DYNAMICAL MASSES AND THE PROTON-NEUTRON MASS DIFFERENCE PROBLEM

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The experimental fact that a neutral hadron may be heavier than its charged partner from the same isospin multiplet nowadays represents one of the outstanding problems of hadron physics. After several decades of studying why the neutron is heavier than the proton,

$$m_p - m_n = (-1.29 \pm 0.00)\ \text{MeV},$$

we are still unable to evaluate this mass shift. However, we at least understand why it is so difficult to calculate this number(1). It is, in fact, clear that a full answer to this question is certainly related to the fundamental questions concerning the internal structure of hadrons and the origin of hadron masses themselves.

Without pretension to solve the problem completely, what will be presented here is merely an effort to make a step forward. In this sense two classical models for geometrization of extended hadrons are considered. They naturally suggest the way how the mass shift should be calculated within a quantum-mechanical model(2).

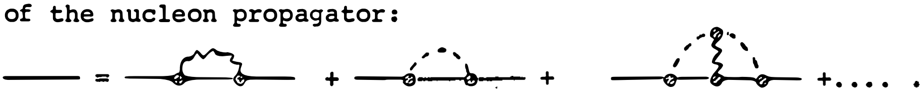
When the nucleon is considered as a classical cloud of hadronic matter with charge and magnetic moment densities as given by Fourier transforms of the corresponding electromagnetic form factors in the Breit frame one obtains

$$m_p - m_n = \frac{\alpha}{\pi} \int_0^\infty dq \left[1 - \frac{\kappa_P^2 - \kappa_N^2}{3m^2} q^2\right] G_D^2(-\vec{q}^{\,2}) = 0.73\ \text{MeV},$$

where $\alpha = 1/137$, κ is the anomalous magnetic moment, G_D is the famous dipole formula for form factors and m is the nucleon mass. The above result is consistent with the generalized Born approximation and suggests that a correct quantum-mechanical treatment must generate a significant contribution to the mass shift from the innermost region of the nucleon cloud.

Furthermore, if we visualize the nucleon cloud in the way as it is "seen" by an external electron in the process of elastic scattering, then the geometrical sizes are given by the measured electromagnetic effective radii. According to the data the neutron is effectively much smaller than the proton. The energy content of the neutron's central region leads indeed to $m_p - m_n < 0$.

At a relativistic quantum-mechanical level, a physical nucleon, being a bag of hadronic matter, is subject to fluctuations. For a certain fraction of time it may be found in any hadronic state having quantum numbers of the nucleon. Accepting the basic idea that the mass is of dynamical origin, in the presence of the strong and the electromagnetic interaction we may write a formal diagrammatical expansion of the nucleon propagator:



Here the full line represents a nucleon, the dashed line a pion and the wavy line a photon. This is the way how the nucleon generates its strong and electromagnetic masses. The smallness of the fine structure constant makes the single photon approximation meaningful. On the other hand, the uncertainty principle suggests that the dominant hadronic components of the internal structure are those with lightest hadrons in the nucleon cloud. While the strong mass contribution cancels in the difference m_p-m_n, we are left to evaluate the first and third diagrams in the above equation. The first diagram is the generalized Born term, while the third one actually represents a radiative correction to the strong mass[3]. The last term is very difficult to evaluate. Its contribution to m_p-m_n is negative, as expected[3]. Of course, diagrams with the same topology when pions are replaced by kaons should also be included. Their effect proceeds in the same direction, but is of less significance.

References

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