**The Coherent Superposition Law of Quark-Gluon Color-Charge Colorless State Wavefunctions in Hadrons**

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**Abstract:**  
This paper aims to reveal the wave-dynamic coherent superposition laws followed by the internal quark and gluon field-combination wavefunctions of hadrons (protons, neutrons) when forming overall color neutrality. The core argument is: The color neutrality of hadrons results from the color-charge wavefunctions of the quark and gluon fields undergoing coherent superposition in specific patterns, achieving constructive interference (forming stable wave packets) and destructive interference (canceling color-charge expectation values), ultimately resulting in a stable wave packet with an overall wavefunction color-charge expectation value of zero. This paper constructs the coherent superposition operator for color-charge wavefunctions and proves that its eigenstates satisfy the color singlet condition By analyzing the specific wavefunction configurations of the proton (uud) and neutron (udd), the necessary phase matching condition and amplitude matching condition for their color-charge wavefunction coherent superposition are derived. This work彻底 (thoroughly) transforms the problem of hadron structure into a problem of wavefunction interference and superposition, providing a new wave-dynamic perspective for understanding color confinement.

Keywords: ABC field-composition theory; Color singlet; Wavefunction coherent superposition; Phase matching; Amplitude matching; Color-charge operator expectation value

1. **Introduction: Color Neutrality as a Problem of Wavefunction Coherent Superposition**

The color neutrality of hadrons (e.g., protons, neutrons) is the cornerstone of Quantum Chromodynamics (QCD). Traditional theory regards it as a zero sum of color charges. This paper proposes a more fundamental wave-dynamic viewpoint: The color neutrality of a hadron is the inevitable result of the coherent superposition of the color-charge wavefunctions of its internal quark and gluon field combinations in specific patterns, achieving constructive interference (forming stable wave packets) and destructive interference (canceling the color-charge expectation value).

1. **Theoretical Framework: Coherent Superposition Theory of Color-Charge Wavefunctions**

**2.1 Mathematical Formulation of Color-Charge Wavefunctions and Color-Charge Operators**

Let be the color-charge wavefunction of a field combination; it is a vector in the representation space of the SU(3) color group. The color-charge operators act upon it. Color neutrality requires its expectation value to be zero:

This condition is equivalent to being in the singlet representation of the SU(3) group.

**2.2 Coherent Superposition Operator and Color Singlet Condition**

Define the coherent superposition operator Its action is to combine multiple color-charge wavefunctions into an overall color-neutral wavefunction:

where incorporates projection and phase adjustment:

Here, is the operator projecting onto a specific color channel, and is the phase factor ensuring constructive interference in that channel. The necessary and sufficient condition for to be a color singlet is:

**2.3 General Conditions for Coherent Superposition**

To achieve the superposing wavefunctions must satisfy:

1. Amplitude Matching Condition:

where are the superposition coefficients, and is the eigenvalue of the i-th component on the color group generator.

1. **Phase Matching Condition:**

This condition ensures the wavefunctions interfere constructively at the superposition point, forming a stable wave packet.

1. **Application: Coherent Superposition Modes of Protons and Neutrons**

**3.1 Coherent Superposition Mode of the Proton (uud)**

The color-charge wavefunction of the proton is a coherent superposition of three quark wavefunctions:

Its coherent superposition path is:

\* Amplitude Matching: The color-charge eigenvalues of each path satisfy

* Phase Matching: Requires to achieve constructive interference in the color singlet channel.
* Overall Color Neutrality:

**3.2 Coherent Superposition Mode of the Neutron (udd)**

The color-charge wavefunction of the neutron is another coherent superposition path:

Its coherent superposition path is:

\* Amplitude Matching: Each path satisfies

* Phase Matching: Requires to achieve constructive interference.
* Overall Color Neutrality:

1. **Mathematical Expression: Dynamical Equation of Coherent Superposition**

The coherent superposition of color-charge wavefunctions is described by the following nonlinear Schrödinger equation:

Where:  
\* is the nonlinear self-interaction term, which causes the wave packet to self-focus, maintaining its spatial locality.

* is the coherent coupling term, which forces the wavefunction to evolve towards the color singlet channel.

The stable solutions of this equation are the color-charge wavefunctions of the proton or neutron,

1. **Conclusion**

This paper reveals the wave-dynamic mechanism of hadron color neutrality formation, drawing the following conclusions:  
1. Essence of Color Neutrality: The color neutrality of hadrons results from the coherent superposition of quark and gluon color-charge wavefunctions, leading to a color-charge operator expectation value of zero.  
2. Coherence Conditions: Superposition requires amplitude matching and phase matching to form a stable color singlet wave packet.  
3. Dynamical Equation: This process is described by a nonlinear Schrödinger equation with projection terms, whose stable solutions correspond to the specific wavefunction configurations of protons and neutrons.  
4. Unified Physical Picture: It transforms the problem of color confinement into a problem of wavefunction interference and stability, providing a new, more fundamental wave-dynamic perspective for understanding hadron structure.

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