Norwegian University of Science and Technology
Department of Physics

Contact: Jacob Linder
Phone: 735 918 68

Suggested solution for Exam FY3403: Particle Physics

NOTE: The solutions below are meant as guidelines for how the problems may be solved and do not necessarily contain all the detailed steps of the calculations.

PROBLEM 1

(a) See page 80 in 2nd edition of the book. It is not required that the student should remember the detailed analytical form of the expressions associated with the vertices in each case. For full score, it should be clear from the student's answer that there is cross-generational coupling between the quarks via weak interactions (Cabbibo angle) whereas there is not for leptons and which types of particles that can interact with the various mediators.

(b) See page 77-78.

(c) This is explained in detail in section 10.3. The student is not required to do the full analytical derivation for a full score, but the main points in the derivation should at least be qualitatively explained.

(d) See section 11.2. The student is not required to provide the full analytical derivation for a full score, but at least the distinction between mass and flavor eigenstates and how these are related to oscillations should be explained.

(e) Helicity is the projection of the spin on the direction of momentum.

(f) See section 10.9. The student is not required to reproduce the analytical derivation at all, but the main points and consequences of the Higgs mechanism should be described, including spontaneous symmetry breaking of a local continuous symmetry, the difference between Higgs field and Higgs boson, how one can make the Goldstone bosons disappear, and that this provides a way to make gauge fields massive.

(g) This theorem states that the laws of physics should be invariant under the combined operation of T, C, and P. The main experimentally measurable consequence is that particles should have the same mass and lifetime as their antiparticles.

(h) See page 285 in 2nd edition of textbook, in particular the footnote.

(i) See page 219-221 in 2nd edition of textbook. For a full score, the student must have discussed both the appearance of divergencies from higher-order diagrams, how these are handled, the finite sized contributions to the coupling constants and masses, the fact that these are energy/momentum-dependent, and preferably also given at least one concrete example of renormalization.

PROBLEM 2

(a) The weak interaction. See page 310 in the book for the diagram.

(b) Assuming that we can use the simplified version of the W propagator (small momentum transfer limit), $\mathcal{M}$ is given in eq. (9.15). The student should explain which rules that have been used to handle vertices, propagators, and external lines.

(c) The derivation is identical to Example 9.1 in the book with the only exception that $u(2)$ in that example is replaced with

$v(2)$. However, since the neutrino mass can be set to zero this is inconsequential. and the final answer is given in eq. (9.16) in the book.

(d) This is explained in detail on page 312. The student is not required to actually follow the analytical steps leading up to eq. (9.30) since the maximum and minimum energies can be found by pure reasoning (see text below eq. 9.30).

(e) The muon lifetime τ is equal to the inverse of the total decay rate Γ. Thus, one solves this problem by integrating $d\Gamma/dE$ over E and inverting the resulting expression, see e.g. equations (9.34) and (9.35) in the book.