Scientific Realism and the Quantum:
Primitive Ontology and the Pessimistic Meta Induction

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Abstract

In this paper I wish to connect the recent debate in the philosophy of quantum mechanics concerning the nature of the wave-function to the historical debate in the philosophy of science regarding the tenability of scientific realism. Being realist about quantum mechanics is particularly challenging when focusing on the wave-function. According to the wave-function ontology approach, the wave-function is a concrete physical entity. In contrast, according to an alternative viewpoint, namely the primitive ontology approach, the wave-function does not represent physical entities. In this paper, I argue that the primitive ontology approach can naturally be interpreted as an instance of the so-called 'explanationism' realism, which has been proposed as a response to the pessimistic-meta induction argument against scientific realism. If my arguments are sound, then one could conclude that: (1) contrarily to what is commonly though, if explanationism realism is a good response to the pessimistic-meta induction argument, it can be straightforwardly extended also to the quantum domain; (2) the primitive ontology approach is in better shape than the wave-function ontology approach in resisting the pessimistic-meta induction argument against scientific realism.

1. Introduction

Scientific realism would be a commonsensical philosophical position if there weren't powerful counter-arguments to it, the most famous of which is the pessimistic meta-induction (PMI) argument: since past successful theories turned out to be false, it is unwarranted to believe that our current theories are true simply because they are successful [Laudan 1981]. Some scientific realists have responded to the PMI argument by restricting realism to a subset of the theoretical entities of the theory. One particular way of doing this is explanationism realism (ER), according to which one should be realist with respect to the working posits of the theory, the ones involved in explanations and predictions. In contrast, one does not need to commit herself to believe in the existence of other presuppositional posits that theory makes, since they are somewhat 'idle' components [Kitcher 1993], [Psillos 1999]. The proponents of this view have argued for it in the framework of classical theories (e.g. Fresnel's theory of light). I think the case for ER is fundamentally incomplete if one does not consider the theory change from classical to quantum mechanics. In this paper, I argue that ER can be extended to the quantum framework. In order to show this, I discuss the different realist approaches to quantum mechanics, which differ in the interpretation of one of the fundamental objects of quantum mechanics: the wave-function. On the one hand, according to the wave-function ontology (WFO) approach, the wave-function is a concrete physical entity [Albert 1996], [Ney 2013], [Lewis 2004]. In contrast, according to the primitive ontology (PO) approach [Allori et al. 2008], [Allori 2013], the wave-function does not represent physical objects. I argue that the PO approach can provide what ER needs to defeat the PMI argument in the classical-to-quantum transition. The PO, and not the wave-function, can be identified with the working posits of the theories, and as such: (1) it is primarily responsible for the success of both classical and quantum mechanics; and (2) it is (suitably) preserved in the classical-to-quantum theory change. Notice that ER so understood provides an argument in favor of the PO approach over the WFO approach: being preserved in theory change, the PO defeats the PMI argument. In contrast, in the WFO approach, since the wave-function does not have any classical analog, it is hard to see how the working posits are preserved.

The paper is structured as follows: in the next section, I overview of the PMI argument and some replies. Then in Sections 3 and 4, I focus on the quantum domain. I present the PO approach and show how the PO is preserved through theory change and how it is responsible for the empirical success of the theories. The last section discusses the advantage of the PO approach over the WFO approach in responding to the PMI argument.

2. The Pessimistic Meta Induction and Explanationism Realism

Scientific realism is, roughly put, the view that scientific theories give us a (nearly) truthful description of the world. The main argument for scientific realism, the no-miracle argument (NMA) holds that the empirical success of a theory can and should be taken as evidence of its truth. Nonetheless, there are very powerful arguments against scientific realism, like the PMI argument. The main idea is that it is not the case that, against the NMA, the empirical success of a theory is a reliable indicator of its truth. In fact, our current theories, even if successful, are more likely to be false than true since many past theories were successful but false.

One way to respond to the PMI challenge is to argue that one should be realist about a restricted set of entities, not about the whole theory. This is what Psillos calls a *divide et impera* strategy: scientific realists may argue that "when a theory is abandoned, its theoretical constituents, i.e. the theoretical mechanisms and laws posited, should not be rejected *en bloc*. Some of those theoretical constituents are inconsistent with what we now accept, and therefore they have to be rejected. But not all are. Some of them have been retained as essential constituents of subsequent theories" [Psillos 1991: 108]. So, if one can show that the entities that are retained in moving from one theory to the next are the ones that are responsible for the empirical success of the theory, the PMI argument is blocked. By restricting realism one provides an alternative explanation for the success of past false successful theories: past theories were successful not because they were (approximately) true in their entirety, but because some parts of them were. If these true constituents of past theories are responsible for the theories' success and they are carried over in theory change, then we are justified in believing that the entities these theoretical constituents represent really exist.

There are various ways to restrict realism. One example is Worrall's structural realism (SR) [Worrall 1989], according to which the PMI is correct in saying that in theory change we often have discontinuity at the level of unobservable entities, but most of the mathematical content of the old theory carries over to the new one. Therefore, the scientific realist may not be justified in believing what the theory says about the nature of physical objects, nonetheless she is justified in believing that the structure that holds between these objects which is preserved in theory change is (approximately) true. There are different varieties of SR, a first rough distinction is the one between epistemic SR and ontic SR. In the epistemic version, which some attribute to Worrall himself, we are only justified in believing that objects stand in certain structural relations with one another. Ontic SR instead goes further and claims that the very notion of objects is problematic and is worth dismissing [French 1998], [Ladyman 1998]. There are other responses to the PMI argument, but in this paper I will focus on ER, developed most prominently by [Psillos 1999] and [Kitcher 1993]. They distinguish between 'working' and 'presuppositional' posits of a theory. The working posits are the ones that are responsible for the theory's empirical success, while the presuppositional posits are theoretical constituents needed to complete the theory. If the working posits are preserved during theory change, the argument goes, past theories were successful because they got something right, namely the working posits, but they are also false when considered in their entirety because they got something wrong too, namely the presuppositional posits. Thus, the realist is justified in believing in the working posits, but there is no need for her to commit to the existence of the presuppositional posits: they are just 'idle' components, which make no difference to the theory's success.

3. The Classical-to-Quantum Theory Change as a Problem for Explanationism Realism

Scientific realism has been motivated and discussed almost exclusively discussing theories other than quantum mechanics. In particular, Psillos and Kitcher argue for ER within Fresnel's theory of light. It was successful because it got the working posit right, namely the electromagnetic waves: they are responsible for the success of the theory, and they were preserved by Maxwell's electrodynamics. In contrast, ether was a presuppositional posit: the success of Fresnel's theory did not depend on it, and it was abandoned by the subsequent theory. Realists are therefore justified in believing that electromagnetic waves exist, but do not have to be committed to believe that ether exists too. Another example extensively discussed in the literature is the caloric theory of heat, or phlogiston's theory of combustion, to again arrive to the conclusion that caloric and phlogiston are presuppositional posits. In reply, these historical examples have been revisited with the intent of arguing that ether, caloric, phlogiston, and the like, contrarily to what it is maintained by ER, played an important role in the success of past theories (see, e.g. [Elsamahi 2005], [Chang 2003]).

Regardless of the outcome of the debate over these examples, the main threat to ER comes from the classical-to-quantum transition. The fact that the discussion was limited to classical theories is not surprising: quantum mechanics has been considered, for a long time, incompatible with realism. While, on the one hand, quantum theory is incredibly powerful in making new and very precise predictions, on the other hand it is extremely difficult to understand. Indeed, quantum mechanics has been taken by many to suggest that physical objects have contradictory properties, like being in a place and not being in that place at the same time, or that properties do not exist at all independently of observation. Given that, many have thought that the real lesson of quantum mechanics is that the dream of the scientific realist is impossible. Luckily, the situation has changed: today we have various proposal of quantum theories that allow for a realist reading. Among these theories, most famously we find Bohmian and Everettian mechanics (BM [Bohm 1952] and EM [Everett 1957] respectively), and the GRW theory (GRW, [Ghirardi et al 1986]): they are empirically adequate fundamental physical theories according to which there is an objective physical world, which can be described by non-contradictory, mind-independent properties.

Even if this framework, the examples from quantum mechanics are brought up to motivate ontic SR rather than ER: "we have learned from contemporary physics is that the nature of space, time and matter are not compatible with standard metaphysical views about the ontological relationship between individuals, intrinsic properties and relations" [Ladyman 2014]. Most importantly, in quantum mechanics we have the Schrödinger equation, which is the evolution equation of the wave-function, an object which is involved in the derivation of most, if not all, predictions and explanations the theory is able to provide, and which arguably does not have any classical analog. If so, ER seems doomed: we have radical discontinuity and therefore the PMI argument has not been blocked. In light of all this, the case for ER has no hope of being compelling if does not cover quantum mechanics. In the next section I show how ER can be extended to quantum theories if paired with a particular view about the metaphysics of quantum mechanics, namely the PO approach.

4. Primitive Ontology and Explanationism Realism

Most philosophers of physics recognize the legitimacy of BM, EM and GRW, but disagree about the metaphysical pictures these theories provide. In this section, I discuss the PO approach, in which these theories can be seen as quantum theories with the same (or suitably similar) working posits as classical mechanics. That is, all these theories have a primitive ontology (PO), such that: (1) it is the primary responsible of the theory's success; and (2) it (suitably) carries over during theory change. If so, assuming that a strategy like ER is successful in defending scientific realism, the PMI argument is blocked: the realist is justified in believing that the PO is real because it does all the work to explain empirical success of theories and it is preserved in theory change.

Here is a brief summary of the PO account [Allori et al. 2008]. The primitive variables in the theory represent matter in three-dimensional space (or four-dimensional space-time): point-particles, continuous fields, and spatio-temporal events (flashes). Some examples of quantum theories with different primitive ontologies are worth mentioning: BM is a theory with a particle PO, GRWm is a theory in which matter is described by a continuous (three-dimensional) matter field localized where the macroscopic objects are, while GRWf is a theory of 'flashes,' spatio-temporal events. In addition of specifying what matter is, we need to specify how it behaves. This is implemented by the nomological variables, most importantly by the wave function. Therefore, even if one could not dispense of the wave function from quantum theories, according to the proponents of this approach, we should not think the wave-function to represent material objects. Rather, it is a necessary ingredient to implement the law of temporal evolution of the PO [Allori 2013]. For instance, in BM the wave-function evolves according to the Schrödinger equation, while in GRWf and GRWm it evolves according to Schrödinger equation and then randomly collapses, following the so-called GRW evolution.

Here are some fundamental features of the PO approach that is crucial to articulate:

(1) [REDUCTIONISM wrt PO] In this approach macroscopic objects are thought to be fundamentally composed of the microscopic entities the PO specifies. As such, the PO approach is (ontologically) reductionist, at least to the extent that it allows to make sense of claims like the PO being "the building blocks of everything else," and of the idea that macroscopic regularities are obtained entirely from the microscopic trajectories of the PO.

(2) [EXPLANATION and PO] The PO explains the macroscopic regularities using reductionist approaches similar to those used in classical mechanics. In fact, in classical mechanics, macroscopic bodies are made of a collection of particles, and their properties are accounted for in terms of the interaction of these particles among each other and the particles of the environment. For instance, the transparency of a pair of glasses is explained in terms of the electromagnetic forces acting between the particles composing the glasses, which are such that incoming light rays will pass through them. Similarly, the PO grounds the explanatory schema of quantum theories: the properties of macroscopic objects are (in principle) accounted for in terms of the PO's behavior (see [Allori 2013]).

(3) [THEOREITICAL VIRTUES] The PO of a theory is postulated, rather than inferred from the formalism, on the basis of some super-empirical virtues such as simplicity, explanatory power, and unification. The PO that provides the simplest, most unifying explanation should be selected (see [Allori 2015]).

(4) [UNDERDETERMINATION of WF] The way the wave-function evolves in time is irrelevant as long as the law of the PO such wave-function defines remains the same. That is, a theory of particles which follow certain trajectories, like BM, can

be obtained by a Schrödinger-evolving wave-function, like in the usual formulation, but also in terms of a collapsed wave-function (see [Allori et al 2008] for details). Two theories with the same trajectories for the PO, regardless of how they have been obtained (i.e., via a Schrödinger evolving wave-function or not) are *physically equivalent*. Since different wave-functions can give rise to the same trajectories for the PO, and since the trajectories of the PO are the ones that account for the macroscopic regularities, the wave-function evolution is underdetermined by the data.

(5) [PREDICTIONS] Once the PO and its law of evolution have been chosen, everything else is determined, including the empirical predictions which are determined as a function of the PO. The wave-function appears into the derivation of the predictions of the theory, but its role is not essential, since the way in which it specifies the law of the PO is underdetermined (see [Allori et al 2014]).

I wish to argue now that the PO can be identified with the working posit of quantum mechanics, while the wave-function is best seen as a presuppisitional posit. In fact, as we saw in (5), the predictions are determined by the PO, not by the wave-function. It appears in the derivation but its evolution is underdetermined by data, as we saw in (4). In addition, as we saw in (2), explanation is in terms of the PO: this reminds of Kitcher's idea that working posits are the entities that play a fundamental role in the theory's explanatory schemata. Moreover, there is the explicit fundamental postulation that the PO represent matter, while the wave-function does not, and that everything is made of the entities the PO specifies, as we saw in (1). All primitive ontologists (or supporters of suitably related views) maintain that one should be realist about the PO, regardless of what they think the wave-function really is. In fact, it has been considered to be, among other things, a law-like object [Goldstein et al. 2013], a disposition [Esfeld et al. 2014], a property [Monton 2006], or a new kind entity [Maudlin 2013]. Nonetheless, one can be 'metaphysically neutral' with respect to the wave function: one does not need to postulate the existence of the wave-function in order to account for the success of the theory. But this is to say that the PO is a working posit, while the wave-function is a presuppositional posit of quantum theories. If so, the PO approach provides a very nice framework for the explanationist realist to extent her view in the quantum domain.

However, this is not enough to successfully reply to the PMI argument: one would have to also show that the PO is preserved during theory change. What is the PO of classical mechanics? Arguably, in classical mechanics matter is made of particles, objects with the fundamental property of having a position in three-dimensional space. Therefore, for quantum theories of particles like BM, the preservation of PO during the classical-to-quantum theory change is obvious. The interesting cases are the ones that involve a mater density PO and a flash PO. In both cases, literally, the PO of classical mechanics has not carried over.

There seems to be two options: either dispute that this is a case of radical discontinuity, or take this to be an argument against non-particle PO. I believe that the latter option would not be very attractive to many, especially if there are strong reasons for preferring a non-particle PO. In fact, some hade argued that 'flashy' theories like GRWf are more compatible with relativity than particle theories like BM (see [Tumulka 2006]). Be that as it may, one could argue that it is not really a case of radical discontinuity. While it is not true that there are particles, or fields or flashes, still there is 'stuff' in three-dimensional space. Consider the case in which people went from believing that atoms are indivisible to believe that they are made of other indivisible particles. What the first theory got right is that there are particles, but it was wrong about which the fundamental particles really were. The situation here is different: we move from a theory in which the fundamental entities are particles, to a theory in which the fundamental entities have another nature. This is, arguably, what would happen from a quantum theory of particles to string theory. In this case we are not getting right the nature of the fundamental entities: before we had one-dimensional particles, now we have bi-dimensional vibrating loops. However, if we 'squint,' then we don't see the fine-grained details, and we take strings to be particles. They are, for all *explanatory* purposes, particles: we need to explain the macroscopic regularities, and we explain them in terms of the PO ignoring the details about what composes it. Just like when we observe a hose from a distance and we think it is one-dimensional while it is actually two-dimensional, or when we look at a poster in the subway and we think it's an image while instead it is a collection of colored dots. At the level of microphysics we may have flashes or a continuous field, but at some mesoscopic level they produce trajectories as if they are produced by particles. So, even if the microscopic PO is not one of particles, there is a mesoscopic scale in which they behave as if they are, and then from that level up to the macroscopic level, the explanation is the same as if they were particles.

The obvious worry here is: isn't that just some sort of (ontic) structuralism? If we do not preserve the nature of 'stuff,' isn't what we preserve some structural content of the theory? If structuralism is the view that there is just structure and no objects, then clearly not, since the PO approach postulates the existence of objects as a starting point. What about a moderate version of ontic SR, like the one proposed by [Esfeld 2004]? The idea behind this view is something like this: one should be realist about structure but, in contrast with the 'eliminativist' ontic SR mentioned above, there are 'things' that stand in the relation the structure prescribes, even if they have no intrinsic identities. In the quantum domain, such structure is the wave-function. Indeed, interestingly enough, [Esfeld forthcoming] proposes that in his moderate ontic SR, the *relata* the wave-function relates are given by the PO: he argues that the PO approach and his moderate ontic SR can help each other make sense of quantum non-locality and entanglement. So, in his view, we should be realist about the PO, and also about the structure that relates the PO, provided by the wave-function. In this sense, the reading I provide of the PO approach is not structural: the strength of the PO approach in responding to the PMI argument is that it regards the wave-function as a working posit. Only because of this, one can show there is continuity of PO during theory change. Instead Esfeld's moderate ontic SR does not have this advantage: if the wave function is the structure the realist should be committing to, then it is difficult to see where this structure was coming from in classical physics.

The PO approach entails something like this: we do not get the nature of objects right because we believe they are particles in classical mechanics and then we discover they are actually, say, flashes in quantum mechanics; but we get some 'structure' right, namely that on some mescoscopic level they behave as if their nature were the one of particles. One may call it structural realism, but it does not seem to have much in common with the other varieties of SR we just examined. Rather, more appropriate seems the connection with ER: what provides the explanation, namely the PO, is what 'ontologically counts,' if it is preserved in theory change.

Finally, the PO approach can help replying to the objection to ER that the working-presuppositional posit distinction is post- hoc. That is, the working posits are what we see have carried over (see, e.g. [Stanford 2003a, 2003b]). The PO is postulated when the theory is proposed, rather than inferred from the formalism, as the one that provides the best combination of simplicity, explanatory and unificatory account of the experimental data. In this way, what is a working posit is selected from the time the theory is proposed, and it is never post-hoc.

5. A New Argument for the PO Approach

The above analysis of the PO approach as an instance of ER also provides the PO approach with an important advantage over the alternative WFO approach. According to this view, the wave-function is a concrete physical field and should be regarded as representing matter. If we analyze this view in terms of ER the wave-function has to be a working posit of quantum theory. The problem with this is that, mathematically, the wave-function is an object that lives in the high dimensional configuration space, and as such is a very different entity from classical particles. In addition, the image of the world provided by the WFO approach is very different from the image of the world given to us by classical mechanics: in the latter there are particles moving in three-dimensional space, in the former there is this matter field in a highly-dimensional space. In the classical-to-quantum transition we discover that not only we were getting the nature of objects wrong (we believed there were particles and actually there are none) but we cannot get our classical picture back by 'squinting,' like in the PO framework, since the fundamental physical space is not three-dimensional. In this way, there is no continuity of working posits between classical and quantum mechanics, and the strategy to resist to the PMI argument along the lines of ER is precluded to the proponent of the WFO approach. If there is truly a quantum revolution, as the WFO approach seems to maintain to a give extent (see [Allori 2015]), and the way in which we understand the word using quantum theory is fundamentally different from the way in which we understood it in classical terms, what is our justification to believe that the theoretical terms used in quantum mechanics are (approximately) true? It is difficult to see how the PMI could be defeated in the WFO framework, unless they go eliminative structural realists, and they may not want to do that, given the numerous objection that have been raised against this view (see, e.g. [Psillos 1999], [Chakravartty 2007], [Cao 2003] among others).

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