A translation of "A New Solution to the Measurement Problem of Quantum Mechanics" by Xianyi Tang and Zhilin Zhang

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**Abstract:** The measurement problem of quantum mechanics has been there for almost a century. Academia tends to regard this problem as a combination of definite outcomes and preferred basis. At the start of this century, John Conway and Simon Kochen proposed the strong free will theorem. This theorem clearly proved that free will exist within any given particle, which implies that particles have perceptions and freedom of choices. A particle’s perception and its free will are then linked with energy, and two principles of energy are reached: the perception-energy principle and the will-energy principle. With these two principles, the measurement problem can be solved, and a new interpretation of quantum mechanics can be revealed.

**Keywords:** measurement problem; interpretations of quantum mechanics; free will theorem; perception-energy principle; will-energy principle

**Section 1: The measurement problem of quantum mechanics**

The quantum measurement problem has been there for almost a century. [1] In the Orthodox Copenhagen interpretation, wave function collapses during a measurement, which is a process that cannot be described by Schrodinger’s equation. This obviously causes problems for the quantum theory. Another problem is the “Schrodinger’s cat”: according to quantum mechanics, the cat is in a “quantum” superposition state of being dead and alive, while to human observers the cat is always either alive or dead, i.e. being “classical”. The “classical” picture of the world, which is based on humans’ experience, is completely different from the “quantum” picture described by quantum mechanics. “Why does the world appear classical to us, in spite of its supposed underlying quantum nature, which would, in principle, allow for arbitrary superpositions?” [2] These problems are together referred as the measurement problem. [3-5]

As studies on the measurement problem accumulate, the limitations of Copenhagen interpretation become obvious. Schlosshauer has formulated these limitations into two problems that should but cannot be answered by quantum mechanics and the orthodox interpretation, as follows: [2]

1. Problem of definite outcomes: Just like in the Schrodinger’s cat case, why do human observers always get a definite state as the result of an actual measurement, instead of getting a superposition?
2. Problem of the preferred basis: Why the definite result of a measurement is always one of a set of “preferred basis”? As any set of orthogonal and complete basis is equivalent to the others in quantum mechanics and none of them is in a “privileged” place. Plus “the expansion of the final composite state is in general not unique, and therefore the measured observable is not uniquely defined either.” [2]

As David Albert pointed out, these problems show that the root of measurement problem is at the discrepancy between the “classical” world and the “quantum” world. The former is made of definite observables and perceivable to humans, while the latter is made of wave functions in the Hilbert space.[5]

To solve the two problems above, and to reasonably reconstruct the classical world upon the quantum one, many interpretations of quantum mechanics have proposed various concepts, rules and criteria. Examples include the stability criterion of decoherence [6-8] , the probability postulate and behavior principle of many worlds interpretation [9, 10], concepts of hidden variables in Bohmian mechanics [11, 12], stochastic reduction process in GRW models [13-15], consistency criterion of the consistent history interpretation [16, 17] and the actualization rule of modal interpretations [18, 19]. However, the common viewpoint is that the measurement problem has still gone unsolved [2, 20].

**Section 2: Perceptions, free wills and two principles of energy**

Based solely on quantum mechanics and the orthodox interpretation, we cannot derive the “classical” world. Consequently, to solve the measurement problem, we need something new, which is not included in the old framework. Clearly, the “classical” world is defined by humans’ perceptions and experiences. Thus, “perception” is a key concept that is new and unavoidable.

Perception always yields a single definite outcome. For example, the pointer in a Stern-Gerlach experiment is in superposition according to quantum mechanics, but always appears either pointing up or pointing down to an observer. Schrodinger’s cat is also in superposition, but the cat itself will certainly not feel that way. The cat will either perceive itself alive or be dead.

Thus, we can see that “perception” has such a feature: the result of it is always one of a series of particular states (preferred states), and never a superposition of them. Here comes the key question: what are these preferred states? What is the essential difference between these states and their superpositions, as the latter can never be perceived? These questions pertain to the nature and attributes of “perception”, and related to the root of the measurement problem.

Do particles have a modicum of the most primitive perceptions (just like “petites-perception” in Leibniz’s Monadology?) In 2006, Conway and Kochen proposed the free will theorem. [21, 22] Based on the assumption that humans have free wills, they used three axioms – SPIN, TWIN and MIN to strictly prove that particles also have free wills, i.e. their behaviors cannot be deduced from the entire history of the whole universe. They further claimed that particles’ free wills are the building blocks of our own. The free will theorem strongly suggests that particles do have perceptions, since blind-free-will will make no difference to pure randomness.

Just like the Schrodinger’s cat will not perceive itself in superposition of being alive and dead, if we admit the petites-perception of an electron, the following two states must be incompatible to it:

State 1: the electron orbits a nucleus.

State 2: the electron annihilates with a positron.

As to the electron, these two states are being “alive” or “dead”, and they are completely different states of existing, i.e. they are two states among that series of “preferred states”, whose superposition is unperceivable.

From the above, we can see that those “preferred states” are closely related to different states of existing. Existing things must have masses, and different masses guarantee different states of existing. Therefore, the preferred states are related to different masses. According to relativity, mass is energy. So we propose the perception-energy principle:

*When perceiving, an object always perceives itself in a state with certain amount of energy, not in a superposition of states with different energies.*

According to the perception-energy principle, particles’ (petites-) perception is linked with energy. So will particles’ free will, as we propose here the will-energy principle:

*When exerting its free will, an object always uses energy, and lowers itself to a state with less energy.*

We will discuss the second principle in details in section 4.

**Section 3: Answering the problem of definite outcomes and problem of the preferred basis**

With the perception-energy principle, the problem of definite outcomes and the problem of the preferred basis can be solved. First, what are those preferred basis (preferred states)? Ultimately, they are different energy states of the observer.

For example, in a Stern-Gerlach experiment, the observer needs to look at the pointer. On the observer’s retina, there are about 100 million photosensory neurons, every of which has the following two possible states:

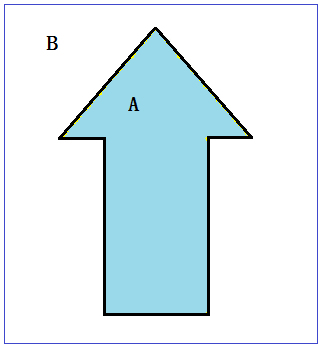
State 1: the neuron absorbs photons and fires an action potential.

State 2: the neuron does not absorb enough photons and does not fire.

These two states have different energies, and are related to different perceptions that are incompatible. Overall, one hundred million cells can provide 2100,000,000 different energy states and visual perceptions. These 2100,000,000 visual perceptions are the natural basis of human sight, whose superpositions are unperceivable according to the perception-energy principle.

Therefore, previously equivalent pointer states are now divided into two groups: the first group consists of pointer up and pointer down, while all superpositions of them are in the second group. All states in the second group are unperceivable to the observer, discussed as follows,

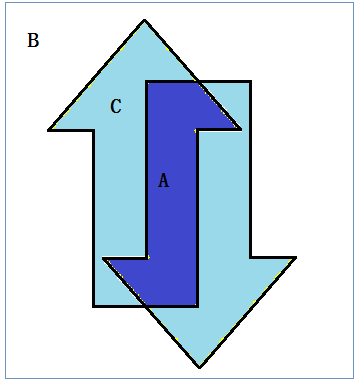
When an observer looks at the pointer, the neural activity on his retina is as follows,



(Figure 1: A simplified illustration of the projection of a pointer onto observer’s retina)

In region A, as seeing the pointer, the neurons are active and firing action potentials; while in region B the neurons are not active, i.e. the image is not projected there. This situation can well correspond to a natural base among the 2100,000,000 different visual perceptions.

However, a superposition of pointer up and down cannot correspond to such visual perception. If a superposition were projected onto the retina, the neural activity would be as follows,



(Figure 2: A hypothetical illustration of the projection of superposed pointers onto observer’s retina)

Neurons are active in region A and silent in region B. But in region C, the superposition of pointer states would cause neurons to be in superposition of firing and not firing. However, according to perception-energy principle, such a state does not correspond to any perception, thus unperceivable to the observer, and therefore cannot be the result of a measurement.

Thus, pointer up and pointer down are “privileged” and become the preferred basis. The problem of the preferred basis is solved.

Second, the problem of definite outcomes is also solved. Why the result of a measurement is always one of the preferred basis instead of superposition of them? Because each preferred base is able to map to a specific state of the observer with a certain amount of energy. Due to perception-energy principle, the observer will only perceive himself in one of these states and never in superposition. Correspondingly, the result of measurement will only be one preferred base.

**Sect 4: Free wills, the flow of energy and quantum measurement**

The problems of definite outcomes and preferred basis are solved, but one question remains: while quantum mechanics derives superposition, why does the observer get single definite outcome? According to the free will theorem by Conway and Kochen and the discussion above, a reasonable answer will be: the result of measurement has already contained the free will of the particle, which has not shown up yet in the superposition. As a mathematical tool, the Schrodinger equation contains and derives all possibilities. The free will, which cannot be predicted by any mathematical function, chooses one out of them.

Now, let’s scrutinize the measurement process and pay attention to three facts: (1) In a measurement, the observer gets information from the measured system; (2) In a measurement, the system always releases energy. For example, in a traditional Stern-Gerlach experiment, kinetic energy of the electron is absorbed by the screen to generate a light spot; In a ECD, kinetic energy of the electron is absorbed by Nitrogen gas, which in turn produces an ion current that can be recorded; when looking, human eyes receive photons from the measured system, etc. The measuring devices always absorb energy that is released by the measured system. (3) As discussed above, the result of a measurement contains free will of the particle, which choosing one possibility from the superposition.

According to “information is carried in energy flows and storages.....” [23], fact (2) can be deduced from fact (1). In addition to fact (3), the complete picture will be that the measured system shows up its free will, gives out information and releases energy. Thus, during any measurement with quantum uncertainty beforehand, the system will exert its free will, meanwhile releasing energy. This is exactly predicted by the will-energy principle.

Here are two complementary processes: for the measured system, it exerts its free will, makes a choice and releases energy; for the measuring observer, he absorbs energy, which in turn changes his energy state and perception. Thus, both free wills and perceptions are connected with energy, the most fundamental physics quantity. These two connections help solve the measurement problem and reconcile the discrepancy between “quantum” and “classical” worlds.

**Section 5: Summary**

In light of Conway and Kochen’s free will theorem and Leibniz’s Monadology, the authors admit that fundamental particles have free wills and perceptions, which are further linked with energy in order to get the perception-energy principle and will-energy principle. With these principles as extensions and complementation of quantum mechanics, the measurement problem is solved. Compared with other interpretations of quantum mechanics, this method is completely compatible with the quantum theory and the decoherence program, while maintains the eigenvalue-eigenstate link. This is one advantage compared with quantum interpretations that weaken or abandon the e-e link when building the “classical” world from the “quantum” one.

Another advantage is the prominence of the role of observer’s perception, which has not been emphasized in all previous quantum interpretations. Since the proposal of free will theorem, the role of the observer has drawn increasing attention [24-26]. In this interpretation, it is exactly the energy states and perceptions of the observer that define the preferred basis and the classical world.

Finally, the two energy principles proposed here are based on quantum mechanics and the free will theorem. These principles reflect the free wills of particles, abandon determinism, deny spatial coordinates as preferred basis, embrace a non-classical description of the microscopic systems and reveal a new interpretation of quantum mechanics.

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