PHILOSOPHICAL SCIENCES

МОДАЛЬНА СЕМАНТИКА МОДИФІКОВАНА ДЛЯ ТОГО, ЩОБ РЕПРЕЗЕНТУВАТИ ІНТЕРПРЕТАЦІЮ КВАНТОВОЇ МЕХАНІКИ БАГАТЬОХ СВІТІВ

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MODAL SEMANTICS MODIFIED TO REPRESENT MANY-WORLDS INTERPRETATION OF QUANTUM MECHANICS

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АНОТАЦІЯ

Ця коротка стаття пропонує проект модальної логічної семантики яка буде представляти не класичні модальності, а багато-світову інтерпретацію квантової механіки.

Вона також розглядає деякі проблематичні методологічні питання доктрини такі як поняття вимірювання та роль інтерпретатора. Особлива увага дана відомим парадоксам КМ таким як парадокс ЕПР та Кішці Шредінгера.

Стаття буде цікава логікам, фізикам та філософам науки.

ABSTRACT

This short paper proposes the project of a modal logical semantics that will represent not the classical modalities but the many-worlds interpretation for the physical theory of quantum mechanics.

It also views some problematic methodological questions of the doctrine such as measurement and a role of an interpreter. Special attention is given to the famous paradoxes of the QM such as EPR Paradox and Schrodinger’s Cat.

The paper will be interesting for logicians, physicists and philosophers of science.

Ключові слова: квантова механіка, модальна семантика, парадокс, теорія відносності.

Keywords: quantum mechanics, modal semantics, paradox, relativity theory.

Introduction

Quantum mechanics is a sub-discipline of physics which studies the phenomena that happen in the quantum world - on spatial scales comparable to Planck Scale. It deals mostly with the elementary particles’ interactions. Laws of quantum mechanics are incompatible with the laws of classical mechanics and relativity theory. Due to their paradoxical nature they are hard to grasp from the point of view of common sense either [3 p. 12].

Interpretation of quantum mechanics is a theory that gives the general theoretical framework for the mathematical models guiding the quantum world and explains its paradoxes. In this way, interpretation theory is both mathematics and philosophy. There are several interpretations of QM existing which all contradict each other.

Many-worlds interpretation of QM was proposed in 1957 by Everett [4 p. 275]. It introduces the concept of an infinite number of parallel universes existing simultaneously with others, each representing an alternative for the course of events in the current world. This explains the probability function of QM and some famous paradoxes like Schrodinger's Cat and EPR Paradox.

Modal semantics is a formal system built to give an explanation to modal logics’ operators. There are different specifications of modal semantics but probably the most famous one is possible worlds semantics. This system proposes the existence of a variety of possible worlds that have alternative laws and course of events in relation to our centered world.

Classical modal logic is not appropriate for the QM as possible worlds have different topology and do not represent the alternative physical realities of the probability function. Very few philosophers dealing with the possible worlds' semantics are realists about it, i.e. believe these worlds are real and not just a methodological tool for analyzing modal contextes.

Nevertheless, it is possible to rebuild this semantics, saving the notion of the possible world only as an initial concept, so new semantics will represent the QM many-worlds interpretation.

Formal logic is widely used for representation of QM including the semantics since the inception of the doctrine - so called quantum logics were proposed by Garret Birkhoff and John von Neumann. This paper just develops this trend a little bit further.

Many worlds interpretation outlined

QM postulates particles and interactions are fundamentally influenced by any measurement. Spatial coordinates and momentum of a given particle cannot be measured simultaneously - the more you know about one of the parameters the more the other one is undefined. Unlike classical objects, quantum particles do not have defined coordinates - instead there a function that maps the area of space with probabilities of a particle being in this exact area in this exact time [5 p. 1268].

The famous two slit experiment shows how particles can behave absolutely differently due to measurement or absence of measurement. If the measurement is performed it behaves as a particle if not - as a wave. So there is also a dualism about the very nature of the surrounding physical reality - particles are both corpuscula and waves [7 p. 409].

The probability function that maps the space with the probability of a particle being there at a given time is also called a wave function. The evolution of the system of particles in time is described by the famous Schrodinger Equation.

The status of a wave function changes from interpretation to interpretation. Some theories claim it is just a mathematical formalism while others give it a status of a special physical entity. Some physicists claim the world shift from the “cloud of probabilities”-state to the classical one is through so-called collapse of the wave function [5]. And there is also the status of the agent who performs the measurement.

Does the collapse of a function happen due to the measurement? Is then the interpreter the cause of the collapse? It brings metaphysical problems as well as purely mathematical problems.

Many-worlds Interpretation rejects the very concept of the wave-function collapse. It is precisely to avoid this concept Everett proposed that there are multiple universes existing each representing the possible alternative to the measurement.

The formal representation for Everett’s model

The semantics for QM is pretty simple, simpler than a classical one. Let us assume we have an ordered triple <<Q1>, R, <Q2>> where R is our classical world at the moment of measurement, <Q1> is an infinite set of the different alternative worlds before R and <Q2> is an infinite set of the alternative worlds after the measurement.

Classical modal semantics postulates the set of the possible world and one actual centered world connected by accessibility relation which defines the relations between worlds and according semantics of modal operators. This semantics varies from system to system but even basic description seems to be more complex than the QM system outlined above.

The trick is the main part of this semantics is the interpretation. As such, modal semantics allows for formal carcasses for particular theoretical concepts. In other words we have a group of symbols, interpretation of each and the relations between them constitutes QM as a complete theory.

Problematic questions

The first and probably main such problematic question is about “R”. What is the classical world? What is measurement? Is “really” defined by measurement? Is the device the cause of measurement or the human interpreter? The answer for each question differs from interpretation to interpretation.

In the case of many-worlds interpretation “R” is a classical world for the observer in a given time. There is no wave-function collapse in this theory so measurement is not that important and we may say that the notion of a classical world is defined by the observer in each particular situation.

If it was the case of collapse the situation would be much more complex. First of all the measurement’s and observer’s relations should be defined precisely together with the methodological questions about measurement outlined above. Then the major problem arises - what are the time limits of the classical world? In what period of time does the classical world exist in relation to the measurement and the observer? Should we establish the chain of Rs to represent the historical evolution of a classical world?

The last is a very interesting and potentially fruitful idea. As we know one of the reasons for incompatibility of the QM and general relativity theory is a different view on time scale. Relativity theory allows for the cause and effect chain to be dependent on the observer [2 p. 16]. If we would have established the mentioned Rs’ chain and defined its relation to the measurements in the QM that problem would be solved.

Relativity also usually deals with very big and complex systems and/or speeds close to the speed of light. What are the borders of “R” to the surrounding giant Universe then? Is it a limited area where the measurement is held? What limits the area? Is it a whole Universe? Or should we rather speak about the different “R-chains” and their relations? All these questions are both metaphysical and physical.

Questions that are more close to Everett's model are those connected to the <Q1> and <Q2>. What are those sets of world? As we know the field in theoretical physics is assumed to be infinite. It is rational to think that the particle is within a rational space area but there is always a very small probability it is near another planet. In many worlds interpretation every such probability is a separate universe.

As the probability function is infinite, so are the sets <Q1> and <Q2>. But there should be a certain spatial-like structure of organization of these worlds in relation to the centered one, something similar to the topology. It is easy to see that the topology of both sets of possible worlds will be established by the probability function and is defined by a simple mapping function.

It is not hard to see that mentioned history of the classic world as a chain of Rs is similar to the Shrodingers equation for the evolution of a particle movement in time. This equation describes the movement of the probability field while “R-chain” will describe the same in relation to the particular measurement. In this way, semantics may have consequences for the famous paradoxes of the QM. The next chapter will outline some of them.

Consequences for the QM paradoxes

The mentioned “R-chain” brings interesting consequences for the concept of QM known as the “hidden parameters” [1]. In the beginning of the development of the QM as a theory some scientists doubted the postulate about the simultaneous indefinability of the particle’s coordinates and momentum. They claimed that this postulate is caused by the imperfect measurements and that QM systems contain hidden parameters that are not measured.

However, the “hidden parameters” concept is widely accepted as a doubtful theory nowadays. No experiment could prove the claim and the postulate of the coordinates and momentum remains at the core of contemporary quantum mechanics.

What is here for the semantics outlined in the paper? Modal semantics cannot prove or disprove the “hidden parameters” theory. Nevertheless, the “R-chain” being completely defined brings a new theoretical approach to the problem. If the classical world is the series of measurements defined on the time scale then the key to proving or disproving the postulate lies in defining the cause effect links in QM and its relation to the cause effect chain in the classical world.

The famous EPR Paradox is a thought experiment designed to prove the existence of the hidden parameters in the quantum systems. It proposes to measure not the single particle but two of them before and after interaction using the additional data to define both the coordinates and the momentum of the particles.

The experimental proof or disproof of the EPR Paradox never happened due to the enormous technical difficulty of the experiment. Opponents of the hidden variables concept claim that the initial thought experiment itself contradicts the axioms of the QM and so cannot be considered to be the argument for anything in this theory.

“R-chain” could have helped clarify the EPR Paradox if the precise relations between segments of the “chain” would have been established.

The similar consequences are brought for another famous thought experiment - Schrodinger's Cat [8 p. 325]. The experiment attacks the mathematical axioms of the QM as a theory from the common sense point of view using the next imaginary situation.

Let us assume we have a cat in a closed box with a special mechanism for deploying the poisonous gas in it. The mechanism has a controlling mechanism that is tied to a measurement device which measures the state of the particle. It may be a radioactive particle with a very short half-life period. The half-life is probabilistic - so in the next few moments the particle will either stay the same or emanate the radioactive ray.

The mechanism with a gas releases the poison if the particle emanates which kills the cat or keeps the gas vat intact if the particle stays in its normal state. According to the axioms of the QM the particle in the moments preceding the measurement is in a so-called superposition. It is both emanating and staying the same. So, the thought experiment concludes that a cat is both dead and alive which is a methodological contradiction for QM.

Our semantics would consider the moment of the measurement the “R” in the “R-chain”. And the paradox will be explained when the exact causation relation in the “R-chain” will be established.

Conclusion

This short paper outlines the project of the modal semantics modified to represent not the classical modalities but the Everett’s many-worlds interpretation of quantum mechanics.

Formal logic was used in the QM from the inception of the doctrine in the first part of the XXth century. However, using the semantics to represent the interpretation is a much more rare case.

The paper views the problematic questions connected to the introduced formalism such as the status of “R-chain” and the old problem of measurement and the interpreter in QM.

The special attention is given to the most famous paradoxes of the QM such as the Schrodinger’s Cat and EPR paradox. It is proved that the outlined formalism can bring new methodological approaches to research in this area of theoretical physics.

The paper will be of interest for theoretical physicists, logicians and philosophers of science.

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