M.Thomson
Easter 2004

PART III PARTICLES EXAMPLES CLASS

Short Questions

1. What are *virtual* particles ?

2. Why are particle beams of high energy needed for probing short distances ?

3. Why can perturbation theory be used to calculate the predictions of quantum electrodynamics to high accuracy ?

4. Explain what is meant by *Electroweak Unification.*

5. Outline an experiment to determine the mass and width of the Z^0 boson. What is the significance of such measurements ?

6. What is charmonium, how was it discovered and what is its significance for the development of the Standard Model ?

7. Why do charmonium states with masses greater than 3740 MeV/c^2 have a large width (10-100 MeV/c^2), whilst those with lower masses have narrower widths ?

Long Questions

1. Give an account of the nature and properties of the strong, electromagnetic and weak interactions, illustrating your answer with Feynman diagrams involving relevant quarks, leptons and gauge bosons.

   Draw possible Feynman diagrams for the following processes, and state what interactions are involved in each case:

   (a) $e^+ + e^- \to W^+ + W^-$ (only two of the lowest order diagrams are required.)

   (b) $\Delta^+(uud) \to n(udd) + \pi^+(u\bar{d})$;

   (c) $\Sigma^+(uus) \to p(uud) + \gamma$.

   [The quark compositions of the hadrons are shown.]

2. During the past 20 years measurements have been made of the electron-positron annihilation processes $e^+e^- \to$ hadrons and $e^+e^- \to$ leptons over a range of energies. Discuss in detail how these have provided information on:

   (a) the quark flavours, and their properties;

   (b) the number of quark and lepton generations;

   (c) the existence of gluons;

(d) the energy dependence of the strong coupling constant, α_s.

Use the following data to estimate the total decay width, Γ_Z, and the lifetime of the Z^0 boson, making clear your assumptions.

Resonant cross-section ratio:

$$\frac{\sigma(e^+e^- \to Z^0 \to \text{hadrons})}{\sigma(e^+e^- \to Z^0 \to \text{leptons})} = 20.7$$

Z^0 partial decay widths:

$$\Gamma(Z^0 \to \mu^+\mu^-) = 83.3 \text{ MeV},$$

$$\Gamma(Z^0 \to \nu_\mu\bar{\nu}_\mu) = 166.5 \text{ MeV}.$$

[$\hbar = 6.582 \times 10^{-22}$ MeVs.]

3. Explain what *Feynman diagrams* are and the ways in which they are useful in the study of particle interactions. Consider the following five reactions:

1. $e^+ + e^- \to e^+ + e^-$
2. $\Lambda_b(udb) \to J/\psi(c\bar{c}) + \Lambda(uds)$
3. $\gamma + p \to \pi^0 + p$
4. $e^+ + e^- \to 3$ jets
5. $\mathrm{K}^0(\mathrm{d}\bar{\mathrm{s}}) \to \mu^+ + \mu^-$

[The quark compositions of the hadrons are shown.]

(a) For **each** reaction, draw **one** Feynman diagram, the simplest you can, to illustrate a possible mechanism. All hadrons should be represented by appropriate quark lines.

(b) Taking into account only those factors which arise from the couplings in your diagrams, arrange the reactions in the order of decreasing transition probability. Give reasons for the ordering you adopt.