Queen Mary
University of London

BSc/MSci EXAMINATION

PHY-653 ELEMENTARY PARTICLE PHYSICS

Time Allowed: 2 hours 15 minutes

Date: 18 May 2006

10.00 - 12.15

Answer ALL questions in section A. Answer ONLY TWO questions from section B. Section A carries 40 marks, each question in section B carries 20 marks. The coursework is worth 20 marks. An indicative marking-scheme is shown in square brackets [ ] after each part of a question.

COMPLETE ALL ROUGH WORKINGS IN THE ANSWER BOOK AND CROSS THROUGH ANY WORK WHICH IS NOT TO BE ASSESSED.

CALCULATORS ARE PERMITTED IN THIS EXAMINATION.

YOU ARE NOT PERMITTED TO START READING THIS QUESTION PAPER UNTIL INSTRUCTED TO DO SO BY AN INVIGILATOR

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Section A

A1. 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. [6]

A2. 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** and (iv) **anti-baryon**. [6]

A3. 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) $\overline{\mathrm{K}}^0 \to \pi^+ + \pi^-$

(ii) $\mathrm{e}^+ + \mathrm{e}^- \to \nu_\mu + \overline{\nu}_\mu$

(iii) $\pi^- + \mathrm{p} \to \mathrm{K}^0 + \Lambda$

(iv) $\mathrm{B}^- \to \mathrm{D}^0 + \pi^-$

A4. Replace the symbols ν with the correct neutrinos or anti-neutrinos in the following: [6]

(i) $\tau^+ \to \mu^+ + \nu + \nu$

(ii) $\nu + \mathrm{p} \to \mathrm{n} + \mathrm{e}^+$

(iii) $\mathrm{K}^- \to \mu^- + \nu$

(iv) $\mu^- + \mathrm{p} \to \mathrm{n} + \nu$

A5. Replace the symbol X by that for a proton, neutron, pion or kaon, or their anti-particles, in the following **Strong Interactions**: [6]

(i) $\mathrm{K}^- + \mathrm{p} \to \mathrm{n} + \mathrm{X}$

(ii) $\pi^+ + \mathrm{p} \to \Delta^{++} + \mathrm{X}$

(iii) $\pi^+ + \mathrm{p} \to \overline{\mathrm{K}}^0 + \mathrm{p} + \mathrm{X}$

(iv) $\pi^- + \mathrm{p} \to \mathrm{p} + \mathrm{n} + \pi^0 + \mathrm{X}$

A6. LEP can collide 95 GeV electrons with 95 GeV positrons head on to produce pairs of W^+W^- particles with masses of 80 GeV/c^2 each. Calculate the **total energy**, **kinetic energy** and **momentum** of each W after the collision. [6]

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Section B

B1. (i) Explain what is meant by a strong interaction **resonance**, in the context of the Quark-Parton Model. Give an example of a **meson** resonance that decays through the strong interaction, and comment briefly on its properties. [5]

(ii) 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]

(iii) Hence explain why the lifetimes are so different. [5]

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

B2. (i) Describe the main properties of **neutrinos**. [3]

(ii) Explain why two ν_μ are produced for each ν_e from the decay of pions from cosmic ray interactions in the upper atmosphere. The fact that the ratio of ν_μ to ν_e at the Earth's surface is measured to be ~ 1.36 is known as the **atmospheric neutrino problem**. [5]

(iii) Explain briefly what is meant by the **solar neutrino problem**. [8]

(iv) Explain how both of these problems may be resolved by possible **neutrino oscillations**. [4]

B3. (i) Explain the difference between **leptonic**, **semi-leptonic** and **non-leptonic** weak decays. Give an example of each type of decay. [3]

(ii) Describe briefly how Cabibbo theory explains the factor of ~ 20 difference in lifetime between $\Delta S = 0$ and $\Delta S = 1$ decays, where ΔS is the change in strangeness. How was the theory extended to include the charm quark? [6]

(iii)Draw Feynman diagrams to illustrate the following decays of the D^0 meson, in each case clearly labelling the quarks and exchanged particles involved. [6]

(a) $D^0 \rightarrow K^- + \pi^+$
(b) $D^0 \rightarrow \pi^+ + \pi^-$
(c) $D^0 \rightarrow K^+ + \pi^-$

(iv) Estimate the relative decay **amplitudes** for these three decays. [5]

B4. (i) What are meant by the terms **Parity** and **Charge Conjugation**? [3]

(ii) Explain why the K^0 and $\overline{K}^0$ are not eigenstates of the CP operator. Draw Feynman diagrams to illustrate the decays of both the K^0 and $\overline{K}^0$ into both $\pi^+ + \pi^-$ and $\pi^+ + \pi^- + \pi^0$. [4]

(iii) Given that the π^0 has $C = +1$ and $P = -1$, deduce the CP of the 2π and 3π states. Hence explain why the K_1 and K_2 states decay predominantly to 2π and 3π respectively. [6]

(iv) Write down the quark contents of the two neutral B mesons B^0_d and B^0_s. Draw Feynman diagrams to illustrate how each of these B^0 mesons can 'mix' to a $\overline{B}^0$ meson. Explain briefly how this process might be observed in e^+e^- interactions. [7]

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B5. (i) Explain briefly the main differences between the **Electromagnetic Interaction** and the **Strong Interaction** and give two examples of reactions or decays that take place through each of them. [4]

(ii) The strength of the electromagnetic interaction, $\alpha = e^2/(4\pi\epsilon_0\hbar c)$, increases with increasing energy whereas the strength of the strong interaction, α_s, decreases with increasing energy. Explain how this supports the concept of **Grand Unified Theories**. [5]

(iii) Explain how Grand Unified Theories predict proton decay. [5]

(iv) A detector contains 1000 tonnes of water. If the proton had a mean life of 10^{30} years, how many proton decays would there be per day in the detector? (Oxygen has an Atomic Number of 8 and an Atomic Mass of 16. Avogadro's number is 6×10^{23} per mole.) [6]

End of Examination Paper
Professor John M Charap