Physics Beyond the Standard Model — Exercise Sheet 1

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1. **Baryogenesis: a very simple model**

   Assume the following: in the very early universe, very heavy particles of type X (which are neutral and equal to their corresponding antiparticles $X = \bar{X}$) were created (e.g. particles related to some Grand Unified gauge theory). Initially, they might have been in equilibrium with the rest, but at some point their interactions became too weak, so they effectively became sterile, interaction-less heavy relics. They were rather stable, with a lifetime of a millisecond or so. Then, after this time, when the rest of the universe had cooled down to a temperature of, say, less than 100 GeV, they decayed.

   a) Look up Sakharov's three necessary conditions for a dynamical generation of a baryon-antibaryon asymmetry in the universe.

   b) At the time of the decay, is Sakharov's condition of deviation from thermal equilibrium fulfilled? Why?

   c) Some possible decay modes might be:

   $$X \to p + \bar{n} + e^-, X \to p + \pi^- + \bar{n}, X \to \pi^0 \nu_e, X \to \bar{p} + e^+, X \to n + Z$$

   and corresponding decay modes might exist with the corresponding antiparticles in the final states. Maybe you can invent further decay modes. Choose some values of branching fractions which lead to a non-vanishing baryon-antibaryon asymmetry of the universe. Explain how the Sakharov criteria are fulfilled for your choice.

2. **A simplified "Standard Model"**

   What happens if you "simplify" the SM by requiring *only* $\mathrm{SU}(2)_L$ gauge invariance (you might set $g_3 = 0$ and $g_Y = 0$ in the usual SM Lagrangian)?

   Assume the Higgs potential and its minimum remains the same.

   Questions: How many gauge fields/gauge bosons exist in this theory? How many massive, how many massless gauge bosons exist? What are the non-vanishing gauge boson masses?

   Note: It is sufficient to evaluate the Lagrangian terms proportial to two powers of gauge fields and two powers of v!