Foreword

It is a characteristic of contemporary culture that the aim of much public discourse in quantum theory is not to educate but to mystify. One encounters a relentless message that "nobody understands quantum mechanics," that "an electron can be at two places at once," and that the world is ruled by "quantum weirdness." In this context the special claim of the scientist is just that she comprehends more deeply than the populace why she does not comprehend. It's a lucrative market and it is rarely mentioned that a rational explanation exists.

A currently popular approach that is often presented as if it is the official quantum worldview is the "many-worlds" interpretation. This interpretation asserts that everything that can happen according to quantum mechanics does happen, somewhere. The suggestion that an individual can have multiple versions may chime with the public but should such a view be afforded special status in science? It seems an extraordinarily inflated (and still to be proven consistent) solution to a comparatively mundane physics problem: achieving consistency between the superposition principle and the individuality of events. That is not to say that the puzzle is not daunting, but there should be proportion between problem and solution. A fashionable argument often adduced in support of the many-worlds option is Occam's razor, roughly the claim that the "less" the premises the "better" the theory. Even if such a complex business as the commensurability of theories could be formulated rigorously through counting concepts, it is not clear why this should be the exclusive criterion, or even a relevant one, in deciding the relative merit of theories, or why "less" means "better" (one can conceive of theories of gravity much simpler than general relativity that are wrong). For example, we might judge a theory's value by examining the range of questions it can answer. The real issue is the *quality of explanation*. A lesser count could, after all, mean that we are operating with an inadequate system of concepts relative to the full set of physical questions it is reasonable to pose.

This is, in fact, the starting point of the rational quantum mechanics initiated by de Broglie and Bohm, in which the origin of the conceptual dilemmas posed by quantum theory is located in the arbitrary rejection of the notion that a material system has a well-defined space–time trajectory. The insistence that the wavefunction provides the most complete physical description that is in principle possible has resulted in nearly a century of confusion. It is as if one removed a key organ from the body and struggled on in ill health insisting all the while that nothing was wrong. The simple step of retaining the trajectory gives the quantum trajectorician a powerful *constructive* tool to counter claims about the alleged incomprehensibility of the quantum world (only one of which is now needed). We shall mention three key benefits of the idea that offer clear advantages over other interpretations, such as many-worlds.

First, the trajectory opens a door—partially closed by Copenhagen—to a discourse of conceptual precision about *physics*. In giving physical meaning to the wavefunction the theory has recourse to a full range of physical concepts including energy, force, momentum, mass, and associated notions of stability, structure, size, and form. This allows a significant improvement in the clarity and consistency with which language is used in quantum theory, where concepts are now no longer just words attached to symbols but are set in correspondence with the actual state of matter. In one way or another, conventional quantum mechanics uses these terms and it is incumbent on a serious interpretation to provide a benchmark against which to measure the efficacy with which it does this. It is surely beneficial that we all agree on what we are talking about, as was unexceptional in pre-quantum physics. Central to this discourse is Bohm's perception that the novelty of quantum theory may be expressed through a new notion of energy. The quantum potential (whose form for two-slit interference is now an iconic figure in the subject) provides a post-mechanical mode of analysis where the interactions between the parts of a system are a function of the whole that contains them, a clear break with classical mechanism where the whole is no more than the sum of parts whose interactions are prescribed uniquely by their intrinsic properties. The relative magnitudes of the quantum potential and force can determine the limits of applicability of the classical description.

In his well-known essays on the foundations of quantum theory, Bell advanced a version of the de Broglie–Bohm theory that truncates its broad conceptual spectrum, the theory comprising just a trajectory determined by a first-order guidance law with an ensemble distributed according to the quantum formula. Certainly, if confronted by a sceptical audience, tactical necessity may well dictate such a pared-down account. Whether Bell regarded this emasculated version as the entire theory is not known but at this primitive stage in the development of trajectory theories such an Occamist stance would surely be misplaced if elevated to a principle. It is, of course, conceivable that, in the quantum context, the deeper conceptual content we have alluded to above may become inapplicable, or at least require modification. Such an analysis has, however, never been given. Conceptual abstinence may even encourage a reactionary mechanistic reading of de Broglie and Bohm that misses how far the old modes of thought have been transcended. For, as indicated above, this is not a theory just about trajectories. Being able to say more—about, say, the meaning of operator eigenvalues, or the physical content of a spinor field, or the energy changes that account for tunneling, or the forces responsible for molecular stability—enhances rather than diminishes our understanding and is hardly redundant knowledge. The particle trajectory realizes its full constructive role only in this wider historical context of explanation.

The original de Broglie–Bohm guidance equation occupies a position somewhat analogous to Einstein's equations in gravitational theory. It was the first, it is battle-tested, but it is only one of many possible laws that are empirically sufficient within the domain of phenomena to which the theory applies. In the gravitational case the contenders have been whittled down by consistency conditions and by enhanced experimental constraints. In contrast, a comparable quantum-theoretical analysis has begun only recently. Indeed, what the trajectory theory most needs is a universal and necessary founding principle, analogous to the principle of equivalence of gravitation and inertia. It is for this reason, perhaps, that this subject still lacks a generally agreed name that captures its essence, a necessary milestone in the full emergence of a scientific theory. And, of course, in the quantum case one cannot appeal to experiment since the predictions of the formalism being interpreted do not depend on the existence of the trajectory. To demonstrate the legitimacy of the idea we must envisage going beyond the conventional formalism. Fortunately, and this is its second benefit, the trajectory potentially provides a way to do this by allowing the precise formulation of questions concerning particle-like concepts such as speed and separation that are ambiguous in a pure-wave context (examples include tunneling times and chaos). Whether these ideas can be made empirical is not yet known. Advances in this direction will presumably entail restrictions on the range of valid trajectory laws.

The third benefit we shall mention, and arguably the most significant recent development in this field, is the observation that the trajectory is a constructive aid in a very practical sense: it can be made the basis of the quantum description in that the evolution of a physical system may be deduced from the dynamics of an ensemble of trajectories. This gives the trajectory theory a status somewhat analogous to Feynman's path integral technique but with a more comprehensible model. This insight has been propelled not by the foundations of the physics community (who are largely unaware of it) but by Robert Wyatt and the quantum chemists. In particular, it highlights the power of a particular analogy between quantum mechanics and hydrodynamics. Not only does the trajectory picture provide an alternative method of solving the wave equation, it may even enable one to arrive at novel facts about quantum dynamics, such as its symmetries, which otherwise would have been difficult to obtain.

The advantages of the trajectory outlook we have mentioned, and others, are strikingly exhibited in the contributions to this book. The breadth of topics attests to the vibrancy of the field. In view of the trajectory's proven value, a reasonable question to ask of conventional quantum treatments is: why has it been dropped?

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