Queen Mary
University of London

BSc EXAMINATION

PHY-653 ELEMENTARY PARTICLE PHYSICS - RESIT

Time Allowed: 2 hours 15 minutes

Date: 23rd May 2005

Time: 14:30

Instructions: **Answer QUESTION 1 and TWO others. Question 1 carries 40 marks. The other questions carry 20 marks. The coursework is worth 20 marks. The total available marks for each part question is given in square brackets.**

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1. This question is COMPULSORY. Please answer ALL Sections.

(a) Explain the following terms and give two examples of each (do not use the same example more than once): (i) **boson**, (ii) **lepton**, (iii) **hadron**, (iv) **anti-baryon** and (v) **meson**. [5]

(b) Draw a table showing all the fundamental fermions (quarks and leptons) in the Standard Model, arranged by generations horizontally and electric charge vertically. For each particle give its name and symbol and approximate mass. [5]

(c) Write down the quark content of the following particles: (i) π^+, (ii) K^+, (iii) D^+, (iv) B^0, (v) $\overline{\Lambda}$, (vi) Λ_b^0, (vii) Υ, (viii) $\overline{K}^0$, (ix) π^0 and (x) Ω^-. [5]

(d) Draw Feynman diagrams to illustrate the following, in each case clearly labelling all the quarks, leptons and exchanged particles and stating what type of interaction is involved (if more than one interaction could be involved give the most likely): [10]

(i)	$e^+ + e^- \rightarrow \nu_e + \overline{\nu}_e$	(iv)	$\pi^0 \rightarrow \gamma + \gamma$
(ii)	$\overline{\nu}_e + p \rightarrow e^+ + n$	(v)	$\omega^0 \rightarrow \pi^+ + \pi^- + \pi^0$
(iii)	$\Lambda \rightarrow n + \pi^0$		

(e) Replace the symbols ℓ with the correct leptons or anti-leptons in the following: [5]

(i)	$\pi^+ \rightarrow \mu^+ + \ell$	(iii)	$\ell + p \rightarrow n + e^+$
(ii)	$\mu^+ \rightarrow \ell + \nu_e + \ell$	(iv)	$\ell \rightarrow e^+ + \nu_e + \overline{\nu}_\tau$

(f) Replace the symbol X by that for a proton, neutron, pion or kaon, or their anti-particles, in the following **Strong Interactions**: [5]

(i)	$K^- + p \rightarrow n + X$	(iv)	$\pi^- + p \rightarrow p + n + \pi^0 + X$
(ii)	$\pi^+ + p \rightarrow \Delta^{++} + X$	(v)	$\rho^0 \rightarrow \pi^+ + X$
(iii)	$\pi^+ + p \rightarrow \overline{K}^0 + p + X$		

(g) A pion of mass 0.140 GeV/c^2 has a momentum of 0.5 GeV/c. Calculate its **total energy** and its **kinetic energy**. The pion collides with a stationary proton of mass 0.938 GeV/c^2. Calculate the **total centre of mass energy** of the system. [5]

2. Explain what is meant by a strong interaction **resonance**, in the context of the Quark-Parton Model. Give an example of a strong interaction **meson** resonance and comment briefly on its properties. [3]

   The Λ and the Δ^0 (udd resonance) both decay predominantly to $p + \pi^-$. The lifetime of the Λ is 2.6×10^{-10}s whereas the lifetime of the Δ^0 is $\sim 10^{-24}$s. Draw Feynman diagrams to illustrate both decays, clearly labeling all the particles involved. [6]

   Hence explain why the lifetimes are so different. [4]

   Explain briefly how the lifetime of the Δ^0 can be estimated. [3]

   What other possible decay modes of the Λ and Δ^0 are there? [4]

3. What are meant by the terms **weak charged current** and **weak neutral current**? [2]

   Draw a Feynman diagram to illustrate the decay $K^+ \to \pi^0 + \mu^+ + \nu_\mu$. [2]

   The branching ratio for the decay $K^+ \to \pi^0 + \mu^+ + \nu_\mu$ is about 3% while the decay $K^+ \to \pi^+ + \nu + \overline{\nu}$ has never been observed. Explain how this implies that there are no direct weak flavour changing neutral currents. Explain briefly how this is explained by the Glashow, Iliopoulos, Maiani (GIM) Mechanism. [10]

   The weak neutral current J^-_{weak} can be expressed for two generations as [6]

$$J^-_{\text{weak}} = (\overline{u}, \overline{c})\, M \begin{pmatrix} d \\ s \end{pmatrix}$$

   Write down the matrix M in terms of the Cabibbo angle θ_C. How is this extended to three generations?

4. Explain how the observation of two long-lived particles in the reaction $\pi^- + p \to K^0 + \Lambda$ led to the introduction of a new quantum number called 'strangeness'. [4]

   Explain why the K^0 and the $\overline{K}^0$ are not eigenstates of the CP operator. Write down the two states K_1 and K_2 which are eigenstates of CP and show that they have eigenvalues +1 and −1 respectively. Express the states K^0 and $\overline{K}^0$ in terms of K_1 and K_2. [8]

   Explain why the cross section for $\overline{K}^0$ interactions with nucleons is larger than that for K^0. [2]

   A beam of K^0 is allowed to decay in vacuum. At a distance downstream of the source, corresponding to $20K_1$ lifetimes, there is a target that absorbs 10% of the K^0 component incident on it and 30% of the $\overline{K}^0$ component. Calculate the relative amplitudes of K_1 and K_2 just before and just after the target. [6]

5. What are the two main pieces of evidence that support the Big Bang model of the Universe? [4]

   Show that the critical mass density of the Universe, ρ_c, is $\rho_c = 3H^2/8\pi G$ where H is Hubble's constant and G is the Gravitational constant. [3]

   Explain what happens in the case (a) $\Omega < 1$, (b) $\Omega = 1$ and (c) $\Omega > 1$ where Ω is the ratio of the energy density of the Universe to the critical energy density. [3]

   Explain how the observation that the rotational velocity of stars in a galaxy is largely independent of their distance from the centre of the galaxy implies the existence of so-called **Dark Matter**. [4]

   Explain, with examples, what is meant by the terms **Baryonic Dark Matter**, **Hot Dark Matter** and **Cold Dark Matter**. [6]

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