
Application of the chiral forces to electroweak processes

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CHAPTER 1

INTRODUCTION

In the second half of XX century physical society faced a problem of describing low-energetic nuclear reactions. Quantum chromodynamics (QCD) is hardly applicable here as it is nonperturbative at low energies what complicates a lot search for the solutions [1].

In the early 1990-ies Weinberg [2, 3] introduced an idea of using a most general Lagrangian satisfying assumed symmetry principles and in particular spontaneously broken chiral symmetry to describe nuclear interactions at low energies. This idea together with effective field theory (EFT) of QCD led to the development of Chiral effective field theory (χ EFT) which nowadays has become one of the most advanced approach to describing nuclear reactions at low energies.

For the EFT it is very important to define a quantity, which powers will determine a perturbation order. In the χ EFT there are two natural scales: so-called soft scale - the mass of Pion $Q \sim M_\pi$ and hard scale - $\Lambda_\chi \sim 1 \text{ GeV}$ (chiral symmetry breaking scale). The ratio between these two scales $(Q/\Lambda_\chi)^\nu$ is being used as an expansion parameter in χ EFT with power ν .

Considering so-called irreducible (the diagrams that cannot be split by cutting nucleon lines), Weinberg [2, 3] came to the identity for the powers of such diagrams[1]:

$$\nu_W = 4 - A - 2C + 2L + \sum_i \Delta_i, \quad (1.1)$$

where

$$\Delta_i \equiv d_i + \frac{n_i}{2} - 2 \quad (1.2)$$

In 1.1, C is a number of pieces which are connected, L - the number of loops in the graph. In 1.2, n_i is a number of nucleon field operators, d_i - the number of insertions (or derivatives) of M_π .

CHAPTER 2

PLAN

- Why we study few nucleon systems
 - Strong interactions (2N and 3N force investigation; QCD, relativistic effects)
 - Electro-magnetic processes (electrons-, photons-induced reactions) (Arenhovel did ...)
 - Weak interactions (neutrons)
- Nuclear forces used in the thesis
 - AV18
 - Chiral (scs, sms; difference between chiral models; regularization problem)
- Currents used in the thesis (regularization of currents to be done)
- Formalism & numerical methods
 - Lippman-Schwinger eq
 - Schrodinger eq for deuteron; wave functions (sms) for deuteron - figures, binding energy
 - Three body: Fadeev eq. for bound (He3, H3) and scattering states
 - Partial wave decomposition, states ($pq\alpha$), Jakobi momenta; operators in PW decomp. (current); Mathematica for PW
 - Theoretical uncertainties: truncation error, cut-off dependency, chiral order dependency
- Results (**find everything what I have calculated: all processes and energies**)
 - H2 photodisintegration
 - He3 and H3 photodisintegration
 - Pion capture
- Summary
- References

BIBLIOGRAPHY

- [1] R. Machleidt and D. R. Entem. Chiral effective field theory and nuclear forces. *Phys. Rept.*, 503:1–75, 2011.
- [2] Steven Weinberg. Nuclear forces from chiral lagrangians. *Physics Letters B*, 251(2):288–292, 1990.
- [3] Steven Weinberg. Effective chiral lagrangians for nucleon-pion interactions and nuclear forces. *Nuclear Physics B*, 363(1):3–18, 1991.