Chapter J1

Q1 The electric charge must be zero if a particle is to be its own antiparticle. However, not all neutral particles are their own antiparticle. For example the antineutron is differentiated from the antineutron by its opposite baryon number.

Q2 It is the spin. Particles with integral spin are bosons and those with half integral spin are fermions.

Q3 (a) The Pauli principle states that no two *identical* fermions can occupy the same quantum state. (b) Applied to the inner shell of an atom the Pauli principle demands that the electrons occupying that state be differentiated in some way. The inner shell has no quantum numbers other than energy and so the only quantum number that can separate two electrons is the spin. One electron can have spin up and the other spin down. So we can have at most two electrons. In the other shells we can have more electrons because the state has other quantum numbers such as angular momentum.

Q4 The photons are bosons since they have spin 1. Hence the Pauli principle does not apply to them.

Q5 There is always a limit to mechanical analogies of things non mechanical and this is one of them. A model that stretches things a bit is to imagine that you are standing next to a friend and you are both trying to get a ball away from each other. This will result in an attractive force between you.

Q6 (a) A Feynman diagram is a pictorial representation of a process and corresponds to a mathematical quantity that is related to the probability of that process actually occurring. (b) See answers in textbook.

Q7 See answers in textbook.

Q8 (a) Zero since it consists of a quark u and the anti u. (b) It would violate momentum conservation. In a frame of reference in which the u and the anti u move in opposite directions with the same speed, the total momentum is zero. A single photon would then carry momentum. (c) See answers in textbook.

Q9 A d quark decays into a u quark an electron and an electron antineutrino. (b) See diagram in answers in textbook.

Q10 (a) The neutron consists of 2 d quarks and 1 u quark. (b) It is W^+. This is a weak interaction changing quark flavor and so we must have one of the charged vectors mesons. It is the positive one in order to conserve electric charge: the d quark has charge $-\frac{1}{3}$ and the u quark has charge $+\frac{2}{3}$. So $+\frac{2}{3}=-\frac{1}{3}+Q \Rightarrow Q=+1$. (c) They are the positron and the electron neutrino.

Q11 The diagrams are shown in the answers to the textbook.

Q12 See answers in textbook.

Q13 See diagrams in answers to textbook.

Q14 See answers textbook.

Q15 (a) Yes it does since the weak force acts on quarks and mesons are made out of a quark and an anti quark. (b) Yes for the same reason: baryons consist of 3 quarks.

Q16 For every vertex in the Feynman diagram a factor of α is assigned to the expression giving the probability for the process. Diagrams with many (*N*) vertices contain a factor of $\alpha^N << 1$ are therefore less likely to occur if $\alpha < 1$ and so can be neglected. For the strong interaction this is not the case since $\alpha \approx 1$ and so $\alpha^N \approx 1$. This means we cannot neglect these diagrams.

Q17 (a) Yes since they have electric charge. (b) No since they do not have electric charge.

Q18 Yes since it contains quarks that have electric charge.

Q19 The antineutrinos have opposite lepton number.

Q20 The mass of the graviton must be zero.

Q21 (a) The Heisenberg principle for energy and time states that $\Delta E\,\Delta t \geq \frac{h}{4\pi}$. One approach is to follow the argument in the textbook (page 729). An alternative is the following: if the exchange particle has range *R* the exchange particle must be able to live long enough to cover this distance. Then $\Delta t \approx \frac{R}{c}$ (the fastest the particle can travel is *c* and so this is the least time it can exist). The corresponding in uncertainty in energy is then $\Delta E \geq \frac{hc}{4\pi R}$. To this energy there corresponds a mass *m* given by Einstein's formula $m \geq \frac{\Delta E}{c^2} = \frac{h}{4\pi Rc}$. (b) The photon is the exchange particle of the electromagnetic interaction and it has zero mass. Hence using the formula, we see that the range is infinite. (c) We use $R \approx \frac{h}{4\pi mc}$ to get $m \approx \frac{h}{4\pi Rc}$ or $mc^2 \approx \frac{hc}{4\pi R}$. Then $mc^2 \approx \frac{6.63\times10^{-34}\times3\times10^{8}}{4\pi\times10^{-15}} = 1.58\times10^{-11}\text{ J} = \frac{1.58\times10^{-11}}{1.6\times10^{-19}} = 9.89\times10^{7}\text{ eV} \approx 100\text{ MeV}$. Hence $m \approx 100\text{ MeV c}^{-2}$.