Analysis of the Mainstream Interpretation of Quantum Physics

Yitian Zhang

College of Arts and Sciences, The Ohio State University, Columbus, USA

*Corresponding author's e-mail: ShiLiShuang@cas-harbour.org

Abstract. Quantum physics is changed in an unexpected way. Scientists believe that the study of quantum physics will play an important role in future technology. Therefore, it is meaningful to study quantum physics. The aim of this paper is to provide an initial explanation of the quantum world through the classical single particle double-slit interpretation experiment, and to answer a few questions about the experiment using mainstream quantum mechanical interpretations, such as the Copenhagen interpretation and the Many-Worlds interpretation. The superposition state, which is the core of the Copenhagen interpretation, is then introduced. The Einstein-Podolsky-Rosen paradox and locality are also introduced, and the relationship between the latter and special relativity is analyzed. The author also discusses whether non-locality leads to retrocausality. Finally, the author discusses the relationship between multi-world interpretation and Schrödinger’s cat, but this may raise some philosophical questions. However, realist and hidden variable interpretation are also consistent as long as locality is abandoned.

1. Introduction

In 1900, Planck discovered that the radiation spectrum of a black body occurs only in discrete energies separated by the value $h\nu$, where $\nu$ is the frequency and $h$ is a new constant, the so-called Planck constant. Each photon carries an energy $E$ proportional to the frequency $\nu$ of the oscillator via Planck’s constant: $E = h\nu$. This solves the ultraviolet catastrophe that at high frequency (short wavelength) the energy associated with each quanta is very large and only a few oscillators will have this much energy at any finite temperature. The next step was taken in 1911 when Ernest Rutherford carried out some experiments in which alpha particles were shot into gold foil. From these results he was able to build an atomic model. In 1913 Bohr visited Rutherford, who solved the problem of the stability of the atomic structure by proposing a quantum orbital for the electron outside the nucleus, providing the first theoretical support for Rutherford's model and enabling an explanation of the emission spectrum of the hydrogen atom. Already in 1925, Born proposed a statistical interpretation in which the square of the absolute value of such a wave function expressed the probability amplitude of the measurement result. The Copenhagen interpretation includes the Complementarity principle proposed by Bohr, Born's rule and Heisenberg's uncertainty principle. The meaning of Hugh Everett's multiple world theory is that in addition to the world that people know, there are countless worlds in the universe. Every time a quantum experiment with different possible results is performed, even if the researcher only knows the world that the researcher knows, the results actually exist in other different worlds. This article will provide a preliminary interpretation of the quantum world by analyzing the classic single-particle double-slit interpretation experiment, and use mainstream quantum mechanics interpretation to understand some of the problems related to the experiment.
2. Single particle double-slit experiment and Delayed choice quantum eraser experiment

Thomas Young first observed the double-slit pavilion experiment in 1801, in which a single ray of light passing through two very narrow slits produced interference pattern.

Maxwell later proposed that light is an electromagnetic wave, so the appearance of interference pattern is reasonable. However, Einstein’s photoelectric effect also showed that light is made up of one discrete photon at a time. Each photon is a small wave, which must choose one of two slits to pass through. But as long as there are more than two photons, interference pattern can appear. Each photon passes through the two slits separately and then interferes behind the slits, thus forming an interference pattern. However, under the conditions of the two-slit experiment with a single photon, interference pattern are still found. In the case of one photon being emitted at a time, interference pattern still appear. At the screen there are bright and dark lines corresponding to large and small values of $|\psi(x)|^2$. $|\psi(x)|^2$ is defined to be:

$$|\psi(x)|^2 = |\psi_1 + \psi_2|^2$$  \hspace{1cm} (1)

$\psi_1$ = Portion of wave passing thru one of slit
$\psi_2$ = Portion of wave passing thru another slit
Many scientists cannot understand why photons choose a certain position with a high probability after passing through a slit. In fact, some quantum properties, such as momentum, energy and spin direction, appear similarly. In quantum physics, the mathematical description of this kind of wave distribution is called a "wave function". At both ends of the double-slit experiment, the position of the particle is known. The particles are more like particles at the ends, and in the middle, they are closer to waves. Therefore, the wave implies information about the possible final positions of the particles. In fact, the wave must give all possible paths of the particle, which suggests that the possible trajectories from the beginning to the end are obtained. Before the particles reach the screen, there are some factors that will make them reach the final position. This leads to a transformation between the wave and the fixed position. The single particle double slit experiment suggests that the region between the creation and detection of the particle may not be clearly present and may not be a particle in the true sense of the word. The momentum and position of the object cannot be known exactly in this region. In any experiment where the slit traversed by the particle can be clearly distinguished, it would leave the interference pattern broken and the particles passing through the two slits in a clump each. It does not matter whether you place the detector in front of or behind the double slit. But it is impossible to measure the wave without destroying it. An experiment in 1999 used a special crystal that absorbs incoming photons and produces two new photons, each with half the energy of the original [3].

Figure 2. Interference pattern in a single particle double slit experiment with electrons [2]
Figure 3. A Delayed Choice Quantum Eraser and this image from Time, PBS Space

In figure 3, the two new photons were a pair of entangled photons. One was emitted towards the screen and the other was used to distinguish which slit the photon was passing through. Detector A lights up to indicate that the photon has passed through slit A. It is then made to fall on the screen according to the wave function before the other photon of its entangled pair reaches the detector. However, backtracking will affect the previous position of the photon that fell on the screen. Since the two photons are in an entangled state, it is said to have not disturbed the other one, and no decoherence occurs. And C and D are quantum erasers, its jobs is to destroy any information about the path of the photons.

3. Copenhagen interpretation

The Copenhagen interpretation is a comprehensive understanding of the atomic world represented by quantum mechanics. The founder was primarily the Danish physicist Bohr, but physicists such as Heisenberg and Born also made very important contributions to the overall understanding of the atomic world. The University of Copenhagen was a pioneer in quantum physics in the 1920s. From the Copenhagen interpretation, the author can know that the function has no physical essence, and the function is actually composed of pure probability. It is clear that the particles in the double-slit experiment exist as a probability wave that contains all paths. It is only when the particle is being detected that its fall position and path are determined. The Copenhagen interpretation refers to this transition between the probability and certainty properties of space as "wave function collapse". This shows that it is meaningless to determine the properties of the particles before they collapse. In the absence of observation, the wave function describing this superposition state is a complete description of reality. The collapse is the cause of the final distribution of particles and the appearance of interference fringes. In the Copenhagen interpretation, the final choice of experiments is completely random in the limit of the wave function. However, Einstein insisted that reality exists objectively and that it is independent of our observations. He insisted that the wave function and quantum mechanics were incomplete, and that there must be hidden variables to reflect the more material underlying reality. Therefore, with Podolsky and Rosen, he proposed a quantum scenario that showed that in order to abandon the assumption of realism. So, Einstein also had abandon a concept that is locality. Locality is the idea that each point in the universe can only interact with its neighbouring position. This is fundamental to Einstein’s relativity that tells us the chain of cause and effect can not propagate any faster than the speed of light. The Einstein-Podolsky-Rosen paradox or EPR paradox introduces quantum entanglement. In a nutshell, measurement of an entanglement pair can theoretically achieve instantaneous transfer at any distance and even back in time, which is violating locality and possibly violating causality. Einstein called this "spooky action at a distance," and proposed Quantum
Mechanics (QM) was incomplete [4]. In 1964 John Stewart Bell proposed an experiment to resolve the debate between Einstein and Bohr. In this experiment, it utilises entangled electron and positron pairs. And spontaneously generated by photons. Such particles will always rotate in opposite directions to each other. However, before taking the measurement, the researcher cannot know the direction of rotation, and can only determine that the two electrons are facing each other. Before this, their wave functions were already entangled. If one particle is measuring spin, the other particle must also be spinning. As a result of these things, Bell figure out a series of observable results known as Bell's inequality. It expects that quantum mechanics requires local hidden variables. But if an entanglement experiment violates Bell's inequality, local reality is also violated. In the early 1980s, the French physicist Alian Aspect succeeded when Aspect found that there was a correlation between the choice of a photon's polarization measurement axis and the final polarization direction of its entangled partner. Bell's inequality was violated [5]. The results of these entanglement experiments do seem to violate local realism, but this may imply a violation of realism or just a violation of locality. In fact, Dr Bell argues that the violation of his inequality only disproves locality. Nonlocality requires that the effects of entangled particles on each other are instantaneous. However, nonlocality and relativity can actually be identical. Relativity requires that information be transmitted at no more than the speed of light. But none of these entanglement experiments allow any real information to pass between particles. Thus, multiple world theory can solve the problem of particle information transmission.

4. MWI
In the Copenhagen interpretation, observation leads to the collapse of the wave function into a single reality, and this collapse represents a shift from the quantum to the classical domain. Schrödinger, the founder of quantum mechanics, thought this was absurd, so he proposed his famous thought experiment, Schrödinger's cat. But proponents of Copenhagen argue that the superposition state of the quantum does not apply to the macroscopic scale. According to the Copenhagen interpretation, the universe chooses an end result among all possibilities, such as the position of a particle on a screen in a double-slit interference experiment. From the Copenhagen interpretation, this choice is essentially random, although not all results have similar possibilities. Although not all outcomes have the same probability. But this is indeed a quantum mechanical interpretation which was proposed by Everett in 1957 [6] and later called MWI. Copenhagen’s explanation shows that the superimposed state of particle trajectories will eventually converge to the observer’s timeline. But according to MWI, integration will not happen, various possibilities will develop individually, and the world that people see is only one of these timelines. For example, in a double-slit interference experiment, many particles fall on a bright interference pattern, but in another world this particle might fall on a dark bands. Reality splits into different branches each time there are different possibilities for quantum states. This would lead to an unimaginable number of split worlds, because each time such an experiment is done, a different world is split. In fact, quantum experiments are very close to people’s lives. Irregular blinks are even quantum physics experiments. But there are actually multiple worlds in the Copenhagen interpretation as well, except that the wave function collapses so that there is only one timeline. MWI is a deterministic interpretation where all possibilities occur and the observer sees exactly the outcome of the current branch. There is no current experimental evidence against MWI, and MWI avoids the collapse of the wave function. The MWI is indeed a less than complete theory from the perspective of the author, and at least possesses unfalsifiability at present.

5. Conclusion
This thesis summarises the development of quantum physics, such as the famous delayed choice experiment and the double-slit interference experiment, and then introduces the mainstream theories of quantum physics and analyses the impact of different theories on quantum physics. The most influential of these is the Copenhagen interpretation [7]. The Copenhagen interpretation is the most influential of all, with contributions from many famous physicists. At this stage, the MWI has some shortcomings, although it solves most of the paradoxes of quantum mechanics, such as Schrödinger's
cat [8]. But the development of MWI could open up a whole new world of analysis for theoretical physicists. In this paper, due to the author’s limited understanding of academic articles in depth, the analysis might be simple. With further study, the author hopes to look up more literature about the quantum physics.

Acknowledgments
I think the first person I would like to thank is Prof. John W. Harris, who taught me how to get into quantum physics. I was having a difficult time because I was taking language exams and he helped me and respected my choice. I was also assisted by my TAs Dai Jianwei and Yang Zhengqiang, who helped me in my TA classes and with my homework.

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