On hadron structure ANSWERS

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Warm-up problems

1. What is a *hadron*? Explain the difference between *mesons* and *baryons*, and give one example of each.
   A hadron is a particle which is made up of quarks. Mesons have a quark and an antiquark, e.g. the π^0, and baryons are made up of three quarks, e.g. the proton.

2. What can you tell about a hadron which has a *strangeness* of -1? How might it lose this strangeness, and what can you say about the interaction that is involved in this process?
   A particle which has strangeness -1 must contain a strange quark (strangeness is a bit unusual in this way, $+1$ would indicate the presence of an antistrange quark). It might lose this strangeness by a decay process, and this must involve the weak interaction, as this is the only one of the four fundamental interactions which can change the strangeness of a particle.

Regular problems

3. There are ten possible combinations of the up, down and strange (u, d, and s) quarks which will make baryons. List these ten combinations.
   u u u, u u d, u u s, u d s, u s s, d d d, d d u, d d s, d s s, s s s.

4. The table below shows eleven baryons.

   (a) Using your list from 3, identify the quark structure in each of the baryons.

particle	Charge (Q) / e	Baryon number	Strangeness	Quark Structure
p	$+1$	1	0	u u d
n	0	1	0	d d u
Λ	0	1	-1	u d s
Σ^+	$+1$	1	-1	u u s
Σ^0	0	1	-1	u d s
Σ^-	-1	1	-1	d d s
Δ^-	-1	1	0	d d d
Δ^{++}	$+2$	1	0	u u u
Ξ^0	0	1	-2	u s s
Ξ^-	-1	1	-2	d s s
Ω^-	-1	1	-3	s s s

(b) Which two baryons have the same quark structure?
Λ and Σ^0

(c) How may they be different to each other?
Difference in rest energy, due to the quarks being in differing energy states.

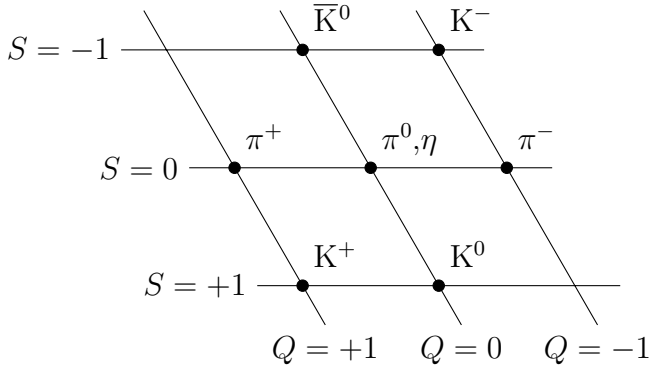
5. There are nine possible combinations of the up, down and strange (u, d, and s) quarks which will make mesons. List these nine combinations.
u $\overline{\text{u}}$, u $\overline{\text{d}}$, u $\overline{\text{s}}$, d $\overline{\text{u}}$, d $\overline{\text{d}}$, d $\overline{\text{s}}$, s $\overline{\text{u}}$, s $\overline{\text{d}}$, s $\overline{\text{s}}$.

6. The table below shows eight mesons. Using your list from 5, identify the quark structure in each of the mesons. Remember that some mesons can be made up of more than one combination.

particle	Charge (Q) / e	Baryon number	Strangeness	Quark structure
π^+	$+1$	0	0	u $\overline{\text{d}}$
π^-	-1	0	0	$\overline{\text{u}}$ d
π^0	0	0	0	u $\overline{\text{u}}$/ d $\overline{\text{d}}$
K^+	$+1$	0	1	u $\overline{\text{s}}$
K^-	-1	0	-1	$\overline{\text{u}}$ s
K^0	0	0	1	d $\overline{\text{s}}$
$\overline{\text{K}}^0$	0	0	-1	$\overline{\text{d}}$ s
η	0	0	0	u $\overline{\text{u}}$/ d $\overline{\text{d}}$/ s $\overline{\text{s}}$

Extension problems

7. The diagram below shows the *meson octet*.



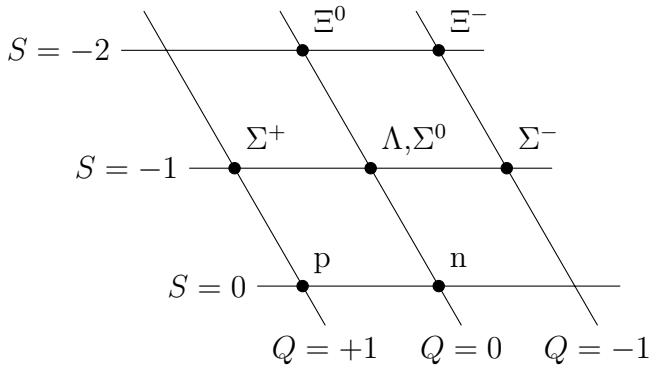
(a) Copy the diagram, and add on the eight particles at the intersections of the lines. (See above.)

(b) Which two mesons occupy the same position on the diagram?
The π^0 and the η.

(c) How may they be different to each other?
Difference in rest energy, due to the quarks being in differing energy states.

8. The diagram below is often called the *Baryon Octet*. Copy the diagram, and add on the eight particles at the intersections of the lines. (Don't put any Δs or the Ω^- on this

diagram.)



9. Why is there no particle with a strangeness of -2 and a charge of $+1$?
   For a baryon to have strangness of -2, it must contain two strange quarks, which would (together) have $Q = -\frac{2}{3}$. There exists no quark with the required properties ($Q = +\frac{5}{3}$, $B = +\frac{1}{3}$, $S = 0$) to make the particle described in the question.