(ナノ構造物性理論)

Research on lattice field theory with supersymmetry.

超対称性を持つ格子場理論の研究

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This research is going on and there has not been any result yet. So it is presented in this poster what the author is interested in and what problems are there. The main topic is what prevents elementary particle physicists from analyzing quantum field theory (or standard model) in the lattice view point. This is known as “doubling problem”. And this yields the difficulty with making supersymmetric lattice field theory.

First of all, it should be made clear the relation between elementary particle physics and nano scale physics. As this work is included in the region of elementary particle physics, you may say that its target is too small in this symposium! Partly yes for the answer of this question. The target of elementary particle physics could be smaller than nano-nano($= 10^{-9} \times 10^{-9}$) meter. However, you know nano-scale structures have effects to much larger scale properties. So who can say nano-nano scale structures have nothing to affect nano scale properties? The investigations of the properties of elementary particles are needed to understand nano scale properties much deeper.

The purpose of elementary particle physics is to find ultimate theory which describe anything in nature. In particular the properties of small objects like quarks are attracting. For that purpose, the powerful tool is quantum field theory. And there is very successful model so-called “standard model” which describes quarks, leptons and gluons.

In order to calculate quantum field theory, the idea of lattice field theory is introduced by Wilson [1]. In this method, the space-time are thought as not continuous one but discrete one. Then the derivative is exchanged to deference between two sites —discrete points of space-time— and integrations over the space-time are exchanged to summations over all of sites. In a continuous theory there is divergence in infrared and/or ultraviolet energy region. Contrastively in discretized space-time theories there is no divergence. The ultraviolet divergence in continuous theories comes from the fact two points of space-time could be very close, so the lattice field theory has no ultraviolet divergence from the starting point of theory. And because of calculation having done in a finite volume in the lattice theory infrared divergence could not appear.

The lattice field theory is a so good idea that we can compare the results of theory and experiments, but there remains a defect to treat the standard model. It is very difficult to describe chiral fermions which play an important role in standard model. Once the theory which includes fermions is discretized, there appear 2^d fermions in the theory. Here d is the number of discretized dimensions. This is a famous problem called "doubling problem".

So many ideas of describing chiral fermions have been come up. One of the most famous idea was proposed by Wilson[2]. Another type is called "staggered fermion", which first suggested by Susskind [3]. And most recent one — and many people think this method efficient — was suggested by Lüscher [4].

The very method the author is attracted to is staggered fermion. In this idea, a spinor field is not at one site, but one component of spinor is at one site, in order to prevent appearing the doubling fermions. It is easy to get a geometric picture from this way. So it has great possibilities of extending to the theory with quantum gravity.

On the other hand, to make this idea accomplished, it is necessary to introduce $2^{d/2}$ copies of fermions. An ordinary interpretation for this degree of freedom is "flavor" — say up (down) quarks, charm (strange) quarks and top (bottom) quarks. But with this interpretation, we need 4th generation quarks and leptons in 4 dimensional space-time. Maybe they are, but there is no evidence for such generation, many people do not think this method seriously.

However the author is interested in this method, because another interpretation is possible[5] (but the object which discussed in this paper is Dirac-Kähler fermion, which is considered as a staggard fermion in the continuous limit). In this idea it is regarded that degree of freedom as the index of R'-symmetry. R-symmetries are following from supersymmetries. Here prime symbol means twisted version of supersymmetries. Supersymmetries are symmetries between fermions and bosons. And these symmetries keep it finite the Higgs propagators. A lot of challenges for getting supersymmetric lattice field theory have been proposed, but no agreement has been reached. One of the difficulties of making supersymmetric lattice models is from the doubling problem. The model made with staggered fermions may give the solution to solve these problems—the doubling problem and the difficulties of describing supersymmetries— at once.

The author aims to make the supersymmetric lattice field theory with staggard fermions. The twisted supersymmetries have connections with topological field theories. So he is carefully checking the lattice version of topological field theories from the viewpoint of staggered fermions.

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