The Effective Range Parameters for Nucleon-Nucleon Scattering at Low Energies

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Abstract: We know that the Quantum Chromodynamics (QCD) fails at low energies. For example, within QCD, we cannot calculate precise mass and spin of nucleons. It does not concern the Scale-Symmetric Theory (SST). Moreover, experimental data show that at low energies the effective range parameters for nn, np, and pp scatterings are similar, but different. Why? Here, applying SST, we calculated the effective range parameters for nn (2.732 fm), for np (2.778 fm), and pp (2.824 fm). These theoretical results are consistent with experimental data. At low energies, the effective range parameters follow from exchanges of virtual pions (which are responsible for the nuclear strong interactions) and production of the virtual condensates (which are responsible for the nuclear weak interactions at low energies). The condensates insignificantly increase the effective ranges. Just at low energies, the effective range parameters for nucleons follow from their strong-weak interactions described within SST. The obtained here and within SST results show that QCD is the incomplete and partially incorrect theory - the same concerns the electroweak theory at low energies.

1. Introduction

The extended General Relativity leads to the inflation field composed of the non-gravitating tachyons (the modified Higgs field) [1]. The succeeding phase transitions of such field lead to different scales described within the Scale-Symmetric Theory (SST) [1]. Within the theory of one of such scales we proved that baryons have the atom-like structure [1].

In baryons, there is the core composed of the torus/charge responsible for the nuclear strong interactions (it produces the pions) and of the ball/condensate in its centre responsible for the nuclear weak interactions. Both the charge and condensate consist of the entangled or confined Einstein-spacetime components i.e. of the neutrino-antineutrino pairs. Equatorial radius of the torus/charge is $A = 0.6974425$ fm. Radius of the condensate is $r_{p(proton)} = 0.8710945 \cdot 10^{-17}$ m $= 0.008710945$ fm ([1]: see formula (49)). Outside the core are the four S states of pions. Radius of the last shell is $R = A + 4B$, where $B = 0.5018395$ fm ([1]: see explanation below formula (31)). The four S states are placed on the plane perpendicular to the half-integral spin of the core. Calculated here the effective range parameters concern such plane so the spins of nucleons must be aligned.

On the surface of the torus/charge are produced virtual bosons and range of the remainder with a mass of $M_{Remainder} = 187.537$ MeV is $4B = 2.007358$ fm ([1]: see the explanation between formulae (31) and (33)). Knowing this range, we can calculate ranges of virtual pions produced by the core of baryons. Initially, centers of the emitted virtual pions overlap with centre of the core. There appear the virtual spheres which radii are defined by the ranges of the virtual pions.

The virtual condensates appear as well on surfaces of the virtual spheres. Condensates that surfaces are tangent to surfaces of the virtual spheres produced by pions increase the range of the strong-weak interactions of nucleons. The condensates produce the standing waves in such a way that the distance between the standing-wave nodes is equal to the size of the condensates i.e. $\lambda = 4\ r_{p(proton)}$. Such method we applied with very good effect in following papers [4], [5]. The increased range of the strong-weak interactions, $R_{range,strong-wak}$, is $R_{range,strong-weak} = R_{range,strong} + \lambda$.

Notice as well that the virtual pions in the strong interactions behave analogically as the photons in the electromagnetic interactions i.e. the virtual pions are emitted when the core of nucleons is charged i.e. are emitted by the charged.core-charged.pion state of the neutrons and by the charged.core-neutral.pion state of the protons ([1]: see formulae (36)-(39)), i.e. at low energies, the neutrons emit virtual charged pions whereas protons emit virtual neutral pions.

2. Calculations

Range, R_{range}, of a virtual or real particle is inversely proportional to its mass M

$$R_{range} = 1 / M. \tag{1}$$

The remarks in Introduction and formula (1) lead to following formula for the effective range parameter r_o

$$r_o = 4\ B\ M_{Remainder} / M + 4\ r_{p(proton)}\ , \tag{2}$$

where B = 0.5018395 fm, $M_{Remainder}$ = 187.537 MeV, $r_{p(proton)} = 0.8710945 \cdot 10^{-17}$ m = 0.008710945 fm.

Table 1. *Effective range parameters r_o*

Aligned-spin NN scattering	Exchanged pions	**Effective range parameter (fm)** Experimental data [2]	**Effective range parameter (fm)** Scale-Symmetric Theory: formula (2)
nn	$\pi^{-,+}$	2.75 ± 0.11	2.732
np	$\pi^{-,+}$ or π^o	2.77 ± 0.05	2.778
pp	π^o	2.85 ± 0.04	2.824

Applying formula (2), for charged pion, $M_{charged-pion}$ = 139.5718(35) MeV [3], we obtain

$$r_{o,nn} = 2.73208\ \text{fm} \approx 2.732\ \text{fm}\ . \tag{3}$$

For neutral pion, $M_{neutral-pion}$ = 134.9766(6) MeV [3], we obtain

$$r_{o,pp} = 2.82387\ \text{fm} \approx 2.824\ \text{fm}\ . \tag{4}$$

For the np scattering is the mean value

$$r_{o,np} = (r_{o,nn} + r_{o,pp}) / 2 \approx 2.778 \text{ fm} . \quad (5)$$

3. Summary

Contrary to the Scale-Symmetric Theory (SST), the Quantum Chromodynamics (QCD) fails at low energies. For example, within QCD, we cannot calculate precise mass and spin of nucleons and effective range parameters for aligned-spin NN scatterings at low energies.

Here, applying SST, we calculated the effective range parameters for nn (2.732 fm), for np (2.778 fm), and pp (2.824 fm). These theoretical results are consistent with experimental data.

At low energies, the effective range parameters follow from exchanges of virtual pions (which are responsible for the nuclear strong interactions) and production of the virtual condensates (which are responsible for the nuclear weak interactions at low energies). The condensates insignificantly increase the effective ranges. Just at low energies, the effective range parameters for nucleons follow from their strong-weak interactions described within SST.

The obtained here and within SST results show that QCD is the incomplete and partially incorrect theory. The same concerns the electroweak theory at low energies. For example, the neutrinos at low energies can exchange the entanglons only which are responsible for the quantum entanglement [1]. At low energies, the neutrinos cannot emit the virtual W or Z bosons. If at low energy the neutrinos could emit the virtual W and Z bosons then matter should not be practically transparent for them.

References

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