2 Quarks and leptons
Answers to practice questions

Question	Answer	Marks	Guidance
1 (a) (i)	the strong interaction	1	Kaons are produced by the strong force, but they decay via the weak interaction.
1 (a) (ii)	the weak interaction	1	
1 (a) (iii)	the strong interaction	1	Strangeness is sometimes conserved in the weak interaction, but not always.
1 (b) (i)	a baryon consists of 3 quarks an antibaryon consists of 3 antiquarks a meson consists of a quark + antiquark	1 1 1	The question is about **hadrons**, so you have to consider both baryons and mesons.
1 (b) (ii)	the charges of the 3 quarks are: u: $+\frac{2}{3}$ d: $-\frac{1}{3}$ s: $-\frac{1}{3}$ 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 $(u\bar{s})$ a meson with a charge of −1 requires either $(\bar{u}d)$ or $(\bar{u}s)$	1 1 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 (i)	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.
2 (ii)	leptons: ν_e, e^+, μ^-	1	
2 (iii)	antiparticles: $\bar{n}$, e^+	1	
2 (iv)	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.
3 (a) (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.
3 (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.
3 (b) (ii)	difference: muon has a much greater rest mass similarity: both are negatively charged, or both are leptons	1 1	The rest mass of the muon is over 200 times that of the electron. Either answer will score the mark.
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.
4 (b)	baryon, hadron	2	1 mark for each.

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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.
5 (a) (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 $-e$.
5 (a) (iii)	0	1	A meson is not a baryon.
5 (b)	baryon number: $0 \rightarrow 0 + 0$, so satisfied lepton number: $-1 \rightarrow -1 + 1$, so **not** satisfied charge: $+1 \rightarrow +1 + 0$, so satisfied	1 1 1	All the particles in this interaction are leptons. Lepton numbers are given in the Data Booklet. Note that lepton conservation applies to each lepton family. The neutrino has no charge.
6 (i)	three	1	Don't be put off by the unfamiliar sigma particle; the question is about general properties. A baryon always contains 3 quarks.
6 (ii)	weak interaction	1	Strange particles always decay by the weak interaction.
6 (iii)	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.
7 (b)	subgroups: baryons and mesons a baryon consists of three quarks a meson is a quark-antiquark combination	1 1 1	This part is testing factual knowledge alone. Particle physics contains a lot of facts.
7 (c)	charge: $0 + 1 \rightarrow 1 + 0$, so obeyed lepton number: $0 + (-1) \rightarrow 0 + (-1)$, so obeyed baryon number: $1 + 0 \rightarrow 1 + 0$, so obeyed	1 1 1	Lepton numbers are given in the Data Booklet. You have to know that $B = 1$ for a hadron.
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 $\pi-$ 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. ($\overline{\nu_e}$)	2	The decay equation is similar to that for β^- decay. 1 mark would be awarded for **any** neutrino symbol.

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9 (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.
9 (c)	total kinetic energy required = 2 × rest energy of a proton = 2 × 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.
10 (a) (ii)	the neutral pion, π^0	1	You need to learn facts like this.
10 (b) (i)	$u\bar{s}$	2	Refer to the Data Booklet. A strangeness of +1 requires an antistrange 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.
10 (b) (ii)	weak interaction	1	Strange particles, such as the kaon, decay via the weak interaction.
10 (b) (iii)	$K^- \rightarrow \mu^- + \bar{\nu}_\mu$	1	Just change the two particles on the right hand side to their corresponding antiparticles.
10 (b) (iv)	leptons	1	These parts again test your knowledge of the facts.
10 (b) (v)	muon has a much greater mass	1	
11 (a)	baryon number: $0 + 1 \rightarrow 1 + 0$, so obeyed lepton number: $0 + 0 \rightarrow 0 + 0$, so obeyed charge: $0 + 1 \rightarrow 0 + 1$, so obeyed	1 1 1	A kaon is a meson. Mesons are hadrons but they are not baryons. No leptons are involved in this process. K^0 is a neutral kaon, π^+ is a positive pion.

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11 (b)	K^0 : $d\bar{s}$	1	Refer to the Data Booklet. A strangeness of +1 requires a 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.