Are there many worlds?

Shan Gao
Research Center for Philosophy of Science and Technology,
Shanxi University, Taiyuan 030006, P. R. China
E-mail: gaoshan2017@sxu.edu.cn.

May 29, 2019

Abstract

It is argued that if the wave function represents the complete physical state and its dynamics is linear, then there are no many worlds.

It's possible for the multiverse to undergo no net change while individual universes do change. — David Deutsch[1]

The many-worlds interpretation of quantum mechanics (MWI) is based on two key assumptions: (1) the completeness of the physical description by means of the wave function, and (2) the linearity of the dynamics for the wave function (Everett, 1957; DeWitt and Graham, 1973; Barrett, 1999; Wallace, 2012; Vaidman, 2014). In this paper, I will argue that these two assumptions permit no existence of many worlds.

Let me first give a classical example. The complete physical state of a classical particle at a given instant is represented by (x, p), where x is the position of the particle, and p is the momentum of the particle. In other words, the state (x, p) means that there is a classical particle being in position x whose momentum is p. Although we can decompose (x, p) as $(x_1 + x_2, p_1 + p_2)$, this is just a mathematical transformation, and it does not mean that there are two particles, one being in position x_1 whose momentum is p_1, and the other being in position x_2 whose momentum is p_2. This can also be proved. Suppose we have a time evolution U which swaps (x_1, p_1) and (x_2, p_2) and keeps (x, p) unchanged. Since (x, p) represents the complete physical state, if it keeps unchanged, then everything physical will not change. Then, since both (x_1, p_1) and (x_2, p_2) change after the time

[1]Personal communication, January 2, 2019.

evolution U, they cannot represent actual physical states. In other words, the state (x, p) cannot represent two particles which are in positions x_1 and x_2, respectively.

Now let us consider the quantum case. In MWI, the complete physical state of a quantum system is represented by its wave function. Suppose the wave function of a system at a given instant, ψ, represents a real physical field in a space. Similar to the classical case, although we can decompose ψ as $\psi = \psi_1 + \psi_2$, this is just a mathematical transformation, and it does not mean that there are two real physical fields, one being represented by ψ_1, and the other being represented by ψ_2.

We can also prove this result. Suppose we have a time evolution U which swaps ψ_1 and ψ_2.[2] Then, by the linearity of the dynamics, U keeps $\psi = \psi_1 + \psi_2$ unchanged. Since ψ represents the complete physical state, if it keeps unchanged, then everything physical will not change. Indeed, if the underlying ontic state does not change, then everything in the physical world cannot change, including those emergent high-level things. Then, since both branches of ψ, namely ψ_1 and ψ_2, change after the time evolution U, they cannot represent actual physical states. In other words, ψ does not represent two real physical fields which are represented by ψ_1 and ψ_2, respectively.

Take Schrödinger's cat as an example. Suppose the wave function of a Schrödinger's cat and its environment is $\psi = \psi_a + \psi_d$, where ψ_a represents the state of an alive cat and its environment, and ψ_d represents the state of a dead cat and its environment. Suppose there is a time evolution U_s which swaps ψ_a and ψ_d. Then it keeps $\psi = \psi_a + \psi_d$ unchanged by the linearity of the dynamics. Again, since ψ represents the complete physical state of the composite system, if it keeps unchanged, then everything physical of the system will not change. Then, since both branches ψ_a and ψ_d change after the time evolution U_s, they cannot represent something physical (although when $\psi = \psi_a$ or $\psi = \psi_b$ they can). In other words, ψ does not represent two real physical fields or two real worlds in which there are an alive cat and a dead cat, respectively.

Admittedly, the whole wave function may undergo no net change while individual branches do change. But this is just a mathematical claim. As I have argued above, if the whole wave function represents the complete physical state and its dynamics is linear, then the individual branches cannot represent something physical such as real worlds (either emergent or not). In this case, it is impossible "for the multiverse to undergo no net change while individual universes do change."

[2] U is similar to the NOT gate for a single q-bit, and it is permitted by the Schrödinger equation in principle (although it may hardly be realized in practical situations).

Acknowledgments

I wish to thank Jeff Barrett, Sean Carroll, David Deutsch, Meir Hemmo, Louis Marchildon, Don Page, Simon Saunders, Paul Tappenden, Lev Vaidman, David Wallace, and Kai-Ning Wang for helpful discussion. This work is supported by the National Social Science Foundation of China (Grant No. 16BZX021).

References

[1] Barrett, J. A. (1999). The Quantum Mechanics of Minds and Worlds. Oxford: Oxford University Press.

[2] DeWitt, B. S. and N. Graham (eds.). (1973). The Many-Worlds Interpretation of Quantum Mechanics. Princeton: Princeton University Press.

[3] Everett, H. (1957). 'Relative state' formulation of quantum mechanics. Rev. Mod. Phys. 29, 454-462.

[4] Vaidman, L. (2014). Many-Worlds Interpretation of Quantum Mechanics, The Stanford Encyclopedia of Philosophy (Fall 2018 Edition), Edward N. Zalta (ed.), https://plato.stanford.edu/archives/fall2018 /entries/qm-manyworlds/.

[5] Wallace, D. (2012). The Emergent Multiverse: Quantum Theory according to the Everett Interpretation. Oxford: Oxford University Press.