Retro-causality in relational quantum mechanics

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Abstract

The Wigner-Friend paradox is discussed in the light of relational quantum mechanics (RQM). It's concluded that RQM requires retro-causality as a logical necessity if quantum mechanics is to be correct with respect to all observers. A more general model of retro-causality in RQM is proposed afterward, in which the entire history of a system changes with time.

Keywords : Relational quantum mechanics; measurement problem, foundations of quantum mechanics; Wigner-Friend paradox; retro-causality

Introduction

Relational quantum mechanics [1] posits an exquisite framework to deal with the collapse problem in quantum theory, a framework analogous to special relativity in classical physics. It gets rid of the classical measuring machine as a fundamental player in the theory, and puts all observers on equal footing.

This framework, however, still can't unambiguously solve the third-person problem, also known as the Wigner-Friend paradox; it can't relate the perspectives of different observers.

My proposal is to resolve the third-person problem in RQM using a logically necessary concept emerging when assuming that quantum theory is correct with respect to all observers. This concept is retro-causality. I generalize the concept in the section that follows. I then go on to discuss the EPR paradox in the final section. I then end with concluding remarks.

1-The Wigner-Friend paradox: a deep dive, and a conclusion

The story starts with two scientists, Wigner and his friend, who decide to carry out an experiment as follows: Wigner waits outside an isolated lab, which has inside of it the friend and a spin ½ particle in the state : $|\psi(0)\rangle = a\left|+\frac{1}{2}\right\rangle + b\left|-\frac{1}{2}\right\rangle$.

After the friend measures the particle inside the lab, they get into the entanglement state $|\psi(t)\rangle = a\left|+\frac{1}{2}\right\rangle\left|+\frac{1}{2}\right\rangle + b\left|-\frac{1}{2}\right\rangle\left|-\frac{1}{2}\right\rangle$, because quantum theory is linear.

After some time, Wigner, knowing $|\psi(t)\rangle$, decides to measure the lab system in the same basis at a later time. He measures either of the pointer states: $\left|+\frac{1}{2}\right\rangle\left|+\frac{1}{2}\right\rangle$ or $\left|-\frac{1}{2}\right\rangle\left|-\frac{1}{2}\right\rangle$. With respect to the friend, however, the lab was in a pointer state from t onward, before any external measurement by Wigner.

So, does the measurement made by the friend at t decide objectively what measurement Wigner makes at later times? If so, then $|\psi(t)\rangle = a\left|+\frac{1}{2}\right\rangle\left|+\frac{1}{2}\right\rangle + b\left|-\frac{1}{2}\right\rangle\left|-\frac{1}{2}\right\rangle$ is an incorrect description of the lab state at time t. This state, obtained from reasoning by quantum theory only, makes it possible for Wigner to get either of the two pointer states of spin-up and spin-down, disregarding the "objective" measurement carried out by the friend in the past.

If we assume quantum theory is always true, this means that the notion of an absolute initial measurement determining the later measurement made by Wigner is to be abandoned, since the later measurement can possibly obtain any of the two pointer states as a realization.

As such, one is left with one uncomfortable possibility: Wigner's measurement after t determines the measurement made by his friend at time t. This is the key result that is obtained this analysis: Retro-causality.

2-Generalizing retro-causality

Schrodinger's equation can predict the future wave-function of a system given its initial wave-function and the Hamiltonian. I here postulate that the Schrodinger equation is also apt to obtain the past of a system, given its wave-function as some time, using the same unitary evolution principle, in a way that disregards any past interactions, since those interactions are themselves dictated by the future measurement. This entails that entire past of a system is not rigid, but changes with future interactions with other systems/observers.

As an example, The well-known Stern-Gerlach (SG) experiment can be used. A silver particle in this experiment moves through a inhomogeneous magnetic field in the SG device from time $t = 0$ to $t = t0$, when it is captured by a metal plate. After its spin is measured at $t0$ by the metal plate, its entire history has to be consistent with the measurement at $t0$. A measurement in this case dictates its entire history according to the Schrodinger equation, extrapolated backward in time. History thus becomes dynamical, a block that itself changes with time.

3- **Entanglement comes handy**

An almost trivial application of the concept is in the case of two entangled particles, say in the state $|\psi\rangle = a\left|+\frac{1}{2}\right\rangle\left|-\frac{1}{2}\right\rangle + b\left|-\frac{1}{2}\right\rangle\left|+\frac{1}{2}\right\rangle$. The two particles can be separated by as much distance as one pleases, but a measurement on one particle must create a past which is compatible with this final state. If the state $\left|+\frac{1}{2}\right\rangle\left|-\frac{1}{2}\right\rangle$ is measured by means of an interaction, it become necessarily the state that defines the past of the two-particle system.

Conclusion

Retro-causality is argued for as an essential concept in relational quantum mechanics. It's shown to solve the Wigner-Friend paradox, and that it leads to an understanding of the EPR paradox in simple terms.

References :

[1] : Rovelli, C. (1997) *Relational Quantum Mechanics*, *arXiv.org*. Available at: https://arxiv.org/abs/quant-ph/9609002 (Accessed: 06 February 2024).