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Frame-like gauge invariant formulation for massive high spin particles

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Abstract

In this paper we extend a so-called frame-like formulation of massless high spin particles to massive case. We start with two explicit examples of massive spin 2 and spin 3 particles and then construct gauge invariant description for arbitrary integer spin case. Similarly, for the fermionic case we start with first non-trivial example—massive spin 5/2 particle and then construct gauge invariant description for arbitrary half-integer spin case. In all cases we consider massive particles in $(A)dS$ spaces with arbitrary cosmological constant (including flat Minkowski space) and this allows one to investigate all possible massless and partially massless limits for such particles.

1. Introduction

As is well known, basically there are two approaches for description of gravity theory—metric one, where the main object is symmetric metric tensor $g_{\mu\nu}$, and frame one with frame $e_\mu{}^a$ and Lorentz connection $\omega_\mu{}^{ab}$. To a large extent these two approaches are equivalent, but for some concrete task one or another approach can more convenient. In particular, to describe interactions of fermionic fields with gravity (e.g. supergravity) one is forced to use frame formulation. Physically, the existence of two such approaches means that for a description of massless spin 2 particles one can use Lagrangians of second or first order in derivatives.

These two approaches admit natural generalization for description of high spin particles (for recent review of high spin theories see e.g. [1–4]). Generalization of metric approach has been

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constructed in [5–10], while generalization of frame approach, the so-called frame-like formalism, has been constructed in [11–13] (see also [14–22]).

As is well known, Lorentz covariant description of massless high spin fields requires a theory to be gauge invariant. This, in particular, lead to so-called constructive approach to investigation of consistent interactions of such fields when interaction Lagrangians and appropriate gauge transformations are constructed iteratively by the number of fields. In turn, common description of massive fields requires that some constraints must follow from equation of motion excluding all unphysical degrees of freedom. In this, at least two general problems appear then one tries to switch on interactions. First of all, a number of constraints could change thus leading to a change in a number of degrees of freedom and reappearing of unphysical ones. At second, even if a number of constraints remains to be the same as in free theory, interacting theory very often turns out to be non-casual, i.e. has solution corresponding to non-luminal propagation.

One of the possible solutions is to use gauge invariant description of massive high spin fields. There at least two basic approaches to such description. One of them based on the powerful BRST method [23–28]. Another one appeared in attempt to generalize to high spins a very well-known mechanism of spontaneous gauge symmetry breaking [29–32] (see also [16,33–36]). In such a breaking a set of Goldstone fields with non-homogeneous gauge transformations appear making gauge invariant description of massive gauge fields possible. Such gauge invariant description of massive fields works well not only in flat Minkowski space–time, but in (anti) de Sitter space–times as well. All that one needs to do is to replace ordinary partial derivatives with the covariant ones and take into account commutator of these derivatives which is non-zero now. In particular, this formulation turns out to be very convenient for investigation of so-called partially massless theories which appear in de Sitter space [19,31,37–39].

It is evident that in any theory of high spin particles most of them have to be massive (and their gauge symmetries have to be spontaneously broken). It means that in any supersymmetric high spin theory like the superstring these particles must belong to some massive supermultiplet. It may seems strange but though explicit realization of massless supermultiplets with arbitrary spins were known for a long time [40] explicit construction for massive supermultiplets was not available until recently [41] (see also [42,43]). The main idea is that massive supermultiplet must be easily constructed out of the appropriate set of massless ones exactly in the same way as massive particle could be constructed using appropriate set of massless ones.

Construction of consistent high spin particles interactions is one of the old, hard and still unsolved problems. For the massless particles it is possible to formulate constructive approach to this problem (for BRST formulation see [44]). In this approach one starts with free Lagrangian for the collection of massless fields with appropriate gauge transformations and tries to construct interacting Lagrangian and modified gauge transformations iteratively by the number of fields so that:

$$\mathcal{L} \sim \mathcal{L}_0 + \mathcal{L}_1 + \mathcal{L}_2 + \cdots, \qquad \delta \sim \delta_0 + \delta_1 + \delta_2 + \cdots,$$

where $\mathcal{L}_1$ is cubic vertex, $\mathcal{L}_2$ is quartic one and so on, while δ_1 are corrections to gauge transformations linear in fields, δ_2 quadratic in fields, and so on. The mere existence of gauge invariant formulation for massive high spin particles allows us to extend such constructive approach for any collection of massive and/or massless particles, see e.g. [45,46].

Till now, in most of the works on gauge invariant description for massive high spin particles metric-like formulation was used (see, however, [16,19]). The aim of this paper is to extend frame-like formulation of bosonic and fermionic high spin particles to massive case, in this we will follow a minimalistic approach [30–32] introducing only minimal number of fields which are