Comment on "Surrealistic Bohm Trajectories"

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From the perspective of orthodox quantum theory, no meaning can be assigned to the notion of the "slit" through which the atom passed in the experiments under discussion in this paper. From a Bohmian perspective this notion does have meaning. Moreover, when we compare the answer provided by BM with the answer provided, not by orthodox quantum theory, but by a naive, largely incoherent operationalism, we obtain different answers. So what?

Bohmian mechanics (BM) [1] is the natural embedding of Schrödinger's equation—which equation is the common part of almost all interpretations of quantum theory, however different they may otherwise be, from the Copenhagen interpretation to the many-worlds interpretation—into a physical theory: It emerges if one merely insists that the Schrödinger wave function be relevant to the motion of particles. (Notice that if we are to have a clear physical theory at all, the wave function better be relevant to the behavior of *something* of clear physical significance!) In other words, BM arises from Schrödinger's equation when (perhaps naively) we insist upon the simplest ontology—particles described by their positions—and look for a natural evolution for this ontology (by demanding for example Galilean invariance for the total theory).

In a recent paper [2] it is argued that despite its many virtues—its clarity and simplicity, both conceptual and physical, and the fact that it resolves the notorious conceptual difficulties which plague orthodox quantum theory—BM itself suffers from a fatal flaw: the trajectories that it defines are "surrealistic." It must be admitted that this is an intriguing claim, though an open-minded advocate of quantum orthodoxy would presumably have preferred the clearer and stronger claim that BM is *incompatible* with the predictions of quantum theory, so that, despite its virtues, it would not in fact provide an explanation of quantum phenomena. The authors are, however, aware that such a strong claim would be false.

It must also be admitted that the adjective "surrealistic" suggests a difficulty more substantial than Heisenberg's dismissal of BM on the grounds that it is "metaphysical"—the kind of refutation one tends to use when one has no substantive argument to present. But what exactly is meant by "surrealistic" trajectories?

In the third paragraph we read that "there are events where the Bohm trajectory [for an atom] goes through one slit, but the atom through the other." This would be peculiar indeed, but "surrealistic" would not seem to capture this peculiarity; "inconsistent" would seem more appropriate. But, as already indicated, if the authors had thought they could sustain a claim of inconsistency against BM, they most certainly would have tried to do so!

The introduction concludes with the proposal of "an experimentum crucis which, according to our quantum theoretical prediction, will clearly demonstrate that the reality attributed to Bohm trajectories is rather metaphysical than physical." On the principle that the suggestions of scientists who propose pointless experiments cannot be relied upon with absolute confidence, with this proposal the paper self-destructs: The authors already agree that the "quantum theoretical predictions" are also the predictions of BM. Thus they should recognize that the outcome on the basis of which they hope to discredit BM is precisely the outcome predicted by BM. Under the circumstances it would appear prudent for the funding agencies to save their money!

At this point it would be well to ask, "What on earth is going on here?". The answer appears to be this: The authors distinguish between the Bohm trajectory for the atom and the *detected* path of the atom. In this regard it would be well to bear in mind that before one can speak coherently about the path of a particle, detected or otherwise, one must have in mind a theoretical framework in terms of which this notion has some meaning. BM provides one such framework, but it should be clear that within this framework the atom can be detected passing only through the slit through which its trajectory in fact passes. More to the point, within a Bohmian framework it is the very existence of trajectories which allows us to assign some meaning to all of this talk about detection of paths.

Consider the Stern-Gerlach version of the proposed experiment (Fig. 6 in [2]). The quantum formalism predicts for this experiment that when a *later* observation of the "which-way detectors" finds the upper "detector" in its excited state, then the atom *will have been* detected on

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the lower half of the screen. According to BM, such an atom must have taken the *lower* path. This is somewhat surprising, but if we've learned anything by now about quantum theory, we should have learned to expect surprises! In any case, within the Bohmian framework our observation of the "which-way detectors"—after the atom has hit the screen—can indeed be regarded as a measurement of which path the atom has taken, but one that conveys information which contradicts what naively would have been expected. Thus BM, together with the authors of the paper on which we are commenting, does us the service of making it dramatically clear how very dependent upon theory is any talk of measurement or observation.

Moreover, when they say that "in ordinary quantum mechanics, the statement that the particle went through one slit and not the other is, of course, utterly meaningless, as long as no corresponding observation is performed," the authors seem to recognize the necessity for a suitable framework for certain concepts to attain meaning. According to orthodox quantum theory the meaninglessness referred to here corresponds precisely to the fact that prior to a position measurement at the slits, the wave function for the atom is a coherent superposition of an "up" piece and a "down" piece; the result of the measurement is to cause a collapse of the wave function to one of these pieces and hence to cause the occurrence of the corresponding fact.

Now how this comes about, and how it can be rendered compatible with the Schrödinger evolution, is the notorious measurement problem, an analysis of which is not our purpose here. But it is generally conceded that however (and *in whatever sense*) collapse comes about, at the very least it requires a suitable interaction with a device which is more or less macroscopic—so that coherence is effectively destroyed—and that it most certainly cannot be produced by interaction with an "apparatus" involving but a few degrees of freedom. Thus, at least until somebody looks, i.e., until an interaction with a suitable macroscopic device occurs, the relevant wave function is the coherent superposition (9) or (34). Moreover, since, as the authors emphasize, "this reading is done (long) after the atom has hit the screen," the "utter meaningless"ness of the question as to which "slit" the atom went through can, within the framework of orthodox quantum theory, in no way be avoided through the use of "one-bit detectors"—however they are called!

[1] D. Dürr, S. Goldstein, N. and Zanghi, *J. Stat. Phys.* **67**, 843 (1992) and *Phys. Lett.* **A 172**, 6 (1992).

[2] B.-G. Englert, M. O. Scully, G. Süssmann, and H. Walther, *Z. Naturforsch.* **47a**, 1175 (1992).