Origin of the Baryon Mass Spectrum and Charge Structure: An ABC Theoretical Model Based on the Coupling of Positive and Negative Color Charge Fields  
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Abstract:  
This paper proposes a comprehensive model based on Li Zhijun’s ABC theory to explain the origin of the baryon mass spectrum and charge structure. The core argument is that the fundamental distinction between up and down quarks lies in their coupling to different components of the color charge vortex field: up quarks couple to the branches (red, green, blue) of the positive color charge field while down quarks couple to the branches (anti-red, anti-green, anti-blue) of the negative color charge field This intrinsic difference, mediated through gluon field interactions (excitation states of the B field), determines the mass difference between protons and neutrons and the distribution of charge. We construct a modified QCD Lagrangian incorporating the coupling of positive and negative color charge fields, derive the field-operator expression of the mass matrix, and compute the N–Δ mass splitting and proton–neutron mass difference using a field-theoretic version of the Bag model. For the first time, this model offers a unified explanation of the static properties of baryons from the perspective of field composition, providing a novel insight into nucleon structure.

Keywords: ABC theory; positive and negative color charge fields; baryon mass spectrum; charge structure; mass matrix; Bag model

1. Introduction

Although the Standard Model of particle physics has been highly successful in describing elementary particles and their interactions, it leaves some fundamental questions unanswered. For example, why does the up quark carry a charge of +2/3e while the down quark carries -1/3e? Why is there a small but significant mass difference between the proton and the neutron? The origins of these fundamental parameters remain unknown. Based on Li Zhijun’s ABC (Electromagnetic–Color Charge–Higgs) vortex field theory, this work aims to provide a foundational explanation for these questions. We propose that the most essential distinction between quarks lies not only in their masses and charges but also in their coupling to the cosmic background field—the color charge vortex field. Specifically, the up quark couples to the positive color charge vortex field while the down quark couples to the negative color charge vortex field This fundamental difference in field coupling, manifested through strong interaction dynamics, ultimately determines the observed charge signs, mass values, and overall properties of baryons.

1. Theoretical Framework: Field-Composition-Based Redefinition of Quarks

In the ABC theory, a complete description of an elementary particle must include its coupling information to the three fundamental fields: A, B, and C. For quarks, the mode of coupling to the color charge field B is the key distinguishing feature.

• Field composition of the up quark: The up quark is defined as a fermion coupled to a specific branch (red, green, or blue) of the positive color charge vortex field Its quantum state is expressed as:

where denotes coupling to a positive color charge branch (c = r, g, b) of the field.

• Field composition of the down quark: The down quark is defined as a fermion coupled to a specific branch (anti-red, anti-green, or anti-blue) of the negative color charge vortex field Its quantum state is expressed as:

where denotes coupling to a negative color charge branch of the field.

Field-Theoretic Interpretation of Charge:  
In this framework, the sign and magnitude of charge are determined by the topological quantum numbers associated with ABC field couplings. Coupling to a field branch yields a positive charge, while coupling to a field branch yields a negative charge. The charge magnitude (2/3 versus 1/3) is determined by the number of coupled branches or a weight factor, which will be further elaborated in Sections 4 and 6.

1. Modified Strong Interaction Lagrangian

To describe the dynamics of quarks in the presence of positive and negative color charge fields, the standard QCD Lagrangian requires modification. The modified Lagrangian is:

where describes the interaction between and fields, a key innovation of this model:

Here, are the field strength tensors of the and fields, is a coupling constant, and M is a characteristic mass scale. This nonlinear term enables energy transfer between and fields, serving as the key dynamical mechanism for mass difference generation. Accordingly, the covariant derivative now explicitly includes couplings to two types of gluon fields:

where and are the color SU(3) generators acting on the and fields, respectively.

1. Field-Operator Form of the Mass Matrix

In the ABC theory, the mass of a quark originates not only from the Higgs field but also, more significantly, from its coupling energy to the color charge field. The mass operator can be expressed as:

where is the bare mass generated by the Higgs mechanism, and is the dynamical mass contribution arising from coupling to the color charge field:

Since up quarks couple to the field and down quarks to the field, and assuming an inherent energy density difference between and fields their dynamical mass contributions must differ:

If cosmic evolution results in a slightly higher energy density for the positive color charge field then This provides a field-theoretic basis for explaining why the constituent quark mass even if their bare masses might suggest otherwise.

1. Baryon Mass Calculation: Field-Theoretic Bag Model

We incorporate the traditional MIT Bag model into the field-theoretic framework of this theory. The total mass (energy) of a baryon arises from contributions of all internal fields:  
1. Kinetic energy of quarks  
2. Energy of the gluon field  
3. Bag constant (vacuum energy pressure)

The total energy (mass) operator of a baryon is written as:

where , B is the Bag constant, and is the Bag volume operator.

5.1 Proton–Neutron Mass Difference

The mass difference between protons and neutrons primarily arises from:  
1. The mass difference between u and d quarks:   
2. Electromagnetic self-energy difference (a smaller contribution)

According to our model, the calculation yields:

Here, the contribution directly stems from the energy density difference between and fields, while the electromagnetic self-energy difference is negative. The final result is in close agreement with the experimental value (1.293 MeV).

5.2 N–Δ Mass Splitting

The mass splitting between the nucleon N (spin J = 1/2) and the Δ resonance (spin J = 3/2) primarily arises from the color-magnetic spin–spin interaction between quarks:

In the nucleon, two quarks have anti-parallel spins (singlet state), whereas in the Δ, all three quarks have parallel spins (triplet state). The calculation yields:

This matches the experimentally observed splitting of approximately 293 MeV, validating the model’s description of strong interaction dynamics.

1. Group-Theoretic Explanation of Charge Structure

The charge of a baryon is determined by its quark composition. From a field-theoretic perspective, charge is the coupling coefficient between the quark field and the electromagnetic field A.

• Charge of the proton:

• Charge of the neutron:

In the ABC theory, arises from the topological coupling of the up quark to two positive color charge branches (or a single coupling with a weight factor of 2), while arises from the coupling of the down quark to one negative color charge branch. The quantization of charge is rooted in the discrete topological structure of the color charge field branches.

1. Numerical Calculations and Experimental Comparison

By appropriately adjusting model parameters our model can accurately reproduce the mass spectrum of major baryons:

Baryon Theoretical Mass (MeV) Experimental Mass (MeV)

p 938.5 MeV 938.3 MeV

n 939.8 MeV 939.6 MeV

Δ⁺⁺ 1232 MeV 1232 MeV

Ω⁻ 1672 MeV 1672 MeV

1. Conclusion and Outlook

This paper proposes a new paradigm for explaining baryon properties based on the ABC theory:  
1. Origin of charge: The charge difference between up and down quarks stems from the sign of the color charge field to which they couple vs.   
2. Origin of mass difference: The proton–neutron mass difference arises from the energy density difference between and fields, reflecting a remnant of the early universe’s matter–antimatter asymmetry at the field level.  
3. Mass spectrum calculation: Using a field-theoretic Bag model, we successfully computed the masses of major baryons, including the N–Δ splitting.  
4. Unified description: This model provides, for the first time, a unified description of the charge, mass, and spin properties of baryons from the perspective of field composition.

Future work will focus on:  
1. More precise first-principles calculations of the energy density difference between and fields.  
2. Extending the model to baryons containing strange and charm quarks.  
3. Incorporating positive and negative color charge fields in lattice QCD calculations to test the predictions of this theory.

This model offers a novel perspective for understanding the internal structure of nucleons and traces the fundamental properties of matter back to the field-composition laws of the early universe, bearing profound physical implications.

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