Physics of Elementary Particles

Fall 2016

Exam 12th December 2016

Read carefully before you start. Questions have unequal difficulty and weight, use your time wisely. Please write clearly and justify your answers concisely.

1 General particle properties [2 points]

a) [0.9] List all interactions and the particles associated with the mediation of the interactions together with their properties (mass, spin, electric charge and color)
b) [0.5] What are baryons and what are mesons?

c) [0.6] Explain if particles consisting of combinations of 4, 5 or 6 quarks and antiquarks could in principle exist.

2 $\Lambda_c^+(udc)$ decays [2 points]

a) [0.5] Draw the Feynman diagrams of the decays below:
A) $\Lambda_c^+ \to \Lambda\pi^+$ ($\Lambda = uds, \pi^+ = u\bar{d}$)
B) $\Lambda_c^+ \to \Lambda K^+$ ($K^+ = u\bar{s}$)
C) $\Lambda_c^+ \to \Lambda e^+ \nu_e$ (or $\bar{\nu_e}$, justify your choice)

b) [0.5] Give a ranking of the probabilities of the different decays and explain (Cabibbo angle = 13deg).

c) [1] Assume a decay of the Λ_c^+ at rest. What is the energy of the Λ in the three decays? ($m_{\Lambda_c} = 2.29\ GeV/c^2, m_{\pi^+} = 135\ MeV/c^2, m_{K^+} = 495\ MeV/c^2, m_\Lambda = 1.12\ GeV/c^2, m_e = 0.5\ MeV/c^2$)

3 Υ decay [2.5 points]

The $\Upsilon(4S)$ ($b\bar{b}$) with a mass of 10.58 GeV/c^2 can be produced in e^+e^- collisions ($e^+ + e^- \to \Upsilon(4S)$). The decay products (mesons containing b-quarks, so-called B-mesons) were used to study CP-violation (difference in decay times of the B-mesons). The experiment Babar at SLAC (1999-2008) used asymmetric electron and positron beam energies (9 GeV and 3.1 GeV) in order to boost the decay lengths of the B-mesons that stem from Υ decays.

a) [0.5] What would be the energy needed in the electron and positron beam assuming equal beam energies to create the $\Upsilon(4S)$?

b) [0.5] What energy would be needed for the positron beam to create an Υ if the energy of the electron beam was 8 GeV?

c) [0.5] Assume a decay of the $\Upsilon \to B^0 + \bar{B^0}$ ($m_{B^0} = 5279.6\ MeV/c^2$) and calculate the maximal decay length measured in the detector for a B-meson with the life time of $\tau = 1.51910^{-12}$s (assuming the beam energies used in Babar to create the Υ). Note the Lorentz transformation of the momentum in a moving frame in the direction of the motion: $p'_z = \gamma(p_z - \beta\ E/c^2)$

d) [1] The B^0 and $\bar{B^0}$ will decay into charged particles. Describe a device to measure the momenta of these and a method for particle identification (distinguishing the different masses).

4 Kaon decay / C / P transformation [1.5 points]

The K^+ meson has spin 0 and decays mainly via $\mathrm{K}^+ \to \mu^+\nu_\mu$. Assume the neutrinos in the following as massless particles.

a) [0.5] Sketch the momentum and spin directions in the rest system of the kaon and then apply to this a parity (P) transformation, a charge conjugation (C) transformation as well as the combination (CP) and sketch the spin and momentum directions in the resulting processes. Which of these processes are allowed? Give a brief explanation.

b) [0.5] Explain why the decay $\mathrm{K}^+ \to e^+\nu_e$ is in contrast to the decay into a muon almost not observed (would not be observed if the electron was massless).

c) [0.5] Explain if the decay $\mathrm{K}^+ \to \pi^0 e^+\nu_e$ should be possible taking hereby into account the considerations of b) (π^0 has also spin 0).

5 Nuclear decays [2 points]

Consider the Weizsäcker formula for nuclear masses as given below.

a) [0.6] What are the different contributions in the mass formula (as described by $a_v, a_s, a_c, a_a, \delta$) related to?

b) [0.7] Consider the particular case of $A = 40$ and the nuclei Cl, Ar, K, Ca and Sc, with $Z = 17, ..., 21$ respectively. Draw their masses (relative difference between them) as function of Z.

c) [0.7] Consider the possible β decay reactions between the nuclei. Indicate them with arrows between the nuclei. Which nucleus (or nuclei?) are (according to these calculations) stable?

Weizsäcker formula

$$M(A,Z) = NM_n + ZM_p + Zm_e - a_V A + a_S A^{2/3} + a_C \frac{Z^2}{A^{1/3}} + a_a \frac{(N-Z)^2}{4A} + \frac{\delta}{\sqrt{A}}$$

$a_V = 15.67 MeV/c^2$, $a_S = 17.23 MeV/c^2$, $a_C = 0.714 MeV/c^2$, $a_a = 93.15 MeV/c^2$,
$M_n = 939.6 MeV/c^2$, $M_p = 938.3 MeV/c^2$, $m_e = 0.511 MeV/c^2$

$$\delta = \begin{cases} -12.6\ MeV/c^2 & \text{for even } Z \text{ and } N \text{ (even-even nuclei)} \\ 0\ MeV/c^2 & \text{for odd } A \text{ (odd-even nuclei)} \\ +12.6\ MeV/c^2 & \text{for odd } Z \text{ and } N \text{ (odd-odd nuclei)} \end{cases}$$