Simplest Quantum Mechanics: Why It Is Better Than Bohmian, Everettian and Collapse Theories

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

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Abstract

In this paper, I propose a new realist alternative to standard quantum mechanics, which I call simplest quantum mechanics (SQM). The ontology of the theory is particles in three-dimensional space whose motion is discontinuous and random, and the wave function represents the propensities of the particles that determine their random discontinuous motion. The time evolution of the wave function is governed by the Schrödinger equation without exception. The Born rule, which connects the wave function with experiment results, is a natural result of the ontology and its dynamics. SQM has fewer assumptions and more explanatory power than existing quantum theories including Bohmian mechanics, the Everett interpretation and collapse theories of quantum mechanics.

1 Introduction

The standard formulation of quantum mechanics (QM), which was originally formulated by Dirac (1930) and von Neumann (1932) and is still taught worldwide in textbooks (e.g. Shankar, 1994; Griffiths, 2016), is plagued by the notorious measurement problem among others (Bell, 1990). Today, there are already several realist alternatives to the theory, such as Bohmian mechanics (or the pilot wave theory of de Broglie and Bohm), the Everett interpretation (or the many-world interpretation) and collapse theories of quantum mechanics. However, these theories also have their own problems. For example, Bohmian mechanics (BM) needs to explain the physical origin of its quantum equilibrium hypothesis, and the many-world interpretation (MWI) has the thorny probability problem, and collapse theories (CT) are plagued by the tails problem. Besides, these theories do not yet provide a satisfactory ontological interpretation of the wave function, although they aim to provide a clear ontology for QM. Then, which theory is the right one or in the right direction? can we find a better quantum theory (consistent with experience) with a clear ontology, a precise dynamics, fewest assumptions and maximum explanatory power?

In this paper, I will propose such a realist alternative to standard quantum mechanics. I call it Simplest Quantum Mechanics (SQM). SQM can be regarded as a mixture of BM, MWI and CT, but it has fewer assumptions and more explanatory power than these theories. This paper is organized as follows. In Section 2, I first introduce SQM, including its ontology, its dynamics, and its consistency with experience. In Section 3, I argue that SQM, being a mixture of BM, MWI and CT, does not belong to any of them. In Section 4, I then argue that SQM is simpler or has fewer assumptions than other quantum theories including BM, MWI, CT and pragmatist approaches to QM. In Section 5, I further argue that SQM has more explanatory power than these quantum theories. This advantage also helps explain why the ontology of QM is particles, not fields. In Section 6, I analyze the empirical predictions of SQM, including the derivation of the Born rule. It is argued that SQM will also give new predictions that are different from single-world quantum theories, including both CT and BM. Conclusions are given in the last section.

2 Simplest quantum mechanics

Simplest Quantum Mechanics (SQM) can be formulated as follows:[1]

1. Ontology: The ontology of SQM is particles in three-dimensional space whose motion is not continuous but discontinuous and random. The wave function represents the propensities of the particles that determine their random discontinuous motion.

2. Dynamics: The time evolution of the wave function is governed by the Schrödinger equation without exception.

3. Consistency with experience: The Born rule can be derived from the ontology and its dynamics.

Here is a more detailed explanation of SQM. First, in SQM, the elementary particles such as electrons are indeed point-like particles (with mass and charge and other state-independent properties) existing in certain posi-

[1]Here I fully agree with Maudlin (2019) when he says that "a physical theory should clearly and forthrightly address two fundamental questions: what there is, and what it does. The answer to the first question is provided by the ontology of the theory, and the answer to the second by its dynamics. The ontology should have a sharp mathematical description, and the dynamics should be implemented by precise equations describing how the ontology will, or might, evolve." (p.xi)

tions in three-dimensional space at each instant,[2] while the motion of these particles is not continuous but discontinuous and random. The random discontinuous motion of particles (RDMP) is determined by two propensities of these particles, represented by two real-valued quantities defined in the configuration space that can further constitute the complex wave function in QM.[3] For example, the modulus squared of the wave function, which is one real-valued quantity, represents the propensity of the particles that determines the density of probability of the particles being in certain positions in space. For a more detailed introduction of RDMP see Gao (2017, chs.6-7).

Second, in SQM, the wave function evolves in time always according to the Schrödinger equation, which means that the theory is linear and unitary and the wave function never collapses. For a rigorous derivation of the free Schrödinger equation see Gao (2017, ch.5).

Third, it can be argued that the RDMP ontology and its dynamics can form a time division multiverse at the macroscopic level, in which different quasi-classical worlds exist in different dense sets of (random and discontinuous) instants or time subflows. Moreover, the Born probabilities indeed come from real randomness and genuine uncertainties, and the Born rule is also a natural result of the RDMP ontology and its dynamics. For a more detailed analysis see Gao (2021c, 2022a) and later discussion.

3 SQM is a mixture of BM, MWI and CT

It can be seen that SQM is a mixture of BM, MWI and CT. It has particles in its RDMP ontology like BM. The RDMP ontology also involves randomess like CT. Moreover, the RDMP ontology and its dynamics can form a time division multiverse as in MWI.

However, SQM does not belong to any of these theories. There is no real collapse of the wave function in SQM, and thus it is obviously not a collapse theory. SQM is not a verison of BM either. First, SQM is not a causal interpretation of QM as Bohm (1952) originally thought and called his theory. The motion of particles is continuous and deterministic in the standard formulations of Bohm's theory such as BM. Second, even if BM admits random motion of particles as in Bohm's theory without trajectories (Bell, 1981), it is still a single-world theory. But SQM is a many-world

[2]Each particle may not only have a position in space but also have other state-dependent properties such as momentum and energy at each instant, which is also consistent with the Kochen-Specker theorem. In a minimum formulation, each particle only has a position in space, as well as the propensities of motion described by the wave function, at each instant.

[3]These two real-valued quantities correspond to the probability density and the probability flux density in standard QM. Based on an analysis of gauge invariance of the QM of a charged particle interacting with a background magnetic field (Wallace, 2014), it can be argued that these two real-valued quantities are the only two gauge-invariant components of the ontology.

theory, and its predictions are not all the same as those of single-world theories including BM. I will discuss this important point in more detail later. Third, the wave function and the particles are distinct entities in BM; the wave function is either a physical field or a law-like entity, which is different from and also independent of the particles. By contrast, in SQM the wave function represents certain properties of the particles or their state of motion, and it is not an independent entity besides the particles.

SQM is not an Everett interpretation or MWI in a strict sense either. In MWI, the wave function is regarded as a continuous field, and thus all worlds co-exist at the same time (Everett, 1957). Moreover, the theory has no real randomness and discontinuity, either in its ontology or in its dynamics, which is widely thought as one major advantage of MWI. However, in SQM, the wave function is regarded not as a field but as a representation of the propensities of particles that determine their random discontinuous motion. As a result, in SQM, there is *only* one world at each instant, and many worlds emerge only during an arbitrarily short time interval around an instant, and different worlds exist in different time subflows. Moreover, the theory has real randomness and discontinuity in its RDMP ontology, although the dynamics for the ontology is still the continuous and deterministic Schrödinger equation.

4 SQM is simpler than other quantum theories

Compared with other quantum theories, SQM is simpler or has fewer assumptions.

First, SQM is simpler than CT. CT revises the Schrödinger equation in SQM by adding an additional stochastic nonlinear noise term to explain the collapse of the wave function, and it also adds a probability rule for the noise to explain the Born rule. Moreover, CT also needs to add additional parameters which are lacking in SQM. For example, the GRW theory and the CSL model introduce two additional parameters, and the Diósi-Penrose model needs to introduce one additional parameter (the natural parameter-free version of the Diósi-Penrose model has been ruled out (Donadi et al, 2021)).

Second, SQM is simpler than BM. This is more obvious. The dynamics of BM is composed of two parts: one part for the particles (the guiding equation) and the other part for the wave function (the Schrödinger equation). By contrast, SQM has only the Schrödinger dynamics for the wave function which represents the propensities of the particles. Moreover, BM needs to introduce a quantum equilibrium hypothesis to derive the Born rule, while SQM needs not to do this.

Third, SQM is simpler than the current formulations of MWI. MWI is plagued by the probability problem (since all results simultaneously occur after a measurement). In order to solve this problem, it needs to introduce additional assumptions to explain the Born probabilities and derive the Born rule (e.g. Wallace's (2012) branching indifference assumption), or simply add the Born rule as an additional postulate (Vaidman, 2020). By contrast, SQM does not have the probability problem, since different results randomly occur at different times after a measurement, and the Born rule is also a natural result of the RDMP ontology and its dynamics.

Finally, it is worth noting that in QBism and other pragmatist approaches to QM the Born rule is either directly assumed or derived based on assumptions that are lacking in SQM (Healey, 2023). Thus these theories are also less simple than SQM.

5 SQM has more explanatory power than other quantum theories

In this section, I will argue that SQM has more explanatory power than other quantum theories, including BM, MWI, CT, QBism and other pragmatist approaches to QM. The key is to analyze the ontology underlying the wave function.

Before my analysis, it should be pointed out that the explanatory power and the predictions of a theory are not the same thing. Even if two theories have the same empirical predictions (in certain domains), they may have different explanatory powers, since the explanatory power of a theory is more closely related to the ontology of the theory. For example, although BM and QM give the same empirical predictions (insofar as the predictions of QM are unambiguous), BM has more explanatory power than QM, e.g. for the double-slit experiment. Thus, it makes sense to say that SQM has more or less explanatory power than other quantum theories, even though they give the same empirical predictions.

First, SQM has more explanatory power than QBism and other pragmatist approaches to QM. This can be seen more clearly by analyzing the results of protective measurements (PMs) (Gao, 2021b, 2022c). The pragmatist approaches to QM deny that the wave function offers a description or representation of the physical world (Healey, 2023). In particular, QBism claims that (the modulus squared of) the wave function represents an agent's personal probability assignments, reflecting his subjective degrees of belief about the outcome of a measurement. However, for PMs, (the modulus squared of) the wave function describes the objective definite outcomes of the interactions between the measured system and the measuring device, and it does not represent probability assignments, either objective or subjective. Thus, QBism and other pragmatist approaches to QM fail to explain the results of PMs. By contrast, SQM can explain the results of PMs using its RDMP ontology and dynamics (Gao, 2017, ch.6).

Second, SQM has more explanatory power than BM, MWI, CT and other theories in which the wave function is regarded as either a law-like entity or a physical field. The nomological view of the wave function is either inconsistent with the Pusey-Barrett-Rudolph (PBR) theorem like the psi-epistemic view or fails to explain the measurement results and their Born probabilities in ontology (Gao, 2023). This result can be argued as follows. First, the nomological view of the wave function is different from the psi-ontic view, which regards the wave function as a physical entity, not a law-like entity. Next, the psi-ontic view can be proved by the PBR theorem, which is based on three assumptions: a realist state assumption, a measurement response assumption and the preparation independence assumption. The nomological view admits the first and the third assumptions. The only way to avoid the inconsistency is to reject the second measurement response assumption. In this case, however, the nomological view will fail to explain the measurement results and their Born probabilities in ontology and even lead to contradiction. For a more detailed analysis see Gao (2023).

Different from the nomological view, the field ontology is fully consistent with the PBR theorem. But it has been argued that the field ontology can hardly explain the non-existence of self-interactions for a quantum system such as an electron (Gao, 2017, 2020). QM and experiments say that there are (electromagnetic and gravitational) interactions between two electrons but no interactions between two parts of the wave function of an electron. This poses a puzzle for the field ontologists, which has two aspects. First, if two electrons are identical in all aspects as usually thought, then it seems that the field of one electron cannot distinguish between itself and the field of the other electron. In this case, it is impossible that the field of one electron has interactions with the field of the other electron but has no self-interactions. Second, even though the field of one electron can distinguish between itself and the field of another electron, the distinguishability alone does not explain the non-existence of self-interactions. It is natural to expect that if the field of one electron has interactions with the field of another electron, then it will also have self-interactions. Compared with the field ontology, the RDMP ontology can more readily solve the above puzzle by providing a natural explanation of the non-existence of self-interactions for an electron. For a more detailed analysis see Gao (2020).

Besides failing to explain the non-existence of self-interactions between two parts of the wave function of an electron, the field ontology can hardly accommodate mass and charge in the ontology and explain the (electromagnetic and gravitational) interactions between two electrons either (Gao, 2022f). For example, for wave function realism which regards the wave function of a N-body system as a physical field in a fundamental 3N-dimensional space (Albert, 1996, 2013), the ontic state localized in a position in this space cannot contain complete information about the masses and charges of the N subsystems (e.g. the ontic state may contain information about the sum of the masses and charges, but the sum does not uniquely determine the mass of each subsystem). Moreover, the ontic state cannot contain the information about the correlation between the mass and charge of each subsystem and the three coordinates of the subsystem in the Schrödinger equation, which should be also included in the ontology. By contrast, the RDMP ontology in three-dimensional space can well accommodate mass and charge in the ontology and explain the (electromagnetic and gravitational) interactions between two electrons. For a more detailed analysis see Gao (2022f).

Third, SQM provides a simplest explanation of Schrödinger's (1926a,b,c) charge density hypothesis and the Born rule. The modulus squared of the wave function appears in two places of QM: one is in the mass and charge density of a quantum system as part of the ontology (which can be measured by protective measurements of a single system), and the other is in the Born rule as probabilities of measurement results (which can be measured by projective measurements of an ensemble of identically prepared systems). The simplest explanation of this coincidence is that the modulus squared of the wave function has a unique physical meaning in the theory, and thus Schrödinger's charge density hypothesis and Born's rule have a common physical origin in ontology.

It has been argued that this common origin is the RDMP ontology (Gao, 2017, 2022a). According to the RDMP ontology, the modulus squared of the wave function of an electron in each position in space gives the density of probability of the electron as a point-like particle being there. Then, at every instant there is only a particle with the total mass and charge of the electron (which explains why there is no self-interactions between two parts of the wave function of an electron), while the time average of its motion will form the (effective) mass and charge distributions throughout space, whose density in each position is equal to the total mass and charge of the electron multiplied by the modulus squared of the wave function of the electron there. This is what Schrödinger's charge density hypothesis says. Similarly, according to the RDMP ontology, for a post-measurement superposition of a measuring device (which is obtained from the Schrödinger dynamics), there is only one device at each instant, and the modulus squared of the amplitude of each result branch of the superposition represents the probability of the device obtaining the corresponding result. This means that the Born rule can be directly derived from the RDMP ontology and its Schrödinger dynamics.

Thus, it is arguable that the RDMP ontology is the common origin of Schrödinger's charge density hypothesis and the Born rule. The resulting theory, SQM, will be the simplest quantum theory. All other quantum theories need to introduce additional assumptions (besides their ontologies) to derive and explain Schrödinger's charge density hypothesis and the Born rule. Here it is worth emphasizing that a realist physical theory is composed only of an ontology and its dynamics, and all others should be derived from the theory. In this sense, the Born rule, which concerns measurements, should be derived from (and not postulated by) a realist quantum theory; otherwise the theory must be incomplete.

Finally, there is still one question that needs to be answered. Although the RDMP ontology seems natural in CT and BM (since they both involve actions at a distance), for Everettians it can hardly be accepted due to its discontinuity and randomness. Then, why introducing the RDMP ontology in a many-world theory? I think there is another reason besides the above advantages of the RDMP ontology over the field ontology. It is that the field ontology in MWI fails to explain how different worlds co-exist in the same place in space, and how two worlds in one place correlate with another two worlds in another place for an entangled state. Although the decoherent and quasi-classical structures can indeed be found in a superposed wave function, it is unclear how the physical worlds represented by these mathematical structures co-exist in the same place in three-dimensional space, since the wave function is a mathematical function defined in the high-dimensional configuration space. Since most Everettians do not accept wave function realism, according to which the wave function represents a real physical field in a fundamental high-dimensional space, this problem is more serious. It seems that the field ontology in three-dimensional space such as spacetime state realism (Wallace and Timpson, 2010) cannot accommodate and differentiate different worlds in the same place in space, since the field has only two physical properties there, a total amplitude and a total phase. Moreover, since the field ontology cannot distinguish worlds in each place, it cannot explain the correlation between two worlds in one place and another two worlds in another place either.

By contrast, the RDMP ontology can readily accommodate different worlds in one place and also explain nonlocal correlation between worlds in different places by time division multiplexing; different worlds in one place may exist in different sets of instants or different time subflows, and two worlds A, B in one place and another two worlds A', B' in another place may also correlate, since the worlds A and A' are in one time subflow, and the worlds B and B' are in the other time subflow.

If the physical ontology exists in our three-dimensional space, then it seems that one must resort to time division to accommodate and differentiate worlds and further explain correlations between worlds, that is, different worlds are represented by different states of the same physical entities existing in different sets of instants. Moreover, when two worlds are well separated in space, it seems that the motion of these physical entities between these two worlds must be discontinuous, since these two worlds are required to exist "at the same time" or during an infinitesimal time interval around a given instant as required by QM. Note that the field ontology permits that worlds can exist at the same time at each instant. Also, since QM provides no further information about which world these physical entities are in at each instant, the discontinuous motion must be also essentially random according to the theory. This explains the origin of discontinuity and randomness in a many-world theory like SQM.

6 Empirical predictions of SQM

In this section, I will analyze the empirical predictions of SQM, including the Born rule and possible new predictions of SQM (that are different from those of QM).

6.1 There is a time division multiverse

As argued in the modern formulation of MWI (Wallace, 2012), environment-induced decoherence results in the emergence of temporally extended and stable quasi-classical structures or worlds.[4] SQM accepts this result, and it further provides an underlying ontology, the RDMP ontology, for accommodating these macroscopic structures or worlds in the same space and time.

In SQM, the wave function represents the propensities of particles that determine their random discontinuous motion in three-dimensional space. At any instant, each particle has a definite position, and there is an instantaneous particle configuration of one world. While during an arbitrarily short time interval around an instant, the random discontinuous motion of these particles forms a time division multiverse, in which different worlds exist in different dense sets of (random and discontinuous) instants or different time subflows, and all these time subflows constitute the whole continuous time flow. Moreover, the propensities of the particles in each world is represented by an effective wave function, namely the corresponding branch of the whole superposition. This picture of many worlds, one of which is our world, is consistent with our macroscopic experience.

It seems that there is an additional fact that needs to be explained in SQM. It is that after a measurement we observers never perceive the jumps from obtaining one result to obtaining another result. Why?[5] The reason is as follows. The (typical) particle configuration that represents a system or an observer in each result branch undergoes independent time evolution due to the linearity of the Schrödinger equation, and the effects of the interactions of these particles with the environment are accumulated only in each result branch, not between different result branches. Thus, the observer only perceives that she continues to exist with the same record, and she will never perceive the jumps from obtaining one result to obtaining another result. Moreover, the observers who obtain different results at different instants

[4]Why creatures like us live in these stable quasi-classical worlds (not other unstable worlds) may be due to natural selection (see also Vaidman, 2021).

[5]This question does not exist for the field ontology.

will have different memories, and they should also be regarded as different observers, not different states of the same observer. In other worlds, the post-measurement superposition corresponds to many worlds, in each of which there is an observer who obtains a definite result.

6.2 The Born rule

Now let's see how the Born rule, which connects the wave function with the probabilities of measurement results, can be derived in SQM.

Consider a typical measurement in quantum mechanics, in which a measuring device or an observer M measures the z-spin of a spin-1/2 system S being in a superposition of two different z-spins. According to the linear Schrödinger equation, the state of the composite system after the measurement will be a superposition of M recording z-spin up and S being z-spin up and M recording z-spin down and S being z-spin down:

$$\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M , \tag{1}$$

where α and β are nonzero and satisfy the normalization condition $|\alpha|^2 + |\beta|^2 = 1$.

In SQM where the ontology is particles, a measurement result is recorded in terms of the positions of particles, e.g. the particle configuration of the pointer of a measuring device. Then, different result states of a measuring device such as $\left|up\right\rangle_M$ and $\left|down\right\rangle_M$ will correspond to different particle configuration of the device, which represent different measurement results. According to the RDMP ontology, for the above post-measurement superposition, at each instant the measurer M has a definite particle configuration, and the probabilities of M being in (or belonging to) the two result branches are $|\alpha|^2$ and $|\beta|^2$, respectively. This means that at each instant after the measurement there is *only* one measurer who obtains a definite result corresponding to one of the two result branches in the post-measurement superposition. Moreover, which result she obtains is randomly determined at the instant, and the probability of she obtaining a particular result is equal to the modulus squared of the wave function associated with the result, namely the probability of she obtaining the result z-spin up is $|\alpha|^2$ and the probability of she obtaining the result z-spin down is $|\beta|^2$. This also means that before the measurement the probabilities for the measurer M to obtain the results z-spin up and z-spin down are $|\alpha|^2$ and $|\beta|^2$, respectively. Then the Born rule can be derived from the RDMP ontology and its dynamics. [6]

At the ensemble level, we can see more clearly that the empirical prediction of SQM is consistent with the experimental observations of the statisti-

[6] This also means that although the jumps of particles between different result branches cannot be detected, the randomness and probabilities inherent in the RDMP ontology can be manifested in the random measurement results and their Born probabilities in experiments.

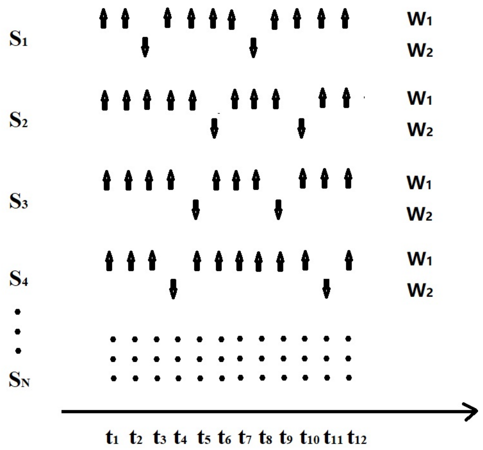

Figure 1: Empirical predictions of SQM

cal regularities of measurement results described by the Born rule. According to SQM, for an ensemble of N identically prepared measuring devices, at any instant after the measurement, there will be $|\alpha|^2 N$ devices which obtain the result z-spin up and $|\beta|^2 N$ devices which obtain the result z-spin down when N approaches infinity (see Fig.1).

Note that a measurer obtaining a result requires a finite time for the measuring interaction to generate a finite effect, the measurement result, which is determined by the Schrödinger dynamics. But after the result has been obtained by a measuring device or perceived by an observer, it will exist as a certain particle configuration at each instant afterwards. In fact, according to presentism, what exists is only the result and the perception of the result at an instant, the present instant, and thus the Born rule refers only to the probability of a result at an instant.[7]

6.3 New predictions of SQM

Although SQM always gives the same predictions as single-world unitary quantum theories for experiments done by us observers (and even for the quantum suicide exeriment),[8] they may disagree with each other concerning

[7]On this view, our perception of duration such as the persistent existence of a result during a short time interval is only a mental function realized by our brain, and it does not reflect reality. As John Bell said, "we have no access to the past. We have only our 'memories' and 'records'. But these memories and records are in fact present phenomena" (Bell, 1981).

[8]Since there is no real collapse of the wave function in SQM, the predictions of SQM (and other unitary quantum theories such as BM) are obviously different from those of collapse theories (CT) concerning the results of interference experiments about macroscopic objects, although these experiments can hardly be done due to environmental decoher-

certain cosmological predictions (Gao, 2021a, 2022e).

The key is to notice that single-world quantum theories predict that our universe is typical, and it most likely evolves from a high-amplitude branch of the initial universal wave function. While SQM predicts that there is a time division multiverse, in which both typical universes and atypical universes exist, and the latter evolve from low-amplitude branches of the initial universal wave function. Now if the high-amplitude branches do not permit the existence of human observers or other macroscopic phenomena but certain low-amplitude branches permit, then the existence of human observers or these phenomena in our universe will prove SQM and refute all single-world quantum theories (with a very high probability). For example, if the initial universal wave function is a superposition of high-entropy states and low-entropy states, and the sum of the squared amplitudes of the low-entropy states is close to zero, then the single-world quantum theories can hardly account for the observed thermodynamic arrow of time in our universe, while SQM can do, and this will provide strong evidence for the existence of many worlds as predicted by SQM (Gao, 2021a, 2022e).

7 Conclusions

Quantum mechanics (QM) is soon one-hundred years old, but we still don't know what it really is and what it tells us about reality. We have several competing quantum theories such as BM, MWI and CT, which are also more than fifty years old, but they are still plagued by their own problems, and in particular, they fail to make sense of the wave function in ontology. The Born rule, which provides a statistical connection between (the modulus squared of) the wave function and measurement results and has been one of the cornerstones of QM,[9] cannot be the final word as a postulate about measurement but must be derived from the underlying ontology and its dynamics in a more complete quantum theory.

An important hint of how to "kill two birds with one stone" is to reconsider Schrödinger's charge density hypothesis. The modulus squared of the wave function appears only in two places of QM: one is in the mass and charge density of a quantum system as part of the ontology, and the other is in the Born rule as probabilities of measurement results. The simplest explanation for the coincidence is that the mass and charge density and the probability density has a common physical origin in ontology. This will lead to the RDMP ontology, according to which the modulus squared of the wave function of an electron in each position in space gives the density

ence. Here we only concern the different predictions of SQM and singlw-world unitary quantum theories such as BM.

[9] In 1954, Max Born was awarded the Nobel prize for physics "for his fundamental research in quantum mechanics, especially for his statistical interpretation of the wave-function".

of probability of the electron as a point-like particle being there, and the ontology of QM is random discontinuous motion of particles (RDMP) in three-dimensional space. This RDMP ontology will generate the effective mass and charge distribution of an electron in space, and when applied to measuring devices or observers, it will also lead to the Born rule in a natural way when assuming the dynamics is simply the linear Schrödinger equation.

The resulting theory is SQM (Simplest Quantum Mechanics), which has a clear ontology and a precise dynamics, full consistency with existing experiments, fewer assumptions and more explanatory power than other theories including BM, MWI, CT, and pragmatist approaches to QM. Moreover, it may also give new cosmological predictions beyond standard quantum mechanics and single-world quantum theories. Should we take SQM seriously? I think the answer is yes. Even if this theory is not the final one, it is at least better than existing theories when considering the strength and simplicity of a theory. Maybe we are indeed very close to understand quantum mechanics before the centenary of its birth. We will see.

References

[1] Albert, D. Z. (1996). Elementary Quantum Metaphysics. In J. Cushing, A. Fine and S. Goldstein (eds.), Bohmian Mechanics and Quantum Theory: An Appraisal. Dordrecht: Kluwer, 277-284.

[2] Albert, D. Z. (2013). Wave function realism. In Ney, A. and D. Z. Albert (eds.), The Wave Function: Essays on the Metaphysics of Quantum Mechanics. Oxford: Oxford University Press. pp. 52-57.

[3] Bell, J. S. (1981). Quantum mechanics for cosmologists. In: Isham, C., Penrose, R., Sciama, D. (eds.) Quantum Gravity 2, pp. 611–637. Oxford: Clarendon Press.

[4] Bell, J. S. (1990). Against 'measurement', in A. I. Miller (eds.), Sixty-Two Years of Uncertainty: Historical Philosophical and Physics Enquiries into the Foundations of Quantum Mechanics. Berlin: Springer, pp.17-33.

[5] Bohm, D. (1952). A suggested interpretation of quantum theory in terms of "hidden" variables, I and II. Physical Review 85, 166-193.

[6] Dirac, P. A. M. (1930). The Principles of Quantum Mechanics, Oxford: Clarendon Press.

[7] Donadi, S., Piscicchia, K., Curceanu, C. et al. (2021). Underground test of gravity-related wave function collapse. Nat. Phys. 17, 74–78.

[8] Everett, H. (1957). Relative State Formulation of Quantum Mechanics, Review of Modern Physics 29, 454-462.

[9] Gao, S. (2017). The Meaning of the Wave Function: In Search of the Ontology of Quantum Mechanics. Cambridge: Cambridge University Press.

[10] Gao, S. (2020). A Puzzle for the Field Ontologists. Foundations of Physics 50, 1541-1553.

[11]

[12] Gao, S. (2021a). Time's Arrow Points to Many Worlds. http://philsci-archive.pitt.edu/19443/.

[13]

[14] Gao, S. (2021b). A No-Go Result for QBism. Foundations of Physics 51, 103.

[15] Gao, S. (2021c). Time Division Multiverse: A New Picture of Quantum Reality. http://philsci-archive.pitt.edu/20055/.

[16]

[17] Gao, S. (2022a). On Bell's Everett (?) Theory. Foundations of Physics 52, 89.

[18] Gao, S. (2022b). Protective Measurements and the Reality of the Wave Function. The British Journal for the Philosophy of Science, 73(3), 777-794 (2022).

[19] Gao, S. (2022c). Can Pragmatist Quantum Realism Explain Protective Measurements? Foundations of Physics 53, 11

[20] Gao, S. (2022d). Quantum suicide and many worlds. http://philsci-archive.pitt.edu/20926/.

[21] Gao, S. (2022e). On the Initial State of the Universe. http://philsci-archive.pitt.edu/21228/.

[22] Gao, S. (2022f). Reality of mass and charge and its implications for the meaning of the wave function. http://philsci-archive.pitt.edu/21317/.

[23] Gao, S. (2023). Can the Ontology of Bohmian Mechanics Consists Only in Particles? The PBR Theorem Says No. Foundations of Physics 53, 91 (2023).

[24] Griffiths, D. J. (2016). Introduction to Quantum Mechanics (2nd ed.). Cambridge: Cambridge University Press.

[25] Healey, R. (2023). Quantum-Bayesian and Pragmatist Views of Quantum Theory. The Stanford Encyclopedia of Philosophy (Winter 2023 Edition), Edward N. Zalta and Uri Nodelman (eds.), URL = https://plato.stanford.edu/archives/win2023/entries/quantum-bayesian/.

[26] Maudlin, T. (2019). Philosophy of Physics: Quantum Theory. Princeton: Princeton University Press.

[27] Schrödinger, E. (1926a). Über das Verhältnis der Heisenberg-Born-Jordanschen Quantenmechanik zu der meinen. Annalen der Physik 79, 734-756. English translation: On the relation between the quantum mechanics of Heisenberg, Born, and Jordan, and that of Schrödinger. Reprint in Schrödinger (1982), pp. 45-61.

[28] Schrödinger, E. (1926b). Quantisierung als Eigenwertproblem (Dritte Mitteilung). Annalen der Physik 80, 437-490. English translation: Quantisation as a Problem of Proper Values. Part II, Reprint in Schrödinger (1982), pp. 62-101.

[29] Schrödinger, E. (1926c). Quantizierung als Eigenwertproblem (Vierte Mitteilung). Annalen der Physik 81, 109-139. English translation: Quantisation as a Problem of Proper Values. Part IV, Reprint in Schrödinger (1982), pp. 102-123.

[30] Shankar, R. (1994). Principles of Quantum Mechanics, 2nd ed. New York: Plenum.

[31] Vaidman, L. (2020). Derivations of the Born Rule. In: Hemmo, M., Shenker, O. (eds) Quantum, Probability, Logic. Jerusalem Studies in Philosophy and History of Science. Springer, Cham.

[32] Vaidman, L. (2021). Many-Worlds Interpretation of Quantum Mechanics. The Stanford Encyclopedia of Philosophy (Fall 2021 Edition), Edward N. Zalta (ed.). https://plato.stanford.edu/archives/fall2021/entries/qm-manyworlds/.

[33] von Neumann, J. (1932). Mathematische Grundlagen der Quantenmechanik. Berlin: Springer-Verlag. English translation: Mathematical Foundations of Quantum Mechanics, translated by R. T. Beyer, Princeton: Princeton University (1955).

[34] Wallace, D. (2012). The Emergent Multiverse: Quantum Theory according to the Everett Interpretation. Oxford: Oxford University Press. pp.369-372.

[35] Wallace, D. (2014) Deflating the Aharonov-Bohm Effect. https://philsci-archive.pitt.edu/10884/.

[36] Wallace, D. and C. G. Timpson (2010). Quantum Mechanics on Spacetime I: Spacetime State Realism. The British Journal for the Philosophy of Science 61, pp. 697-727.