**The Microscopic Origin of Nuclear Force Short-Range Nature: A Unified Model Based on Field-Composition Wave Dynamics and Gluon Exchange**

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**Abstract:**Based on Li Zhijun’s ABC field-composition theory, this paper proposes a unified theoretical framework to describe the short-range nature of the nuclear force. The core argument is: The short-range nature of the nuclear force stems from two essential characteristics of its microscopic mechanism: 1) The nucleon, as a composite field-composition state, has an intrinsic quark-gluon wavefunction with a strongly localized distribution; 2) The nuclear force is realized through the exchange of gluons, and the effective propagation of gluons is confined within a critical coherence length determined by the locality of the nucleon wavefunction. This paper first provides a rigorous mathematical definition of the nucleon’s field-composition wavefunction and the nonlinear coupled Schrödinger-Dirac equations it satisfies. Furthermore, through multi-body wavefunction overlap integrals and the calculation of the quantum expectation value of the gluon propagator, the expression for the proton-neutron equivalent interaction potential is rigorously derived. Mathematical calculations show that this potential is the result of the convolution between the nucleon’s intrinsic structure and the gluon propagator, which necessarily exhibits short-range behavior of the form for where This model, for the first time, unifies the nucleon’s intrinsic structure and the exchange mechanism of the interaction within a wave-dynamics mathematical framework, providing a complete and self-consistent explanation for the short-range nature, saturation, and exchange character of the nuclear force.

**Keywords:** ABC field-composition theory; Nuclear force short-range nature; Gluon exchange; Nonlinear Schrödinger-Dirac equation; Wavefunction overlap; Propagator

1. **Introduction: Construction of a Unified Framework**

The short-range nature (~1 fm) of the nuclear force is a core problem in nuclear physics. Traditional theory attributes it to the finite mass of the meson. This paper aims to provide a more fundamental and unified microscopic explanation: The short-range nature of the nuclear force is both an emergent property of the nucleon’s intrinsic wavefunction structure as a composite particle (field-composition wave dynamics) and a quantum field effect manifested by the strong interaction force through the fundamental process of gluon exchange. Both are unified under the mathematical framework of quantum wave dynamics.

1. **Theoretical Framework: Nucleon’s Intrinsic Structure and Interaction Mechanism**

**2.1 Nucleon’s Field-Composition Wavefunction and Dynamical Equations**

The field-composition state of a nucleon (proton or neutron) is constituted by the direct product of the wavefunctions of three vortex fields:

Where:  
\* : Dirac spinor wavefunction of the electromagnetic vortex field (A-field), describing charge distribution and electromagnetic interaction.  
\* : Color spinor wavefunction of the chromo-charge vortex field (B-field), describing color charge distribution and strong interaction.  
\* : Scalar wavefunction of the Higgs vortex field (C-field), describing mass density distribution.

Its evolution is described by nonlinear coupled Schrödinger-Dirac equations:

The nonlinear term is the mathematical root of color confinement, leading to a highly localized B-field wavefunction.

**2.2 Nuclear Force as a Quantum Field Effect of Gluon Exchange**

The nuclear force is a residual strong interaction generated by the exchange of gluons between quarks inside nucleons. The equivalent interaction potential between two nucleons originates from their color current-color current correlation:

Where:  
\* is the quark color current density within the nucleon, its distribution determined by the nucleon wavefunction .  
\* is the gluon propagator, whose free form in the QCD vacuum is

1. **Unified Derivation of the Nuclear Force’s Short-Range Nature**

The short-range nature of the nuclear force is an inevitable result of the combined action of intrinsic structure and propagation mechanism.

**3.1 Locality Effect of the Nucleon’s Intrinsic Structure**

Solving the dynamical equations yields the nucleon’s intrinsic density distribution:  
\* Color charge density distribution:   
\* This strongly localized distribution confines the color current source within a range of ~1 fm.

**3.2 Locality Correction to Gluon Propagation**

The dense color charge distribution inside the nucleon polarizes the surrounding QCD vacuum, thereby modifying the propagation behavior of gluons. The effective propagator is no longer free; its momentum-space form is corrected to:

Where the polarization function reflects the screening effect of the nucleon’s intrinsic structure on gluon propagation. For a localized source:

This causes the propagator in real space to take the form of a Yukawa potential:

**3.3 Convolution and Rigorous Proof of Short-Range Nature**

The equivalent potential is the convolution of the source distribution and the effective propagator:

Substituting and and rigorously calculating this integral via Fourier transform and the residue theorem, yields:

When the dominant term is The short-range nature of the nuclear force is proven.

1. **Conclusion**

This paper establishes a unified microscopic model for the short-range nature of the nuclear force, drawing the following conclusions:  
1. Dual Origin: The short-range nature of the nuclear force stems from both the strong locality of the nucleon’s intrinsic wavefunction (field-composition wave dynamics) and the finite-range propagation of gluons in a polarized vacuum (gluon exchange mechanism).  
2. Mathematical Essence: The nuclear force potential is the result of the convolution between a localized source distribution and a Yukawa-type propagator. Its mathematical form is an inevitable product of this convolution.  
3. Parameter Determination: The characteristic mass is not a fundamental particle mass but is determined by the nucleon’s intrinsic scale through whose value coincides with that of   
4. Unified Framework: This model integrates the internal structure of the nucleon and its external interactions into a unified wave-dynamics framework, providing a complete, self-consistent, and profound physical picture for understanding the short-range nature of the strong interaction.

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