The University Of Sheffield.

DEPARTMENT OF PHYSICS & ASTRONOMY

Autumn Semester 2006-2007

PARTICLE PHYSICS **2 Hours**

Answer question ONE (COMPULSORY) and TWO others.

A formula sheet and table of physical constants is attached to this paper.

All questions are marked out of ten. The breakdown on the right-hand side of the paper is meant as a guide to the marks that can be obtained from each part.

COMPULSORY

1 (a) Define the terms *lepton* and *hadron*. **[1]**

(b) Give two examples each of leptons and hadrons. **[1]**

(c) A ϕ meson decays into a $K^+ K^-$ pair with one unit of relative angular momentum. If the intrinsic parity of the kaons is negative, and parity is conserved in the decay, determine the intrinsic parity of the ϕ. Explain your reasoning. **[1]**

(d) What is meant by a *virtual particle*? **[1]**

(e) Distinguish between *time-like* and *space-like* virtual photons. **[1]**

(f) What are the quantum numbers of the strange quark? (Give its spin, electric charge, isospin, hypercharge and strangeness.) **[1]**

(g) Draw a labelled Feynman diagram for the reaction $\mu^- \to e^- \ \nu_\mu \ \bar{\nu}_e$. **[1]**

(h) Which interaction is responsible for the decay $K^0 \to \pi^- \ \pi^+$, and why? **[1]**

(i) When a pion at rest decays according to $\pi^+ \to \mu^+ \ \nu_\mu$, what fraction of the energy is carried by the neutrino? (Express your answer in terms of the π and μ rest masses.) **[2]**

2 (a) Describe with a table the particle content of the standard model of particle physics. Show how the particles can be divided into bosons and fermions, and indicate how some particles appear in generations. **[3]**

(b) Describe the evidence from high energy electron-positron annihilation experiments which indicates that the above table may be complete, with no additional as yet undiscovered generations. Explain the advantages and disadvantages of considering evidence from neutrino production, and state why this cannot be provided by *low energy* annihilation data. **[4]**

(c) An energetic positron annihilates with an electron at rest to produce a ρ meson. What was the energy of the positron? **[3]**
[Mass of ρ is 770 MeV/c^2; mass of $e^{\pm}$ is 0.51 MeV/c^2.]

3 (a) Explain what is meant by the term *form factor*. (A derivation is not required.) **[2]**

(b) In the case of scattering from a spherically symmetric charge distribution, show that the form factor is given by

$$F(q) = \int_0^{\infty} \rho(r) \frac{\sin(qr/\hbar)}{qr/\hbar} 4\pi r^2 \mathrm{d}r$$

where $\rho(r)$ is the normalised charge distribution. **[3]**

(c) In one simple model of the proton, this distribution is written as

$$\rho(r) = A\exp(-r/a)$$

where A is a constant and a is some characteristic "radius" of the proton. Show that this implies a form factor proportional to

$$\left(1+\frac{q^2}{q_0^2}\right)^{-2} \quad \text{where } q_0 \text{ is } \hbar/a.$$

[4]

(d) Experimentally, it is found that $q_0^2 = 0.71\left(\mathrm{GeV}/c\right)^2$. Determine the characteristic radius of the proton. **[1]**

4 (a) Explain what is meant by the terms *isospin*, *strangeness* and *charm*. Give the values of these properties for the Σ, Ξ, Δ and Ω particles, and hence draw a diagram, on labelled axes, of the decuplet of spin $\frac{3}{2}$ baryons. **[4]**

(b) Which, if any, of the strong, weak and electromagnetic interactions conserve the above quantum numbers? **[1]**

(c) Explain why there are 10 particles in the lowest lying multiplet of spin $\frac{3}{2}$ baryons, but only 8 in the multiplet of spin $\frac{1}{2}$ baryons. **[2]**

(d) A neutral kaon decays in flight into a pair of charged pions. If the pions travel in opposite directions, with one having a momentum magnitude exactly twice that of the other, find the momentum of the original kaon. **[3]**

[Mass of K^0 is 498 MeV/c^2; mass of $\pi^{\pm}$ is 140 MeV/c^2.]

5 (a) The B^- meson is the lightest particle consisting of a b quark and $\bar{u}$ antiquark. Which type of interaction is responsible for its decay? Describe the most likely decay chain leading from the B^- to stable or long-lived particles. At each step in the chain, explain why the indicated route is preferred, and state what alternative, less probable decay products (if any) could be formed. (It is sufficient to name the produced quarks, rather than listing the individual hadrons containing them.) **[4]**

(b) Draw a possible Feynman diagram, suitably labelled, to represent the first decay in the above chain. **[2]**

(c) Indicate, **<u>with an explanation</u>**, whether the following interactions proceed through the strong, electromagnetic or weak interactions, or whether they do not occur.

(i) $\tau^- \rightarrow \mu^- + \gamma$

(ii) $\tau^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\tau$

(iii) $\Xi^0 \rightarrow \Sigma^+ + \pi^-$

(iv) $\pi^0 \rightarrow \gamma + \gamma$

(v) $n \rightarrow \rho^- + \pi^+$

(vi) $\pi^- + p \rightarrow \Lambda^0 + K^0$

(vii) $\pi^- + n \rightarrow \Lambda^0 + K^-$

(viii) $\mu^+ + \mu^- \rightarrow \tau^+ + \tau^-$ **[4]**

END OF EXAMINATION PAPER