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Quantum gauge freedom in very special relativity

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Abstract

We demonstrate Yokoyama gaugeon formalism for the Abelian one-form gauge (Maxwell) as well as for Abelian two-form gauge theory in the very special relativity (VSR) framework. In VSR scenario, the extended action due to introduction of gaugeon fields also possesses form invariance under quantum gauge transformations. It is observed that the gaugeon field together with gauge field naturally acquire mass, which is different from the conventional Higgs mechanism. The quantum gauge transformation implements a shift in gauge parameter. Further, we analyze the BRST symmetric gaugeon formalism in VSR which embeds only one subsidiary condition rather than two.

1. Overview and motivation

In recent times, the violations of Lorentz symmetry have been studied with great interest [1–6], though special relativity (SR), whose underlying Lorentz symmetry is valid at the largest energies available these days [7]. However, the violation of Lorentz symmetry has been considered as a possible evidence for Planck scale physics [8]. In this context, Cohen and Glashow [9] have proposed that the laws of physics need not be invariant under the full Lorentz group but rather under its subgroups that still preserve the basic elements of SR, like the constancy of the

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velocity of light. Any scheme whose space–time symmetries consist of translations along with any Lorentz subgroups is referred to as very special relativity (VSR). Most common subgroups fulfilling the essential requirements are the homothety group $HOM(2)$ (with three parameters) and the similitude group $SIM(2)$ (with four parameters) [9]. The generators of $HOM(2)$ are $T_1 = K_x + J_y$, $T_2 = K_y - J_x$, and K_z, where J and K are the generators of rotations and boosts, respectively. The generators of $SIM(2)$ are $T_1 = K_x + J_y$, $T_2 = K_y - J_x$, K_z and J_z. These subgroups will be enlarged to the full Lorentz group when supplemented with discrete space–time symmetries CP. Recently, the three-dimensional supersymmetric Yang–Mills theory coupled to matter fields, (supersymmetric) Chern–Simons theory in $SIM(1)$ superspace formalism [10] and $SIM(2)$ superspace formalism [11] are derived. The Feynman rules and supergraphs [12] in $SIM(2)$ superspace also have been studied.

VSR admits natural origin to lepton-number conserving neutrino masses without the need for sterile (right-handed) states [13]. This implies that neutrinoless double beta decay is forbidden, if VSR is solely responsible for neutrino masses. Further, VSR is generalized to $N = 1$ SUSY gauge theories [14], where it is shown that these theories contain two conserved supercharges rather than the usual four. VSR is also modified by quantum corrections to produce a curved space–time with a cosmological constant [15], where it is shown that the symmetry group $ISIM(2)$ does admit a 2-parameter family of continuous deformations, but none of these gives rise to non-commutative translations analogous to those of the de-Sitter deformation of the Poincaré group. The VSR is generalized to curved space–times also, where it has been found that gauging the $SIM(2)$ symmetry, which leaves the preferred null direction invariant, does not provide the complete couplings to the gravitational background [16]. The three subgroups relevant to VSR are also realized in the non-commutative space–time [17,18] and in this setting the non-commutativity parameter $\theta^{\mu\nu}$ behaves as lightlike. VSR has been generalized in various contexts. For example, the generalization of VSR ideas to de Sitter spacetime is studied where breaking of de Sitter invariance arises in two different ways [19]. This has also been shown that the event space underlying the dark matter and the dark gauge fields supports the algebraic structure underlying VSR [20]. A generalization of VSR in cosmology is also proposed where an anisotropic modification to the Friedmann–Robertson–Walker (FRW) line element occurs and for an arbitrarily oriented 1-form, the FRW space–time becomes of the Randers–Finsler type [21]. The VSR modifications to the quantum electrodynamics and the massive spin-1 particle are reported in Refs. [23,22]. Furthermore, the generalization to the case of non-Abelian gauge fields is made in [24] and, in this context, the spontaneous symmetry-breaking mechanism to give a flavor-dependent VSR mass to the gauge bosons is also studied. VSR is also studied as background field theory, where averaging observable generates the nonlocal terms familiar from $SIM(2)$ theories, while the short-distance behavior of the background field fermion propagator generates the infinite number of higher-order vertices of $SIM(2)$-quantum electrodynamics [25]. The electrostatic solutions as well as the VSR dispersion relations for Born–Infeld electrodynamics are investigated to be of a massive particle with nonlinear modifications in VSR scenario [26]. Recently, VSR generalization of the tensor field (reducible gauge) theories has also been analyzed using a Batalin–Vilkovisy (BV) formulation [27]. A rigorous construction of quantum field theory with a preferred direction is also studied very recently [28]. We would like to generalize the VSR in gaugeon formalism as gaugeon formalism is important in studying quantum gauge symmetry as well as in renormalization of gauge parameter.

The basic idea behind the gaugeon formalism [29] is to introduce the so-called gaugeon fields to the action which represent quantum gauge freedom. Originally, this formulation was developed in the case of quantum electrodynamics to settle the issues of renormalization of gauge parameter.