**Document Title: Electromagnetic Field Threshold for Energy-Matter Conversion: A Study on Strong-Field Quantum Electrodynamics Based on the ABC Theory**  
Authors: Zhijun Li, Guangyao Zhao

**Abstract**

Based on the ABC theory framework proposed by Professor Zhijun Li, this paper aims to construct a comprehensive dynamical model describing the conversion of energy into matter particles via strong electromagnetic fields and to determine its critical conditions. The core argument is as follows: The conversion of energy into matter is not merely encapsulated by the mass-energy equation but represents a profound dynamical process. This process requires the energy density of the electromagnetic field (A-field) to reach a specific threshold sufficient to polarize the vacuum, thereby exciting specific branches of the chromo-charge field (B-field) and the Higgs field (C-field), ultimately forming stable field composites (i.e., elementary particles). We demonstrate that this process exhibits a critical electromagnetic field strength whose value is determined by the rest energy of the particle to be produced and its coupling strength with the electromagnetic field.

By solving the Dirac equation under strong fields and applying non-equilibrium quantum field theory methods, we first rigorously derive the critical field strength for creating electron-positron pairs known as the Schwinger limit:

Subsequently, we estimate the equivalent field strength required for producing proton-antiproton pairs Considering the composite nature of hadrons and the quark confinement effect, this field strength is significantly higher, with an order-of-magnitude estimate of ~

This paper compares the field strengths achievable with current state-of-the-art high-intensity laser technology (approximately ~ with the aforementioned theoretical thresholds, highlighting the vast gap (4 to 10 orders of magnitude) between them. Finally, we explore potential pathways—such as future ultra-high-intensity lasers, dense astrophysical environments (e.g., neutron star magnetospheres), and quantum simulations in condensed matter systems—to approach these extreme conditions and indirectly study the related physical processes. This model provides a rigorous theoretical foundation and feasibility assessment framework for achieving the conversion of electromagnetic energy into matter in laboratory settings.

**Keywords**: ABC theory; energy-matter conversion; Schwinger effect; critical field strength; vacuum polarization; pair production; strong-field QED

1. **Introduction: From Mass-Energy Equivalence to Field Composite Creation**

Einstein’s mass-energy equation profoundly reveals the equivalence between energy and mass. However, the dynamical process of converting massless forms of energy (e.g., electromagnetic field energy) into particles with rest mass remains an incompletely resolved problem. The ABC theory proposed by Professor Zhijun Li offers a new physical perspective: elementary particles can be regarded as stable “field composites” formed by the coupling of cosmic energons on the space-time manifold with specific branches of the electromagnetic field (A-field), the chromo-charge field (B-field), and the Higgs field (C-field). Thus, the microscopic essence of energy-to-matter conversion can be understood as injecting sufficient energy density into the electromagnetic field (A-field) to excite specific vacuum configurations of the B-field and C-field, thereby dynamically “assembling” particles with specific mass and charge.

1. **Theoretical Framework: Vacuum Instability and Pair Production under Strong Fields**

2.1 Production Mechanism: Schwinger Effect

In electromagnetic fields with intensities comparable to the critical field strength, the quantum vacuum becomes unstable and may spontaneously produce particle-antiparticle pairs (e.g., This phenomenon is known as the Schwinger effect. Its physical picture is that a strong electric field performs work on virtual particle pairs produced by vacuum fluctuations, providing sufficient energy for them to tunnel through the potential barrier and separate into real particles.

In the field-composite language of the ABC theory, this process can be described by the following mapping:

This expression indicates that the strong electromagnetic field provides the energy required to break vacuum symmetry, excite specific branches of the B-field and couple with the Higgs field vacuum, ultimately “assembling” the field composites of electrons and positrons.

2.2 Quantum Mechanical Derivation of the Critical Field Strength

Consider the creation of a pair of particles with mass and charge in a uniform electrostatic field By solving the Dirac equation or using the WKB approximation, the expression for the pair production rate per unit time per unit volume is obtained:

where is the fine structure constant. The production rate grows exponentially with the electric field strength Defining the critical field strength as the field strength when the argument of the exponential term equals 1, we have:

For electrons ( precise calculation yields the famous Schwinger limit:

This is the theoretical critical electromagnetic field strength required for creating electron-positron pairs.

1. **Estimation of Critical Field Strength for Different Particle Production**

3.1 Lepton Pair Production

* Electron-positron pairs : ~
* Muon-antimuon pairs : The muon mass so the critical field strength is:

3.2 Hadron Pair Production

The production of hadrons (e.g., protons p) is more complex due to their quark structure and the quark confinement effect.

* Point-particle approximation estimate: If the proton is treated as a point particle with mass naive estimate gives:
* QCD-corrected estimate: The actual production process involves the creation of quark-antiquark pairs and their subsequent hadronization. Considering the Compton wavelength scale corresponding to the proton rest energy ~ more realistic order-of-magnitude estimate is:

In summary, the equivalent critical field strength required for producing hadron pairs is approximately:

1. **Comparison with Current Technological Levels and Future Prospects**

4.1 Current State: Maximum Laser Field Strength

Currently, the peak focused electric field strength of the world’s most advanced ultra-high-intensity laser systems (e.g., ELI-NP) is approximately:

This is about 4 orders of magnitude lower than the Schwinger limit for electron pairs and 7 to 10 orders of magnitude lower than the field strength required for hadron pair production.

4.2 Future Potential Pathways

1. Ultra-high-intensity laser technology: Developing Exawatt ~乃至 Zettawatt ~ lasers, combined with novel focusing technologies such as plasma lenses, could potentially enhance local field strengths to the order of ~ gradually approaching the Schwinger limit region.
2. Dense astrophysical environments: The magnetic field strength on the surface of neutron stars can reach ~ corresponding to an electric field strength on the order of ~ Such environments provide natural cosmic laboratories for studying physics under extreme field strengths.
3. Quantum simulation in condensed matter systems: In Dirac materials (e.g., graphene), the effective mass and effective speed of light of electrons are very low, which can significantly reduce the equivalent Schwinger field strength:

For example, in graphene, can be as low as ~ enabling tabletop experiments to simulate the Schwinger effect.

**5. ABC Theory Perspective: Excitation and Recombination of Field Composites**

From the field-composite perspective, the process of matter creation by strong electromagnetic fields can be decomposed into the following steps:

1. Energy injection and vacuum polarization: The strong electromagnetic field injects extremely high energy density into the electromagnetic vortex field (A-field), causing significant vacuum polarization.
2. Chromo-charge field excitation: When the energy density exceeds the threshold, the excitation of the A-field can effectively polarize and excite specific branches of the chromo-charge field (B-field) (e.g.,
3. Field composite formation: The excited B-field branch couples with the vacuum expectation value of the Higgs field (C-field), dynamically assembling into a particle field composite with specific quantum numbers (charge, mass).
4. Charge conservation and pair production: To maintain overall charge neutrality, this process necessarily accompanies the production of a charge-conjugated field composite

Thus, the critical field strength physically represents the minimum energy density required to excite specific B-field and C-field configurations and successfully “assemble” a complete particle, expressed in the form of an electric field.

1. **Conclusion**

Based on the field-composite concept of the ABC theory, this paper systematically analyzes the critical conditions required for converting energy into matter using electromagnetic fields and derives key theoretical thresholds:

1. The critical field strength for creating electron-positron pairs is ~ (Schwinger limit).
2. Due to the involvement of quark confinement and hadronization processes, the production of hadrons (e.g., proton-antiproton pairs) requires a significantly higher equivalent field strength, on the order of ~

Analysis shows that the field strength produced by the most powerful current laser technology ~ still lags far behind these theoretical thresholds (by 4 to 10 orders of magnitude). However, developing next-generation ultra-high-power lasers, utilizing extreme environments in dense astrophysical objects, and conducting quantum simulations based on condensed matter systems provide feasible pathways to approach and explore this extreme physical process at different levels. This research not only deepens the understanding of the dynamics of energy-matter conversion but also lays a theoretical foundation for ultimately creating fundamental matter particles from pure electromagnetic energy under laboratory conditions.

**References**

[1] Li, Z. J. (2023). The ABC Mechanism in the Universe.  
[2] Schwinger, J. (1951). On Gauge Invariance and Vacuum Polarization. Physical Review.  
[3] Dunne, G. V. (2004). Heisenberg-Euler Effective Lagrangians: Basics and Extensions. arXiv:hep-th/0406216.  
[4] Di Piazza, A., et al. (2012). Extremely high-intensity laser interactions with fundamental quantum systems. Reviews of Modern Physics.  
[5] ELI-NP Whitebook. (2015). Extreme Light Infrastructure Nuclear Physics.