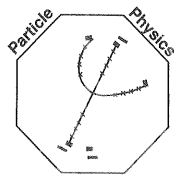

Hadrons and Conservation Laws

The following coded-answer questions are about hadrons; they have been divided into areas of similar content. To answer these questions you should refer to a table of particle properties (see Student Sheet 4.2). Answers and notes are given on a separate sheet.

Section A Hadrons, baryons and mesons

Questions 1 and 2 both refer to a neutral atom of $^{7}_{3}$Li. For each of Q1 and Q2, choose *one* of the responses below.

A None
B 3
C 4
D 7
E 10

Q1 How many *baryons* are there in an atom of $^{7}_{3}$Li?

Q2 How many *mesons* are there in an atom of $^{7}_{3}$Li?

Q3 Which *one* of the following statements about the properties of mesons is *false*?

A Mesons are members of the hadron family of particles
B There is no limit to the number of mesons that can be created in a reaction, provided there is enough energy
C Mesons always have lower mass than baryons
D Mesons can interact strongly
E Mesons must have baryon number zero

Section B Interactions and conservation laws

Q4 Select from the list below the *one* strong interaction that *cannot* occur:

A $\Delta^+ + p \longrightarrow K^+ + \Sigma^+$
B $\pi^+ + n \longrightarrow K^0 + \Sigma^+$
C $p + n \longrightarrow p + n + \pi^+ + \pi^-$
D $K^+ + n \longrightarrow \pi^0 + \Delta^+$
E $p + p \longrightarrow \Delta^+ + \Delta^+$

Q5 This question concerns the collision of a π^- meson and a proton, in which they interact strongly, producing only two particles ($\pi^- + p \longrightarrow$ two particles). Which *one* of the following options correctly specifies a combination of two particles that *could* in principle have been produced by this reaction?

A Two protons
B Two π^0 particles
C A proton and a ϕ
D A π^0 and a neutron
E A K^0 and a ϕ

Q6 This question concerns the following strong interaction between two colliding particles, a Σ^- and a proton. The interaction has been observed at Fermilab in the USA:

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

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

Q7 Consider the following strong interaction between two colliding protons, $p + p \longrightarrow p + n + X$, where X is an unidentified particle. Select from the following list the *one correct* statement about X:

A The rest mass of X cannot be greater than $1.3 \times 10^{-3}\,\text{GeV}/c^2$

B X will not leave a track in a drift chamber

C X is a lepton

D X is an electron.

E X has baryon number B = 0

Q8 Which *one* of the strong interactions in the list below *cannot* occur?

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

B $\pi^- + p \longrightarrow \pi^0 + n$

C $\pi^- + p \longrightarrow \pi^- + \pi^+ + n$

D $\pi^- + p \longrightarrow \Lambda + n$

E $\pi^- + p \longrightarrow \phi + n$

Q9 In Figure 1, a drawing made from a bubble-chamber photograph, two curved tracks emerge from a single point, which is not connected to any other visible track.

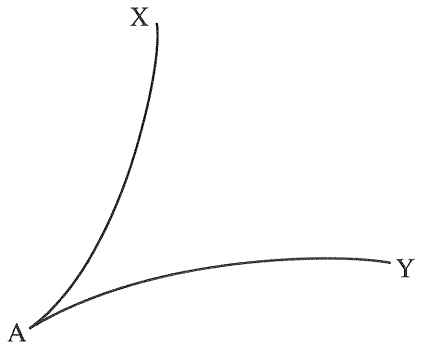

FIGURE 1

By carefully analysing the photograph, a physicist *correctly* deduces that the two curved tracks were left by particles X and Y formed during the decay of particle A, and that no other particles were involved in the decay (i.e. $A \longrightarrow X + Y$). Which *one*

of the following conclusions can be *correctly* drawn about the nature of the particles?

A Particle A must be a hadron

B Neither particle X nor particle Y can be a meson

C Particle A must be charged

D If particle A is a baryon then particle X and particle Y must both be baryons

E If particle X is positively charged, then particle Y must be negatively charged

Section C Deep inelastic scattering and the structure of protons

Q10 A neutrino beam, of sufficiently high energy, can be used to probe the structure of the proton. This is done by observing the scattering of the neutrinos by the proton's constituent particles. Which *one* of the following statements *correctly* describes the fundamental interaction that is principally responsible for this scattering?

A Strong interaction between neutrinos and protons

B Strong interaction between hadrons

C Electromagnetic interaction

D Weak interaction

E Gravitational interaction

Answers and notes for questions on Student Sheet 4.1

Q1 D.

Q2 A.

$^{7}_{3}$Li consists of three protons and four neutrons (in the nucleus) and three electrons (in orbit). Protons and neutrons are baryons; electrons are leptons. Baryons, mesons and leptons are all *different* types of particle (though baryons and mesons are both hadrons). Therefore, there are seven baryons in this atom. There are no mesons in this (or any other) atom.

Q3 C is false.

Most mesons do indeed have lower mass than most baryons, but this is not always the case—for example, the table on Student Sheet 4.2 shows that the ϕ (a meson, because it has $B = 0$) is more massive than many baryons (the neutron and the proton, for example).

Q4 Reaction A cannot occur, as it does not conserve baryon number.

Q5 Reaction D can occur.

Reactions A and C do not conserve charge; reactions A, B and E do not conserve baryon number.

Q6 B is correct.

Conservation of B and Q require that X has $B = 1$ and $Q = 1$.

Q7 E is correct.

The upper limit to the rest mass of X depends on the kinetic energy of the colliding particles (A incorrect). Conservation of charge requires that X has Q = 1, and so it could leave a track in a drift chamber (B incorrect). Lepton conservation means that both C and D are incorrect.

Q8 D cannot occur as it violates conservation of baryon number.

Q9 E is the only correct conclusion.

All that can be deduced about particle A is that it is unchanged as it has left no trail in the bubble chamber, therefore neither A nor C is correct. All that can be deduced about particles X and Y is that they are both changed (they both leave trails) and that their charges are opposite in sign (their trails curve in opposite senses, and they were produced in the decay of the uncharged particle A). Therefore B is incorrect. (Particle A *could* be a baryon, and X and Y *could* be mesons, but that cannot be deduced from the information given. There are many examples of unchanged particles, some of which are baryons, that decay to produce changed particles, some of which may be mesons. For example, n (baryon) $\longrightarrow$ p + e^- + $\bar{\nu}$; K^0 (meson) $\longrightarrow$ $\pi^+ + \pi^-$.) If A is a baryon (i.e. it has B = 1) then *either* X *or* Y (but not both) must also be a baryon, as baryon number is always conserved.

Q10 D is the correct description of the interaction.

Neutrinos can only interact via the weak interaction (unless they have mass, in which case they may also interact gravitationally, but any gravitational interaction between subatomic particles is negligible anyway).