Answers to examination-style questions

Answers	Marks	Examiner's tips
1 (a) (i) the strong interaction	**1**	Kaons are produced by the strong force, but they decay via the weak interaction.
(ii) the weak interaction	**1**	
(iii) the strong interaction	**1**	Strangeness is sometimes conserved in the weak interaction, but not always.
(b) (i) a *baryon* consists of 3 quarks	**1**	The question is about **hadrons**, so you have to consider both baryons and mesons.
an *antibaryon* consists of 3 antiquarks	**1**	
a *meson* consists of a quark + antiquark	**1**	
(ii) the charges of the 3 quarks are: u: $+\frac{2}{3}$ d: $-\frac{1}{3}$ s: $-\frac{1}{3}$	**1**	You have to look at how a quark-antiquark combination can form a charge of either +1 or −1 and thus produce a charged meson. Only these four arrangements are possible.
2 of these must make a quark-antiquark combination with a charge of 1		
a meson with a charge of +1 requires either $(u\bar{d})$ or $(u\bar{s})$	**1**	
a meson with a charge of −1 requires either $(\bar{u}d)$ or $(\bar{u}s)$	**1**	
2 (a) hadrons: p, $\bar{n}$, π^0	**1**	In all parts, you have to write down all the correct particles for the mark to be awarded.
(b) leptons: ν_e, e^+, μ^-	**1**	
(c) antiparticles: $\bar{n}$, e^+	**1**	
(d) charged particles: p, e^+, μ^-	**1**	
3 (a) (i) positron, neutron, neutrino and positive pion	**2**	The weak interaction acts on hadrons and on leptons when they decay. All 4 particles are required for 2 marks. You lose 1 mark for each error.
(ii) electron, proton, negative muon	**2**	Electromagnetic forces act only between charged particles. All 3 particles are required for 2 marks. You lose 1 mark for each error.
(b) (i) $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$	**1**	You simply have to exchange the particles on the right hand side for their corresponding antiparticles.
(ii) *difference*: muon has a much greater rest mass	**1**	The rest mass of the muon is over 200 times that of the electron.
similarity: both are negatively charged, or both are leptons	**1**	Either answer will score the mark.

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4 (a) u d d	**2**	An incorrect answer that showed 3 quarks (at least one u and one d) would gain 1 mark out of 2.
(b) baryon, hadron	**2**	1 mark for each
5 (a) (i) meson (not muon)	**1**	The particle consisting of $\bar{u}d$ is a negative pion, π^-. A muon is no longer regarded as a meson.
(ii) -1, or -1.6×10^{-19} C, or $-e$	**1**	$\bar{u}$ has a charge of $-\frac{2}{3}$ e, and d has a charge of $-\frac{1}{3}$ e, giving a total of $-e$.
(iii) 0	**1**	A meson is not a baryon.
(b) *baryon number*: $0 \rightarrow 0 + 0$, so satisfied	**1**	All the particles in this interaction are leptons.
lepton number: $-1 \rightarrow -1 + 1$, so **not** satisfied	**1**	Lepton numbers are given in the Data Booklet. Note that lepton conservation applies to each lepton family.
charge: $+1 \rightarrow +1 + 0$, so satisfied	**1**	The neutrino has no charge.
6 (a) three	**1**	Don't be put off by the unfamiliar sigma particle; the question is about general properties. A baryon always contains 3 quarks.
(b) weak interaction	**1**	Strange particles always decay by the weak interaction.
(c) proton	**1**	All the other baryons decay into protons. The proton is the only stable baryon.
7 (a) hadrons experience the strong nuclear force (or they consist of quarks)	**1**	The weak interaction acts on both leptons and hadrons when they decay, but leptons do not experience the strong force.
(b) *subgroups*: baryons and mesons	**1**	This part is testing factual knowledge alone. Particle physics contains a lot of facts.
a baryon consists of three quarks	**1**	
a meson is a quark-antiquark combination	**1**	
(c) *charge*: $0 + 1 \rightarrow 1 + 0$, so obeyed	**1**	Lepton numbers are given in the Data Booklet. You have to know that B = 1 for a hadron.
lepton number: $0 + (-1) \rightarrow 0 + (-1)$, so obeyed	**1**	
baryon number: $1 + 0 \rightarrow 1 + 0$, so obeyed	**1**	

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8 contains two quarks $\bar{u}d$ $\bar{u}$ has charge of $-\frac{2}{3}$ e, and d has charge of $-\frac{1}{3}$ e, so the charge of π^- is $-1e$	**1** **1** **1**	The evidence is that this is a meson, and so a quark-antiquark combination. The charge of quarks is given in the Data Booklet.
9 (a) symbol for an electron antineutrino, i.e. $(\bar{\nu}_e)$	**2**	The decay equation is similar to that for β^- decay. 1 mark would be awarded for **any** neutrino symbol.
(b) *charge*: $0 \rightarrow 1 + (-1) + 0$ *baryon number*: $1 \rightarrow 1 + 0 + 0$ *lepton number*: $0 \rightarrow 0 + 1 + (-1)$	**1** **1** **1**	All three conservation laws are satisfied, so the decay is possible.
(c) total kinetic energy required = $2 \times$ rest energy of a proton = $2 \times 938 = 1880$ MeV E_K required by one proton = $\frac{1}{2} \times 1880$ = 940 MeV	**1** **1**	The reaction creates a proton and an antiproton, so the colliding particles need enough kinetic energy to create the total rest energies of these new particles.
10 (a) (i) antibaryon	**2**	1 mark would be awarded for baryon or hadron.
(ii) the neutral pion, π^0	**1**	You need to learn facts like this.
(b) (i) $u\,\bar{s}$	**2**	Refer to the Data Booklet. A strangeness of +1 requires an strange antiquark, charge $+\frac{1}{3}$ e. The kaon's charge is +e, requiring the accompanying quark to be an up quark, charge $+\frac{2}{3}$ e. 1 mark would be awarded for any quark-antiquark combination.
(ii) weak interaction	**1**	Strange particles, such as the kaon, decay via the weak interaction.
(iii) $K^- \rightarrow \mu^- + \bar{\nu}_\mu$	**1**	Just change the two particles on the right hand side to their corresponding antiparticles.
(iv) leptons	**1**	These parts again test your knowledge of the facts.
(v) muon has a much greater mass	**1**	
11 (a) *baryon number*: $0 + 1 \rightarrow 1 + 0$, so obeyed	**1**	A kaon is a meson. Mesons are hadrons but they are not baryons.
lepton number: $0 + 0 \rightarrow 0 + 0$, so obeyed	**1**	No leptons are involved in this process.
charge: $0 + 1 \rightarrow 0 + 1$, so obeyed	**1**	K^0 is a neutral kaon, π^+ is a positive pion.

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(b) K^0: d $\bar{s}$	**1**	Refer to the Data Booklet. A strangeness of +1 requires an strange antiquark, charge $+\frac{1}{3}$ e. The neutral kaon's charge is zero, requiring the accompanying quark to be a down quark, charge $-\frac{1}{3}$ e.
π^+: u $\bar{d}$	**1**	A charge of +1e and a strangeness of 0 is required from a quark-antiquark combination. An up quark has charge $+\frac{2}{3}$ e and a down antiquark $+\frac{1}{3}$ e.
p: u u d	**1**	$\frac{2}{3}$ e + $\frac{2}{3}$ e + ($-\frac{1}{3}$ e) = +1e, as required for a proton.
correct number of quarks and antiquarks in each of the above three answers	**1**	This acts as a bonus mark if you get all three correct, but it can also be a consolation mark for those who get them almost correct.