The University Of Sheffield.

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

DEPARTMENT OF PHYSICS & ASTRONOMY

Autumn Semester 2015-2016

PARTICLE PHYSICS **2 HOURS**

Answer question ONE (Compulsory) and TWO other questions.

Please clearly indicate the question numbers on which you would like to be examined on the front cover of your answer book. Cross through any work that you do not wish to be examined.

The compulsory question is marked out of 20. All other questions are marked out of 15. 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.

THIS QUESTION IS COMPULSORY.

1 (a) Define the terms *fermion* and *boson*, and give one example of each. **[2]**

(b) How are the symmetry properties of a fermion system different from those of a boson system? Give one consequence of this difference. **[2]**

(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. **[2]**

(d) What are the quark contents of the K^+ and the K^- particles? **[2]**

(e) Draw a labelled Feynman diagram for the reaction $\nu_e\, n \rightarrow p\, e^-$. **[2]**

(f) Which interaction is responsible for the decay $\pi^0 \rightarrow \gamma\,\gamma$, and why? **[2]**

(g) Explain why baryons – bound states of three quarks – exist, but there are no bound states of two quarks. **[2]**

(h) A charged pion at rest decays into a muon and a neutrino (which can be treated as massless) according to $\pi^+ \rightarrow \mu^+\, \nu_\mu$. What energy does the neutrino have? **[3]**

[Mass of π^+ is 139.6 MeV/c^2; that of μ^+ is 105.7 MeV/c^2.]

(i) Explain what is meant by the term *jet* in particle physics. **[1]**

(j) Give four key properties of the boson responsible for the strong interaction. **[2]**

2 (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. **[5]**

(b) Which, if any, of the strong, weak and electromagnetic interactions conserve the above quantum numbers? **[2]**

(c) Explain why, even though there are 10 particles in the lowest lying multiplet of spin $\frac{3}{2}$ baryons, there are only 8 in the multiplet of spin $\frac{1}{2}$ baryons. **[4]**

(d) An Ω^- baryon decays in flight into a Λ and a K^-. It is observed that the Λ is produced at rest. What is the energy of the K meson? **[4]**

[Mass of Ω^- is 1672 MeV/c^2; mass of Λ is 1116 MeV/c^2, mass of K^- is 494 MeV/c^2.]

3 (a) Explain what is meant by a virtual particle. How are space-like and time-like virtual photons distinguished? **[3]**

(b) Starting from the quantum mechanical operators for kinematic quantities, give a simple derivation of the Yukawa potential,

$$V(r) \propto \frac{e^{-mcr/\hbar}}{r},$$

and so determine the relationship between the "range" of a force and the mass, *m*, of the exchanged boson. **[5]**

(c) Using the Born approximation, the amplitude of scattering by a spherically symmetric potential $V(r)$ with a momentum transfer q is given by

$$A = \int_0^\infty \frac{\sin(qr/\hbar)}{qr/\hbar} V(r) 4\pi r^2 \mathrm{d}r .$$ **[3]**

Show that in the case of a Yukawa-type potential, this leads to an amplitude proportional to $\left(q^2 + m^2c^2\right)^{-1}$. **[4]**

(d) An experiment was performed to measure the differential cross-section when scattering high energy neutrinos off electrons. A precise measurement was made at low momentum transfer. At a momentum transfer of 5 GeV/c there was no observable difference in the measured cross-section compared with that at low momentum transfer, within a measurement precision of 1%. What can you deduce about the mass of the exchanged boson?

4 (a) The B^- meson is the lightest particle consisting of a b quark and $\bar{u}$ antiquark. Which 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.) **[6]**

(b) Draw a possible Feynman diagram, suitably labelled, to represent the first decay in the above chain. **[3]**

(c) Indicate, *with an explanation*, 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) $\Omega^- \rightarrow \Lambda^0 + \pi^-$;

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

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

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

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

(viii) $\mu^+ + \mu^- \rightarrow \tau^+ + \tau^-$. **[6]**

5 (a) Explain what is meant by the anomalous magnetic moment of a charged lepton, and sketch the Feynman diagram which represents the dominant process leading to this anomaly according to quantum electrodynamics. Give a simple estimate of the order of magnitude of the anomaly. **[4]**

(b) Outline the principal features of an experiment to measure the anomalous magnetic moment of the muon. Indicate what rôle parity non-conservation in the weak interaction plays in the detection of the polarisation of the muon when it decays. **[6]**

(c) A tau lepton, with an energy of 2,500 MeV, decays into a pion and a neutrino. Sketch the decay configuration which leads to the neutrino having the maximum possible momentum, and calculate the magnitude of this value. **[5]**

[Mass of tau is 1,777 MeV/c^2, mass of pion is 140 MeV/c^2.]

END OF QUESTION PAPER