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RESEARCH ARTICLE

QUANTUM MEASUREMENT IN THE FRAMEWORK OF PHILOSOPHY.

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Abstract

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The philosophical challenge arising from the interpretations for quantum measurement is the fundament in all the philosophical challenges of quantum mechanics, which is also the core of understanding of quantum theory. In this paper, we discuss the different interpretations for quantum measurements from the ontology of physical measurements and the logical consistence in the interpretations for the performances of physical experiments. Finally, we analyze the realism in the quantum measurement.

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Significance of Quantum Measurement:-

It is well known that the essential feature of physics science is that he physical phenomena are observable in experiments and the measurements are in principle exact. However, the term of “measurement” in the quantum realm distinguishes significantly from the classical one. The macroscopic objects, such as the Mercury, water-drop in cloud chamber, the solar system, and so on, can be directly observed by appropriate instruments. During the measuring process, the interactions between the classical objects and the instruments can be adjusted to negligible. So we can in principle measure the isolated classical objects themselves. However, the quantum objects, such as electrons, cannot be directly seen [1] and just can measure some observable properties, even with the help of instruments. Once the measurement occurs, the quantum objects interact with the measuring instrument. By considering the significance of Planck constant, the order of interactions is comparable to the energy of the quantum objects. Therefore, the measured results are not the real state of the objects, but the aftereffects of the interactions between the particles and the instruments. Consequently, it needs to establish a logical consistence in the theory of quantum measurement in order to make the interference occurring during measuring process to be intrinsic to the quantum physical process [2].

In the framework of quantum mechanics, a quantum system just shows the potential possibility to evolve, without real physical events, if it doesn’t interact with the classical instrument and just evolves according to the Schrödinger equation. It is the measurement that relates the quantum theory and mathematical formulation to the classical experiences, which causes the occurence of quantum events and the realization of isomorphism. So it requires exact analysis about how to figure out the quantitative estimate from qualitative observations, which is the ontological reason why we need interpretation for quantum measurement.

There is a vicious circle in the standard form of quantum mechanics, which can be considered as both one of the fundamental principles and a subclass of interactions. That is to say, the quantum theory is established on the experiences, which comes from the reports of measurements. However, the measurements include the interferences,

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which obeys the principles of quantum mechanics. It is the duality of the quantum measurement that needs a logically self-consistent theory of quantum measurement, which is the epistemological reason.

Philosophical Challenge in Quantum Measurement:-

In the framework of classical physics, the theoretical value of a mechanical quantity appears during the measuring process as a state with the definite probability of either "1" or "0". The difference between the theoretical value and measured value is called as "error", which cannot affect either the objectivity of the measured results or the essential state of the measured system. The error arises just from the deficiency of the observers' knowledge and the inaccuracy of the apparatus, which can be avoided by improving the accuracy of the apparatus and the knowledge of the observers. However, the measured value of a quantum system just can report the probability of the corresponding result. During the measuring process, the probability of measured values locate in the region between "0" and "1", which gives distinct meaning comparing with the theoretical estimation. Consequently, not all the interactions between the quantum system and apparatus, from the classical view of measurement, can be considered as measurements, because of the randomness of the measured results.

We divide the evolution of the state function of a quantum mechanical system into two tracks [3]. One follows the Schrödinger equation, without the occurence of interactions between the quantum system and the classical apparatus, which describes a consecutive and reversible evolution of the state as a function of the time. The other is the jump of the quantum state, which describes the transformation from the superposition state of the combined system of the quantum object and the apparatus to a special state. Such quantum transformation results from the interactions between the quantum objects and the apparatus, which is inconsecutive and irreversible. When the measurement ends, we observed the entangled state of the quantum system, the apparatus, and the observer, instead of a recorded single and definite value, in which we introduce the concept of ontology. Therefore, it is the interaction that helps us to finish the quantum measurement, during which all the measuring system obeys the law of quantum mechanics, except the consciousness of observers.

The two distinct tracks manifest the essential difference between the ways of evolutions of two kinds of physical systems, i.e. the evolutionary way of one quantum system subject to a given dynamical equation and the other evolutionary way including the observational subject, called as the "projection postulate" [4, 5], which is the difficulty of the theory of quantum measurement. The problem lies in the right moment, at which the "projection postulate" occurs. If it occurs in the interaction between the measuring objects and the consciousness of the observational subject, the final state of the measuring system depends on the behavior of subjective observation. As a result, "projection postulate" can just interpret the measured system in its eigen-state and cannot explain the non-ideal quantum system with perturbations.

Accordingly, the essential problem of the quantum measurement lies in both the boundary between the quantum system and the classical measuring system and the violation of Schrödinger equation during the reduction of wave-packet [6]. The problem results from the logical contradiction between the universal validity of the Schrödinger equation and the observational reliability of observers [7, 8]. The key rests with the modification of classical logistics and the proposal of mechanism of non-reduction realism.

Interpretations for Quantum Measurement:-

Few people believe that the interpretations of two evolutionary tracks and the reduction of wave-packet give the sound theoretical description for the quantum measurement. Under the influence of the new pragmatism, most physicists put more attention of the theory on its practical effectiveness, i.e. the accuracy in the prediction for the results. According to the pragmatism, it is usually the choice to finding most effective method in practice to fall all practical purposes, without the attention of details. In such pragmatic principle, we can construe the quantum measurement as a framework for solving problems. On the ground of such understanding, the core concept of measurement is the quantum state, which is characterized by both the consecutive evolutions and random fluctuations. We can define the mechanical quantities of a macro-system, such as coordinate and momentum, at given time. Although often uses, no physicist applies the pragmatism to the solution for the quantum measurement and develops it further.

The consistent historical interpretations [9, 10] give probabilistic illustrations for the occurrence of historical sequence at different moments to the whole measuring system. The "histories" here are defined as sets of projection operators at different time sequence. However, not all the historical sets have probabilistic values, which must satisfy two conditions: (1) the summation of probability of all sets should be “1”, and (2) all the historical sets should be on one single orthogonal set. The historical family satisfying both conditions can be treated as frameworks and realms. In the framework of consistent histories interpretations, the whole process of quantum measurement just follows one dynamical evolution, which excludes the observers. The quantum mechanics is considered as a standard deductive theory, and we can deduce the classical physical states according to the dynamics and logistics from the principles of quantum mechanics. In this sense, quantum mechanics becomes part of the science, instead of the academic discussions. Unfortunately, such interpretation breaks the principle of unicity [10] and needs to resort to the context of measurement when using.

Operationalism [11] can be considered as the modern development of Copenhagen interpretation, which claims that physicists pay attention to the experimental results, instead of the objective reality behind it, and that quantum mechanics cannot describe the objective reality without the consideration of observers. The essence of science is not the offer for a realistic view, but the description and prediction for specific experiments. The wave function is just the mathematical tool, without any characteristic of reality [12], by which we can learn and predict the quantum world. The quantum measurement depends on the context. The possible states of a quantum system are characterized by the positive operator-valued measurement in Hilbert space. The theory just can tell us the possible values of each measurement. The quantum states just record the possible values of different measured results, instead of the characteristic of a real physical process. During the measuring process, the subjective interferences with the quantum system cannot be avoided, and there is no objective physical state.

Context and Realism in Quantum Measurement:-

The construction and development of quantum theory indicates that science is on the borderline between man and nature. The scientific reality described by the quantum theory is not the simple duplicates of self-reality, but the dynamically constructive copy for the objective reality. The randomness in the quantum field is pure randomness, without any reason. The essential of quantum mechanics lies in the non-locality. Based on these new features, the realism in core problem of quantum mechanics, i.e. quantum measurement, forms and transcends the classical realism in different direction and on different level.

In the context of quantum observations, it is impossible to distinguish the subjective behaviors from both the measured object and the measuring instrument, because of the effect of Planck constant. The interactions between the quantum object and the apparatus impose underlying influence on the quantum phenomena themselves [13], especially the out of exact control for the reaction of quantum object to the apparatus, in order to keep consistent with the uncertainty principle. As a result, the observations in quantum measurement become a problem of epistemology. On one hand, it needs to put the objects on the opposite of the observing subject, in order to describe the mental activity of the observer. On the other hand, there is no obvious borderline between the objects and subject, because the subject belongs also to the mental content. In this sense, although the observation depends on the observing condition, the quantum observation is pure objective behavior, if the acceptance of quantum phenomenon doesn’t obviously involve the specific observer. Actually, the concept of observing objectivity has changed, which doesn’t reveal the intrinsic properties of the quantum object before the measurement and possesses effective in the inter-subjective sense. It is not to say that the measurement produces the physical properties of quantum objects. Therefore, we can describe the context of quantum observations as Fig. 1.

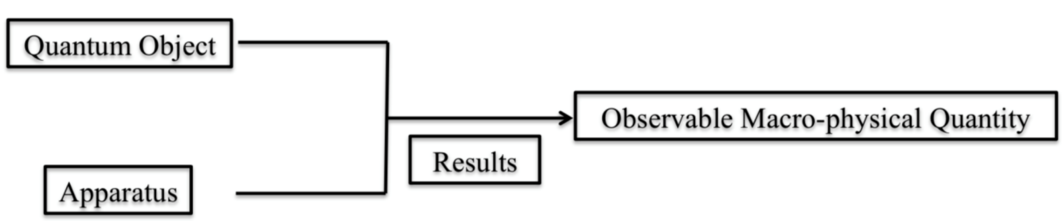

Fig 1:-

In the context of relation between quantum object and apparatus, we cannot neglect the interacting energy, because of its comparability with the total energy of the quantum object. The most importance is that the interaction in measuring the coordinate is uncertain. If we want to measure and determine the coordinate on the space-time for an electron, we also interfere with its state of motion. The repellency between the coordinate and the state of motion satisfy the Heisenberg’s uncertainty principle. Such uncertainty relation arises from the intrinsic properties of the quantum system, instead of the lack of knowledge about the coordinate and momentum. Consequently, we should consider the quantum object and the apparatus as an entirety, because of the inconsecutive and uncertain interaction. Therefore, quantum object and the apparatus forms the context of holism in the quantum measurement, described by Fig. 2. In the holistic context, the phenomenon is always an observed phenomenon. There is no any meaning of quantum phenomenon without observations. The measured result represents the state of both quantum object and apparatus. The quantum object and the apparatus form a dynamical entirety, the changes of the apparatus leads to the change of manifestation of quantum object. The object and apparatus also form a contextual whole, and the properties of the object depend on the frame of reference determined by the apparatus.

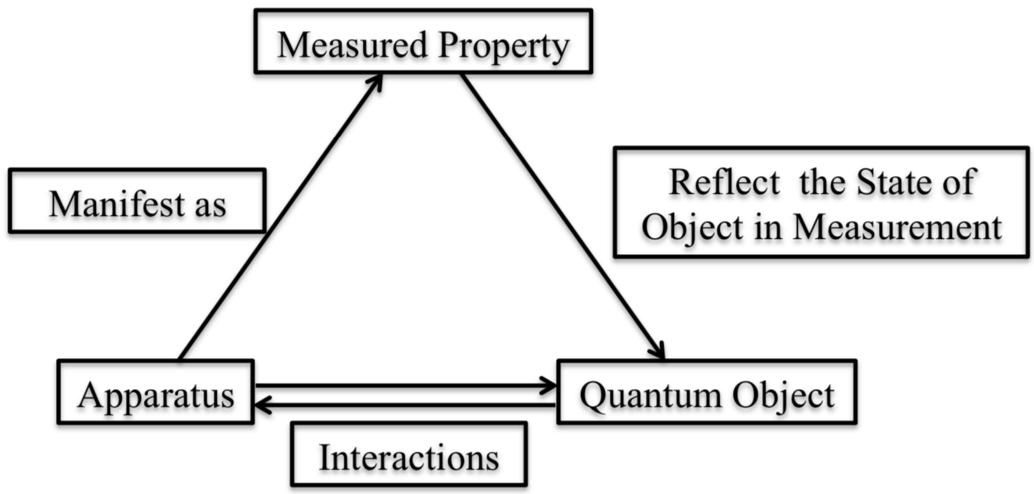

Fig 2:-

In the context of phenomenon observed in the quantum measurement, the interacting quanta lead to the concept of discontinuity and the postulate of indivisibility, which produces a series of fundamental problems. The discontinuity causes the ineffectiveness of classical concept. However, the indivisibility makes us to consider the manifestation and the experiment as a whole. Then it is necessary to questionize the range of application for the underlying classical concepts. In addition, the wave-particle duality of quantum objects is related by the interacting quanta. Accordingly, we should use both “particle” and “wave” to describe the quantum object, and the accuracy is limited by the uncertainty principle. In this limit, we use classical language to discuss quantum phenomenon, which limits both the accuracy of description and the relation between object and phenomenon. In order to completely describing

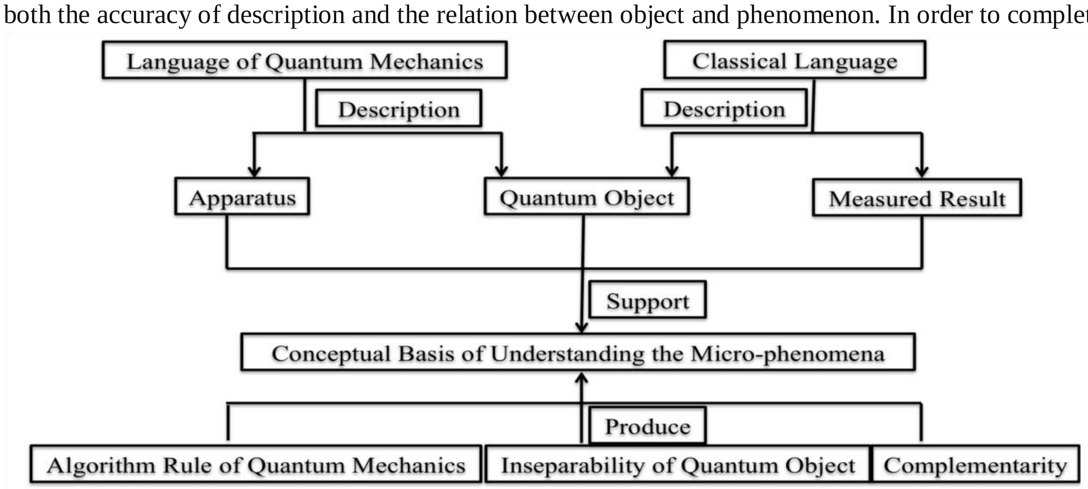

Fig 3:-

the properties of a physical reality, the two kinds of language should be complementary with each other, and the accuracy also is limited by the uncertainty principle. Such exclusion and complementarity of two kinds of classical language can be shown in Fig. 3.

Summary:-

As the core problem of quantum mechanics, the interpretation and understanding for quantum measurement are a mixture of semi-classical and semi-quantum. However, the holism of quantum measurement reflects the function of objective realism. The quantum measurement represents our knowledge and viewpoint about the realism and the constructive characteristics of the theory. The holistic realism in the interpretation of quantum measurement is the unified realism of self-realism, objective realism, and scientific realism.

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