Dissertation Description

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A physical theory consists in a mathematical apparatus, the so-called formalism, along with some basic correspondence rules that indicate how to apply the formalism to certain physical situations, thus allowing us to make empirical predictions. To provide a physical theory with an interpretation is to say what the world could be like if the theory was true. An interpretation primarily consists in a fundamental ontology associated with a physical theory, as well as an indication of how the appearances emerge from the proposed fundamental ontology. An interpreted physical theory is commonly taken to give us some understanding of what the physical world can be like and how it appears to us the way it does, within the domain of application of the theory.

It so happens that classical physical theories can be interpreted as a representation of local, deterministic, causal interactions between systems with definite properties. Orthodox quantum theory, which happens to be one of our most empirically successful theories, is notoriously resistant to being interpreted in terms of that framework. Bell-type theorems and Bell-type experiments have dramatically worsened this situation. In the early sixties, John Bell demonstrated that any theory that represents its domain in terms of the above framework satisfies some inequalities, the so-called Bell inequalities. Some experiments have been completed on quantum systems, and the result is almost uncontroversially taken to be that quantum phenomena violate Bell-type inequalities. By a simple modus tollens, the upshot is that no theory that includes all of the elements of the framework above can give an account of all quantum phenomena.

Given this situation, one response is to adopt an instrumentalist point of view. The formalism of quantum theory is simply a tool for generating true predictions. Many physicists and philosophers do not content themselves with the instrumentalist point of view. Physicists have developed alternative accounts of quantum phenomena, in which at least one element of the framework above is abandoned. Philosophers have been trying to interpret this result, that is, to understand what the world can be like if it is true that physical interactions between systems are non-local, or they are non-deterministic, or physical systems do not possess definite properties. This line of thought found its climax in the so-called "experimental metaphysics" that developed after the violation of Bell-type inequalities was observed. Experimental metaphysics consists in deriving metaphysical conclusions from Bell-type experimental results and the assumptions that were used to derive the inequalities violated. The mainstream interpretation is that Bell-type experiments force us to accept some form non-local and perhaps non-causal processes at the ontological level.

In my dissertation, I assess to what extent philosophical investigation can help us decide what the world is like on the basis of our best physical theories, from the point of view of the quantum domain and with an emphasis on Bell-type phenomena. My conclusions point to a more modest view of the possible achievements of philosophy of physics than advocates of experimental metaphysics might hope for.

In the first part of my dissertation, I investigate what role philosophy of physics can legitimately hope to have in the development of, and in the evaluation of various accounts of quantum phenomena. I begin by briefly presenting these accounts, that is, Many-Worlds Interpretations, Bohm-type theories and GRW collapse theories, explaining that each of them gives up one of the elements of the framework presented above, that is, either definite properties, locality, or deterministic evolution, respectively. Given the internal coherence of, and the empirical equivalence (up to our experimental abilities) of these accounts, we do not seem to possess any good criterion to favor one of these interpreted theories over others.

Some have claimed that the degree to which an interpreted theory is understandable could count as a good criterion of choice between interpreted theories. In the second chapter of my dissertation, I argue against such a view. I investigate the case between Many-Worlds interpretations and Bohm-type theories. I propose that the understandability of an interpreted theory is the combination of the understandability of the theory and the understandability of its interpretation. I argue that these notions of understandability do not provide a means to decide between Many-Worlds interpretations and Bohm-type theories. Moreover, I argue that understandability is in general a weak criterion of choice for interpreted theories because it has nothing to do with the truth of a theory, which remains, even ideally, our goal when constructing theories.

In the light of the foregoing, I claim that it is not the role of philosophy of physics to impose criteria of acceptability on physical theories, besides coherence and empirical adequacy. In particular, it is not the role of philosophy of physics to impose such criteria of acceptability on the basis of contingent features of human cognition. By contrast, I argue that a legitimate role for philosophy of physics is to clearly distinguish between what is imposed by the phenomena and/or our best theories from what is a matter of preferences on the basis of the structural analysis of phenomena and theories. I argue that a modest version of the semantic view of scientific theories, insofar as it offers a clear definition of structure and of structural relationship, constitutes the appropriate tool for such an analysis. In defense of the semantic view, I address the criticisms recently leveled against the semantic view in the literature, that scientific models are not logical models and vice versa. I explain that such criticisms rely on a strong interpretation of the semantic view, an interpretation that is arguably unfaithful to the initial project, as defined and developed by Suppes since the sixties. I define a modest interpretation of the semantic view, and show that the modest version of the semantic view is both tenable and still a promising research program for the analysis of scientific theories.

In the second part of my dissertation, I turn to the more specific case of the interpretation of Bell-type theorems and Bell-type phenomena. I assess the mainstream interpretation according to which Bell-type phenomena force us to accept a form of non-locality, but a form that we can consider benign because it is of a non-causal type. Bell-type phenomena would not be interpreted as indicating that some non-local causal processes occur in the world, but rather that quantum systems are holistic.

That Bell-type phenomena force us to accept a form of non-locality, whether benign or not, has been constantly challenged by Fine for more than twenty-five years. I propose a systematic assessment of Fine's criticisms. I distinguish between three different strategies in Fine's criticisms. I show that none of these strategies is successful. One of his strategies is to claim that there exists a hidden assumption in the framework from which Bell-type inequalities are usually derived, namely, the definition of some joint probabilities. If true, then we do not have to conclude from the violation of Bell-type inequalities that the world cannot be represented by local theories, but only that the world cannot be represented by theories in which these joint probabilities are well-defined. This first strategy of argumentation fails because it concerns only a restricted class of frameworks for the derivation of Bell-type inequalities: non-contextual frameworks. Contextual frameworks fall outside of Fine's argument, and hence, for these frameworks, Bell-type theorems and Bell-type phenomena are still relevant. A second line of argumentation makes use of Fine's famous Prism Models. Fine is well known to have constructed some local models for Bell-type experiments. Fine hopes to use the existence of his models as a de facto proof that locality does not have to fail in models of quantum phenomena. In short, this argument fails because Prism Models are models of the actual experiments and not of the quantum domain. Prism Models are successful because of a specific trait of our actual experiments, which is that not all of the relevant particles involved in Bell-type experiments are detected. In his models, Fine interprets what we take to be a defect of our detectors as a physical property of quantum systems. This implies that, within Prism Models, some quantum systems will not respond to some experimental questions. This in turn is in contradiction with quantum theory, in which all quantum systems have some result or spectrum of results, associated with a given measurement. Fine's last strategy of argumentation is to claim that the derivations of Bell-type inequalities starts with an inconsistent set of assumptions, so that a contradiction between the inequalities and experimental results is not surprising. I show that this is only true under a strong assumption about the ontological status of probabilities. Such an assumption is controversial and unsupported; Fine's last strategy of argumentation is unsuccessful. At the end of the day, Fine's ways to dismiss the importance of Bell-type theorems and Bell-type phenomena are not conclusive: Bell-type theorems and phenomena are intriguing and deserve our attention.

In the three final chapters of my dissertation, I give my own analysis of the mainstream interpretation of the experimental violation of Bell-type inequalities. The mainstream interpretation relies on a distinction that Jarrett and Shimony have drawn between two notions of locality – outcome independence and parameter independence – which together imply the notion of locality from which Bell-type inequalities are derivable. Given this analysis of locality, Bell-type phenomena force us to give up only one of these two forms of locality. Jarrett and Shimony claim that failure of outcome independence corresponds to a benign form of non-locality. Such a benign form of non-locality has been further interpreted as a non-causal interaction and an instance of holism. A difficulty arises from the fact that the argument that Jarrett, Shimony and their followers have given in favor of their interpretation is unsuccessful. This has been shown by various authors over the last twenty-five years. This, obviously, does not imply that the mainstream interpretation is undermined. In my dissertation, I undertake a systematic examination of the mainstream interpretation.

I begin by arguing that it includes three different claims. A first claim concerns the issue of locality: failure of parameter independence is indicative of a non-local underlying process, while failure of outcome independence is not. A second claim concerns the issue of causation:

failure of parameter independence is indicative of an underlying causal process, while failure of outcome independence is not. The third claim consists in interpreting such a non-causal process as a form of holism. Hence, the third claim cannot stand if the second does not. When it comes to assessing these three claims, a difficulty arises from the fact that, in the Bell literature, locality and causation are solely discussed in terms of restrictions on conditional probability distributions over events. Such a focus on probability distributions seems to be a remnant of Reichenbach's analysis of causation in terms of probability distributions and a challengeable association of local and causal processes. That said, prima facie, it is not clear that the framework of conditional probabilities is appropriate for dealing with issues of either locality or causality.

First, arguably, a definition of locality should be intimately related to the spacetime structure that events are embedded in. Prima facie, restrictions on conditional probability distributions do not alone indicate how events are embedded within a spacetime structure. I propose a rigorous spacetime framework for assessing whether or not parameter and outcome independence are locality conditions. I show that a rigorous argument can be made to the effect that outcome independence is not a locality condition, while parameter independence corresponds to a form of Einstein Locality. The upshot is that, concerning locality, a rigorous argument can be made in favor of the mainstream interpretation.

Second, I examine whether or not failure of outcome and parameter independence are indicative of underlying causal interactions using theories of probabilistic causation. There are at least three viable theories of probabilistic causation: Lewis's couterfactual account, Woodward's manipulability theory, and Salmon and Dowe's spacetime theory. Jeremy Butterfied has shown that the received view is not supported by the former. I focus on the latter theories. My conclusions are: (1) none of these theories of causation support the received view, if the received is understood as a strong metaphysical thesis about the causal structure of the world; but (2) the received view can be rigorously supported if its claims are restricted to the empirical or pragmatic levels.