T**he Photon Field-Composition Wavefunction Mechanism of Electromagnetic Force’s Long-Range Nature: A Mathematical Model Based on Large-Wavelength Coherent Superposition**

**Authors:** Li Zhijun, Zhao Guangyao

**Abstract:**  
Based on Li Zhijun’s ABC field-composition theory, this paper proposes a rigorous wave-dynamics model to explain the long-range nature of the electromagnetic force (theoretically infinite action distance). The core argument is: The long-range nature of the electromagnetic force stems from its propagator—the photon—having a field-composition wavefunction with an extremely large characteristic wavelength (theoretically infinite), which causes its equivalent potential to decay slowly at long distances (following the Coulomb’s law form of ). This paper constructs the mathematical formulation of the photon’s field-composition wavefunction wherein the dominant electromagnetic vortex field (A-field) wavefunction satisfies a massless wave equation, whose solutions naturally support plane wave modes of any large wavelength. By calculating the quantum expectation value of the photon propagator in momentum space, , and performing its Fourier transform using the residue theorem, the Coulomb potential form in coordinate space, , is rigorously derived. This model demonstrates that the long-range nature of the electromagnetic force is a direct manifestation of the photon’s massless property within the dynamics of its field-composition wavefunction, forming a sharp contrast with short-range nuclear forces.

**Keywords:** ABC field-composition theory; Electromagnetic force; Long-range force; Photon field-composition wavefunction; Propagator; Coulomb’s law

1. **Introduction: The Puzzle of Electromagnetic Force’s Long-Range Nature and the Wavefunction Perspective**

The electromagnetic force is one of the fundamental forces in nature with the longest action distance; its potential energy decays with distance as , contrasting sharply with the short-range nature of nuclear forces (). Traditional quantum electrodynamics (QED) attributes this to the zero rest mass of the photon (the propagator of the electromagnetic force). From the wavefunction perspective of the ABC field-composition theory, this paper proposes a more profound view: The long-range nature of the electromagnetic force本质上 (essentially) stems from the fact that within the field-composition wavefunction of its propagator—the photon—the dominant electromagnetic vortex field (A-field) component, due to its massless property, can exist and coherently superimpose modes of any large wavelength (low momentum); these long-wavelength modes contribute the primary amplitude in long-distance interactions.

1. **Theoretical Framework: The Photon’s Field-Composition Wavefunction and Dynamics**

**2.1 Definition of the Photon’s Field-Composition Wavefunction**

In the ABC theory, the photon’s field-composition state can be expressed as:

Where:  
• is the wavefunction of the electromagnetic vortex field (A-field), it is the main carrier of photon energy, manifests as a transverse wave, and describes the wave nature and propagation of the photon. Its massless property () is key to the long-range force.

• is the ground state wavefunction of the chromo-charge vortex field (B-field), representing that the photon carries no color charge (color singlet).

• is the ground state wavefunction of the Higgs vortex field (C-field), representing the photon’s effective rest mass being zero ().

Since the B-field and C-field are in their ground states with minimal energy contribution, the physical properties of the photon are primarily determined by the A-field wavefunction

**2.2 Dynamical Equation of the Photon’s A-Field Wavefunction**

The free evolution of the photon’s A-field is described by the massless Klein-Gordon equation (or more precisely, by its quantum field theory form):

Its plane wave solution takes the form:

where is the four-dimensional wavevector, satisfying the massless dispersion relation , i.e., . This relation allows the wavevector to take arbitrarily small values, corresponding to wavelengths that can be arbitrarily large. This is the mathematical root of the long-range force.

When an external source current is present, the evolution of the A-field is described by the coupled Maxwell’s equations:

where

1. **Electromagnetic Force as a Wavefunction Superposition Process via Photon Exchange**

The electromagnetic interaction between two charged particles (e.g., electrons) is achieved by exchanging virtual photons. This process, at the wavefunction level, can be understood as: the virtual photon field-composition wavefunction emitted by one electron propagates to the position of the other electron and is absorbed by it. The contributions from all possible momentum (i.e., all possible wavelength) modes of the virtual photon need to be coherently superimposed (i.e., integrated).

**3.1 Photon Propagator and Interaction Potential**

In quantum field theory, the interaction amplitude between two currents is given by the expectation value of the photon propagator. In momentum space, the photon propagator is:

where Due to the photon being massless (), the propagator has a pole at This pole means that at low energy scales (small ), the value of the propagator can be very large, making the contribution of long-wavelength (large wavelength) modes significant.

The interaction potential energy between two stationary point charges (with charges and ) can be obtained by calculating the Fourier transform of the photon propagator. In the Lorentz gauge, the static potential relates to the propagator as:

**3.2 Rigorous Derivation of the Coulomb Potential (Mathematical Proof of Long-Range Nature)**

Calculating the above integral yields the Coulomb potential. Using spherical coordinates:

Simplified:

First, integrate over u:

Substitute back:

The known integral (for r>0). Therefore:

This is precisely the form of Coulomb’s law; the potential energy decays as , with an infinite range. The key to the derivation lies in the photon being massless, causing the propagator denominator to be rather than which makes the integral converge to the form. If the photon had mass (), the propagator would become , and the integration result would be the Yukawa potential with a finite range.

1. **Conclusion**

Based on the ABC field-composition theory, this paper establishes a wave-dynamics model for the long-range nature of the electromagnetic force, drawing the following conclusions:  
1. Fundamental Origin: The long-range nature of the electromagnetic force stems from the massless property of its propagator (the photon), which allows modes of any large wavelength (low momentum) to exist and be coherently superimposed within its field-composition wavefunction (especially the A-field wavefunction).  
2. Mathematical Proof: By calculating the Fourier transform of the massless photon propagator, the Coulomb potential is rigorously derived, proving its long-range nature from first principles.  
3. Physical Picture: Electromagnetic interaction is realized through the exchange of virtual photons. The wavefunctions of these virtual photons contain all possible wavelength components. Those components with extremely large wavelengths can effectively connect charges over long distances, thereby allowing the interaction to extend to very far ranges.  
4. Unified Perspective: This model treats the photon as a complete field-composition state, whose long-range characteristics are determined collectively by the respective properties and composition of the A, B, and C fields, providing a unified wavefunction perspective for understanding fundamental interactions.

**References**[1] Li, Z.J. “On the Wave-Function Mechanism of Long-Range Electromagnetic Force”. Preprint (2023).  
[2] Peskin, M.E., Schroeder, D.V. An Introduction to Quantum Field Theory. Westview Press (1995).  
[3] Jackson, J.D. Classical Electrodynamics (3rd ed.). Wiley (1999).  
[4] ’t Hooft, G. “Gauge Theories of the Forces between Elementary Particles”. Scientific American (1980).  
[5] Feynman, R.P. “The Theory of Positrons”. Physical Review (1949).