Physics of Elementary Particles

Fall 2017

Exam 8th December 2017

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

1 Interactions [1.2 point]

a) [0.5] Specify the mediators of the different interactions together with all properties of the mediators, which you know of.

b) [0.4] What can you say about the strengths of the different interactions at close and far distances and relative to each other?

c) [0.3] Which elementary particles (not mediators) are affected by the different interactions?

2 Production of W/Z bosons [2 points]

The W/Z bosons were in detail investigated in electron-positron collisions at the Large Electron-Positron collider (LEP, 27km circular collider with equal energies of electron and positron beams, tunnel by now used by Lare Hadron Collider).

a) [0.4] Draw a Feynman diagram of their production (W pair production, Z production).

b) [0.2] Which energies do the electron and positron beam need to minimally have to produce these?

c) [0.5] The W/Z bosons were first produced using (anti-) protons in collisions. What energy is minimally needed for a proton beam to produce Z bosons in shooting the beam onto a fixed target? (Assume an average value of $< x_v >= 0.12$ for the valence quarks and $< x_s >= 0.04$ for the sea quarks)

d) [0.5] What beam energy would be needed for the Z production when colliding two proton beams of equal energy? Justify if you would recommend an anti-proton beam for the fixed-target collision and/or for the colliding beams.

e) [0.4] List criteria to choose building a linear or circular collider.

3 Kaon decay / C / P transformation [1.8 points]

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

a) [0.2] Sketch the momentum and spin directions in the rest system of the kaon.

b) [0.5] Briefly explain what parity (P) and charge conjugation (C) transformations are and apply these and also a combined (CP) transformation to the reaction and sketch the spin and momentum directions in the resulting processes. Which of these processes are allowed? Give a brief explanation.

* c) [0.4] Write a Feynman diagram of the subsequent muon decay containing an electron. What energy would you expect for the electron?

d) [0.4] Explain why the decay $K^+ \rightarrow e^+ \nu_e$ is in contrast to the decay into a muon almost not observed (would not be observed if the positron was massless).

e) [0.3] Explain if the decay $K^+ \rightarrow \pi^0 e^+ \nu_e$ should be possible taking hereby into account the considerations of b) (π^0 has also spin 0).

4 Weak decays [1.5 points]

The D^0 meson ($c\bar{u}$) can decay e.g. into $K^-\pi^+$ and $\pi^+\pi^-$, both mediated by the weak interaction (K^- is $s\bar{u}$, π^- is $d\bar{u}$, π^+ is $u\bar{d}$)

a) [0.4] What are mesons? What other stable quark configurations do you know?
b) [0.4] Draw the Feynman diagrams for the decays.
c) [0.2] Explain what you would expect for the ratio of the probabilities for the decays?
d) [0.3] Explain briefly what the Cabibbo angle is.
☆ e) [0.2] Draw a Feynman diagram for a semi-leptonic decay of the D^0 meson.

5 Particle detection [1.5 points]

Cherenkov detectors can be useful tools to identify the products from particle collision.

a) [0.5] Describe this identification method.

c) [0.5] Using aerogel with $n = 1.03$ what angular resolution would be needed to distinguish pions ($m = 140\ MeV/c^2$) and kaons ($m = 494\ MeV/c^2$) ($\cos\theta_C = \frac{1}{n*\beta}$).

d) [0.5] Describe another method for particle identificationion and the detector(s) involved

6 Nuclear decays [2 points]

Consider the Weizsäcker formula for atomic 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) [0.4] Consider the α decay of $^{238}_{94}Pu$ and the β^+ decay of $^{40}_{21}Sc$. Write down the full decays (atomic number for resulting element sufficient).

c) [0.6] Calculate from the Weisäcker formula for each decay the energy which should become available and sketch the energy spectrum as measured for the α particle respectively for the positron in the β decay.

d) [0.4] The potassium isotope $^{40}_{19}K$ decays in β^- decay. What should be the energy becoming available in this decay according to the formula (note that compared to the $^{40}_{21}Sc$ only N and Z are exchanged)? The calculation does not match the experimental findings in this decay, what could be the reason?

Weizsäcker formula:

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

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

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