Who's Afraid of the Measurement Problem? On the Incompatibility between Scientific Realism and Quantum Mechanics

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Abstract

Call 'the realism problem' the problem of providing realist understandings of quantum theory. Scientific realists usually claim that this problem is settled by solving the measurement problem. In this paper instead I argue that there are different views about what the realism problem is. I distinguish between an adequacy problem, a precision problem (which is the measurement problem), and a completeness problem. I argue that the reason why people disagree is that they have different realist commitments: 'relaxed' realists like proponents of the information-theoretical interpretation of quantum theory, think it is enough to solve the adequacy problem, 'modest' realists like wavefunction realists instead believe that there is also a precision problem, while 'robust' realists like primitive ontologists insist that quantum theory needs to be suitably completed. This in turn depends on the type of theories one finds satisfactory: while relaxed realists favor principle theories, robust realists prefer constructive theories, and modest realists provide a non-constructive dynamical hybrid. I argue that this type of explanatory structure raises two challenges for the modest realist. First, I show that modest realist theories, despite being designed to solve the precision problem, they actually solve the adequacy problem, and this undermines the motivation for modest realism. Second, I argue that modest realists have to admit different types of explanation in different contexts without any plausible justification for why they are different.

1. Introduction

Quantum theory, while being so successful, suffers from what we can call the *realism problem*: the theory is incompatible with scientific realism, as it cannot provide, in its standard textbook formulation, a picture of reality. Traditionally scientific realists think that one can deal with the realism problem by solving the *measurement problem,* namely the problem of precisely suppressing the unobserved macroscopic superpositions predicted by the theory. Solutions of the measurement problem include the GRW theory, the pilot-wave theory, and the many-worlds theory. Even in a realist framework, people disagree about which solution is best. In this paper I argue (section 2) that they disagree because they are looking at different problems: there is an adequacy problem (the theory has to faithfully reproduce observations), a precision problem (the measurement problem as usually intended, namely making the theory empirically adequate in a precise way), and a completeness problem (the wavefunction is not the right type of object to describe physical objects). I also show how the reason why different people look at these distinct problems is that they have diverging realist commitments (section 3), and that they think of theories differently (section 4). I maintain that those who think the realism problem is the adequacy problem endorse a relaxed realist attitude, as they think that a theory

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should objectively systematize the phenomena in terms of principles. Instead those who think quantum theory is incomplete have in mind a robust realist understanding, where a theory explains the phenomena constructively, in terms of the dynamics of the microscopic three-dimensional constitutes of the world. Then in the middle those who think that the precision problem is the one to be solved endorse a modest version of realism, which combines an interest of the reality behind the phenomena with a non-constructive understanding. I conclude by discussing two challenges for modest realism (section 5). First, I show that the theories favored by modest realists end up solving the adequacy problem, despite having been proposed to solve the precision problem. If so, given that the adequacy problem can be solved also by von Neumann's collapse rule, it is difficult to understand why someone would ask for more. Moreover, there is an explanatory mismatch problem, as modest realists need to allow for a constructive as well as a non-constructive type of explanation without a reason for why that has to be the vase.

2. Quantum Problems

When discussing quantum mechanics as presented in physics books, it is often pointed out that the theory is merely a recipe for predicting experimental results. As such, it is incompatible with scientific realism, the view that theories can give us information about the nature of the world. As anticipated, let us call this incompatibility *the realism problem*. Traditionally, it is argued that the realism problem is the measurement problem. This problem arises when we assume that the wavefunction, the main object of the theory, evolves according to a suitable linear equation, the Schrödinger equation. Since a solution of this equation describes possible states of affairs, and since the Schrödinger equation is linear, also any sum of solutions (superpositions) describes possible physical situations. If one also assumes that every system is completely described by such wavefunction, then there will be 'superpositions of states' at all scales.

2.1. The Adequacy Problem

The first problem of quantum theory is that it is *not empirically adequate*: it predicts something we do not observe. This problem is solved in physics books by postulating the collapse rule: when we observe, we make a measurement, and then the Schrödinger-evolving wavefunction randomly and instantaneously collapses into one of the terms of the superposition.

While the collapse rule arguably works for an anti-realist perspective, there are also realists who think that there is no realism problem left. Proponents of the information-theoretic (IT) approach are an example. For them quantum theory lays out a set of constraints imposed on the empirical data. They are realist about the fact that these data exist objectively and mind-independently, but they do not think they need to tell any additional story about how these data are generated.[2] Similarly, QBists think of quantum theory as providing constraints on

[2] Bub and Pitowsky (2010).

measurement outcomes.[3] Moreover Rainforest Realism, according to which objects, both at the microscopic and the macroscopic level, are seen as real patterns, defined by their usefulness, fits this profile.[4]

2.2. The Precision Problem

However, many are not convinced, and find the collapse rule unsatisfactory, as it is unclear when one is supposed to apply it (what is a measurement?), and why it applies (why is a measurement process not a particular type of physical interaction?). In other words, they identify the realism problem as a *precision problem*: the unobserved macroscopic superpositions predicted by the theory need to be accounted for *without mention of observers or measurements*. This is the measurement problem as usually understood. Its most promising solutions are recognized to be: the many-worlds theory, in which all terms of the superpositions exists but never interact with one another;[5] the pilot-wave theory, in which the complete state of the system is specified by the wavefunction and by the particles' position;[6] the GRW theory in which the wavefunction collapses a as matter of law.[7]

These theories are taken to be theories about the wavefunction, with the exception of the pilot-wave theory which also has particles. This view, when the wavefunction is understood as a physical field in configuration space, is called *wavefunction realism*.[8] When instead it is taken to be a vector in Hilbert space, it is called *vector space realism or Hilbert space fundamentalism*.[9] If the wavefunction, or better the quantum state, is instead taken to be in its own category of existence, then one talks about *quantum state fundamentalism*.[10] In the many-worlds framework, some also have endorsed a view called *spacetime state realism*, which takes the states associated to spacetime regions as fundamental.[11] A distinctive approach is the one of Vaidman, who, while claiming that some three-dimensional entity has to be extracted from the wavefunction to explain our experiences, believe that a precise specification is not needed.[12]

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[3] Fuchs (2010); Fuchs, Mermin, and Schack (2014); Fuchs (2017) and references therein. Here is an interesting quote: "What is the stuff of the world? QBism is so far mostly silent on this issue, but not because there is no stuff of the world. The character of the stuff is simply not yet understood well enough. Answering this question is the goal, rather than the premise" (DeBrota, and Stacey 2019).

[4] Ladyman and Ross (2007, 2013); Ladyman, (2016). This view follows the ideas of Dennet (1991) and Wallace (2003a).

[5] Everett (1957).

[6] Bohm (1952).

[7] Ghirardi, Rimini and Weber (1987).

[8] Albert (1996, 2013, 2015), Ney (2012, 2013, 2015, 2017, 2021) and references therein.

[9] Carroll (2022) and references therein.

[10] Maudlin (2019).

[11] Wallace and Timpson (2009).

[12] Vaidman (1998, 2019, 2022). He thinks that while interference experiments have shown that matter is wave-like as opposed to particle-like, the mathematical description of the phenomena provided wavefunction is contingent: other descriptions, in terms of density matrices or the like, may be useful or convenient in other contexts. What is essential instead is that this wave-like object cannot live in three-dimensional space: because of entanglement, it has to live in $3N$ dimensional space. So, when Vaidman claims that 'reality is only wavefunction,' this is a slogan to convey that 'reality is wave-like, and such a wave is entangled.' In addition, however, in contrast with wavefunction realists, he

2.3. The Completeness Problem

Others instead have argued that *quantum theory is fundamentally incomplete*, as it is a theory of the wavefunction, which is not suitable to describe physical objects. Under this understanding, not all solutions of the precision problem are satisfactory: GRW and many-worlds, being purely wavefunction theories, need to be supplemented with something else. This attitude can be historically tracked down for instance to Lorentz, who objected to Schrödinger that his wavefunction was physically unacceptable because it is a field in configuration space (which is a space with $3N$ dimensions, if there are N three-dimensional particles), rather than a three-dimensional field like electromagnetic fields.[13] Similar concerns were raised by Einstein,[14] (at least) an early Schrödinger,[15] de Broglie,[16] and even Heisenberg, which arguably pushed him toward anti-realism.[17] This idea has recently implicitly resurfaced in the primitive ontology framework.[18] They propose that in all quantum theories material entities are not represented by

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believes that three-dimensional space and some three-dimensional 'properties' extracted from the wavefunction (such as the matter density field, or the particle density field) are fundamental. Therefore, in this respect Vaidman seems more similar to spacetime state realism, or perhaps to the multi-field interpretation of the wavefunction (even if he would disagree with the latter that there's something special about the description of reality given by the wavefunction aside from describing a wave-like object displaying entanglement). Indeed, his view seems to also share some similarities with the theories proposed by primitive ontologists in which the primitive ontology depends on the wavefunction, like the matter density (see GRWm, or Sm). Vaidman leaves unspecified which of these fields should be extracted from the wave function to explain our experience, but he is adamant that these are what need to be looked at.

[13]Here is what Lorentz writes to Schrödinger: "If I had to choose now between your wave mechanics and the matrix mechanics, I would give the preference to the former, because of its greater intuitive clarity, so long as one only has to deal with the three coordinates x, y, z. If, however, there are more degrees of freedom, then I cannot interpret the waves and vibrations physically, and I must therefore decide in favor of matrix mechanics" (Lorentz in Przibram, 1967).

[14] Einstein in a letter to Lorentz dated May 1st, 1926, writes: "Schrödinger's conception of the quantum rules makes a great impression on me; it seems to me to be a bit of reality, however unclear the sense of waves in n-dimensional q-space remains." Similarly, here is an excerpt from a June 18th, 1926 letter that Einstein sent to Paul Ehrenfest: "Schrödinger's works are wonderful – but even so one nevertheless hardly comes closer to a real understanding. The field in a many-dimensional coordinate space does not smell like something real." Both these quotes are taken from Howard (1990).

[15] "The direct interpretation of this wave function of six variables in three-dimensional space meets, at any rate initially, with difficulties of an abstract nature."[15] Also: "Of course this use of the q-space is to be seen only as a mathematical tool, as it is often applied also in the old mechanics; ultimately [...] the process to be described is one in space and time" (Schrödinger 1926).

[16] Before settling for the pilot-wave theory, in which there are particles guided by the wavefunction, de Broglie worked on what he called 'the theory of the double solution,' in which particle behavior was supposed to be interpreted as singularities of a physical wave u guided by an abstract wave ψ in configuration space. He wrote: "Physically, there can be no question of a propagation in a configuration space whose existence is purely abstract: the wave picture of our system must include N waves propagating in real space and not a single wave propagating in the configuration space" (de Broglie 1927, reprinted in de Broglie 1956).

[17] Heisenberg has been reported to have said, very vividly, referring to Schrödinger's work: "Nonsense, […] space is blue and birds fly through it "(Bloch 1976). This expresses his unacceptability of a theory with no fundamental three-dimensional fields and with no fundamental three-dimensional physical space.

[18] Dürr, Goldstein, and Zanghí (1992); Dürr, Goldstein, and Zanghì (1997); Allori *et al.* (2008); Allori (2013a); Allori (2013b). For a review, see Allori (2015); Allori (2019).

the wavefunction but by the *primitive ontology*, namely some entity in three-dimensional space (or four-dimensional in space-time). There are different ways of completing quantum theory. The pilot-wave theory is arguably the simplest way of doing this: the simplest type of ontology (particles), and the simplest evolution equations. But it is not the only way to go: GRWm is a theory in which matter is described by a (three-dimensional) field defined in terms of the wavefunction.[19] GRWf is instead a theory with an ontology of spatiotemporal events, dubbed the 'flashes.'[20] Otherwise, one can have GRWp, a spontaneous localization theory of particles.[21] Similar completions has been done for many-worlds by adding a particle ontology, a matter density ontology, or flashes.[22]

There is another way of thinking of the wavefunction which arguably could be understood in the primitive ontology framework. Multi-fielders believe that the wavefunction is the ontology of quantum theory provided that one understands it as a multi-field in three-dimensional space which assigns a set of values, rather than only one, to each three-dimensional location in which it is nonzero.[23] Arguably, one could think of this view as solving the completeness problem. By instead understanding the wavefunction as a three-dimensional multi-field, one effectively adds a three-dimensional field ontology which can serve as (additional) primitive ontology.[24]

3. Quantum Realism(s)

From the discussion in the previous session, it emerges that there is a disagreement about what the realism problem is, which means that there is disagreement about what being a scientific realist means. In general, a scientific realist believes that theories are approximately true descriptions of the world. However, one can disagree about what a theory needs to do in order to provide such an accurate description. In this section, I distinguish between different realist commitments.

3.1. Relaxed Realism

Those who take the realism problem to be the adequacy problem, such as the IT interpretation, QBism or Rainforest Realism, think that quantum theory with the collapse rule can be interpreted as a realist theory. It does not matter whether the collapse rule is precise or not, because in IT and QBism measurements are unanalyzable primitives, while in Rainforest Realism nothing is primitive. Once this rule to suppress macroscopic superpositions is in place,

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[19] Benatti, Ghirardi and Grassi (1995).
[20] This theory was first proposed by Bell (1987b), and then adopted in Tumulka (2006), who developed a relativistic extension.
[21] Allori (2020a).
[22] Allori *et al.* (2008, 2011), Allori (2019), and references therein. Note that these theories can still be labelled many words theories because the primitive ontology inherits the superpositions generated by the linearly evolving wavefunction.
[23] Forrest (1988), Belot (2012), Chen (2017), Hubert and Romano (2018), Romano (2020).
[24] The disagreement between multi-fielders and primitive ontologists has to do with symmetries properties, as discussed in Allori (2021).

the realism problem 'dissolves.' Usually, these attempts are taken to be 'not realist enough.'[25] However, while anti-realists will presumably say that physical theories are not the kind of things which can give us a description of what is unobservable, the proponents of these approaches acknowledge that there are many possible microscopic descriptions for the same macroscopic phenomena but, because of underdetermination concerns, one should remain agnostic about which the correct one is. Or even that no microscopic description is needed to have a satisfactory explanation. So, they do not deny that a microscopic reality exists, just that it is neither possible nor necessary to provide a description of it. Let's call this perspective *relaxed realism*.

3.2. Modest Realism

Those who care about the precision problem think that solving the adequacy problem is not enough, as they also care about having all physical objects and processes being governed by a unified, precise dynamics. Nonetheless, I will call them *modest realists*, for reasons which hopefully become clear later.

Consider the many-world theory first. As anticipated, it can be considered either as a theory of the wavefunction in some high dimensional space, or of some three-dimensional field extracted from the wavefunction. If one endorses an approach in which the ontology is not in three-dimensional space, such as wavefunction realism or vector space realism, there are the following problems: 1) account for the three-dimensionality of our experience; 2) explain why the different words are 'transparent' to one another; 3) show where probabilities come from in such a deterministic theory.[26] If instead one adopts a three-dimensional ontology, such as spacetime state realism, they only have the last two problems. The solution strategy adopted by wavefunction realists to solve the first problem is to argue that the three-dimensional world is *emergent or derivative*. There are two main attempts. First, Albert's *functional enactment* is a functionalist reduction of three-dimensional microscopic objects from the wavefunction.[27] The idea is that it is possible first to functionally define what it means to be a three-dimensional object, and then that the wavefunction can play the role of a three-dimensional object. Instead, in Ney's approach three-dimensional objects derivatively exist in virtue of considering symmetry properties as fundamental facts about the world, and then particles are seen as suitable partial instantiations of the wavefunction.[28] A similar strategy is employed in vector space realism, in which three-dimensionality is recovered in terms of the energy eigenvalues of the Hamiltonian.[29] The second problem, the non-interactions between worlds, is solved by appealing to decoherence: because of the interaction with the environment, the different terms

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[25] See Egg (2019) for a set of arguments that some implementations of this type of realism, such as the one of Ladyman and Ross and of Bub and Pitowsky, do not deserve to be labelled as realist.

[26] There are also other problems, such as the preferred basis problem, which is to explain why, among all possible ways to write the wavefunction the branches happen in the position basis. However, I think what if one solves the first and second problem, the solution of this problem will come about naturally.

[27] Albert (2015).

[28] Ney (2021).

[29] Carroll (2022).

of the superposition never interact with one another and thus are describable 'as if' they live in different 'worlds.' The third problem, namely in what sense someone on a branch will be uncertain about which branch she will subsequently occupy, is solved by assigning suitable weighing to the branches and justifying them using additional assumptions.[30]

In GRW understood as a theory of the wavefunction, sometimes dubbed bare GRW to distinguish it from GRWm, GRWf, and GRWp, arguably one does not have the problem of probabilities and the world interference. Instead, similarly as the many-worlds theory, there is the problem of extracting the appearances of three-dimensionality from the high dimensional reality provided by the wavefunction, and the wavefunction realist strategies equally apply in this context.

3.3. Robust Realism

Let us now discuss primitive ontologists who think that quantum theory is fundamentally incomplete. This view is driven by the idea that macroscopic phenomena need to be explained in terms of the dynamics of their three-dimensional microscopic constituents.[31] This is the sense in which we will call them *robust realists*, in contrast with modest realists discussed in the previous section.[32]

They insist on adding primitive ontologies to GRW and many-worlds because they are committed to this specific brand of realism. The reason why wavefunction realists, for instance, and primitive ontologists disagree about which theory counts as satisfactory is that they have a different perception about which problem quantum mechanics needs to solve, which in turn depend on the fact that they have in mind different accounts of scientific realism.

Since primitive ontologists want a three-dimensional microscopic ontology to complete quantum theory, their goal to reconcile quantum theory with realism should have always been to solve the completeness problem, rather than the precision problem (that is the measurement problem). Instead, surprisingly, in their presentation the measurement problem seems to be their focus. This, I believe, was a mistake on their part, as it makes their position, which is instead quite straightforward, unnecessarily mysterious. Moreover, it is puzzling that theories like GRWm, GRWf, GRWp or similar for many-worlds, have been proposed by the primitive ontologists: there seem to be no reason to consider other completion of quantum theory if one already has the simplest way of doing that, namely the pilot-wave theory.[33]

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[30] These assumptions are understood as rational constraints in, e.g. the following: Deutsch (1999), Wallace (2003b, 2006, 2007), Saunders (2003), Greaves (2004, 2007), Saunders and Wallace (2008). Instead in Vaidman (1998, 2019) they are thought about empirical hypothesis necessary to recover the quantum mechanical predictions.

[31] This is explicit in Allori (2013a, 2013b, 2015, 2019).

[32] The definition introduced here to distinguish the various types of realisms should be understood as technical terms. So that the term 'robust,' say, should always be understood as defined and not in the intuitive sense.

[33] In Allori (2020a) these points have been finally clarified, and it is explained that the value of looking at GRW-type theories with a primitive ontology is to explore the compatibility with quantum mechanics and relativity, as

4. Quantum Explanations

Wavefunction realists, *contra* primitive ontologists, argue that bare GRW, say, needs no completion because it is another, fundamentally different, way of solving the precision problem. Primitive ontologists disagree, I have argued, because they think that, *contra* wavefunction realists, the precision problem does not solve what they think the realism problem actually is, namely the completeness problem. In the previous section I have shown that the reason for this is their commitment to a specific, very stringent, type of realism. In this section I discuss how the tendency of endorsing one type of realism goes hand in hand with the tendency of endorsing a particular type of theory. I show how relaxed realists favor principle theories, how robust realists instead look for constructive theories, while modest realist end up endorsing a hybrid of the two.

According to Einstein, theories are either constructive theories or they are theories of principles.[34] *Principle (or kinematical) theories* are formulated in terms principles, which are used as constraints on physically possible processes. They spell out principles that the phenomena need to conform to, and they are 'kinematic' theories because the explanations they provide do not involve equations of motion and they do not depend on the interactions the system enter into. Instead, by definition *constructive theories involve the dynamical reduction* of macroscopic objects in terms of the motion and interactions of their microscopic three-dimensional constituents. An example of a principle theory is thermodynamics (e.g. "energy is conserved"), and an example of constructive theory is statistical mechanics, which reduces the behavior of gases to the motion of atoms. Another example of principle theory is the 1905 theory of special relativity (before the introduction of Minkowski spacetime), as it was formulated in terms of the two principles of equivalence of inertial frames for all physical laws, and constancy of the velocity of light. This theory explains relativistic effects (such as length contraction and time dilation) as the physical phenomena compatible with the theory's principles. By contrast, Lorentz's theory (1909) is a constructive theory, as it derives the relativistic transformations and the relativistic effects from the electromagnetic properties of the ether and its interactions with matter.

4.1. Principle Theories

Some have argued that principle theories are preferable. For instance, Bub and Pitowsky have argued that quantum theory is best understood as a principle theory. They maintain that to explain is to constrain the phenomena without the need of a dynamical account. More specifically, Hilbert space is thought as "the kinematic framework for the physics of an indeterministic universe, just as Minkowski space-time provides the kinematic framework for

relativistic extensions of GRWm and GRWf without a foliation exist, in contrast with relativistic pilot-wave theories, while with Lorentz invariant laws, all have a privileged spatiotemporal structure. However, in a later manuscript, she argued that it is unclear that the GRW theories with primitive ontology can bring quantum theory closer to relativity than the pilot0wave theory (Allori 2022).

[34] Einstein (1919).

the physics of a non-Newtonian, relativistic universe."[35] They believe that we should favor explanations given in terms of principle theories: "there is no deeper explanation for the quantum phenomena of interference and entanglement than that provided by the structure of Hilbert space, just as there is no deeper explanation for the relativistic phenomena of Lorentz contraction and time dilation than that provided by the structure of Minkowski space-time." This positive attitude toward principle theories fits well with their relaxed realism and their idea that to solve the realism problem one needs no more than solving the adequacy problem: if a theory needs to systematize the phenomena, it can successfully do it using principles, no dynamical explanation is necessary. Flores (1999) has convincingly argued that principle theories are explanatory because they unify, so they are top-down.[36] So if one thinks that to explain is to unify, all things being equal they will likely prefer principle theories.

4.2. Constructive Theories

Instead Einstein believed that physics should look for constructive theories, and accept principle theories only when one has no other option.[37] Brown (2005) has argued that dynamical theories are more explanatory because in contrast with kinematical theories they provide insight of the reality underlying the phenomena.[38] Along these lines, primitive ontologists can be seen as thinking of quantum theory as *thermodynamics*. Both these theories are principle theories, so the quantum recipes describe the phenomena by specifying the statistics of the experimental results, just as thermodynamics provides constraints on macroscopic phenomena. And they both are in need of a constructive counterpart, a microscopic three-dimensional description that would dynamically explain why one gets the results they get. The pilot-wave theory already provides such an understanding, while the many-worlds theory and bare GRW need to be supplemented by a three-dimensional ontology to even begin being considered as constructive theories.

4.3. Non-constructive, Dynamical Theories

If a robust realist favors constructive theories, and a relaxed realist prefers principle theories, what about modest realists? The explanatory strategies developed by modest realists discussed in section 3.2 are not constructive in the sense that the macroscopic phenomena are not explained in terms of the three-dimensional microscopic dynamics of the constituents of the world. Rather, they seem much closer to the type of explanation provided by principle theories. In fact, for someone like wavefunction realists and vector state realists, the wavefunction is not in three-dimensional space, and it does not make sense to think of it as 'microscopic' or

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[35] Bub and Pitowsky (2010).
[36] Friedman (1976), Kitcher (1989).
[37] He thus expressed his own dissatisfaction for the theory of special relativity at the time. However, he could have said something similar for quantum theory: his preference for constructive theories is compatible with his idea that quantum mechanics is incomplete. Moreover, it fits well with his statistical interpretation of quantum theory, as it is a principle theory by constraining the phenomena with suitable rules.
[38] See also Brown (2005), Brown and Pooley (2004), Brown and Timpson (2006). See also Flores (1999) for a connection with Salmon's mechanistic view of explanation (1984). See also Felline (2011).

'constituting' something. Moreover, Albert uses functionalism, Ney uses symmetries and partial instantiation to establish the derivative reality of three-dimensional objects, thereby providing principles that constrain the phenomena. Albert constrains them by postulating what the Hamiltonian needs to be, and Ney by postulating that certain symmetry properties should hold. A similar proposal has been put forward by Carrol within vector state realism: three-dimensionality emerges as a result of decomposing the whole of Hilbert space into subsystems with a simple internal dynamics observable via interactions with other subsystems. This is also true for the three-dimensional approaches such as spacetime state realism. In fact, the appeal to decoherence used in many-worlds to suppress interference between different words amounts to add constraints on the phenomena rather than providing a dynamical explanation. Similarly, the problem of assigning different weighing to the branches is solved by adding suitable assumptions whose purpose is, again, to constrain what's physically possible.
On the other hand, these explanations are not entirely principle explanations. In fact, we know that modest realists, in contrast with relaxed realists, care about the dynamics in virtue of wanting to solve the precision problem. Moreover, Albert's functionalist account takes the dynamics into account using the *form* of the Hamiltonian (rather than its solutions) to 'recover' three-dimensional objects. Similarly, Ney's focus on symmetries can be understood as her taking the dynamics seriously. Likewise, in Carrol's account the Hamiltonian allows for the partition of Hilbert space into subsystems.[39]

These two features, having a non-constructive explanation and nonetheless giving importance to the dynamics, seem to pull in opposite directions: the former pushes towards relaxed realism, while the latter towards robust realism, making wavefunction realism a peculiar hybrid of the two positions. The following table summarizes this conclusion.

Table 1:

Type of Realism	**Type of Problem**	**Type of Explanation**	**Acceptable Theory**
Robust	Completeness	Constructive/dynamical	'Hidden variables' type
Modest	Precision	Non-constructive/dynamical	Pilot-wave, GRW, many-worlds
Relaxed	Adequacy	Principle/kinematical	Collapse rule

[39] A different case seems to be one of Vaidman. As noticed earlier, his approach seems similar to the primitive ontology approach is that three-dimensionality is important, and experiences are accounted for in terms of three-dimensional 'properties' extracted from the wave function. Moreover, he does not try to use emergent notions to recover experiences. The Schrödinger equation determines the evolution of the wavefunction (and their three-dimensional properties), which branches into different (three-dimensional) worlds. The worlds do not interact due to decoherence (as in the other approaches) but the problem of probability is solved by postulating that the worlds are weighted as needed for empirical adequacy of the theory (Vaidman, p.c.). In this way, it seems that the macroscopic properties of the objects of our everyday experience are recovered reductively from the dynamics of the ontology, rather than in terms of principles to constrain the phenomena.

5. Two Puzzles for Modest Realists

In this section I argue that, by combining a non-constructive type of explanation with giving importance to the dynamics, modest realism faces two challenges.

To begin with, I show that it is difficult to justify why one would want to solve the precision problem, undermining the motivation for considering the precision problem as a serious problem over and above the adequacy problem, thereby the whole idea of modest realism. Second, I argue that it seems natural to assume that if one favors one type of explanation in a specific area, then, all things being equal, they should also favor the same type of explanations in general. I show instead that this is not the case for modest realism, leaving the approach with an explanatory mismatch that needs to be accounted for.

Focusing on the first challenge, I start by arguing that the strategies proposed by modest realists recover the appearances, and then I show that this means that they're solving the adequacy problem. From this it follows that there is no need to solve the precision problem, and thus no need to endorse modest realism.[40] In the many-worlds theory, the absence of interference between worlds is an appearance problem: we do not see superpositions, and the many-worlds theory explains why it appears as if they are not. The probability problem is also an appearance problem: we have certain credence, and the many-worlds theory explains why it appears we do. A similar argument can be run for bare GRW which, like many-worlds, has the problem of recovering three-dimensionality. This is again a problem of appearances: we perceive the world as three-dimensional, and the theory explains why it appears to us as such. If both many-worlds and GRW solve problems of appearance, they actually solve the adequacy problem: the observed phenomena are the appearances which need to be accounted for by the theory. That is, these theories solve the precision problem in the sense that they solve the adequacy problem in a precise manner. However, if all these strategies are doing is solving the adequacy problem, one may question the need for precision, as appearances do not need to be reproduced precisely. This is what is emphasized by the proponents of the IT approach, but also by Wallace (2012), who insists on patterns and on the fact that they are unproblematically vague. Nonetheless, if both the relaxed and the modest realists solve the adequacy problem, with the only difference that the second does it precisely, and if to recover appearances one needs no precision, it is unclear what the point of modest realism is. The crucial question is: why would one want a precise rule if she cares only about recovering the appearances? One obvious reply is that they care about having a *unified dynamics applicable at all scale*. However, why are modest realists interested in the dynamics at all, if they provide a non-constructive explanation?

The second challenge is the following. Whatever their motivation, if someone favors a given type of explanation in quantum mechanics, presumably, absent reasons to think otherwise, they should be favoring the same type of explanation also in other contexts. However, this is not the

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[40] For a similar argument that many-words solve only the adequacy problem, which uses a distinction between the big and the small measurement problem related to the ones I develop here, see Bub and Pitowsky (2010).

case for (some) modest realists. Think about the Boltzmannian understanding of the laws of thermodynamics in terms of the classical dynamics: it is a constructive explanation. Albert (2000), which in my classification is a modest realist, defends the statistical mechanical explanation of thermodynamics. In addition, he argues that the same explanatory strategy used in the classical domain would extend in the quantum domain, and that bare GRW, because it is a probabilistic theory, would fare better than the alternatives (Albert 2021). Still, the explanation given by bare GRW is non-constructive, while the quantum statistical explanation instead is. How are they compatible? The existence of this explanatory mismatch, between quantum non-constructive and classical constructive, is something that seems to require an explanation, as it is unclear why one has one type of explanation in one context and not another.

6. Conclusion

I have argued in this paper that, contrarily of the common understanding, it is not obvious what problem one needs to solve to make quantum mechanics amenable to a realist interpretation. While usually realists think it is the measurement problem, namely the problem of precisely eliminating unobserved macroscopic superpositions (what I have called the precision problem), I have argued that some instead think that one can still have a realist theory, even if in a relaxed sense, by solving an adequacy problem by postulating the collapse rule. Instead robust realists, interested in a dynamical and constructive understanding of the phenomena, focus on completing quantum theory with a three-dimensional ontology. Finally, modest realists, who start with solving the measurement problem, provide non-constructive but dynamical explanations. This type of understanding, I argue, creates two tensions. First, modest realist theories, while being developed to solve the measurement problem (the precision problem) actually only precisely solve the adequacy problem, and this undermines the reason to solve the precision problem to start with. Second, it is unclear how to reconcile the quantum non-constructive explanation with the classical constructive explanation in statistical mechanics without any reason of why one has two different explanatory frameworks.

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