PC312

ONE HOUR THIRTY MINUTES

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

Particles, Nuclei and Cosmology

27th January 1998, 2.00 p.m. - 3.30 p.m.

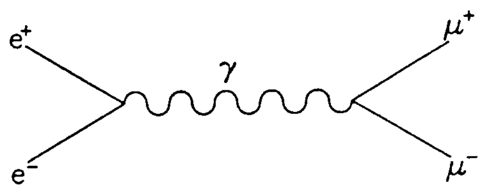
Answer TWO questions

Electronic calculators may be used, provided that they cannot store text.

The numbers indicate the relative weights of the different parts of each question and do NOT represent a marking scheme.

P.T.O.

1. An electron and a positron annihilate into a virtual photon which then produces a $\mu^+\mu^-$ pair, as shown below



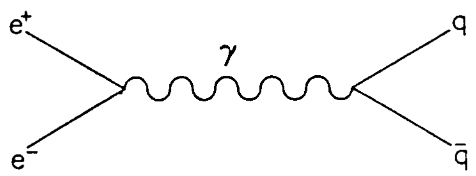
What is the fundamental interaction responsible for this process?

[3 marks]

Explain why the cross-section is proportional to α^2 (α is the fine structure constant).

[5 marks]

In a similar interaction at the same initial energy a quark-antiquark pair is produced as shown.



Explain why the cross-section for the production of a particular pair of quarks differs from that for $\mu^+\mu^-$ production by a factor of $3e_q^2$ where e_q is the magnitude of the electric charge on the quark (in units of the electron charge).

[6 marks]

If the initial energy is high enough to produce all quark flavours except top, show that if measured at the same initial energy

$$R = \frac{\sigma(e^+e^- \rightarrow hadrons)}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} = \frac{11}{3}$$

[7 marks]

Explain briefly how the strong interaction converts the quarks into the experimentally observed hadrons.

[4 marks]

[In units of the electron charge, the electric charges on the u, d, s, c, b, t quarks are $+\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3}, +\frac{2}{3}, -\frac{1}{3}, +\frac{2}{3}$]

2. Write down an expression for the mass of a stable nucleus, $M(Z, A)$ in terms of the masses of the individual proton (M_p), and neutron (M_n) constituents.
Hence define the term nuclear binding energy.

[4 marks]

Make a sketch of the measured nuclear binding energy in (MeV/nucleon) as a function of mass number A, showing all the relevant features.

[4 marks]

Describe briefly how the semi-empirical mass formula is evolved from an analogy between the nucleus and a charged liquid drop.

[7 marks]

Show how the main terms in the mass formula can account for the broad dependence of the measured binding energy on A.

[5 marks]

A more detailed examination of the measured binding energy curve reveals that the nuclei ${}^{4}_{2}He$, ${}^{16}_{8}O$ and ${}^{208}_{82}Pb$ have significantly higher binding energies than their near neighbours. Give an explanation for this increased stability.

[5 marks]

3. Discuss at least two pieces of evidence which suggest that we may live in a Universe of finite age.

[8 marks]

Why is it believed that in the early phase of the history of the Universe, a radiation 'fireball' played a dominant role?

[5 marks]

The Universe is imagined to run back in time from the present epoch t_o, with scale parameter $R(t_o) = 1$. At approximately what temperature $T(t)$, and scale parameter $R(t)$ would the temperature begin to rise high enough to provide the 1eV necessary to start the ionisation of some hydrogen atoms? You may assume that $R(t)$ is inversely proportional to $T(t)$. Assuming that the Universe is matter-dominated during the 'run-back' period, how old was the Universe at this temperature? [Take the present age of the Universe to be $t_o = 1.5 \times 10^{10}$ yrs.]

[8 marks]

The isotropy and thermal uniformity of the 2.7K cosmic background radiation suggests an equilibrium due to causal connection. How does this give problems to the above model?

[4 marks]