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Interpretation Neutrality in the Classical Domain of Quantum Theory

In this paper, I seek to alleviate a tension that arises in the effort to account for macroscopic Newtonian behavior within quantum theory: namely, the tension between, on the one hand, a desire to have a clearly defined quantum theory to serve as the basis of the analysis (that is, a theory that avoids the vagueness and *ad hoc-ness* of the conventional interpretation of quantum theory) and, on the other hand, a certain hesitancy prevalent among many philosophers of physics to commit to any of the existing realist proposals for correcting the vagueness of conventional quantum theory. *Prima facie*, it would seem that the task of retrieving Newtonian behavior from quantum mechanics in the macroscopic realm depends strongly on the particular interpretation of quantum mechanics that one adopts – specifically, because the question of how one extracts the determinacy of Newtonian descriptions from a theory that allows indeterminate superpositions depends entirely on the attitude that one takes toward the measurement problem and its resolution. In this paper, I argue that, within the context of realist approaches to the measurement problem, the manner of accounting for Newtonian behavior is to a very large extent independent of the particular realist interpretation that one adopts as the basis for the analysis.

To illustrate this claim, I consider the three leading realist ``interpretations" of quantum theory: namely, the Everett, de-Broglie-Bohm, and GRW-Pearle interpretations. The scare quotes here are intended as a reflection of the fact, which has been emphasized repeatedly by Wallace, Albert and others, that these three are more properly regarded as separate theories rather than as separate interpretations of a single theory since they offer metaphysically and mathematically distinct descriptions of the world (and, in the case of GRW theory, empirically distinct as well). Nevertheless, in keeping with common usage I will continue to refer to them as interpretations of quantum theory. Also, it must be acknowledged in spite of their distinctness that these interpretations share a great deal of common mathematical structure, associated with what is sometimes called the ``bare formalism" of quantum mechanics - i.e., the formalism of quantum mechanics without collapse, in which the quantum state evolves unitarily according to the Schrodinger dynamics at all times.

Indeed, these commonalities of mathematical structure play an essential role in supporting my central thesis: that accounting for macroscopic Newtonian behavior is a largely interpretation-neutral matter. The argument is based on the observation that all three interpretations are bound to reproduce the same tremendously successful empirical predictions of conventional quantum mechanics and so share a great deal in common: most importantly, all three interpretations will typically model a given system using the same Hamiltonian operator and the same Hilbert space. Thus, if we wish to know how a given physical system is to be described in any given interpretation, we can adopt the common starting point of modeling the system on the bare formalism - including a specification of the Hamiltonian and Hilbert space - and only at the end of the analysis specialize to incorporate the collapse or effective collapse mechanisms particular to each interpretation.

Thus, in addressing the issue of how macroscopic, approximately Newtonian systems are to be modeled in each of the three interpretations, I begin by providing an account of macroscopic Newtonian behavior on the bare formalism. The analysis that I provide elaborates on the discussion given in Ch. 3 of Wallace's *The Emergent Multiverse*, assembling and consolidating a number of results from authors such as Zurek, Caldeira and Legett, Gell-Mann and Hartle, Griffiths, and Halliwell [12], [13], [14], [3], [4], [5], [7], [8], [10]. I make significant use of the decoherent histories formalism in my treatment, though treat this formalism simply as a useful mathematical tool for analyzing the branching structure of the wave function that results from unitary evolution, rather than as an interpretation in its own right. I also emphasize a crucial step that is typically not made explicit in existing discussions of the classical domain: namely, the invocation of a generalization of Ehrenfest's Theorem to open, decohering quantum systems. Applications of the usual form of Ehrenfest's Theorem to the explanation of macroscopic Newtonian behavior are dubious insofar as Ehrenfest's Theorem is derived on the assumption that the system in question is closed and in a pure state – an assumption that is patently false for the kinds of macroscopic systems we know in reality to exhibit Newtonian behavior. The generalization of Ehrenfest's Theorem that I discuss, on the other hand, fully accommodates the fact that real Newtonian systems are open from a quantum perspective, and best described by mixed rather than pure states. Moreover, this result serves to explain why, relative to an individual branch of the quantum state, the evolution of the macroscopic degrees of freedom of certain systems takes the form of small quantum fluctuations about a classically evolving mean of position and momentum. In broad strokes, the analysis of macroscopic Newtonian systems on the bare formalism consists in showing that decoherence lends the quantum state a particular branching structure, and that, as a consequence of the generalized Ehrenfest Theorem, the behavior of certain macroscopic systems relative to a single branch is approximately Newtonian on appropriate timescales.

After providing an analysis of macroscopic classical behavior on the bare formalism, I go on to argue that there is a strong sense in which the job of accounting for Newtonian behavior on the Everett, de-Broglie-Bohm and GRW interpretations is nearly all but complete in that the portions of the analysis particular to each interpretation can be tacked on at the end of the analysis. Through decoherence, the bare formalism serves to define the different possible sequences of determinate states for a macroscopic system, with each sequence associated with a different branch in the total superposition; upon specializing to a particular interpretation, it is straightforward in each case to explain how and in what sense one such sequence or branch is selected as the one that ``actually obtains."

In the case of the Everett interpretation, the mathematical structure is just that of the bare formalism; the appearance of a single determinate classical history is accounted for by the usual Everettian strategy of interpreting the individual branches of the wave function in the bare formalism as emergent, dynamically autnomous ``worlds" [11]. One may not agree that this is a viable interpretative strategy, but if we take the Everett interpretation on its own terms, it is clear that in order to account for actual macroscopic Newtonian behavior on this picture, one must have a quantum state with the structure multiple parallel worlds in which the degrees of freedom evolve in approximately Newtonian fashion.

In the case of the de-Broglie-Bohm interpretation, my claim that the main portion of the analysis has no need of the interpretation's extra mathematical structure is likely to be more controversial. Numerous advocates of this interpretation believe that the structure associated with the additional variables of Bohm's theory furnish special mathematical resources for explaining Newtonian behavior - in particular, because the evolution equations of these extra variables can be written in a form that is classical except for an extra ``quantum potential" or ``quantum force" term. On the basis of this result, a number of authors have claimed that extracting Newtonian behavior from the de-Broglie-Bohm theory is simply a matter of setting the quantum potential or quantum force to zero [9], [2], [1]. I argue that the quantum potential and quantum force are a red herring as regards the explanation of realistic classical behavior, in particular because this approach does not take adequate account of decoherence, which is essential to the de-Broglie-Bohm mechanism for effective collapse. While the fact that the beable configurations in Bohm's theory are always determinate may seem to mitigate the need for decoherence or effective wave function collapse on Bohm's theory, this is not the case: decoherence and the effective collapse mechanism of de-Broglie-Bohm theory constitute the primary means whereby the theory is able to reproduce the phenomenology associated with the appearance of wave function collapse and the Born Rule. Moreover, decoherence is required by the Bohm theory in order to sustain a Newtonian evolution for configurations of macroscopic bodies that is robust against wave packet spreading and interference effects.

On the GRW theory, decoherence also is required to trigger the collapse mechanism of the theory, as the non-unitary collapse term in Schrodinger's equation only becomes significant in cases where many particles are entangled in a sufficiently spread-out spatial superposition; such entanglement, in turn, is induced by decoherence [6]. Thus, beginning with the branching structure of the bare formalism, which delineates the set of possible evolutions of the quantum state, the non-unitary term in GRW dynamics serves at each node in the branching structure of the quantum state to lop off all but one branch (if we permit ourselves to disregard well-known issues arising from residual ``tails" that remain post-collapse in GRW theory).

Ultimately, I hope to convince readers that we can fruitfully describe the quantum description of macroscopic Newtonian systems from a realist point of view without having to commit at the start of the analysis to a particular realist interpretation (as indeed many are hesitant to do). Most essential portions of the analysis are interpretation-neutral.

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