Chapter 9
Do Dispositions and Propensities Have a Role in the Ontology of Quantum Mechanics? Some Critical Remarks

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9.1 Dispositions and the Interpretive Task of Quantum Mechanics

In trying to understand the role of propensities or dispositions, if any, in the interpretations of quantum mechanics (henceforth QM), I think that one can do no better than start from a fundamental question once posed by John S. Bell: 'What are quantum probabilities *probabilities of?*'

As I see it, this question addresses two deeply related issues, both of which are relevant to evaluate the role of dispositions in QM. The first is an *ontological* question, namely an attempt to connect the formal structure of quantum theory with entities in the physical world, in order to try to figure out *what the theory is about*. I take it that, in all generality, interpreting the mathematical formalism featuring in physical theories ought to mean:

1.1 understanding the ontological implications of physical theories ('*the scientific image*');
1.2 connecting the postulated ontology with our pre-theoretical experience of the world ('*the manifest image*').[1]

In the case of QM, however, such an interpretive task is complicated by the fact that there is no agreed-upon 'theory', except operationally of course, or, in Bell's words (Bell, 1990) 'For All Practical Purposes' (FAPP). Therefore, the interpretive task of QM cannot consist, contrary to what it has been often maintained, in figuring out 'what the world must be like if quantum mechanics accurately describes it' (van Fraassen, 1981, 230; Hughes, 1989, 296; Healey, 1989, 7), because we don't know what 'quantum mechanics' *is* without an explicit interpretation in the two senses above. For instance, according to some interpretations, QM should

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[1] The distinction between scientific and manifest image of the world is Sellars' (1963).

M. Suárez (ed.), *Probabilities, Causes and Propensities in Physics*, Synthese Library 347, DOI 10.1007/978-1-4020-9904-5_9,

be supplemented with a genuine process of collapse of the wave function, while according to others it shouldn't. For my purpose, it follows that the question of discussing the role of propensities or dispositional properties in QM can only have *interpretation-dependent results*.

The second issue raised by Bell's question above has to do with the meaning of the notion of *probability*, a question upon which the philosophical and scientific community so far has reached no agreement (see Hájek, 2010). Are quantum mechanical probabilities – that figure so prominently in the theory – to be regarded as frequencies, propensities, or simply epistemic states of subjects, as in Bayesian accounts?

Given what I said above, it should be clear why having a clear answer to the first issue is essential to figure out a response to the second: as is well known, if one adopts a Bohmian interpretation, probabilities may be regarded as merely epistemic, or due to our ignorance of the positions of the particles, while in collapse theories, or in the Copenhagen interpretation, probabilities are typically regarded as frequencies, chances, or *propensities*, i.e., objective properties or powers of individual states or events of the physical world. Consequently, in what follows, I will dedicate more attention to explore the first issue by defending the following two claims:

(i) In dynamical reduction models *à la* Ghirardi, Rimini and Weber (1986), propensities or dispositions *might* have a role, despite their (temporary?) irreducibility to non-dispositional, categorical properties;
(ii) In no-collapse interpretations, dispositions are *dispensable*: they are either reducible (as in Bohmian mechanics), or their ascription amounts to a mere 're-labelling' of the predictive content of the wave function (Bohr, Heisenberg).

The 'might' in (i) can be interpreted as a concession to prudence, and therefore can be read in a conditional form: *if* there are dispositions in the quantum world, *then* they are at home in collapse theories, and in particular in the dynamical models proposed by GRW. In this paper, I am not trying to argue that GRW type of theories *require* dispositions. For an unconditional defense of this claim, see Dorato, Esfeld (2010). However, I am claiming that a dispositional reading of a particular version of GRW provides an interesting alternative to the so-called 'flash ontology' presented in Tumulka (2006a, 2006b) and in Allori, Goldstein, Tumulka, and Zanghì (2008). Furthermore, the skeptical conclusion in (ii) does not prevent the fact that Bohr's interpretation can be made much clearer by an appeal to dispositions, especially in order to make sense of his somewhat obscure appeal to 'mutually exclusive and jointly exhaustive properties'.

The plan of the paper is as follows. Since a basic question posed by the attempt to introduce dispositions in QM is to clarify the very meaning of the concept of 'dispositional properties', in the *first* section I will briefly review some of the main problems in the metaphysical literature on dispositions, in order to show that the distinction between *occurrent* (i.e., non-dispositional) and *dispositional* properties is not at all clear and sharp. The fact that in ordinary language no clear demarcation criterion is available seems to push the philosopher of QM in two opposite directions: either *all* properties are to be treated as dispositional also in QM – sure-fire dispositions and propensities alike, as maintained by Suárez (2004b) –, or a clear criterion can be found only in the particular context of QM.

In order to justify the legitimacy of linking the metaphysical notion of 'disposition' with the formal structure of QM, in the *second* section I will first discuss Clifton and Pagonis' (1995) proposal to regard the dispositional properties as the contextual properties, and then advance my own view. In the third section, I will review recent *relativistic* extensions of GRW type of dynamic reduction theories, mainly due to Tumulka (2006a,b), and show how the so-called 'flashes ontology' of GRW type of dynamical reduction models could be supplemented by an ontology of irreducibly probabilistic dispositions. In the *fourth*, final section, I will discuss the sense in which non-collapse views might be interpreted in a dispositional fashion, and will conclude by briefly discussing the *selection approach* to QM advocated by Suárez (2004a,b). Suárez's approach deserves in fact a special discussion, as he claims that the passage from the possession of a purely dispositional property (like spin or position) to the manifestation of such a disposition in a measurement setting *is* a real physical process. And yet his theory cannot be classified among the genuine dynamical reduction models, as he does not provide any detailed physical story about how such a process should occur (the *when?, how? and where?* questions that a model like GRW's tries to tackle).

9.2 Is the Distinction between Dispositional and Non-Dispositional Properties *Genuine*?

First of all, and in order to fix terminology, I should state at the outset that in the context of QM 'dispositions' or 'tendencies' are to be interpreted as *qualitative*, *intrinsic* properties of physical systems. *Propensities* are to be regarded as probabilistic, *quantitative measures* of the dispositions that single systems might have, say, to localize in a region of space, as in certain dynamical reduction models.

Both physics and ordinary language are replete with what philosophers call dispositional properties (in short dispositions): think of the paradigmatic cases of 'fragility' 'permeability' or 'irritability'. However, it is much more difficult to characterize the feature of such properties that distinguishes them from non-dispositional, or categorically possessed properties. And yet, a minimal success in this enterprise seems important to all interpretive projects trying to establish some role for dispositions in QM. *If we were not able to distinguish dispositional from non-dispositional properties even in ordinary language, what would we gain by introducing dispositions in the philosophy of QM?* For example, if we had to conclude that, from a general metaphysical viewpoint, all properties, physical and non-physical, turned out to be dispositional,[2] referring to dispositions in QM

[2] As in theories in which properties are regarded as the causal powers of the entities having them (Shoemaker, 1984).

would either be empty (one could simply talk about properties *tout court*) or would deprive the philosophy of quantum mechanics of any vital contact with more general metaphysical issues.[3]

A first attempt at distinguishing the categorical from the dispositional might be suggested by the fact that dispositions typically have a context of manifestation ('glass is fragile because in certain situations it breaks easily'), something pushing us toward the claim that dispositions might be *relational* properties, i.e., properties that are non-intrinsic or extrinsic in Langton and Lewis' sense (1998).[4] However, the attempt of drawing the distinction between the dispositional and the non dispositional in terms of 'intrinsically possessed' vs. relational or extrinsic *fails*: I agree with various scholars that a window pane would count as fragile independently of any breaking context, and even if it will never break (see Mumford, 1998; Suárez, 2004b). So not only is relationality not necessary, but also not sufficient for dispositionality, since 'being a brother' clearly does not count as a *prima facie* dispositional property. The fact that there are some apparently *extrinsic* dispositions, like 'weight', should not prevent us from acknowledging that at least some dispositions look intrinsic and non-relational.

This remark seems to be relevant also for the philosophy of QM, as Popper's relationalism (1982) about dispositions notoriously led him to interpret quantum dispositions as *relational properties of quantum entities*, linking them to the whole experimental setup. According to Popper, who was obviously influenced by Bohr's thesis about the non-separability between quantum entities and classical apparatuses, an isolated particle would have no dispositions whatsoever. It seems plausible to maintain that while the context of manifestation of fragility or permeability is the necessary epistemic ground to believe in the existence of the relevant disposition, a piece of glass would count as fragile even if it never broke, i.e., even if it never manifested its disposition.

All this is well-known and basically agreed upon. However, it could be objected that in a different possible world, made just of glass and liquid stuff that cannot be accelerated beyond the speed that would be sufficient to break a pane of glass,[5] *glass would not count as fragile* because no harder stuff would be present to break it. Wouldn't this show that there is a certain amount of relationality in the property in question, as in all properties? In this case, fragility might seem to depend on the fact that the laws of nature in the 'liquid world' prevent that liquid stuff from being accelerated beyond a certain speed. And if laws are dependent on local facts in this

[3] The reason for this second alternative is that it might be possible to define the difference between the dispositional and the categorical just in terms of the formalism of QM, while admitting that such a distinction has no application elsewhere. However, this option would raise some doubts about the faithfulness of the explication of the word 'disposition', since part of its intuitive meaning would be lost.

[4] A property is intrinsic when its attribution to an entity *x* does not presuppose the existence of any other entity. It is extrinsic or relational when it is not intrinsic.

[5] This is added so as to prevent that the impact between glass and very fast-moving blobs of water could break the glass.

world, as Lewis's Best System Analysis has it, there would still be a dependency of fragility on what else is occurring in the world and on the presence of harder stuff. And fragile objects would seem to be possessing their dispositional property in an extrinsic way. On the other hand, *if* fragility were regarded as a microscopic property of glass – that is, if it were reducible to, or fully explainable in terms of – the microscopic structure and forces of the crystals composing glass, *then* it would seem that the disposition in question could be ascribed to glass as one of its intrinsic properties. But the meaning of the term, in the different possible world made just of glass and liquid stuff in which glass never breaks, would be quite different.

Be that as it may, the possible dependence of (the ascription of the property) 'fragility' on the properties of other materials in the environment simply shows that analyzing the distinction between dispositional and non-dispositional in terms of the distinction between *extrinsic* and *intrinsic* carries the additional risk of attributing any vagueness of the latter distinction to the former. And this is an additional reason against accepting the above analysis.

Another possible attempt at distinguishing dispositional from non-dispositional properties might consist in the fact that the former could be regarded as directly observable only in the context of manifestation, while the latter would be *always* observable. 'Fragility' might be the *intrinsically possessed* property of glass that becomes manifest or directly observable *only* when a piece of glass breaks, while a broken window pane displays the corresponding property at all times, and would therefore be always observable. Analogously, a disposition like *permeability*, unlike the property expressed by 'being wet', is *not* directly observable all the times, but becomes observable only when the entity exemplifying it interacts with water or other fluids.[6]

But also this attempt at distinguishing dispositional from categorical properties fails: the earth's gravitational field manifests the disposition to attract bodies toward the ground at all times, and not just when we observe its manifestation in falling bodies. By exerting an attracting force, the earth infact keeps any object firmly attached to the ground *at all times*.[7] Furthermore, to the extent that fragility and permeability are regarded as being identical with the microscopic, molecular structure of glasses and sponges respectively, one could note that such a structure can be considered to be observable at all times, albeit indirectly with the aid of electronic microscopes. After all, don't we observe through a microscope?

In a word, also this second criterion does not secure any firm ground, and fails.

For a more fruitful attempt at indicating the distinction in question, we could look at the *role* performed in ordinary language by obviously dispositional terms. Consider dispositions like 'irritable' or 'poisonous', which manifest themselves

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[6] It is possibly for this reason that Carnap argued that dispositional predicates were intermediate between theoretical and observational terms (Carnap, 1936).

[7] After general relativity, we may need to redescribe the situation by saying that the surface of the Earth constantly manifests its disposition to not be penetrated, by pushing objects out of their free fall. Thanks to Carl Hoefer for reminding me the need to take into account the post-Newtonian paradigm of gravitation.

when people get angry and, say, mushrooms poison the blood. From these examples, it would seem that the function of dispositional terms in natural languages is to encode useful information about the way objects around us *would* behave, *were* they subject to specific causal interactions with other entities (often ourselves). This remark shows that *the function of dispositional predicates in ordinary language is essentially predictive.* Consider the evolutionary advantage of classing all animals or people around our ancestors as 'dangerous' or 'innocuous', as 'peaceful' or 'ferocious'. In learning that a particular mushroom is 'poisonous', a child learning the language also learns to stay away from it whenever she recognizes one.

Clearly, this analysis of the distinction between dispositional and categorical properties can be correct only if it can be shown that *prima facie* examples of categorical terms, like 'is broken' (*vs.* 'is fragile') or 'is dissolved in water' (*vs.* 'is soluble') do *not* have a similar predictive function. And it seems to me that a distinction 'of degree' between the categorical and the dispositional can be traced in such cases. I say 'of degree', because any attribution of a property to an entity involves a certain amount of predictability, even if one does not accept Sellar's and Brandom's inferential theory of meaning (Brandom, 1994). If we know that 'salt has dissolved in water', of course we also know a good amount of things about salted water (a categorical state/property of the liquid),[8] and this might be true simply in virtue of the fact that *properties just are the causal powers of entities*. In this case, however, any clear-cut distinction between dispositional properties (powers) and non-dispositional properties is also dissolved.

Despite this remark, I think that it is still fair to say that in dispositional terms the predictive role is much more explicit or evident, a fact which could explain why natural languages and especially folk psychology, are so replete with predicates like jealous, amiable, and peaceful, etc. I say 'more evident' because of the well-known link of dispositions with the modal talk presupposed by causes, counterfactuals and laws. A stone *causes* the manifestation of the disposition 'fragile' (and therefore causes the breaking of the glass) because it causally interacts with its microscopic structure, the categorical basis of fragility itself. Counterfactuality is involved because the attribution of the disposition 'soluble' to salt entails that in the appropriate context, salt melts, while the regularity with which the fragility of glasses is manifested refers to a regularity or a law of nature capturing the behaviour of the micro-constituents of glass.

In a word, the fact that we cannot analyze dispositions by using conditionals does not prevent us from advancing the following claim: *dispositions express and encode, directly or indirectly, those regularities of the world around us that enable us to predict the future.* If this is their main role and function in ordinary language, we understand why their distinction from intuitively non-dispositional properties is just one of degree.

That the distinction between dispositions and categorical properties cannot be so sharp is further confirmed by Mumford's analysis of the problem of the reducibility

[8] Likewise, if the window is broken, we know we shouldn't walk bare foot in that area.

of dispositions to their so-called ‘categorical basis’. According to Mumford (1998), the difference between a dispositional property like fragility and the microscopic property of glass constituting its categorical basis is merely *linguistic*, and not *ontological*. Referring to a property by using a dispositional term, or by choosing its categorical-basis terms, depends on whether we want to focus on, respectively, the functional role of the property (the causal network with which it is connected), or the particular way in which that role is implemented or realized.

But notice that if we agree with Mumford’s analysis, it follows that it makes little sense to introduce irreducible *quantum dispositions* as *ontological* hypotheses. If, by hypothesis, no categorical basis were available, we should admit that we don’t not know what we are talking about when we talk the dispositional language in QM, quite unlike the cases in which we refer to ‘fragility’ or ‘transparency’, in which the categorical bases are available and well-known. Introducing irreducible quantum dispositions would simply be a black-box way of referring to the functional role of the corresponding property, i.e., to its predictive function in the causal network of events.

The upshot of this brief survey on the metaphysics of disposition should be clear. The predictive function of dispositions illustrated above – as well as Mumford’s view about the conceptual, non-ontic distinction between the categorical and the dispositional – should be attentively kept in mind when we will discuss the ‘dispositional nature’ of microsystems before measurement, or the irreducible ‘dispositions to localize’ possessed by microsystems in dynamical reduction models.

In a word, the use of the language of ‘dispositions’ by itself does not point to a clear ontology underlying the observable phenomena. On the contrary, when the dispositions in question are irreducible and their categorical bases are unknown, such a use should be regarded as a shorthand to *refer to the regularity that phenomena manifest and that allow for a probabilistic prediction*. Consequently, attributing physical systems *irreducible* dispositions may just result in a more or less covert *instrumentalism*, unless the process that transforms a dispositional property into a categorically possessed one is explained in sufficient detail.

In a word, friends of dispositions might end be up using an elaborate or fancy metaphysical language to redescribe measurement interactions, especially if they are not ready to provide a precise, exact physical theory about when and how a dispositional property corresponding to a state of a system which is not an eigenstate of the observable turns into a categorically possessed property. As we will see, this is the main difficulty with Bohr’s philosophy interpreted in a dispositional way, or with Suárez’s otherwise brilliant attempt at using dispositions to solve the measurement problem (2004b).

9.3 Dispositions and Categorical Properties in QM

The history of the attempts at introducing dispositions in QM is long and significant (Margenau, 1954; Heisenberg, 1958; Redhead, 1987; Maxwell, 1988), but here I will discuss only the two most recent attempts at linking the language of dispositions to the formalism of QM.[9] The first is due to Clifton and Pagonis (1995) and links dispositionality to *contextuality*. The second is due to Suárez (2004b), and relates dispositions to a *selective interpretation* of QM. If one is careful enough to avoid some misleading associations of the word 'contextual' with 'relational', I think that both are perfectly compatible with each other and with my own view.

As I see the matter, the introduction of a dispositional language in QM is based on the replacement of 'dispositional properties' with 'intrinsically indefinite properties', i.e. properties that before measurement are objectively and actually 'indefinite' (that is, without a precise, possessed value). The following two postulates express what I regard as the essential tenets of a dispositionalist approach to the interpretation of QM, and specify the *meaning* of a dispositional property in the context of the formalism QM:

P1 a property of a system describable by QM is categorically possessed if and only if the state it corresponds to is an eigenstate of the observable. Otherwise it is dispositional. In this sense, mass, charge, spin are to be regarded as intrinsic, categorically possessed properties, since they are always definite.[10]

P2 the passage from dispositional to non-dispositional magnitudes is the passage from the indefiniteness to the definiteness of the relevant properties, due to in-principle *describable*, genuine physical interactions of quantum systems with other systems, that typically possess a much larger number of particles.

P2 in particular refers to the process that transforms an objectively, mind-independently indefinite magnitude into a definite one, and allows me to link the manifestation of dispositions with precisely described measurement interactions between quantum systems and larger physical systems.

This sense of dispositionality will be adopted here in order to interpret the GRW dynamical reduction models from a metaphysical viewpoint, and seems quite close to what Heisenberg had in mind in the following, often quoted passage, which refers to the well-known thesis that QM reintroduces Aristotelian *potentiae* as intermediate 'between full being and nothingness': 'Therefore, the transition from the 'possible' [dispositional] to the 'actual' [categorical] takes place during the act of observation [a correlation] ... we may say that the transition from the 'possible' to the 'actual' takes place as soon as the interaction of the object with the measuring device, and thereby with the rest of the world, has come into play; it is not connected with the act of registration of the result by the mind of the observer.' (Heisenberg, 1958, 54).[11]

The best way to justify these two postulates, and especially the second, is by briefly reviewing the interpretive proposals offered by Clifton and Pagonis and Suárez.

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[9] For a review, see Dorato (2007) and Suárez (2007).

[10] Here I respect the standard eigenvalue-eigenvector link.

[11] Words in square brackets have been added by me and reformulate Heisenberg's language by using the key terms adopted here.

9.3.1 Clifton and Pagonis on Dispositionality as Contextualism

P1 is equivalent to Clifton and Pagonis' strong contextuality. The idea of contextuality is simple. Assign a certain value to the square of the operator 'spin in the *z* direction' – call it $S^2{}_z$ – when it is measured together with $S^2{}_x$ and $S^2{}_y$ in the direction *x* and *y*. If $S^2{}_z$ is *not* contextual, we must get the same value if we measure it together with $S^2{}_{x'}$ and $S^2{}_{y'}$, assuming that the direction *x'* and y' are *different* from *x* and *y*. Contextualism is quite widespread a phenomenon in QM, and it seems to entail that some QM 'properties' are not sharply possessed before measurement, since otherwise they could *not* manifest themselves in different ways, according to the type of measurement we perform.

Consequently, in QM we seem to have *two* kinds of intrinsically possessed properties, depending on the way the system has been prepared before measurement. If the system has a definite value also before measurement and the latter just reveals it with probability 1, we have either a non-dispositional, categorically possessed property, (a weakly contextual property), or we have what we could call a deterministic, 'sure-fire' disposition (Suárez, 2007). On the contrary, if the value revealed by measurement causally depends on the interaction, we have a *strong* form of contextualism that, according to Clifton and Pagonis, implies the presence of intrinsic dispositions (Clifton and Pagonis, 1995, 283), or simply probabilistic dispositions, i.e., propensities.

This aspect of Clifton and Pagonis' approach is quite similar to my first postulate above; put it in different words, we could also express the identification of the dispositional with the contextual by noting that in QM we cannot assume that there is a one-to one correspondence between an operator and an observable: contextualism or dispositionalism as expressed in P1 bans a certain form of 'naïve realism about operators' (Daumer et al., 1996).

The proposal to establish a significant link between contextuality *and* dispositionality is open to two objections, which, in my opinion can both be tackled.

The first objection is based on the fact that contextuality itself has recently been the target of various critical remarks, especially by philosophers working in the bohmian group. They claim that, after all, it is quite trivial that if we perform different measurements, we are going to obtain different results (see Goldstein, 2009, Section 12). Why make such a fuss about contextualism? If this objection were correct, however, also dispositionalism as defined by Clifton and Pagonis would be a trifling matter, since it is *defined* in terms of the former notion. The second objection points to the fact that contextualism entails a kind of extrinsic-ness or relationality of dispositions, a position that we have already rejected. Let us analyze these two objections in turns.

I disagree with Goldstein's opinion for two different reasons. First, contextuality has an important role as a premise of fundamental no-go theorems against the possibility of assigning simultaneously definite values to systems whose dimension is greater than 2 (Kochen and Specker, 1967). And these theorems seem certainly important contributions to our understanding not just of the formal structure of QM, but also of the possibility of simultaneously attributing well-definite properties to certain quantum systems, which is part and parcel of the interpretive task spelled out in Section 1. The fact that we can deny the significance of these theorems for QM only by endorsing contextuality/dispositionality (alternatively, by denying non-contextuality) is *not* a trifling matter. In classical physics, measurements typically *do* reveal pre-existing properties, and the fact that in quantum systems before measurement one cannot rely on categorically possessed properties in the sense given above by P1) and P2) cannot be deemed as being without significance.

The second counter-objection is that the superposition principle is *the* distinguishing mark of QM with respect to classical mechanics (Dirac, 1930), and superpositions are not ignorance interpretable. It follows that the passage from 'the dispositional' to 'the actual/categorically possessed' is a very important feature of QM, because it is the passage that takes us from a superposition of states to one particular state with a certain probability. Such a passage is obviously involved in the process of measuring a quantum entity in a superposed state, which is arguably *the* central aspect of the theory that still needs to be explained.

Going now to the second objection, what is instead potentially misleading about identifying dispositionalism with contextualism is the fact that contextual properties seem to have been identified with extrinsic, relational properties, contrary to what was argued in Section 9.2. If the value of the spin measured on S_x^2 depends on whether we observe it with S_y^2 or $S_{y'}^2$, there seems to be a clear sense in which not only is the spin in question not possessed before measurement, but the disposition itself (i.e., the property of manifesting a definite spin in a given direction) depends on other properties of other entities. However, we should notice that it is the *manifestation* of the spin that is relational, not the disposition itself, which is as intrinsic at it may be.

A simple example, made by Albert (1992), will help us to make the point. If we reverse the polarity of a magnet of a Stern-Gerlach apparatus, and measure the spin of a particle that is in a superposition of spin in the *z* direction, we obtain a result that is opposite to what we obtained before the reversal. The very same intrinsically possessed disposition can, depending on what measurement we perform, be manifested in different ways, for the simple reason that there is no preexisting definitely possessed property of having spin in the *z* direction. So there is a legitimate way to defend the (correct) view that dispositionality is as intrinsic as it may be.

9.3.2 Suárez on Dispositions

Suárez construes dispositions in QM in a similar manner, but links his understanding of dispositions to Fine's proof of the unsolvability of the measurement problem (Suárez, 2004b). According to Suárez, dispositions are possessed by quantum systems all the time, even when they are not manifest, and this agrees with the previous point that dispositions are *intrinsic* properties of quantum systems. Importantly, selections are a subclass of measurements, since while the latter are interactions with *all* the properties of a quantum system, selections pick out just *one* of the many intrinsic dispositions of quantum systems.

There is one minor difference between Suárez's view and my definition P1, as in a recent paper he introduces sure-fire dispositions: '*If* object O possesses the deterministic propensity D with manifestation M *then*: were O to be tested (under the appropriate circumstances $C_1, C_2, \ldots$ etc) it would definitely M with probability one.' (2007, p. 429).[12] This would entail that preparing a system in state ψ and measuring it afterwards would count as measuring a sure-fire disposition rather than a categorical property.

Although this difference might seem purely terminological, I prefer to refer to use 'disposition' for properties of entities whose state is not an eigenstate of the observable, i.e., for magnitudes that are not sharply possessed. First of all, my choice helps to focus on 'the collapse' of a state ψ in superposition as a transition from indefiniteness to definiteness of magnitudes, rather than as a transition from propensities to sure-fire dispositions. Furthermore, in bohmian mechanics the particles' positions would count as dispositional properties in Suárez view ('a sure-fire disposition'), and their difference with spin would be specifiable simply in terms of a probabilistic rather than a deterministic descriptions. On the contrary, if we accept the view that we have dispositions relative to observable O whenever we do not have previous values for $O = \sum_n a_n \, |v_n\rangle\langle v_n|$, the interesting question will of course become whether dispositions are *reducible* to some kind of categorical basis, as it is the case with Bohmian mechanics, or are not so reducible, as it is in the case in other interpretations to be discussed.

There is one last objection that we must discuss before broaching the GRW's ontology from a dispositionalist viewpoint: what sense does it make to claim that a system has a dispositional property when it lacks a precise value for the corresponding quantity? Shouldn't we say that when a physical system lacks a precise value before measurement, not only is there no corresponding categorical property, as it is obvious, but also that there is no dispositional property either? Shouldn't we say that talking of properties, *even if* dispositional ones, is made obsolete by QM's contextuality, and that we should not pour old metaphysical wine in the new barrels provided by mathematical physics? (Daumer et al., 1996).

Well, claiming that a quantum system in a superposition of spin has a disposition for acquiring a precise spin even when if it has no precise spin is at the heart of a dispositional reading of QM. But we should admit that claiming that a system has no precisely possessed property at all before measurement, and that it possesses a disposition to manifest a definite property after a correlation with a larger system, should not be regarded as two *perfectly equivalent* ways of speaking. In the latter description, we are finding a request of explaining something that we still don't understand in detail, namely the existence of a genuine transition from an indefiniteness to a definiteness that is to be regarded as a real physical process, and which should be further studied with the experimental and technical resources of physics.

Accepting the claim that a quantum entity is to be (currently) regarded as a node of dispositions is not a crazy idea, as long as this way of speaking presents some

[12] I thank Suárez for having sent me his manuscript.

advantages relatively to the other, non-property talk. But what kind of advantage can it be, considering that dispositions, typically, don't explain much? Are we back to the *virtus dormitiva* explanation? This is what we will have to inquire in the next section.

9.4 Adding Dispositions and Propensities to GRW

I should make clear from the start that GRW's dynamical reduction models do *not* explicitly rely on dispositions. However, neither do they exclude their existence. In order to see what we could gain by introducing a dispositional language, I will therefore try to summarize the main features of the best known dynamical reduction models by relying on a language introducing irreducible propensities.

According to one of the non-relativistic versions of the dynamical reduction models proposed by GRW (Ghirardi et al., 1986), each non-massless micro-system whose wave function has a certain spatial spread has *an irreducible probabilistic disposition* – a *propensity* – to localize in a region of space given by a diameter of $\sigma = 10^{-5}$cm, in average once every 10^{16} s. The probability of a decay per second is therefore $1/\tau = 1/10^{16}$. These two parameters become two new constants of nature, and specify *to what* and *how often* the localization process occurs.

Obviously, if the system is composed only by one particle, this can remain unlocalized in average for 100 million years (approximately corresponding to 10^{16} s), but since the propensity for a localization is defined with a Poisson distribution such that the probability for the localization of N non-massless particles is N/τ, a system made of $N = 10^{23}$ particles will undergo in average 10^7 localizations per second, and will therefore remain in a dispositional, superposed state for less than 10^{-7} s. Accordingly, in a cubic centimetre, there are approximately $10^7 = 10^{23}/10^{16}$ events of localization, *or 'flashes',* which ensure and explain the localization of the *macroscopic* objects with which we are familiar from our experience.

The localization of a whole system is a consequence of the fact that even if a system is in a dispositional, superposed state, the multiplication of the wave function by a Gaussian localization operator ('the hit') effectively kills the other components of the superposition that are not located close enough to the center of localization.

Analogously, in the relativistic extension of the GRW theory, due to Tumulka (2006a, b), we are given a set of localization events (flashes) and a rule for calculating the probability for the next flash to occur as specified by the wave function.[13] Here is how J. S. Bell summarized this flashy view of the physical universe: 'However, the GRW jumps (which are part of the wave function, not something else) are well localized in ordinary space. Indeed each is centred on a particular spacetime point (x, t). So we can propose these events as the basis of the 'local

[13] Interestingly, in this flash model there is no need of postulating a privileged frame for the localization, as it happens with the model in which the mass-density localize. Still, the model suffers from other difficulties on which here I cannot enter.

beables' of the theory. These are the mathematical counterparts in the theory to real events at definite places and times in the real world .... *A piece of matter then is a galaxy of such events*.' (Bell, 1987, 205).

In a different model of the theory, the fundamental entity is a scalar field $\rho = \rho(\boldsymbol{r}, t)$ defined on Newtonian spacetime, with ρ being, at the macroscopic scale, what we call *mass density* of physical objects. In this interpretation, the wave function $\psi(r_1, \dots r_n, t)$ describes the system at a given time, and the square modulus of ψ determines, for each particles i, how much stuff (ρ_i) there is in a given cell: $\rho(r, t) = \sum_i m_i \rho_i(r, t)$. Even though the density of microscopic objects can be in a superposed, dispositional state and therefore enjoy 'the cloudiness of waves', due to the localization mechanisms the mass density of macroscopic objects acquires a precise value in a split second, and the object localizes somewhere via an irreducibly stochastic event.

We should notice that while the wave function leaves in an abstract $3N$ dimensional space, the flashes and the scalar field are both in spacetime, since they are localized wherever the collapse events occur. Important for the purpose of introducing irreducible propensities is the remark that the time and place of the localization processes (their center of collapse), as well as the particular particle or cell that is involved, are chosen at random, and so the localizations themselves are to be regarded as 'spontaneous', or simply *uncaused*. The crucial question at this point is: if this is correct and intended in the model, why introducing dispositions or single-case propensities, *if* the latter are regarded as *causes* of the localizations that are 'inherent' in each microsystem?

First of all, propensities need not be presented as *causes* of the localization process, since we cannot rule out that the collapse be 'spontaneous', or uncaused. Admittedly, there is nothing in the formalism of GRW suggesting this reading, and if the theory remains 'phenomenological' as it is now, the propensity theorist is happy to accept that the real tendency that each single microsystem has to localize is irreducible, but still needed to attribute *single case probabilities* to individual particles. In this hypothesis, it would make sense to say that a universe composed by a single proton would harbour a particle with a disposition to localize once every 100 million years: no reference to ensembles of particles would be possible and therefore no frequencies. In our universe, frequencies would simply be supervenient on, and a manifestation of, such individually possessed propensities.

Frigg and Hoefer (2007), however, have argued that a Humean Best System (HBS) analysis of GRW's probabilities is more plausible than a dispositionalist analysis, and that single case propensities are not needed to defend the view that the probabilities introduced by GRW are as objective and as non-epistemic as it gets. (Frigg and Hoefer, 2007). After all, HBS' *chances* are based on all the local facts in the universe's entire history, and are therefore not to be conflated with subjective degrees of belief as in Bayesian probabilities. Since HBS chances have a factual grounding, they must be regarded as 'objective'. Only, these local facts in the universe history are to be conceived non-dispositionally; probabilities, consequently, are not grounded in modally conceived propensities or powers.

However, it seems to me that the main weakness of a HBS analysis of GRW probabilities depends on its reliance on Lewis' analysis of the nature of laws of nature. If GRW probabilities depend on the probabilistic laws organized within a HBS of the theory, but such laws are, as Lewis has it, supervenient on the local, non-modal facts of the history of the entire universe, how can we make sense of conditional probabilities, which refer to *relations* among state of affairs, and therefore to *universal*? In my view of laws, law-statements are made true by, or more prudently, simply refer to, the dispositions or causal powers possessed by physical systems (Dorato, 2005). From this viewpoint, it is not clear how a HBS reading of the GRW theory can defend an *objectivist* view of probabilities or chances (namely, a non-subjectivist, non-Bayesian approach allowing us to go beyond states of beliefs) without committing itself to some mind-independent *property* or *relations* that microsystems have, and therefore, in a plausible view of properties or relations, *to dispositions or causal powers*.

In Lewis' original idea, what propensity theorists call 'disposition to collapse' really refers instead to *the whole mosaic of local states of affair*, on which collapse laws supervene as axioms or theorems of a single theory combining *simplicity* and *strength*. However, not only are simplicity and strength language-dependent virtues, but they are also intersubjectively shared but *merely epistemic virtues*. Laws in HBS denote nothing but lists or histories of events or occurrent facts, and it is not clear at all whether the Humean mosaic includes or not properties or universals. This alternative generates a dilemma.

If we opt for the former, nominalistic reading of HBS (no property is admitted in the HBS/Lewisian ontology) there are troubles that cannot be overcome. As anticipated before, the probability of the next flash given a set of flashes and the initial wave function is a conditional one, so what we really have is a *relation* between them. Now, how can we claim that this conditional probability describes something in an objective way and is not epistemic if it doesn't refer to such a relation but is simply about a bunch of disconnected, local states of affairs? The question is that if HBS theorists granted that laws in HBS describe relations, they would have thereby overcome nominalism, and therefore one of the main motivations of an HBS' analysis of laws and probabilities.

But perhaps there is nothing inherent in the Lewisian point of view that rules out properties being part of the Humean mosaic, as long as they are conceived as occurrent properties, as opposed to modal ones.[14] Modally conceived properties would infact be dispositions or propensities. And this is the second horn of the dilemma: on a reasonable view of properties, in fact, X is a property of Y if and only if X is a causal power of Y or X is identified by the causal powers of Y (Shoemaker, 1984). And modally conceived properties or propensities have to be readmitted again also by the HBS theorist.

Well, maybe we should not saddle the interpretation of quantum probabilities with complicated metaphysical questions about the identity conditions for

[14] This objection has been voiced by Roman Frigg.

properties. But even if we granted this point, there seems to be another difficulty looming for the HBS reading of the GRW's chances. It is not clear to me how, without asking some help from actual frequentism about actual histories, one is going to distinguish between chancy histories governed by probabilistic laws from 'deterministic histories' governed by sure-fire laws. But since Frigg and Hoefer correctly claim that an appeal to frequentism is a non-starter for GRW, shouldn't they be committed to the existence of propensities in order to make sense of objectivist chances, in the same sense in which Lewis himself is committed to universals in order to add some objectivist constraint to the simplicity and strength of our chosen language? (Lewis, 1983).

Frigg and Hoefer could reply that frequencies *are* part of the Humean mosaic and hence ground probability claims. The difference between HBS and frequentism is that the former position does not assign probabilities *solely* on the basis of frequencies and also takes other epistemic virtues into account (simplicity, strength, etc.). In this way the HBS theorist may drop the notion of a *Kollektiv*, which causes well-known troubles to the von Mises-type frequentist. But this does not mean that the HBS theorist is oblivious of frequencies, or that he needs to resort to propensities.[15]

However, note that virtues like simplicity or strength are *possibly* intersubjectively shared (weakly objective), but are at best a guide to discover mind-independent facts, as they are *epistemic* and language-dependent virtues. In conclusion, the only grip on mind-independent (strongly objective) probabilities that the HBS theorist has is yielded by frequencies: the HBS position then faces a dilemma, since it seems either to collapse on frequentism with all its known problems, or onto *epistemic* views of probability, which are close to subjectivism or bayesianism.

An additional important reason to introduce propensities in GRW should be considered: in the mass density version of the theory, we could try to defend the view that the propensities to localize that each microsystem possesses allow to *explain* the definiteness of the macroworld, in the sense that they allow a *unification of the micro and the macro-world*, characterized by a unique dynamics.[16] And in the flash version of the theory, where *macroscopic* objects *are* collections of 'hits', we could redescribe the ontological assumption of the theory by saying that quantum, non-massless *microscopic* objects whose wave-function has a certain spread in space are a collection of propensities to localize in a small region of space. In both versions, according to GRW, QM is a universal theory, governed by a modified, non-linear Schrödinger's equation. 'Universal' here means that it applies to the micro and macro-world: while single non-massless particles or the microscopic density of stuff may be in superposed states for a long time, despite their propensity to localize, macroscopic bodies are a collection of localization processes.

However, there are two objections to the view that propensities in GRW might explain. One is that all dispositions are in general explanatory empty, the other is that in our particular case the explanatory work is really performed by the actual flashes

[15] This objection was raised by Frigg.

[16] For the theory of explanation as unification, see Friedman (1974), and Kitcher (1976).

or by the localization of mass density, which are *events* or *processes* in spacetime. To the extent that GRW explains by unifying, it is flashes or the localization process of the mass density that 'unify', not the propensities to localize, which are unnecessary. Let us quickly analyze these two objections in turn.

The first objection is well-known: do I explain why a piece of glass broke by pointing to its fragility? Well, if I know what fragility refers to (the microscopic structure of certain stuff), I *do* explain why this piece of glass broke by mentioning its fragility, but simply because fragility refers to the structure of glass. However, since the alleged propensity to localize in GRW is *ungrounded* – according to GRW collapses are spontaneous and there is no hidden mechanism for them – how can I claim to explain the localization by adducing an ungrounded disposition? Nevertheless, if I claim that a cloth is impermeable and know nothing about the fabric of the stuff it is made of, there is a sense in which I do explain why I did not get wet, even though for a deeper explanation I need to revert to chemistry. If we agree that explanations have a pragmatic component, and can be regarded as answers to why-questions that depend on the knowledge state of the questioners, why would the piece of information that the coat is impermeable to water fail to provide a *prima facie* explanation for why I did not get wet? If I did not know that the coat was impermeable, coming to know this makes me understand why something occurred. For sure, the kind of information provided by dispositions is *weakly* explanatory, but in some circumstances it can be regarded as providing comprehension.

In the case of the second objection, it must be admitted that the localization process and the propensity to localize are equivalent in terms of unification: we can either describe an object as a swarm of flashes, or depict it as made of particles with a propensity to localize. Equivalently for the mass density version of the theory. The unification is realized in both ways of speaking: if propensities are not indispensable, however, they cannot be ruled out either.

Three final advantages of the propensity talk can be mentioned: if the propensities to localize are metaphysically prior to the localization events, and, contrary to Allori et al. (2008), are 'metaphysically primitive', we can presuppose that localization events are something that *occurs* to microsystems in both versions of the theory. And then, by starting with continuants endowed with propensities we might have a better chance to reconstruct a more stable notion of our familiar objects, as bare flashes could not be sufficient[17] (see Frigg and Hoefer, 2007).

Second, if we do not consider the manifestation of the disposition (i.e., the flash itself) as explanatorily ultimate, but leave the room open for a future grounding of the disposition to localize, we may have heuristic reasons to develop GRW, which is still a merely phenomenological theory, into a deeper theory, possibly invoking noise coming from gravitational phenomena (quantum gravity).

[17] This objection is voiced by Frigg and Hoefer (2007), without attempting to counter it.

Third: we do not take into our ontology the configuration space, as Albert and Clifton and Monton did also for GRW: in order to make sense of the role of the wave functions, propensities to localize are enough.[18]

While it must be admitted that none of these three arguments is knock-down, there is little doubt that if we characterize dispositions as we did in the second section, the transition from the indefinite to the definite required by P2 in the present case is illustrated by a theory that is *exact* in the sense of Bell, as it tells us precisely *how often* and *where* the propensity to localize is manifested. It is in this sense that GRW is the best illustration of Heisenberg's idea that QM reintroduces potentiae (which however are to be regarded as real properties) and subsequent transitions to actuality: if we believe that quantum systems before measurements do not have precise values, GRW's postulation of propensities to localize gives us a reason to believe that objects have definite properties when we look at them.

9.5 Dispositions in (some) Non-Collapse Models: Bohr's Interpretation

Despite the fact that trying to figure out what Bohr really thought about QM is a difficult, if not desperate enterprise in the space of a short paper, there seem to be *two* main readings of his approach.

The first comes from a peculiar combination of neopositivist and kantian influences, the second, too often neglected, is based on a dispositionalist reading of his principle of complementarity, to be proposed in the remainder or this section.

The neopositivist strand comes from an application of Einstein's analysis of the notion of simultaneity (1905) within the context of the measurement process of QM. Exactly as, according to Einstein, it is *meaningless* to claim that two events are simultaneous, unless we have specified a particular operational criterion to establish when and in which circumstances two spacelike-related events are to be regarded as 'co-occurring', according to Bohr it is meaningless to attribute a definite property to a quantum system unless we specify a classical measurement context.

Such a first reading of Bohr's understanding of a quantum system before measurement is authoritatively preferred, for example, by Michael Redhead (1987, 49–51). Jan Faye, stressing as he does that Bohr was an entity realist while accepting a form of antirealism about QM as a theory[19] (Faye, 1991), could certainly concur with the view that according to the Danish physicist it is meaningless to attribute before, and independently of, measurement *any kind of properties to quantum systems*.

The Kantian strand of this first reading comes from the possibility of considering the classical language with which we describe the measurement apparatuses as

[18] A similar point has been advocated by Suárez for Bohm's ontology (2007).

[19] This means that the wave function for him was simply a bookkeeping devise good for predictions, but theoretical entities existed in a mind independent fashion

a transcendental condition of possibility to refer to the quantum, noumenal world. Notice that classical apparatuses and quantum entities for Bohr are inseparable, due to the non-divisible nature of the quantum of action that is exchanged between the two. Now, if we really wanted to develop an analogy with Kant's theory of knowledge, we should say that the Kantian categories and the pure forms of intuition are to phenomena of the outer world like the classical apparatuses are to the quantum world. Exactly as the 'phenomena' for Kant are the way in which the noumenal world *appears* to minds endowed with pure forms and categories like ours, the manifestation of the quantum world *via* the choice of a classically describable apparatus must be regarded as an inextricable relation between the noumenal (an Sich) unknowable quantum world and a non-quantum, classical measurement system.

Such a Kantian strand can somehow introduce the second dispositional reading of Bohr that I want to broach now and that I prefer. According to Bohr, two properties are complementary if and only if they are *mutually exclusive* and *jointly exhaustive* (see Murdoch, 1987). I take that this slogan is a central part of Bohr's interpretation of QM. We say that they are *mutually exclusive* because, from the point of view of the classical language, they can be attributed to the same system at the same time only via a contradiction: in classical terms, nothing can be both a particle and wave (if we regard 'having position' and 'being a wave' as referring to *categorical* properties).

However, from a *dispositional* point of view, if we refer to a *quantum* entity, this duality is perfectly legitimate, because we can attribute the *same* particle at the *same* time (i.e., before measurement) a disposition for a particle-like behaviour and a disposition for a wave-like behaviour. Such dispositions are later *selected* by the kind of experiment we wish to perform. The choice of this word 'selection' in not casual, as Suárez bases his dispositionalist approach to QM on the view that measurements chooses or selects a particular, intrinsic disposition of the quantum entity (Suárez, 2004b). This shows, by the way, that his view is *not* at all too distant from Bohr's as I presented it here.

The presence of two dispositions is the reason why in a double-split experiment, complementary properties like the trajectory of the particle (its position) and the interference pattern cannot be simultaneously revealed by the same experiment, given that any apparatus obeys classical physics. Either we know the split through which the particle went, but then we destroy the pattern of interference, or we save the interference, but then we cannot know where the particle went.

On the other hand, if we refer to a quantum system *before* measurement, the complementary properties must be regarded as *jointly exhaustive*, because any attempt at attributing a not-yet measured system only *one* of the two properties would yield an incomplete description of the quantum system. In a word, *an electron is neither a particle nor a wave, but has dispositional features belonging to both concepts*.

Despite lack of direct evidence for the interpretation of Bohr that I am suggesting, I think that it is not absurd to attribute to an entity realist like Bohr the view that microsystems have real tendencies to display well-defined measurement values in a given experimental context, that somehow 'extract' some 'latent aspect' from a mind-independent entity. In this way, Bohr's reading would not differ too much from Heisenberg's.

At this point, it should be obvious why also my second claim seems to be supported. If we attribute a micro-system M a 'real disposition' to show a certain definite value in a measurement context described by a classical apparatus, we explain away certain apparent contradictions of his philosophy, of which he has been accused even by Bell (1987). The problem of a dispositional talk is that in the context of his philosophy it does not improve the physics, as it just amounts to saying that *if we measure a quantum system in a superposition with a particularly prepared physical system, we get a definite result. Since we are not told how, when and why such a definiteness comes into being, the corresponding lack of exactness seems fatal to a realistic project of understanding the physical world.*

Despite the introduction of dispositions, all well-known problems of Bohr's philosophy remain intact, in particular whether the distinction between the classical and the quantum world is *pragmatical* and *contextual*, or is rather physically describable in a precise way.[20] In the former case, Bohr's solution to the measurement problem, even with the addition of intrinsic dispositions for position, momentum, spin, etc, is fine for all practical purposes but is simply an instrumentalistic manoeuvre, covered with a realistic-tasting spice, given by the introduction of dispositions. Of course, there is nothing wrong with instrumentalism per se, but it should be recognized that adding dispositions to a philosophy that, like Bohr's, denies the reality of the collapse, simply adds coherence to his view of QM without increasing our understanding of the physical world.

9.5.1 Suárez's Selective Approach to the Measurement Problem

Unfortunately, it seems to me that the same analysis holds also for Suárez approach to dispositions as selections: 'A selection is an interaction designed to test *a* particular disposition (Fine's 'aspect') of a quantum system. Among the dispositional properties I include those responsible for values of position, momentum, spin and angular momentum. In a *selection*, the pointer position interacts only with the property of the system that is under test' (Suárez, 2004b, 232). In order to represent a given dispositional property, Suárez claims that we can exploit the fact that 'for every property of a quantum system originally in a superposition there is a mixed state which is probabilistically equivalent (for that property) to the superposition' (Suárez, 2004b, 242). Take for instance the two following states, representing respectively the pure state of spin along x, and the mixture $W(x)$:

$$\psi = \left({}^{1}\!/\!\sqrt{2}\right) |\text{up}_x\rangle_1 \, |\text{down}_x\rangle_2 - \left({}^{1}\!/\!\sqrt{2}\right) |\text{down}_x\rangle_1 \, |\text{up}_x\rangle_2$$

$$W(x) = \frac{1}{2} P_{[\text{up, down}]} + \frac{1}{2} P_{[\text{down, up}]}$$

[20] The complaint that Bohr's philosophy relies on an unclear distinction between the classical and the quantum has been notoriously voiced by Bell (1987).

Suárez supposes that the pointer position interacts with only one property of the system $W(O)$, in the example represented by $W(x)$, with O being a particular observable, in our case 'spin along x'. $W(O)$ is not the full state of the system, but simply the state corresponding to its property O.

Now, I think the decisive question to ask is the following: how does a selection of a disposition occur, namely *is the selection a physical process*? If we deny that selections are physical process, the ascription of dispositions to quantum systems is deprived of any interest. By taking this horn of the dilemma, of course we don't have to provide detailed explanations of the selection process, but the ascription of dispositions that are selected by the measurement apparatus looks like a merely *formal trick* to give an account of the transition from pure states to mixtures. It is a solution *by fiat*, so to speak.

On the other hand, by taking the other horn of the dilemma and accepting that selections are *genuine* physical processes,[21] then we need to know more about them, in terms of a more precise, exact *physical* description, of the kind provided by dynamical reduction models. Namely, a description that can, in principle, be tested by experiments, even though the experiments that we can *actually* perform are not capable of testing the theory. If we claim that a measurement 'selects' the appropriate disposition via a genuine physical interaction, we either have the duty to formulate physical hypotheses as to the *when*, *how* and *why*, quantum systems go from a superposition (which is not ignorance-interpretable) to a well-defined value (and then we embrace dynamical reduction models of the GRW type), or we must argue that no such description is possible. But the latter choice is tantamount to give up the hope of explaining what happens in a measurement interaction. Furthermore, if we don't describe the selective process in a more detailed way, we end up treating measurements as special physical interactions and this is certainly unwanted.

In other words, claiming that measurements *are* selections of dispositions without providing physical descriptions of the selecting, genuinely real physical process amounts to sweeping the dust under the carpet. In practice, this would be equivalent to adopting an instrumentalist solution to the measurement problem, which is certainly not in the intention of a proponent of the view that dispositions are real, intrinsic properties of quantum systems.

In a word, we should conclude that selections are an interesting but purely provisional account of measurement interactions. Contrary to the author's intentions, Suárez's alleged solution to the measurement problem is *very similar to* Bohr's, and in order to avoid this trap, he needs to supplement his account with a detailed theory of collapse that can in principle be refuted by experiments: *Suárez's dispositional reading of QM is really committed in some way to the program of dynamical reduction models*.

This conclusion can perhaps be better supported if we conclude by briefly surveying Rovelli's relational account of quantum interactions. According to Rovelli, it is meaningless to attribute an intrinsic, absolute property to a non-correlated system, since 'S has q' is true only for observer/physical system O and may not be true for

[21] This is indeed Suárez's own position (personal communication).

O'. To the extent that 'a variable (of a system *S*) can have a well-determined value *q* for one observer (instrument) (*O*) and at the same time fail to have a determined value for another observer (*O*')' (Laudisa and Rovelli, 2008, Section 2), in this interpretation of QM no sense can be made of any non-dispositional, categorically possessed properties. We could certainly interpret Rovelli's view (and Everettian views, to that effect) as a way to deny the existence of *any* categorically possessed property, and as a way to regard entities as *loci* of purely dispositional properties, whose manifestation is completely dependent on the kind of entity they correlate or interact with.

Notice however, that also this view is hardly explanatory; despite the centrality of the notion of *correlation* or relative state in Rovelli and Everett's view, there is explicitly no intention to offer a clear hypothesis as to *how* and *when* do the correlations occur. Rovelli's view is therefore not different from a form of instrumentalism about the descriptive content of the theory which we have already found in Bohr.

Finally, there is no need of arguing that another important no-collapse view, Bohmian mechanics, renders dispositions wholly dispensable: Bohm's dispositions (the so-called contextual variables) are in fact reducible to positions and context of measurement (Clifton and Pagonis, 1995).

In sum, *if* dispositions have a role in the metaphysical foundations of QM, they must be looked for in GRW kind of theories. Elsewhere, they might contribute to the coherence of an instrumentalist rendering of the theory, but do not help us at all in the interpretive effort that is the task of the philosophy of physics as delineated in the first section of the paper.

Acknowledgement I thank the audience in Madrid for helpful questions and criticism. In addition, I am highly indebted to Roman Frigg, Carl Hoefer and Federico Laudisa for their critical comments to a previous version of this paper, which significantly improved the final result, of which, of course I am the only responsible.

References

Albert D. (1992), *Quantum Mechanics and Experience*, Cambridge: Harvard University Press.

Allori V., Goldstein S., Tumulka R., and Zanghì N. (2008), On the common structure of Bohmian mechanics and the Ghirardi-Rimini-Weber Theory, *The British Journal for the Philosophy of Science*, 59(3), 353–389.

Bell J. S. (1987), *Speakable and Unspeakable in Quantum Mechanics*. Cambridge: Cambridge University Press.

Bell J. S. (1990), Against 'measurement, *Physics World*, 8, 33–40.

Brandom R. (1994), *Making it Explicity*, Harvard, MA: Harvard University Press.

Carnap R. (1936), Testability and Meaning, *Philosophy of Science*, 3(4), 419–471; 4(1) (January 1937): 1–40.

Clifton, R. and Pagonis, C. (1995), Unremarkable contextualism: Dispositions in the Bohm theory, *Foundations of Physics* 25(2), 281–296.

Daumer, M., Dürr D., Goldstein S., and Zanghì N. (1996), Naive realism about operators, *Erkenntnis* 45, 379–397.

Dirac, P.A. (1930), *The Principles of Quantum Mechanics*. Cambridge: Cambridge University Press.

Dorato, M. (2005), *The Software of the Universe*, Aldershot, Hampshire: Ashgate.

Dorato, M. (2007), Dispositions, relational properties, and the quantum world, In M. Kistler, and Gnassounou, B. (eds.), *Dispositions and Causal Powers*, Aldershot, Hampshire: Ashgate, pp. 249–270.

Dorato, M. and Esfeld, M. (2010), GRW as an ontology of dispositions, *Studies in History and Philosophy of Modern Physics* 2010(41), 41–49.

Faye, J. (1991), *Niels Bohr: His Heritage and Legacy*, Dordrecht: Kluwer

Friedman, M. (1974), Explanation and scientific understanding, *Journal of Philosophy*, 71, 5–19.

Frigg, R. and Hoefer C. (2007), Probability in GRW, *Studies in History and Philosophy of Modern Physics*, 38, 371–389.

Ghirardi, G. C., Rimini A., and Weber T. (1986), Unified dynamics for microscopic and macroscopic systems, *Physical Review* D 34, 470–496.

Goldstein, S. (2009), Bohmian mechanics, In E.N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2009 Edition), URL = http://plato.stanford.edu/archives/spr2009/entries/qm-bohm/

Hájek, A. (2010), Interpretations of probability, In E.N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2010 Edition), URL = < http://plato.stanford.edu/archives/spr2010/entries/probability-interpret/>

Healey, R. (1989), *The Philosophy of Quantum Mechanics: An Interactive Interpretation*, Cambridge: Cambridge University Press.

Heisenberg W. (1958), *Physics and Philosophy: The Revolution in Modern Science*, New York, NY: Harper and Row.

Hughes, R. I. G. (1989), *The Structure and Interpretation of Quantum Mechanics*, Cambridge: Harvard University Press.

Kitcher, P., (1976), Explanation, conjunction and unification, *Journal of Philosophy*, 73, 207–212.

Kochen, S. and Specker E. (1967), The problem of hidden variables in quantum mechanics, *Journal of Mathematics and Mechanics*, 18, 1015–1021.

Langton, R. and Lewis D. (1998), Defining ‘intrinsic’, *Philosophy and Phenomenological Research* 58, 333–345.

Laudisa, F. and Rovelli, C. (2008), Relational quantum mechanics, In E.N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2008 Edition), URL = <http://plato.stanford.edu/archives/fall2008/entries/qm-relational/>.

Lewis, D. (1983), New work for a theory of universals, *Australasian Journal of Philosophy*, 61(4), 343–377.

Margenau, H. (1954), Advantages and disadvantages of various interpretations of the quantum theory, *Physics Today*, 7, 6–13.

Maxwell, N. (1988), Quantum propensiton theory: A testable resolution of the wave/particle dilemma, *British Journal for the Philosophy of Science*, 39, 1–50.

Mumford, S. (1998), *Dispositions*, Oxford: Oxford University Press.

Murdoch, D. (1987), *Niels Bohr's Philosophy of Physics*, Cambridge: Cambridge University Press.

Popper, K. (1982), *Quantum Theory and the Schism in Physics*, volume III of the postscript to the logic of scientific discovery, London: Hutchinson.

Redhead, M. (1987), *Incompleteness, Non-locality and Realism*, Oxford: Clarendon Press.

Sellars, W. (1963), Philosophy and the scientific image of man, *Science, Perception, and Reality*. London: Routledge & Kegan Paul, pp. 1–40.

Shoemaker, S. (1984), *Identity, Cause and Mind*. Cambridge: Cambridge University Press.

Suárez, M. (2004a), On quantum propensities: Two arguments revisited, *Erkenntnis*, 61, 1–16.

Suárez, M. (2004b), Quantum selections, propensities, and the problem of measurement, *British Journal for the Philosophy of Science*, 55, 219–255.

Suárez, M. (2007), Quantum propensities, *Studies in the History and Philosophy of Modern Physics*, 38(2), 418–438. Accessed June 2007.

Tumulka, R. (2006a), A relativistic version of the Ghirardi–Rimini–Weber model, *Journal of Statistical Physics*, 125, 821–840.

Tumulka, R. (2006b), Collapse and relativity, In A. Bassi, Dürr, D., Weber, T., and Zanghì, N. (eds.), *Quantum Mechanics: Are there Quantum Jumps? and On the Present Status of Quantum Mechanics*, American Institute of Physics Conference Proceedings 844, Melville, NY, pp. 340–351.

Van Fraassen B. (1981), A modal interpretation of quantum mechanics, In E. Beltrametti and Van Fraassen, B. (eds.), *Current Issues in Quantum Logic*, New York, NY: Plenum Press, pp. 229–258.