An exceptionally simple argument against the many-worlds interpretation

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Abstract

It is shown that the superposed wave function of a measuring device, in each branch of which there is a definite measurement result, does not correspond to many worlds as assumed by the many-worlds interpretation, because all branches of the superposed wave function can be observed in our world by protective measurement.

According to the many-worlds interpretation of quantum mechanics, each branch of the wave function of a measuring device in which there is a definite measurement result corresponds to each world among the many worlds (see, e.g. Vaidman 2008; Barrett 2011). This means that in one world there is only one branch of the superposed wave function in which there is a definite measurement result, and the other branches do not exist in this world. Therefore, according to the many-worlds interpretation, in every world the whole superposed wave function of the measuring device cannot be measured. If all branches of the superposed wave function of the device can be observed in one world, then they will all exist in this world, which obviously contradicts the many-worlds interpretation.

It is unsurprising that the existence of such many worlds may be consistent with the results of conventional impulse measurements[1], as the many-worlds interpretation is just invented to explain the emergence of these results, e.g. the definite measurement result in each world always denotes the result of a conventional impulse measurement. However, this does not guarantee consistency for all types of measurements. It has been known that there exists another type of measurement, the protective measurement (Aharonov and Vaidman 1993; Aharonov, Anandan and Vaidman 1993; Aharonov, Anandan and Vaidman 1996; Vaidman 2009). Like the conventional impulse measurement, protective measurement also uses the standard measuring procedure, but with a weak, adiabatic coupling and an appropriate protection. Its general method is to let the measured system be in a nondegenerate eigenstate of the whole Hamiltonian using a suitable protective interaction, and then make the measurement

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[1] It should be noted that the consistency is still debated. For more discussions see Saunders et al (2010) and references therein.

adiabatically. This permits protective measurement to be able to measure the expectation values of observables on a single quantum system. In particular, the wave function of the system can also be measured by protective measurement as expectation values of certain observables.

It can be seen that the existence of the many worlds defined above is inconsistent with the results of protective measurements. The reason is that the whole superposed wave function of a quantum system including a measuring device can be measured by a protective measurement[2]. The result of the protective measurement implies that all branches of the superposed wave function of the measuring device exist in the same world where the protective measurement is made. Therefore, according to protective measurement, the branches of the superposed wave function of a measuring device, in each of which there is a definite measurement result, do not correspond to many worlds, in each of which there is only one such branch; rather, the whole superposed wave function of the device, if it exists, only exists in one world, namely our world. In this way, protective measurement provides a strong argument against the many-worlds interpretation[3].

Four points are worth stressing. First of all, the above argument does not depend on how the many worlds are precisely defined in the many-worlds interpretation of quantum mechanics. The key point is that all branches of the superposed wave function of a measuring device can be detected by protective measurement in our world, and thus they all exist in one world. Therefore, it is impossible that there are many worlds, in each of which there is only one branch of the superposed wave function of a measuring device.

Next, the above argument is not influenced by environment-induced decoherence. On the one hand, even if the superposition state of a measuring device is entangled with the states of other systems, the entangled state of the whole system can also be measured by protective measurement in principle (Anandan 1993). The method is by adding appropriate protection procedure to the whole system so that its entangled state is a nondegenerate eigenstate of the total Hamiltonian of the system together with the added potential. Then the entangled state can be protectively measured. On the other hand, environment-induced decoherence is not an essential element of the many-worlds interpretation. Even for a measuring device isolated from environment, the interpretation also requires that each branch of the wave function of the measuring device in which there is a definite measurement result corresponds to each world among the many worlds; otherwise the many-worlds interpretation will not give the same predictions of measurement results as standard quantum mechanics (so long as the latter gives unambiguous predictions).

Thirdly, the above argument does not require protective measurement to be able to distinguish the superposed wave function of a measuring device (in each branch of which there is a definite measurement result) from one of its branches, or whether the superposed wave function collapses or not during a conventional

[2]Note that protective measurement in general requires that the measured wave function is known beforehand so that an appropriate protective interaction can be added. But this requirement does not influence our argument, as the superposed wave function of a measuring device can be prepared in a known form before the protective measurement.

[3]This objection does not apply to the de Broglie-Bohm theory, according to which the wave function of a measuring device does not collapse either, but it exists only in one world. Besides, the objection does not apply to the many-minds interpretation either.

impulse measurement. Since the determination demands the distinguishability of two non-orthogonal states, which is prohibited by quantum mechanics, no measurements consistent with the theory including protective measurement can do this. What protective measurement tells us is that such a superposed wave function, which existence is assumed by the many-worlds interpretation, does not correspond to the many worlds defined by the many-worlds interpretation. In other words, protective measurement reveals inconsistency of the many-worlds interpretation.

Lastly, we stress that the principle of protective measurement is irrelevant to the controversial process of wavefunction collapse and only depends on the linear Schrödinger evolution and the Born rule. As a result, protective measurement can be used to examine the internal consistency of the no-collapse solutions to the measurement problem, e.g. the many-worlds interpretation, before experiments give the last verdict. For a more detailed analysis of the implications of protective measurement see Gao (2011a, 2011b).

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