**Coupled-Branch Theory of Fundamental Particle Charges: From Cosmic Energyon Fields to Condensed Matter Topological Phases**  
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 **Abstract**  
Based on the “ABC Mechanism in the Universe” framework, this paper proposes a coupled-branch theory for the origin of fundamental particle charges. Through topological coupling between the cosmic energyon field and the color vortex field , we establish a charge quantization mechanism . For the first time, the theory unifies the description of charge origins for fermions, gauge bosons, and Higgs particles, constructing a complete correspondence between the branch number and SU(3) representations. At cosmological scales, we derive quantitative effects of the cosmic energyon field on expansion dynamics, primordial perturbations, and dark energy. In condensed matter systems, we provide mathematical realization pathways in quantum spin liquids and fractional quantum Hall effects, predicting quantum conductance plateaus and topological phase transitions. This work offers a unified framework bridging particle physics, cosmology, and condensed matter physics.  
 **1. Introduction**  
The quantization of fundamental particle charges remains a core challenge in particle physics. While the Standard Model successfully describes interactions, the origins of quark fractional charges () and lepton integer charges () lack a unified explanation. This paper introduces the coupled-branch theory, establishing a universal charge quantization mechanism via topological coupling between the cosmic energyon field and the color vortex field . The theory extends to gauge bosons and Higgs particles, connecting cosmological effects with condensed matter realizations to form a cross-scale physical picture.  
**2. Theoretical Framework: Coupled-Branch Theory**  
 **2.1 Topological Coupling of Cosmic Energyon and Color Vortex Fields**  
The Lagrangian for the cosmic energyon field (second-rank antisymmetric tensor) and the color vortex field (SU(3) adjoint representation) is:

where is the coupling constant and is the SU(3) field strength. The equations of motion are:

**2.2 Charge Quantization Mechanism**  
Define the branch selection operator and charge generation operator :

The eigenstate satisfies:

**Physical Interpretation:**  
- → Quark fractional charges (color triplet/antitriplet)  
- → Lepton integer charges (singlet)  
- → Neutral particles (photon, Z boson, gluon)  
**3. Complete Correspondence Between Branch Number and SU(3) Representations**

#### **3.1 Extension to Gauge Bosons and Higgs Particles**

| **Branch Number** | **SU(3) Rep.** | **Particle Type** | **Charge** | **Physical Significance** |
| --- | --- | --- | --- | --- |
| 0 | 1 | Neutrino | 0 | Weak neutral lepton |
| 1 | 3 | Down-type quark (d,s,b) |  | Color triplet, fractional charge origin |
| 2 |  | Up-type quark (u,c,t) |  | Antitriplet, charge complementarity |
| 3 | 1 | Charged lepton (e,μ,τ) |  | Charge quantization ground state |
| -1 |  | Anti-down-type quark |  | Antimatter symmetry |
| -2 | 3 | Anti-up-type quark |  | CPT conjugate state |
| -3 | 1 | Positron (anti-lepton) |  | Antiparticle charge reference |
| 0 | 1 | Photon () | 0 | U(1) gauge boson, EM mediator |
| 3 | 1 | boson |  | Weak charged current carrier |
| -3 | 1 | boson |  | Antiparticle of |
| 0 | 1 | Z boson | 0 | Weak neutral current carrier |
| 0 | 8 | Gluon () | 0 | SU(3) color gauge field, strong mediator |
| 0 | 1 | Higgs boson () | 0 | EM neutral, mass generation |
| 3 | 1 | Charged Higgs () |  | Supersymmetric extension |
| -3 | 1 | Charged Higgs () |  | Antiparticle of |

#### **3.2 Topological Coupling for Gauge Bosons**

* **W/Z Bosons**: Couple to lepton branch number via weak interaction, charge .
* **Gluons**: SU(3) adjoint representation (8-dimensional), , satisfying color charge conservation.
* **Higgs Particles: Vacuum expectation value induces mass; charged Higgs () arises from supersymmetric extensions.**
* **4. Cosmological Effects: Self-Consistent Model of Cosmic Energyon Field**

#### **4.1 Self-Consistent Dynamics**

* Energy density and pressure:

Modified Friedmann equation:

where is the Hubble parameter, and are matter and radiation densities.  
 **4.2 Primordial Perturbation Power Spectrum**  
Power spectrum from quantum fluctuations:

**Physical Effects:**

* Long-wavelength limit () → Power spectrum suppression → Large-scale structure anomalies.
* Short-wavelength limit () → Standard scalar perturbation spectrum.  
  #### **4.3 Dark Energy Contribution**  
  When (current Hubble constant), the equation of state is:

**Conclusion**: The cosmic energyon field acts as a dark energy candidate, driving cosmic acceleration.  
 **5. Realization in Condensed Matter Systems**  
 **5.1 Mathematical Realization in Quantum Spin Liquids**  
Kitaev honeycomb lattice model:

Low-energy effective theory:

Charge quantization condition:

**5.2 Realization in Fractional Quantum Hall Systems**  
Topological field theory at filling factor :

Quasiparticle excitation charge , corresponding to branch number .  
 **5.3 Ginzburg-Landau Theory Description**  
Free energy for topological superconductors:

where ( excitation), and the order parameter carries fractional charge.  
 **5.4 Observable Effects**  
**Quantum conductance plateaus**:

**Topological phase transition critical point**: Correlation length divergence

where is the coupling constant and the critical value.  
 **6. Conclusion and Outlook**  
This paper proposes the coupled-branch theory, unifying the origin of fundamental particle charges:

**6.1Particle Physics**: Establishes complete correspondence between branch number and SU(3) representations, covering fermions, gauge bosons, and Higgs particles.

**6.2Cosmology**: The cosmic energyon field drives dark energy, modifies primordial perturbation spectra, and explains large-scale structure anomalies.

**6.3Condensed Matter**: Realizes charge quantization in quantum spin liquids and fractional quantum Hall systems, predicting quantum conductance plateaus and topological phase transitions.  
**Future Directions**:

* **Experimental Verification**: Detect charged Higgs at LHC; observe primordial perturbations via CMB.
* **Condensed Matter Realization**: Design fractional charge excitation devices in topological materials.

## **Theoretical Extension:** Couple to gravitational fields, exploring charge quantization in quantum gravity**.**

### **References**

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