King's College London

UNIVERSITY OF LONDON

B.Sc. EXAMINATION

CP/3240 Theoretical nuclear and particle physics

Summer 1997

Time allowed: THREE Hours

Candidates must answer SIX parts of SECTION A, and TWO questions from SECTION B.

Separate answer books must be used for each Section of the paper.

The approximate mark for each part of a question is indicated in square brackets.

You must not use your own calculator for this paper.
Where necessary, a College Calculator will have been supplied.

TURN OVER WHEN INSTRUCTED

Reduced Planck constant $\hbar = 6.6\times10^{-16}$ eV s

SECTION A. Answer any six questions.

1.1 By considering the relevant conservation laws determine which of the following reactions and decays are allowed by first-order processes:

$$\pi^0 \rightarrow e^+ + e^-$$
$$p \rightarrow n + e^+ + \nu_e$$
$$\mu^+ \rightarrow e^+ + e^+ + e^-$$
$$K^+ + n \rightarrow \Sigma^+ + \pi^0.$$

For those which are allowed, state which force is involved. For those which are not, state a conservation law which is violated.

[7 marks]

1.2 State which force is most likely to mediate the following processes:

$$e^+ + e^- \rightarrow e^+ + e^-$$
$$e^+ + e^- \rightarrow \mu^+ + \mu^-$$
$$e^+ + e^- \rightarrow \nu_e + \bar{\nu}_e$$
$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-.$$

Draw an appropriate Feynman diagram in each case.

[7 marks]

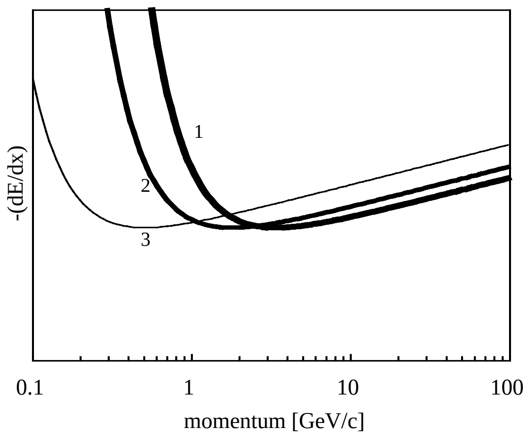
1.3 The Σ baryon exists in three charge states, +, 0 and –. Show, by writing down its quark structure, that it must have strangeness $S = -1$.

Why are baryons and antibaryons placed in separate multiplets in the quark model, while mesons and their corresponding antimesons are in the same multiplets?

[7 marks]

1.4 The figure below shows the rates of energy loss of pions, kaons and protons as they pass through a detector. State which process determines the rate of energy loss for these particles, and give the reason for the minima of the curves. Identify which curve (1, 2 or 3) corresponds to each of the types of particle. Why is the curve describing the rate of energy loss for electrons different from those shown?

[7 marks]



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1.5 Show, by use of an appropriate diagram, how *phase stability* leads to bunching of charged particles in a cyclic accelerator such as a synchrotron.

[7 marks]

1.6 In 1974 the following types of interaction were observed in an electron–positron colliding beam experiment when the energy in each beam was above about 1.8 GeV

$$e^+ + e^- \rightarrow e^\pm + \mu^\mp + \text{missing energy.}$$

Discuss the interpretation of these observations, and write down a full set of reactions describing the processes which took place.

[7 marks]

1.7 Show that as a result of the Pauli Exclusion Principle a state consisting of two identical fermions must be described by an antisymmetric state function.

[7 marks]

1.8 The strong interaction is considered to take place through the exchange of gluons. Describe qualitatively an important difference between this and the exchange of photons in the electromagnetic interaction. Briefly discuss the implications of this difference.

[7 marks]

SECTION B. Answer two questions.

2. Discuss the reasons for the introduction of the concept of *weak neutral currents*. Draw a Feynman diagram, in terms of neutrinos and quarks, for the neutral current process

$$\nu_\mu + p \rightarrow \nu_\mu + p.$$

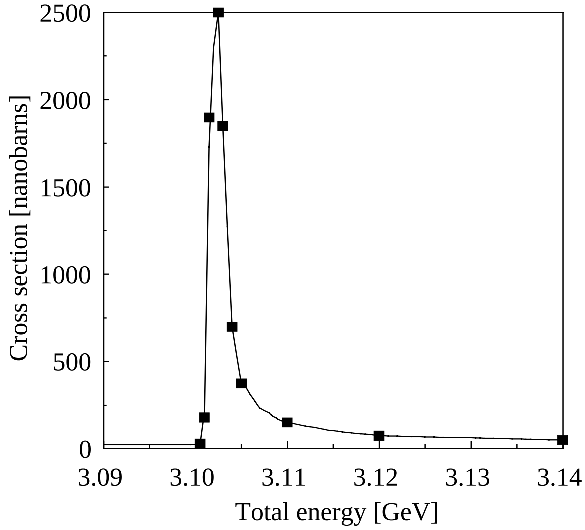
[8 marks]

Draw Feynman diagrams for a neutral current process and for a charged current process which could each describe the decay

$$K^0 \rightarrow \mu^+ + \mu^-.$$

Discuss how the low observed rate of this decay led to the prediction of the charmed quark and an estimate of its mass m_C.

[14 marks]



The figure shows a plot of the cross section for electron–positron collisions as a function of total energy. Discuss why this plot is considered to be due to the production and subsequent decay of a meson consisting of a charmed quark and a charmed antiquark. *Estimate* the mass and lifetime of this meson, and discuss whether its mass is consistent with the predicted value of m_C.

[8 marks]

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3. Discuss the reasons for the introduction of the quark model, and the early difficulties associated with its acceptance. Why did the quark model lead to the concept of *colour*?

[12 marks]

Write down the quark content of the proton (p), the negative pion (π^-) and the lambda (Λ) and draw Feynman diagrams, in which the quarks are explicitly represented, describing the decays

$$\Lambda \rightarrow p + \pi^-$$

and

$$\Lambda \rightarrow p + e^- + \bar{\nu}_e.$$

[6 marks]

A group of researchers claim to have seen the following interaction:

$$K^- + p \rightarrow M^{++} + B^{--} + K^0 + K^0$$

where M^{++} is identified, through its subsequent decay, as a meson with strangeness $S = -3$ and B^{--} is identified as a baryon with $S = 0$. Explain how the observation, if confirmed, is inconsistent with the simple quark model.

[12 marks]

4. Write down the three fundamental properties of *SU*(3) multiplets, illustrating your answer by use of a weight diagram (hypercharge versus third component of isospin).

[8 marks]

Draw the weight diagrams of the fundamental *SU*(3) triplet **3** and its conjugate $\bar{\mathbf{3}}$.

[4 marks]

Show how **3** and $\bar{\mathbf{3}}$ may be used to construct octets and singlets representing mesons, and singlets, octets and decuplets representing baryons.

[18 marks]

5. Write notes on **TWO** of the following topics:

a) Dirac's formulation of relativistic quantum mechanics which led to the prediction of antimatter.

[15 marks]

b) The prediction and discovery of the neutrino.

[15 marks]

c) CP violation and the matter / antimatter asymmetry.

[15 marks]

d) The unification of the fundamental forces.

[15 marks]

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