions.

Q3 All these strong reactions have been observed to occur.

(i) $\pi^- + p \longrightarrow n + \pi^+ + \pi^- + \pi^0$

(ii) $K^- + p \longrightarrow \Sigma^- + \pi^+$

(iii) $\pi^+ + p \longrightarrow \Sigma^+ + K^+$

Each conserves charge and baryon number.

(a) Using Table 1, list the quark content of the particles involved in each of reactions (i) to (iii).

(b) If you count each quark as +1, and each antiquark as −1, what do you notice about the total number of quarks on either side of each reaction?

(c) Now look only at the numbers of u quarks and $\bar{u}$ antiquarks in each reaction. What do you notice about their numbers in each reaction? Do the d quarks and s quarks seem to obey the same rule as the u quarks?

Q4 The following strong reactions have *never* been observed:

(i) $\pi^- + p \longrightarrow n + p + \pi^-$

(ii) $K^- + \pi^+ \longrightarrow \Sigma^- + \pi^+$

(iii) $\pi^+ + p \longrightarrow \Sigma^+ + K^+ + n$

They would all conserve charge, but would not conserve baryon number.

(a) Using Table 1, list the quark content of the particles in each of reactions (i) to (iii).

(b) Look at the quarks that would be involved in each of reactions (i) to (iii), and refer to your answers to Q3. Write down a general conservation law that seems to describe the behaviour of quarks in a strong reaction.

Section C Quarks and conservation laws in weak reactions

Question 5 illustrates a law that applies to all weak reactions, and reveals a unique feature of the weak interaction.

Q5 Both these weak reactions have been observed to occur:

(i) $n \longrightarrow p + e^- + \bar{\nu}_e$

u	u		
	u		
d	d		
d			

(ii) $K^+ \longrightarrow \pi^0 + \pi^+$

u	$u\bar{u}$	or	$d\bar{d}$	u
				$\bar{d}$
$\bar{s}$				

[Note that π^0 can be made up of either $u\bar{u}$ or $d\bar{d}$.]

Examine the quarks involved in each reaction. What general conservation law seems to describe the behaviour of quarks in weak reactions?

Q6 Use the laws illustrated in Q3 to Q5 to write down rules about how (a) the total baryon number *B*, and (b) the total strangeness *S*, are affected by strong and weak reactions.

Section D Using conservation laws

Q7 The Ω^- decays in the following ways:

$\Omega^- \longrightarrow \Xi^0 + \pi^-$

$\Omega^- \longrightarrow \Xi^- + \pi^0$

$\Omega^- \longrightarrow \Lambda + K^-$

Which fundamental interaction is responsible for the Ω^- decays? Explain your answer.

Q8 Which *one* of the following strong reactions could *not* occur in an experiment in which a beam of high energy protons passes through a hydrogen bubble chamber?

A $p + p \longrightarrow p + p + \pi^+ + \pi^-$

B $p + p \longrightarrow p + \Xi^- + K^+ + K^+$

C $p + p \longrightarrow p + \Delta^+ + K^+ + \pi^-$

D $p + p \longrightarrow p + p + K^+ + K^-$

E $p + p \longrightarrow p + \Delta^+ + \pi^+ + \pi^-$

Questions 9 and 10 concern the following strong interaction between two colliding particles, a Σ^- and a proton:

$$\Sigma^- + p \longrightarrow X + K^- + n$$

This interaction has been observed at Fermilab in the USA.

X is a particle that was not identified by the experimenters who studied the interaction.

Q9 Which *one* of the following statements about X is *correct*?

A X is a meson

B X is a baryon

C X is an antibaryon

D X is a lepton

E X is uncharged

Q10 What is the strangeness of X?

A −2

B −1

C 0

D +1

E +2

TABLE 1 Properties of quarks

Type of quark	Charge Q	Baryon number B	Strangeness S	Approximate rest mass/ (GeV/c^2)
u	+2/3	+1/3	0	0.005
d	−1/3	+1/3	0	0.01
s	−1/3	+1/3	−1	0.2

Each quark has a corresponding antiquark. For each variety of quark, its values of Q, B and S are opposite to that of the corresponding antiquark, whereas its rest mass is the same as that of its antiquark.

TABLE 2 Further properties of hadrons

Symbol	S	Quark content
Δ^-	0	ddd
Δ^+	0	uud
Δ^{++}	0	
Δ^0	0	udd
K^-	−1	$\bar{u}s$
K^+	1	$u\bar{s}$
K^0	1	
$\bar{K}^0$	−1	$\bar{d}s$
Λ	−1	uds
n	0	udd
Ω^-	−3	sss
ϕ	0	$s\bar{s}$
π^-	0	$\bar{u}d$
π^+	0	
π^0	0	$u\bar{u}$ *or* $d\bar{d}$
p	0	uud
ρ^0	0	$u\bar{u}$ *or* $d\bar{d}$
Σ^-	−1	
Σ^+	−1	uus
Σ^0	−1	uds
Ξ^-	−2	dss
Ξ^0	−2	