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Research on the Equivalence between Quantum Mechanics and Quantum Field Theory

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Abstract: Quantum mechanics is a branch of physics that studies the law of motion of micro particles in the material world, including the basic theories of atoms, molecules, condensed matter, as well as the structure and properties of nuclei and basic particles. Together with relativity, it forms the theoretical basis of modern physics. Quantum field is an effective concept to describe the law of micro-motion. It not only reflects the fluctuation of micro-objects, but also reflects its particularity. This paper demonstrates the equivalence between quantum mechanics and quantum field theory to provide some references for relevant researchers.

1. From Quantum Mechanics to Quantum Field Theory

At the end of the 19th century and the beginning of the 20th century, when classical physics was considered to be perfectly developed, a series of phenomena that could not be explained by classical theory were discovered one after another [1]. In the period of classical mechanics, physics mainly explores the theorems and theories of physical phenomena that can be touched by more direct experimental research. Newton's theorem and Maxwell's electromagnetic theory are good natural laws in the macro and slow world. For the physical phenomena in the micro world, classical physics seems powerless, and many phenomena have not been explained.

In 1900, Planck deduced a formula for blackbody radiation: $\mu = \frac{8\pi h v^3}{c^3}\frac{1}{e^{\frac{hv}{kT}}-1}$. This formula is called Planck's formula. After that, he devoted himself to finding out the real physical meaning of the formula. According to Boltzmann's idea, he made the following hypothesis: the blackbody is composed of charged harmonic oscillators, whose energy cannot change continuously, but can only take some discrete values.

We apply the principle of special relativity to quantum mechanics and obtain a single-particle Hilbert space with an irreducible unitary representation of SL(2,C)*R4 [2]. For the multi-particle problem, we seem to consider the tensor product of the single-particle state directly. However, as the above analysis shows, things are not as simple as we imagined. The problem arises when the degree of freedom N infinity, and the research methods we are used to fail. You can think of these "failures" as problems caused by infinite degrees of freedom, but rather than problems, it is the nature of quantum field theory itself. The relationship between quantum field theory and quantum mechanics is not only to add a degree of freedom, but also to replace one-variable function with multi-variable function. There is new physics in quantum field theory. This is particularly evident in the path integral method. Formally, the path integral in quantum mechanics can reveal most of the properties and calculations of the path integral in quantum field theory. But quantum field theory has an important concept, renormalization. In a sense, these problems can be avoided by reorganization, at least at the physical level.

From a practical point of view, the biggest difference between quantum mechanics and quantum field theory is that there is no "coordinate" in quantum field theory. Physically, this is because particles can be produced and annihilated in vacuum under relativistic conditions, so the measurement of their position is limited in principle by accuracy: if you irradiate particles with too high frequency light to expect a very accurate measurement of their position, then the light can even excite particle-antiparticle pairs from vacuum, because of the homogeneity of particles. You will not be able to distinguish the subsequent particles from the original particles to be measured, thus making the measurement of position meaningless. Therefore, the position uncertainty of particles in quantum field theory cannot exceed, in principle, its mass. But in quantum mechanics, particle coordinates can be said to be the most important quantity, because the wave function is based on it. In quantum field theory, we only have momentum space wave function, not coordinate space wave function in the strict sense - only in the case of low energy, coordinate is an observable quantity. From the physical perspective, the biggest difference between quantum mechanics and quantum field theory is ontological. The essence of quantum field theory is field. Particles are only the excitation of field, so they can be produced and annihilated as long as the law of conservation of energy and momentum permits. The essence of quantum mechanics is particles, which is somewhat similar to Newton's classical mechanics, where particles are immortal. The world under field theory is much richer than quantum mechanics. Vacuum is not empty, but full of quantum fields.

2. Conceptual Basis of Quantum Field Theory

After the establishment of quantum mechanics and relativity theory, the core problem of the basic theory of physics is mainly the combination of the two. Whether it is quantum electrodynamics, quantum gauge field theory, quantum gravity, supersymmetry theory and superstring theory, they are trying to solve this problem. In contrast, quantum gauge field theory is the most successful, especially in the standard model of particle physics. On the theoretical level, quantum field theory achieves a good combination of quantum mechanics and special relativity. Just as the success of quantum mechanics still has the problem of philosophical interpretation, on the one hand, the achievements of quantum field theory have not completely solved the philosophical problems of quantum mechanics, on the other hand, their own achievements will lead to new philosophical problems [3].

In the article "Conceptual Basis of Quantum Field Theory", Herald Tehaft and his teacher Weltman, who proved that weak electric theory can be reformed, won the Nobel Prize in Physics in 1999, gave an authoritative introduction to the basic ideas of quantum field theory. Its intriguing opening remark is that "there are so many valuable scientific achievements that they have achieved far more than they should have achieved, and quantum field theory is one of them if one considers that it is based on apparently unstable logic." All known subatomic particles seem to follow with astonishing accuracy a model rule of quantum field theory, which has a very common standard model'. The founders of the model never expected such a success, and people could naturally ask where it was. In Telford's view, the effective energy in quantum mechanics description of sub-atomic interaction is equal to or often larger than its static energy mc2, and its speed is often close to the speed of light, so relativistic effect will be equally important. Until the 1960s and 1970s, the quantum gauge field theory answered this question. Tehoft is trying to explain how quantum field theory answers this question [4].

It is this requirement that conflicts with the fact that the vast majority of vector particles in the subatomic world carry mass, which requires the introduction of the Higgs mechanism. The Higgs mechanism is precisely aimed at the requirement of precise localized norm invariance. In the introduction of Higgs mechanism, Tehoft first introduces the case of SO (3) group and the example of normative fixing, then focuses on the standard model, which in Tehoft's view is only a case of Higgs mechanism, and its normative group is SU (3)x SU (2) U (1). It includes three families formed by fermions in the standard model. These are based on mathematical skills and experimental data. Especially, the realization of the standard model depends on the renormalization of the normative theory, including the so-called renormalization group and renormalization group transformation, among which the mathematical method plays a leading role.

3. Algebraic Quantum Field Theory

In addition, we must ensure that the results meet the requirements of quantum statistics, that is, the correct spin statistical relationship. These requirements have been met in quantum field theory. In the framework of quantum field theory, a general proof of spin statistical relation is given. The physical images given by quantum field theory are: there are various fields in the whole space, which permeate and interact with each other; the excited states of the field are the emergence of particles, and the number and state of particles are different.

The interaction of the fields can cause the change of the field excited states, which can be expressed as the various reaction processes of particles. After considering the interaction, all kinds of particles can interact with each other. The number of particles is generally not conservative, so quantum field theory can describe the spontaneous emission and absorption of light in atoms, as well as the generation and annihilation of various particles in particle physics, which is also an important feature of quantum field theory which is different from elementary quantum mechanics. All fields are vacuum in the ground state. From the physical meaning of the quantum field theory mentioned above, we can know that vacuum is not without matter. The field in the ground state has the zero-point oscillation and quantum fluctuation peculiar to quantum mechanics. The physical effect of vacuum can be observed in experiments when the external conditions are changed. For example, when a metal plate is placed in vacuum, the interaction force between two non-charged metal plates caused by the change of zero-point energy of vacuum and the vacuum polarization caused by the change of the distribution of positive and negative electrons in vacuum under the action of external electric field. Quantum field theory is essentially the quantum mechanics of an infinite-dimensional system of degrees of freedom. In the branch of physics such as quantum statistical physics and condensed matter physics, the object of study is the system of infinite degrees of freedom.

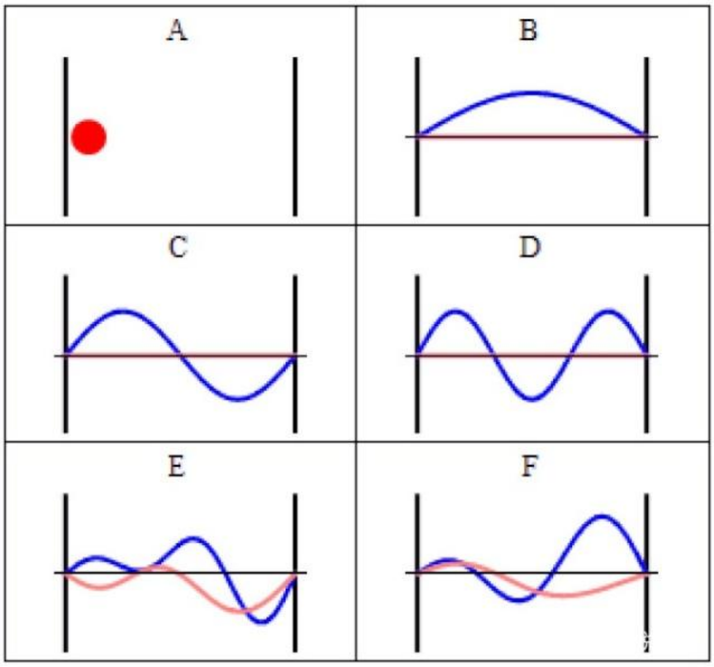

Figure 1. Particle trajectory in classical mechanics and quantum mechanics

In classical mechanics (A) and quantum mechanics (B-F), the trajectory of a particle in an infinite square well. In (A), particles move at a constant speed and bounce back and forth. In (B-F), the wave function solutions of the time-varying Schrodinger equation with the same geometry and potential are given. The horizontal axis represents the position, and the vertical axis represents the real part (blue) and the imaginary part (red) of the wave function.

In the pre-quantum universe, particles are just dots, individual entities with a series of attributes. But in the quantum universe, the particle must be replaced by a wave function, which is replaced by a set of probability parameters, such as position or momentum.

If Hilbert space of quantum mechanics, Minkowski's four-dimensional space-time theory of special relativity and Riemann geometry of general relativity become the mathematical basis of relevant theories, then quantum field theory has not yet been comparable to the mathematical basis. But the success of quantum field theory, especially the achievement of the standard model of particle physics, is better than that of quantum mechanics and relativity. The key is that some philosophical problems can only be deduced on the basis of theoretical mathematics, especially on issues such as ontology. The aim of algebraic quantum field theory is to find its own position in the mathematical world. The important physical information in quantum field theory is not contained in a single algebra, but in the algebraic network, that is, the mapping from a finite space-time region to a localized observable quantity. The key point is that in order to fix the quantities of physical significance, it is not necessary to specify the observable quantities explicitly. The method of linking the algebra of local observable quantities with the space-time region is sufficient to provide the observable quantities of physical significance. All locally observable quantities are different from subalgebras containing physical information of observable quantities, that is, the network structure of algebras is important. On the basis of operator algebra, Watson began to discuss the non-locality problem. He believed that quantum correlation in algebraic quantum field theory also holds under certain conditions.

4. Quantum Field Theory: A Unified Interpretation

Within the framework of gravitational quantum field theory, four basic forces, gravitational force, electromagnetic force, weak force and strong force, can be described in a unified way, and all equations of motion of quantum field containing gravitational field effect and conservation laws corresponding to all basic symmetries can be derived. Just as Newton's motion theory can be used as the expression of special relativity in low energy state, Einstein's general relativity theory can be used as the low effective theory of gravitational quantum field theory.

In addition, the quantum effects in gravitational quantum field theory can explain the early cosmic inflation. The establishment of gravitational quantum field theory plays a fundamental role not only in understanding the origin and evolution of the universe, but also in the universality and self-consistency of quantum theory itself. For example, in the interpretation of quantum mechanics, we can at least say that states are vectors in Hilbert space and quantities are Hamiltonian linear operators in Hilbert space, but what is the correct set of States and quantities in infinite dimensional quantum field theory is unclear. What is completely different is that there is no ready-made formal system to explain in the infinite-dimensional quantum field theory. It is in this sense that we can say that philosophy of science is the continuation of science. For example, in order to describe a free Bose quantum field, according to the idea of quantum mechanics, we need a Hilbert space formed by vectors representing the states of the field, which can be obtained by solving the classical Klein-Gordon equation, and further define the concept of product by complex numbers. Unfortunately, at least two different definitions of product lead to different Boson fields.

There are even tit-for-tat debates between D. Wallace and D. Fraser. In the well-known Journal of the history and philosophy of modern physics, Wallace published papers seriously dealing with particle physics: criticism of the algebraic method of quantum field theory, and how Fraser took particles seriously. Physics: In response to the further justification of axiomatic quantum field theory, two competing methods are concerned about the relationship between different mathematical systems and techniques and experimental phenomena. More importantly, the discussion of many problems in quantum field theory, including ontological epistemology and scientific methodology, depends on the choice or coordination of the two methods.

Moreover, the two competing methods themselves involve the coordination and combination of quantum mechanics and relativity, as well as the relationship between quantum field theory and other physical theories. In a word, the current interpretation of quantum field theory is to study the relationship between algebraic quantum field theory and traditional quantum field theory. The equivalence between quantum field and quantum mechanics of multi-particle system under non-relativistic theory is obvious. The non-interaction part of the corresponding physical operators in the multi-particle system can be constructed by using the particle elimination and generation operators and the moment elements of the single-particle physical operators.

The particle elimination and generation operators are transformed into field operators and their Hermitian yokes in coordinate space. The multi-particle physical operators are constructed by field operators as quantum field physical operators. The evolution of multi-particle system in Heisenberg image can be attributed to the evolution of particle extinction and production operator, which is reflected by Heisenberg equation of motion, and then transformed into quantum field equation of motion, which is similar to single-particle Schrodinger wave equation in form. From a technical point of view, the development of single-particle quantum mechanics into canonical quantum field theory can be directly realized by secondary quantization.

5. Conclusion

Quantum field theory is quantum mechanics when special relativity is considered. Quantum field theory is more about fusion. In short, from the point of view of ordinary people, quantum field theory is less innovative in concept than quantum mechanics. But in the view of physicists, the contribution of quantum field theory to theory is no less than relativity, but this contribution can only be seen after a long period of study.

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