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Towards a unified theory of the fundamental physical interactions based on the underlying geometric structure of the tangent bundle

Joachim Herrmann*

Max Born Institute, Max Born Str. 2a, 12489 Berlin, Germany

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Abstract This paper pursues the hypothesis that the tangent bundle (TB) with the central extended little groups of the $SO(3,1)$ group as gauge group is the underlying geometric structure for a unified theory of the fundamental physical interactions. Based on this hypothesis as a first step, I recently presented a generalized theory of electroweak interaction (including hypothetical dark matter particles) (Herrmann in Eur Phys J C 79:779, 2019). The vertical Laplacian of the tangent bundle possesses the same form as the Hamiltonian of a 2D semiconductor quantum Hall system. This explains fractional charge quantization of quarks and the existence of lepton and quark families. As will be shown, the $SU(3)$ color symmetry for strong interactions arises in the TB as an emergent symmetry similar to Chern–Simon gauge symmetries in quantum Hall systems. This predicts a signature of quark confinement as a universal large-scale property of the Chern–Simon fields and induces a new understanding of the vacuum as the ground state occupied by a condensate of quark–antiquark pairs. The gap for quark–antiquark pairing is calculated in the mean-field approximation, which allows a numerical estimation of the characteristic parameters of the vacuum such as its chemical potential, the quark condensation parameter and the vacuum energy. Note that a gauge theoretical understanding of gravity was previously achieved by considering the translation group $T(3,1)$ in the TB as gauge group. Therefore, the theory presented here can be considered as a new type of unified theory for all known fundamental interactions linked with the geometrization program of physics.

1 Introduction

The development of the Standard Model (SM) of elementary particles was a great triumph of modern physics. However,

despite its enormous success in explaining a large number of experiments, it cannot be considered as the ultimate theory of particle physics. The SM is incomplete and contains several open problems that cannot be solved on the basis of this model, as well as phenomenological elements that have not yet been explained on a microscopic basis. A fundamental problem in the SM is the question of the physical origin of the internal symmetry groups assumed a priori for phenomenological reasons. Several other unanswered questions are the mysterious existence of three families of leptons and quarks (also called generations) that differ only in their masses and the origin of the hierarchy of fermion masses, the microscopic understanding of the spontaneous symmetry breaking by the Higgs mechanism and the hierarchy problem, the lack of understanding of fractional quark charges, the missing explanation of dark matter and dark energy, and others.

There have been many attempts to formulate a unified theory beyond the SM that could solve the above puzzles. In Grand Unified Theories, the electroweak and strong interactions are embedded in a larger gauge group, such as the $SU(5)$ group first proposed by Georgi and Glashow [1] or in the $SO(10)$ group [2]. There have also been some attempts to understand the origin of families in the SM by using a so-called family symmetry [3,4]. Despite many subsequent attempts, no unified model exists that is able to solve all these problems on a unified basis, and none of them is considered to be universally accepted.

The SM of particle physics is based on the gauge principle, with local symmetry transformations of the variables of the phenomenologically determined continuous gauge groups $SU(2) \otimes U(1)$ in electroweak interactions and $SU(3)$ in strong interactions (quantum chromodynamics, QCD) acting in an “internal space” related to the symmetry group. The geometric or physical origin of the internal symmetries given by the gauge transformations remains unknown. Here we follow the hypothesis that the gauge principle is not a

* e-mail: jherrman@mbi-berlin.de (corresponding author)

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