**The Microscopic Origin of Interaction Range: A Unified Model Based on Photon and Meson Field-Composition Wavefunctions**

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**Abstract:**  
Based on Li Zhijun’s ABC field-composition theory, this paper proposes a unified microscopic wave-dynamics model to explain the range of interactions (long-range and short-range). The core argument is: The range of an interaction depends on the intrinsic properties of its propagator’s field-composition wavefunction—specifically, whether the mass of the propagator field’s dominant component is zero. The photon field composition due to its A-field component’s zero mass supports arbitrarily large wavelength modes, resulting in the electromagnetic force exhibiting a long-range potential. The meson field composition due to its C-field component’s non-zero effective mass has its wavefunction restricted in momentum space to Fourier transformation of this leads to the nuclear force exhibiting a short-range Yukawa potential. This paper rigorously calculates the coherent superposition integrals and Fourier transforms of these two types of propagator wavefunctions, uniformly deriving both the Coulomb and Yukawa potentials, thereby revealing the microscopic mechanism for the difference in interaction range from first principles. This model integrates electromagnetic and nuclear forces into a unified field-composition wavefunction framework, providing a profound physical picture for understanding the scale characteristics of fundamental interactions.

**Keywords:** ABC field-composition theory; Interaction range; Photon field composition; meson field composition; Propagator; Coulomb potential; Yukawa potential

1. **Introduction: A Unified Framework for the Problem of Interaction Range**

Fundamental interactions in nature have vastly different ranges: the electromagnetic force is theoretically infinite in range, while the nuclear force is about 1 femtometer (fm). Traditional theories explain this separately using the photon’s zero mass and the meson’s finite mass. This paper aims to establish a unified wave-dynamics model that reveals the common essence of this range difference from the intrinsic properties of field-composition wavefunctions.

1. **Theoretical Framework: Propagator Field-Composition Wavefunctions and Interaction Range**

**2.1 General Formulation of Propagator Field-Compositions**

The propagator of any interaction can be regarded as a field-composition state:

where X represents the type of propagator (e.g., or ). Its range depends on the overall properties of this state, particularly its effective mass determined by the mass of the dominant field.

**2.2 Photon Field-Composition: Origin of Long-Range Force**

The photon’s field-composition state is:

\* Dominant field: Electromagnetic vortex field (A-field), with rest mass

* Wavefunction (Characteristic): The A-field wavefunction satisfies the massless wave equation Its plane wave solution supports infinite wavelength modes as .
* Effective mass:

**2.3 Meson Field-Composition: Origin of Short-Range Force**

The meson’s field-composition state can be expressed as:

\* Dominant field: Higgs vortex field (C-field), with an effective mass (originating from spontaneous chiral symmetry breaking).

* Wavefunction特性 (Characteristic): The C-field wavefunction satisfies the massive Klein-Gordon equation Its wavevector is restricted to unable to support modes with wavelengths .
* Effective mass:

1. **Unified Derivation: From Wavefunction to Interaction Potential**

The interaction potential is the Green’s function of the propagator wavefunction in coordinate space, obtained by calculating the Fourier transform of its propagator

**3.1 Photon Propagator and Coulomb Potential (Long-Range)**

The photon propagator in momentum space is:

Due to its massless nature in the static limit the propagator becomes:

Performing a three-dimensional Fourier transform on this, i.e., calculating the integral:

This integral converges to:

Therefore, the electromagnetic potential is the Coulomb potential: with infinite range.

**3.2 Meson Propagator and Yukawa Potential (Short-Range)**

The meson propagator in momentum space is:

Due to its massive nature in the static limit, the propagator becomes:

Performing a three-dimensional Fourier transform:

This integral can be calculated using spherical coordinates:

Using the residue theorem, this integral evaluates to:

Therefore, the nuclear force potential is the Yukawa potential: where the range

1. **Comparison and Unification: The Wave-Dynamic Interpretation of Range**

The following table uniformly compares the two interactions from the perspective of field-composition wavefunctions:

| **Characteristic** | **Electromagnetic Force (Photon Field-Composition)** | **Nuclear Force ( Meson Field-Composition)** |
| --- | --- | --- |
| Propagator Field-Composition |  |  |
| Dominant Field | A-field (Electromagnetic field) | C-field (Higgs field) |
| Dominant Field Mass |  |  |
| Allowed Wave Modes | All |  |
| Propagator |  |  |
| Potential | Coulomb potential | Yukawa potential |
| Range | Infinite | Finite, |
| Physical Mechanism | A-field mass zero, supports global coherence | C-field effective mass cuts off long-wavelength modes |

1. **Conclusion**

By constructing field-composition wavefunction models for the photon and the meson, this paper provides a unified explanation for the microscopic origin of interaction range:

1. Unification: Both long-range and short-range interactions can be understood within the framework of field-composition wavefunctions. Their range depends on whether the mass of the propagator field’s dominant component is zero.
2. Mathematical Essence: The difference in range mathematically stems from the different pole positions of the propagator’s Green’s function in momentum space ( vs. ), leading to and after Fourier transformation, respectively.
3. Physical Picture: A massless field supports excitations of any long wavelength, leading to global coherence and a long-range force. A massive field’s excitation has a gap, suppressing long-wavelength modes, leading to local coherence and a short-range force.
4. Theoretical Depth: This model not only uniformly describes the difference in range but also profoundly reveals the fundamental role of “mass” in determining the spatiotemporal scale of interactions, providing a new perspective for exploring deeper physical laws.

**References**  
[1] Li, Z.J. “On the Unified Origin of Interaction Range from Field-Composition Wavefunctions”. Preprint (2023).  
[2] Peskin, M.E., Schroeder, D.V. An Introduction to Quantum Field Theory. Westview Press (1995).  
[3] Yukawa, H. “On the Interaction of Elementary Particles”. Proc. Phys. Math. Soc. Japan (1935).  
[4] Feynman, R.P. “Space-time approach to quantum electrodynamics”. Phys. Rev. (1949).  
[5] Weinberg, S. The Quantum Theory of Fields: Foundations. Cambridge University Press (1995).