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論文内容の要旨

Today particle physics except for gravity is well described by the standard model. However, gravity cannot be quantized in the same method because we cannot renormalize it. Therefore the main problem of current particle physics is to establish a consistent quantum theory which contains both the standard model and gravity. Under these circumstances, the most hopeful and popular candidate is the string theory.

The reason to favor the string theory is its wonderful nature. We can give as concrete examples that the theory has no ultraviolet divergence and includes gravitational field as well as matter and gauge fields automatically. However, due to the infinite ground states, this theory has no capability to predict; therefore we cannot answer why the standard model emerges. On the other hand it is possible to consider that this problem is the problem in the framework of perturbative formulation of the theory, because the completed region of the string theory is only the perturbative region. So if the non-perturbative formulation of the theory is accomplished, it is quite likely that this problem is resolved. Of course, it is pure speculation, but it seems quite probable that the non-perturbative effects turn infinite ground states into single one.

What must not be forgotten is that one theory never finish before the non-perturbative formulation is completed. One of candidates for the non-perturbative formulation of the string theory at present is the string field theory. Although a considerable number of studies have been conducted on these theories, the only successful string field theories so far are the ones formulated in the light-cone gauge. So it is not clear whether we can extract some essential information of the non-perturbative effects. Another candidate is what is called the matrix model. With the advent of the BFSS model as a starter, many proposals have been being made since. The common idea of these models is that they reproduce sting or membrane theory in the large-N limit. In a sense the matrix model is similar to the lattice gauge theory, which is the non-perturbative formulation of the field theory, in that they can be analyzed using numerical simulation. Therefore it is reasonable to suppose that we will develop current matrix models a little further and find the true model.

A virtue of the matrix model is that it has a possibility of putting an interpretation on the space-time itself. However, some important questions such as "what would be the real mechanism to realize the 4-dimensional world from the 10(or 11)-dimensional universe" and "how is the diffeomorphism introduced into the theory" remain unsettled. One of them is the question of background independence. Consider the IKKT model for example. This model has an $SO(10) \times SU(N)$ symmetry, and this is just a symmetry like *some theory* was expanded around the flat background. Therefore we cannot deny the existence of different matrix model whose expansion around a special background gets the IKKT model. On this point Smolin proposed a new type of matrix model in which the action is cubic in matrices. Matrices are built from the super Lie algebra $osp(1|32;\mathbf{R})$, and one multiplet is pushed into a single supermatrix. Smolin's conjecture is that the expansions around different backgrounds of the $osp(1|32;\mathbf{R})$ matrix model will reduce to the BFSS or IKKT model. However, as far as the IKKT model is concerned, the theory made from Smolin's way dose not reproduce the supersymmetry of the IKKT model. That is, indeed the 10-dimensionality is realized, but the *half* of supersymmetry required by the IKKT model cannot be held. Anyway, the model described by a single matrix alone is very attractive, and Smolin's courageous attempt demonstrated one concrete possibility.

Moreover, as Smolin's $u(1|16,16)$ model has demonstrated, the matrix models are not irrelevant to the *loop quantum gravity* which is another approach to the Theory of Everything. Furthermore, it was pointed out that the matrix string theory has a connection with the matrix model based on the exceptional Jordan algebra $\mathfrak{J}$, while B.Kim and A.Schwarz have discussed a tie-in between the IKKT model and the Jordan algebra $\mathfrak{j}$ with its spinor representation. For these reasons, doing research on extended matrix model is very interesting and important. Over and above, we should not overlook the fact that several approaches which are very similar to the matrix model have been pursued by other fields. It might be inferred from these circumstantial evidence that the attempt to renounce the space-time as a *continuum* holds one important key to the future progress of physics. It seems at least that there is no need to relate the matrix model to the string theory alone.

For these purposes, we investigate new types of matrix models based on the complex exceptional Jordan algebra and the super Lie algebras. In the former case, a matrix Chern-Simons theory is directly derived from the invariant on E_6. It is stated that the same argument as Smolin which derives an effective action similar to the matrix string theory can also be held in our model. The only difference is that our model has twice as many degrees of freedom as Smolin's model has. One way to introduce the cosmological term is the compactification on directions. It is of great interest that the properties of the product space $\mathfrak{J}^c \times \mathcal{G}$, in which the degrees of freedom of our model live, are very similar to those of the physical Hilbert space. In the latter case, we investigate three super Lie algebras, $osp(1|32;\mathbf{R})$, $u(1|16,16)$, and $gl(1|32;\mathbf{R})$. In paticular, we study the supersymmetry structures of these models and discuss possible reductions to the IKKT model. In addition to those, a different $u(1|16,16)$ model from Smolin's, and some kind of *topological* effective action derived using Wigner-Inönü contraction are also discussed.

論文の審査結果の要旨

大鷲雄飛君の博士論文は、超弦理論の非摂動的な定式化として有望視されている行列に基礎をおいた模型（以下行列模型）の理論的研究である。

素粒子物理学において残された大きな謎の一つが重力の量子化、そして時空の根元的な理解である。今まで重力の量子化に関して多くの試みがなされてきたが、現在、最も有望視されているのが超弦理論である。この理論では、今までの点粒子による記述とは異なり、物質をつくる基本的な物体が紐の様な一次元的に広がった物から構成されていると考える。超弦理論は、紫外発散が無く完全に整合的である、重力だけでなく物質までも統一的に記述する、超対称性やゲージ対称性などの高い対称性を自然に持つ、などの理論的に好ましい性質を多くもっており、その上、モデルが相互作用定数まで含めて一切のパラメータを持たない完全にユニークな理論であることが知られている。ところが、超弦理論は１０次元という高い次元で定式化されており、そこから我々の世界を記述する４次元の理論をつくろうとすると、どの様に残りの６次元部分を小さくするのか（コンパクト化と呼ばれる）に関して無数の可能性が許されてしまい、とたんに現実世界に関する予言能力を失ってしまう。これを解決するためには摂動展開に依らないで真空の性質を議論できる定式化を構築しないとならない。この様な定式化をここでは、超弦理論の構成的定式化と呼ぶ。今までにいくつかの定式化が提案され、その中でも行列に基づく模型が有望視されているが、まだ完成された模型は存在しない。

大鷲君の研究は、超弦理論の構成的定式化を目指す理論的研究であり特に超対称性をもつリー代数や例外群と呼ばれるリー代数に基づいた模型を提案している。理論の構成的な定式化を構築する場合、一番重要になるのがどの様な対称性を重視するかであり、ここでは特に超対称性に焦点を当てている。

前半部分の研究では、例外リー代数に基づく理論を提案している。この様な模型に関しては、スモーリンという研究者がジョルダン代数に基づく模型を提案していたが、大鷲君はこれを拡張し例外群に基づく模型を提案しその性質を解析した。

後半部分の研究は、OSp(1,32) 及び U(16,16,1) というスーパーリー代数に基づく模型の提案とその解析である。これらの群は、１０次元のタイプ II A 型超対称性の持つ代数構造となっており（もしくは１１次元の超対称代数）超弦理論の重要な対称性の一つと考えられる。大鷲君らはスーパーリー代数を基礎にするという新しい観点から模型を提案し、従来の行列模型との関係について詳細に議論している。これらの模型では、行列のみが基本変数となっているため、時空の解釈が重要なポイントとなるが、この論文では、どの様に一般座標不変性などの時空の性質が埋め込まれているかについての非常に興味深い議論も行っている。

以上の研究は、数物科学研究科 素粒子原子核専攻の博士学位論文として高い水準であり、博士学位論文として十分な内容を持つと判断される。