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Dispositions, Relational Properties and the Quantum World[1]

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> «As soon as I find a position in the philosophy of quantum mechanics, I lose momentum…»
>
> Anonymous joke

1. Is Quantum Mechanics connected with philosophical issues about dispositions?

Given the controversial status of the various interpretations of non-relativistic quantum mechanics (QM for short), it may seem crazy to use the philosophy of quantum physics to try to learn some lessons about the prevailing problems in the literature on dispositions and causal powers. However, such an attempt seems worthwhile for at least *three* reasons.

The first is more internal to the philosophy of QM. Apart from a seminal paper by Robert Clifton and Constantine Pagonis (1995), who investigated the issue of dispositional properties in Bohmian mechanics, to my knowledge no one has tried to shed some light on the role played by dispositions in the various interpretations of QM. This seems particularly surprising if one considers that some of the founding fathers of quantum physics, notably Werner Heisenberg, have made direct reference to *Aristotelian potentiae* to refer to and interpret the mysterious nature of the atomic and subatomic world "in se", or before measurement: «Such a probability function [i.e. the statistical algorithm of quantum theory] combines objective and subjective elements. It contains statements on possibilities, or better tendencies ("potentiae in Aristotelian philosophy), and such statement are completely objective, they don't depend on any observer…the passage from the "possible" to the real takes place during the act of observation» (Heisenberg 1958, p. 67-69)

Some years before, Henry Margenau had already characterized the properties of quantum systems as merely *latent*, in contrast to the properties intervening in the description of classical systems, which are always definite even when they are merely dispositional (1954, p. 6). Similarly Karl Popper (1982) and Nicholas Maxwell (1988) have defended some sort of a propensity interpretation of probability, and a view of quantum reality essentially characterized by irreducibly probabilistic propensities. Influenced by this tradition, Michael Redhead's influential textbook on the philosophy of QM distinguishes among *three* different interpretations of the theory, the second of which presupposes *real* propensities and potentialities and attributes to measurements the function of «converting latent values in possessed values» (1987, p. 48).[2] Clearly, for this second interpretation to make less than an instrumentalistic sense, one needs to construe potentialities and dispositions as *real* properties of systems.

Consequently, it seems important to try to get a firmer grasp of the sense in which some interpretations of QM need irreducible dispositions to shed light on the nature of the properties of quantum systems before measurements, *in particular when the state of such systems is not an eigenstate of the relevant physical observable*.

The second reason to look into the relationships between the philosophy of QM and the literature on dispositions comes from a methodological prescription that I regard as very important for the well-being and the prosperity of analytic philosophy in general: rigorous conceptual, *a priori* analysis, typical of this philosophical tradition, should always be accompanied by massive injections of *a posteriori* knowledge coming from the empirical sciences. Consider as an example the discussions on the reality of becoming stemming from McTaggart's celebrated paper on the reality of time (1908). If we were to conclude that becoming as explicated by some *metaphysical* theories of time is incompatible with well-confirmed physical theories (in particular, with the special and general theories of relativity), we should make appropriate adjustments in the metaphysical theories and not try to change the physical theories to eliminate the conflict with our metaphysical prejudices![3]

Analogously, if, say, Armstrong's thesis of the reducibility of dispositional to categorical properties (Armstrong 1996) were to prove incompatible with the most reasonable understanding of QM, I take it that the defenders of such a reductionist thesis should consider the conflict of their metaphysical hypothesis with a fundamental physical theory at least as worrisome. In a word, to the extent that one is not an instrumentalist about scientific theories in general, the incompatibility of a *metaphysical* view with a well-established *physical* theory is an excellent starting point for a philosophical analysis.

As a third reason to venture into our project, consider that establishing some conceptual links between the foundations of QM and the debate on the nature of dispositions may have interesting consequences for both QM and such a debate. For instance, it may be interesting to ask whether minimally realist readings of QM naturally pair with realism about dispositions or causal powers, or whether the two forms of "realism" are independent of each other.

After having given some motivations for the paper, I can state its main thesis: *independently of the preferred interpretation of quantum mechanics,* dispositional properties are extremely important to make sense of what we find in experimental practice in QM. Both in Bohm's and Bohr's interpretations for instance, despite their remarkable differences, the nature of quantum reality – whose mind-independence Bohr never denied – is highly "relational". This essentially means that what an quantum entity *is,* namely the properties it has, relationally depends not just on what other entities it has interacted with in the past (non-locality), but also on the whole experimental arrangement with which it interacts (quantum holism). In a word, *the experimental context provides the context of manifestation of quantum mechanical properties that must be conceived as essentially dispositional*. If two interpretations of QM that are so metaphysically and methodologically different as Bohr's and Bohm's are, end up sharing such an important core, the dispositional nature of the quantum world seems a feature of the world that is here to stay.

A final word of reassurance for the non-specialist metaphysician: since the paper should be read as an invitation to look at the wonders of quantum physics, in matters quantum mechanical it is as self-contained and devoid of technical terms as possible.

2. Should we distinguish between *dispositional* and *categorical* properties?

One of the main *metaphysical* problems in the literature on dispositions and categorical (or occurrent) properties is the nature of their relationship. Can we consider physical, *dispositional* properties like fragility or conductivity as being *identical* to (micro-structural) *categorical* properties – as Armstrong (1996) and Mumford (1998) have it— or should we rather say that the latter *causes* or realizes the former in such a way that dispositional and categorical properties are to be regarded as different – as Place (1996) has it? And furthermore, within monistic philosophies of dispositions, in which the difference between categorical and dispositional properties merely depends on the way *we* pick them up with our predicates, should we claim that dispositions don't exist because all properties are categorical (what Mumford calls "Categorical Monism", (1998, p. 19) or should rather adopt "Dispositional Monism", according to which all properties are dispositional?

In order to try to answer these questions by bringing to bear the philosophy of QM, we need a clear account of the "contrast class" of dispositions: what is the difference between a dispositional and a non-dispositional property? If we can find no difference, we can conclude for monism even before trying, and in any case the questions above will turn out to be not well posed.

Let us start from a simple analysis of ordinary language, by considering unquestionably clear examples of dispositional terms, like "irritable" or "poisonous". As is well known, the properties in question are dispositional because they tend to manifest themselves and become actual or "occurrent" only in appropriate contexts. It seems to me that one way to make progress in understanding the questions above is to recall that the function of dispositions in our language is to encode useful information about the way objects around us *will* behave *if* subject to causal interactions with other entities (mainly ourselves). If true, 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.

I think that the predictive role of dispositional terms is the main explanation of the reason why our languages are so rich with dispositional terms, and also points, more or less directly, to the complex relationships linking dispositions with *causes*, with *counterfactuals* and, eventually, with *laws of nature* as they are expressed in our *scientific languages*. Dispositions express directly or indirectly those regularities of the world around us that enable us to predict the future: "if I were to eat this mushroom, I would die" is a piece of information that seems to be *entailed* by the predictive content of "poisonous". Such an information, importantly, refers not just to the nature of the mushroom "in itself", but to the "meaning" it has for us: its "poisonous-ness" matters for us, of course, and refers to the power a particular *type* of mushroom has when entering in causal contact with a human body.

Notice that by stressing the relational role that dispositions have in ordinary language, I am not thereby endorsing an analysis of dispositional predicates in terms of conditionals, material or counterfactual as they may be. Rather, I am merely claiming that the function of dispositional terms in our "background" experiential knowledge of the world is essentially predictive, independently of whether such terms refer to properties to be regarded as irreducibly real or are just a shorthand to refer to a micro-structural, categorical basis together with a context of manifestation.

The "survival value" of dispositional properties – possibly referring to the "meaning" that the objects around them had for hunters-gatherers trying to find their way around in a threatening world – also points to another, related feature of dispositional properties, first stressed by the founders of modern mechanical philosophy, and before them by the ancient atomists. This feature corresponds to the fact that dispositional terms, besides expressing predictions, also refer to the way the world "in itself" *appears* to us. "Hard" and "soft", "cold" and "warm", "odorous" and "stinking", "sweet" and "sour", "red" and "white", for philosophers like Galileo, Boyle, Descartes and Locke, do not point to properties existing in themselves (independently of mind), but to the products of the interaction of the "primary qualities" of objects with our senses.

In this second sense, the meaning of dispositional predicates does not just lie in their predictive value, but in their mediating role between the mathematizable, quantitative world inhabited by primary qualities and what Husserl later called the *Lebenswelt*, the bountiful "world of life". The second role of dispositions in the philosophical language seems to call attention to the fact that human beings filter and respond selectively to the mind-independent properties of the external world, either through their nervous system or their minds. "Being hard”, “impenetrable”, “red”, “hot” implies a hidden conditional: if the object endowed with certain hidden or well known-powers (in Locke’s words) were perceived by a human being, then it would appear red, hard, soft, etc.

Notice furthermore that in both of their functions, the ordinary and the more philosophical one, dispositional properties seem to be *relational properties* or *causal interactions* of some sort: the property of “being soluble” needs an interaction with some liquid to manifest itself, in the same sense in which the odorousness of a flower needs the interaction of certain chemicals with human nostrils for its manifestation. Given the relational nature of dispositional predicates, shouldn’t we *identify* the non-dispositional properties (categorical properties) with the merely *intrinsic* properties of an object, namely with those properties whose attribution to an entity does not presuppose any other entity?

The shape, the height, the length or the volume of a body would seem to fit this requirement, at least to the extent that we are ready to claim that (i) such geometric features are mind-independent properties of objects and that (ii) length, height and volume can be characterized independently of the units of measures with respect to which they would become relational.

However, if we identify the distinction between the dispositional and non-dispositional with the distinction between relational and intrinsic properties, most properties would come out as relational or extrinsic, so that the former distinction might seem to collapse with the latter. It could be argued that when carefully examined, many properties that seem to be intrinsic turn out to be relational (extrinsic): are there any interesting intrinsic physical properties that are not geometrical?

Spin, charge and mass may superficially appear to be intrinsic properties, but it is controversial whether they are really so classifiable.[4] On the one hand, to the extent that by “mass” we refer to the *gravitational mass,* we imply that there must be a certain context for the property to manifest itself, namely the presence of a gravitational field: on this account "having gravitational mass" would count as dispositional. Likewise, since *inertial mass* measures the resistance of a body to accelerations, also its manifestation seems to presuppose the presence of something else, namely a force. Even "being charged", referred to a particle, may be regarded as the disposition to behave in a certain way in test-situations, something that seems to indicate that *all physical concepts* – linked as they are to possible operations we must perform for detecting them – *are dispositional*.

On the other hand, this claim seems to be refuted by a distinction between the *ontology* and the *epistemology* of properties. Granting that the properties of entities are *epistemically identified* by the causal powers they have, if we separate the "operational side" of having spin, mass and charge – a side referring to certain experimental contexts as the empirical conditions for testing the presence of the property – from the *physical fact* that some system possess them independently of any manifestation, it would seem that "being massive" (regarded as possessing a certain quantity of matter), or "being charged", regarded as the possession of properties that have certain causal powers, and "having spin", can be legitimately considered to be intrinsic properties of physical systems, namely properties whose attribution does not presuppose the existence of any other entity.

A couple of remarks are appropriate at this point. First, relationality is not sufficient for dispositionality, as the example of the relational property "being married to" clearly shows. It follows that being relational is only *necessary* for being dispositional and that, by contraposition, being an intrinsic property can be a merely *sufficient* condition for being non-dispositional. In a word, we cannot identify or analyze the term "dispositional" with "relational", and "categorical" with "intrinsic".

Second, despite this limitation, the fact that the criterion to separate intrinsic from relational properties yields some clear instances suggests that also the distinction between dispositional and categorical is *conceptually* sound.[5] Nevertheless, the possibility that we might refer to the same entity under two different descriptions, does not rule out the fact that the distinction between intrinsic and relational might be purely epistemic or conceptual, and, as such, *devoid of any ontological import*. How can we exclude that, according to our different purposes, we might in some cases consider an *intrinsic* attribute of an entity (call it *A*) independently of any other entity and conclude for its categoricity, and in other cases consider its effects on other entity, while still referring to the *very same A*? It seems that the vagueness of our intuitions does not help us to settle the issue of the reducibility of dispositional concepts to categorical ones.

3 Dispositions in QM

In order to try to overcome this ontologically unclear situation, I propose to bring to bear the philosophy of QM, and to connect the debate we have so far illustrated with real-life physics. Within QM, it seems natural to replace "dispositional properties" with "non-definite properties", i.e. properties that before measurement are objectively and actually "fuzzy" (that is, without a precise, possessed value). *So the passage from dispositional to non-dispositional is the passage from the indefiniteness to the definiteness of the relevant properties*.

Of course, in those situations in which the system possesses a precise value of a certain observable (property) even before measurement (when its state is an eigenstate of the observable), the measurement interaction provided by an experimental context simply amplifies the microscopic value to a macroscopic, classical scale. Consequently, we seem to have *two* kinds of contextualism, 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, we have an *unremarkable* kind of contextualism, call it *contextualism*$_1$. On the contrary, if the value revealed by the measurement interaction causally depends, at least in part, on the interaction, we have a stronger, *remarkable contextualism*$_2$ (this notation is due to Clifton and Pagonis 1995, p. 283).

In this second case, the idea is that the property that is experimentally manifested by the microsystem depends on the measurement context; if this is the case, the microsystem possesses only a *relational* form of identity, given that the properties that it manifests depend on the whole experimental context. If this sort of holistic view is what QM enforces upon us, *I propose to redefine the distinction between dispositional (relational) and non-dispositional (intrinsically, categorically possessed) properties simply in terms of contextual*$_2$ *and contextual*$_1$. Besides enabling us to connect the philosophy of dispositions with the philosophy of QM, this stipulation has the advantage of clarifying the unclear distinction between dispositional and categorical properties in terms of the well-defined difference between *states* of physical systems (i.e., properties) that are *not* and are in an eigenstate of the relevant observable.

Now we can raise the following questions: are there interpretations of QM admitting only categorical or intrinsically possessed properties (contextual$_1$) or QM is in need of dispositional properties (contextual$_2$) independently of any interpretation? We will see that the latter alternative is the case, something that shows that quantum holism, common to various interpretations, has something to do with the dispositional nature of the quantum world, in the sense of “dispositional” adopted here. Most importantly, we will also see how quantum dispositional properties turn out to be *irreducible* in most interpretations, with the exception of Bohmian positions, which, within the hidden variable interpretation, are the only non-contextual observables.

4 Dispositions in Bohr's interpretation of quantum mechanics

Despite the fact that the distinguished physicist Rudolf Peierls could say as recently as 1986 that «there is only one way in which you can understand quantum mechanics…so when you refer to the Copenhagen interpretation of the mechanics what you really mean is quantum mechanics» (quoted in Whitaker 1996, p. 160), by now the philosophical (and in good part also the scientific) community have stopped supporting this view. Together with this interpretation, we will therefore analyze the role of dispositions in other interpretations of the formalism, such as the so-called many worlds or many minds interpretations, which we will group together, and in other theories, such as Bohm's (hidden variables) and GRW's (spontaneous collapse theories).

In presenting Bohr's view, it is useful to draw a fundamental distinction between *ontological* and *metaphysical assumptions*, the first concerning the mere *mind-independent existence* of quantum systems, and the second concerning what we can say about their *properties*. If we distinguish ontology as the problem of establishing what there is from metaphysics as the study of the *properties* of what exists, we can classify Bohr as an ontological realist but a metaphysical antirealist. Even if we were to follow Redhead in thinking that according to Bohr it is simply *meaningless* to attribute a system whose state is not an eigenstate of the relevant observable any property before and independently of measurement (Redhead 1987, pp. 49-51), Bohr certainly believed in the reality or mind-independence of atomic systems (Faye 1991) and defended a strong form of *experimental contextuality,* which is exactly what interests us here. Actually the relationship between the principle of complementarity of non-commuting observables, the contextuality and the dispositional nature of quantum entities has been first stressed by Bohr, and has not been sufficiently noticed by physicists and philosophers writing on Bohr.

According to Bohr two properties are complementary if and only if they are *mutual exclusive* and *jointly exhaustive* (see Murdoch 1987). We say that they are *mutual exclusive* because, from the point of view of the classical language, they can be attributed at the same time to the same system only *via* a contradiction. In fact, complementary properties cannot be simultaneously revealed by the same experiment, given that any apparatus obeys classical physics. 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: an electron is neither a particle nor a wave, but has features belonging to *both* concepts.

In order to be coherent with his complementarity view of QM, Bohr claims that the quantum world must be irreducibly dispositional and $contextual_2$, where irreducible refers to his disbelief in hidden, deterministic variables grounding the fuzzy dispositional state of the system before measurement, and $contextual_2$ refers to the holistic nature of the micro-system, *the manifestation of properties depending on the kind of experiment one wants to perform*.

Granting that Bohr believes – as he does – in the mind-independence of atoms and particles, the dispositional character of the quantum world is therefore an essential characteristic of his interpretation of QM. The main reason for this claim is given by the fact, often repeated by Bohr especially in his debate with Einstein (Laudisa 1998), that the manifestation of the "properties" of quantum systems requires an experiment, and the nature of the experiment determines which aspect (which of the complementary properties) of the quantum system will be revealed.

Take the familiar apparatus for a two-slits experiment: do we want to observe the interference effects and thereby manifest the typical wave-like nature of the quantum system on the fluorescent screen behind the slits? Then we must renounce to have any information about its particle-like aspect or, to put it more realistically in order to remain faithful to Bohr's ontic realism, we must somehow destroy a *dispositional aspect* of the system, related to its particle-like, complementary nature. While antirealist philosophers that follow Bohr always stress there in this case there is no way to *find out* which of the two slits the particles has gone through, in more realistic terms we could just say that the disposition to manifest the particle-like nature of the system has somehow got lost.

For our purposes, it is important to note that the quantum system's wavelike *manifested property* causally depends on its causal interaction with the apparatus, and therefore on what we decided to measure. According to Bohr's interpretation, we cannot assume that there is a categorical basis for the manifestation of the wavelike property *independently of given experimental contexts*, since this would be equivalent to assume that the wavelike aspect was there all along, at the exclusion of the particle-like, complementary aspect. If we assumed such a categorical basis for the wave-like aspect of the system, we could not explain why, if we close one of the two slits, the interference effects due to the superposition are lost,[6] and on the screen we just observe an enlarged image of the slit. By extracting information about the position and the spatiotemporal trajectory of the particle-like aspect of the quantum system, we lose information on its wavelike aspect, and we don't see any interference; in more realistic terms, by closing one slit we prevent the dispositional, wave-like aspect of the quantum system from manifesting itself in the experimental context.

Using the stipulations given above, we are now in the position to understand Bohr's refusal of hidden variable theories (and the consequent belief in the completeness of QM) as equivalent to the claim that there is no categorical basis for the dual, "complementary" aspect of the quantum systems. Furthermore, to the extent that QM is, as Bohr thought, complete, there is no possessed, contextual$_1$ value (categorical property) *before* measurement, since it is meaningless to attribute one to the quantum system independently of a measurement context.

The value revealed *after* measurement is caused by the interaction of the quantum system with the classical apparatus, in the sense that the definiteness of the property is literally brought about by it: a formally possible value of a contextual_2 observable (Heisenberg's Aristotelian potentiae) gets transformed into an actual value.

I should insist that according to Bohr the quantum system and the apparatus are *inseparably linked* to each other as phenomena and categories are in Kant's epistemology: the classical language for Bohr is literally the transcendental condition of the possibility of a meaningful talk of the quantum world, while Kant's noumenal world corresponds to the quantum world before and independently of the classically describable measurement contexts. Of this noumenal world, in Bohr's reading of it, we can just say that it exists, while its properties can be meaningfully referred to only when they manifest themselves *via* the interventions of specific classical measurements apparatuses. This parallel with Kant's philosophy also extends to the fact that if we tried to apply one of the two complementary concepts (wave or particle, position or momentum) to the quantum world *an Sich*, we would run into contradictions analogous to those described by Kant (antinomies), caused by the application of the categories (i.e., the classical language) to the noumenal world, that is, beyond the world of phenomena.

Clearly, I will not try to defend this reading of Bohr by helping myself with textual evidence. All I am claiming is that Bohr's entity realism, as plausibly defended by Faye, requires to be connected with his widely-documented holism on the one hand (contextualism_2), and his peculiar brand of neo-Kantism on the other. This gives us a belief in irreducible dispositions, a language that Bohr himself never used, but to which, I submit, he would have not objected. If we were to take this reading of Bohr seriously, we would have to admit that the monistic thesis that identifies dispositional and categorical properties would be refuted by a physical theory. *To the extent* that before measurement the quantum system can be legitimately attributed a probabilistic dispositional property – some instrumentalists, by rejecting the mind-independent existence of the quantum systems, would refute even this move – we must admit that the refusal of hidden variables entails the refusal of the existence of a categorical (intrinsic or $contextual_1$) property grounding the dispositional ($contextual_2$) one. *Quantum properties, according to the minimally realistic reading of the Copenhagen interpretation I am defending here, are irreducibly dispositional.*

Of course the reductionist about disposition may try to resist the attempt at assigning some mind-independent property, fuzzy as it may be, to the quantum system in pre-measurement states, by claiming that any talk of a quantum world is either void or utterly meaningless, since we can only talk about a *measured* quantum world. In this respect, perhaps it is worth recalling that the following, famous quotation, usually attributed to Bohr, is really due to Aage Petersen, one of his life-long assistants (Jammer 1974, p. 204): «There is no quantum world. There is only an abstract physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature».

Last-minute instrumentalists have illegitimately used this quotation to claim that Bohr denied any mind-independent reality to the quantum world. Giving Bohr his due, however, is not to say that his position is immune from difficulties, *especially* once the quantum world is admitted as a mind-independent, noumenal "crutch" on which to hang the experimentally detected properties. Bohr in fact never gave us any clear indication as to how we should draw the exact boundary between the classical and the quantum world.

5 Dispositions in Bohm's interpretation of QM (hidden variables)

In this interpretation, QM as is standardly interpreted is regarded as incomplete and is supplemented by explicit reference to an unknowable additional “variable”, the changing-in-time position of particles, a variable that is perfectly definite at all times but that can be revealed to us only by measurements.[7] Besides its deterministic features, it is of paramount importance to remind the reader that this interpretation regards the physical observables as belonging to two categories, the non-contextual ones or contextual$_1$ and the contextual$_2$, and that *position is the only non-contextual*$_2$ *observable*. This essentially means that position is the only variable that can be regarded as being possessed before measurement, in such a way that “faithful measurements” just *reveal* it.

The contextualism of this interpretation is enhanced by its non-locality, and can be explained in the following way. Suppose we have three observable properties, P, P_1 and P_2, such that P_1 and P_2 cannot be measured simultaneously. The contextuality of property P essentially means that if we measure P together with P_1 we obtain a result that is *different* from what we obtain by measuring P with P_2, even if the hidden variables (positions) remain the same. To put it with a slogan, “positions being equal, different measurements yield different results”.[8]

Clearly, it is interesting for us to ask in what sense we can attribute to P something more than a merely dispositional tendency to show a definite result in a certain measurement context.[9] In order to be more specific about this question, let P be the direction of the spin of a quantum system, measurable with a Stern-Gerlach magnet: is the property of “having spin in a given direction” an irreducible disposition, in the same sense in which the contextuality$_2$ of all observable in Bohr’s interpretation led us to conclude that the relative properties were irreducibly dispositional?

Suppose that we are trying to measure the spin in the z-direction of a particle that is in a superposition of being |z-up> and |z-down> in that direction (i.e., suppose that before the measurement the particle has spin in the x-direction and is therefore in a superposition of the two previous states). If we invert the polarity of the apparatus (from *P_1 to P_2*) and leave everything else unchanged, we change the measurement result on spin in the z-direction: if we had obtained z-up in the previous measurement, we obtain z-down in the second. Given this result, the property of "having a definite spin in the z-direction" is not categorical, intrinsic or faithfully measured: measurements do not in general reveal the pre-existing possessed value of spin along the z-direction, for the simple reason that there isn't any! If by switching the magnet and leaving everything else unchanged we change the experimental outcome from z-up to z-down, there is no definite property of having a spin in the given direction at all. In the terminology introduced before, the property "spin along a given direction" is therefore contextual_2, for the simple reason that the experimental outcome causally depends on the measurement context together, of course, with the "hidden", non-contextual_2 value of the position of the particle.

Exactly for this reason, however, in the Bohmian interpretation the dispositional properties of "spins along a given direction" – referred to particles that before measurement are in a state of superposition with respect to that direction – *are* reducible to position and the context of measurement (Clifton and Pagonis, pp. 285-6). The idea of reducibility is based upon the fact that our hypothetical knowledge of the position of the particle plus knowledge of the orientation of the magnet would allow us to deduce the result of the outcome with certainty. However, for the reasons illustrated above, there is nothing pertaining to "spin in the z-direction" that is categorically, intrinsically and definitely possessed by the particle before measurement, precisely in virtue of the above stipulation that a property is categorical if and only if it has a definite value before measurement and is therefore non-contextual_2.

Except for position then, *both* in Bohm's *and* in Heisenberg-Bohr's interpretations, all properties of micro-systems are contextual_2 and therefore *dispositional*, but in the

Copenhagen interpretation, unlike in the Bohmian case, *all* such dispositions are of an *irreducible* type. As Clifton and Pagonis correctly remarked, if we assumed that spin-directions and other properties were *irreducibly* dispositional, we would lose the benefits of the completeness of the theory! (1995, p.288).

6. Dispositions in non-collapse views: the relational interpretation of QM (Rovelli)

Rather than assigning an ontological meaning to the wave function, the relational interpretation of QM focuses on the sequence of actual measurement outcomes q_1, q_2, q_N,… But such outcomes are to be regarded as the result of *correlations* of quantum systems with particular "observing physical systems" *S*, and no absolute meaning is attached to the intrinsic properties of an isolated quantum system *Q*. A quantum system *Q* can be said to possess a certain property *q* only relative to a *system S*, and relative to another observing system *S'*, *Q* and *S* may be in an indefinite state, i.e., in a superposition.

Relational quantum mechanics (Rovelli 1996) is therefore a way of reconciling the universality of application of the principle of quantum superposition with the fact that the observed world is characterized by uniquely determined events. In Rovelli's and Laudisa's words: «there is no meaning in saying that a certain quantum event has happened or that a variable of the system *S* has taken the value *q*: rather, there is meaning in saying that the event *q* has happened or the variable has taken the value *q for O*, or *with respect to O*… If I observe an electron at a certain position, I cannot conclude that the electron *is* there: I can only conclude that the electron *as seen by me* is there. Quantum events only happen in interactions between systems, and the fact that a quantum event has happened is only true with respect to the systems involved in the interaction. The unique account of the state of the world of the classical theory is thus fractured into a multiplicity of accounts, one for each possible "observing" physical system.» (Rovelli and Laudisa 2002, sect. 2)

This interpretation combines features of the Copenhagen view of QM (limitation of what we can say about unmeasured systems) with the Everett's view to be presented later. Since in this interpretation we cannot talk about intrinsic properties of physical systems, for our purpose it is important to stress that according to Carlo Rovelli's interpretation *the quantum world possesses no categorical properties at all.* All properties are clearly contextual$_2$ and therefore, in our language, irreducibly dispositional; in this interpretation, the notion of "correlation" is so central that all properties of the quantum universe are relational: there cannot be any categorical, intrinsic property. It is meaningless to even think of categorical properties that ground the disposition to show certain values of position, spin etc.: while correlations may be ascribed physical reality, the quantities that are the terms of the correlations cannot (Mermin 1998).

Considering a view of the world in which only (cor)relations have a determinate reality and their relata don't, couldn't we take the correlated systems *S*+*O* to be the basic, categorical ontological ingredient, and thereby avoid the dispositionality of all non-relational physical properties? This move is unfortunately going to be unsuccessful, since in its turn the joint system *S*+*O* will possess a determinate property only relatively to another system *S'*, and may well be in a superposed state (and therefore fail to be determinate) relatively to *S''*.

6.1 Dispositions in many worlds/many minds interpretation

The main ontological difference between Rovelli's relational view and Everett's view in its various versions (many worlds, many minds, etc.) derives from the fact that while

Everett takes the ψ-function as the ontological basis of QM, Rovelli regards as (relationally) real only the outcomes of *two-systems* correlations.

As Carlo Rovelli and Federico Laudisa stress, it is one thing to say that a definite value or property or event is relative to *a system*, as in Rovelli's interpretation; quite another to say that definiteness is relative to the *state* of a system, as in Everett's: «According to the relational interpretation, after the first measurement the quantity *q* has a given value and only one for *O*, while in Everett's terms the quantity *q* has a value for one state of *O* and a different value for another state of *O*, and the two are equally real.» (2002, sect. 5).

In this quotation, Rovelli and Laudisa are clearly referring to the many-worlds interpretation of Hugh Everett's interpretation (1957), according to which there is an ontological multiplicity of realities, one for each component of the superposed state representing the total physical system (see infra). In the many-minds version, on the contrary, there is a *plurality of mental "viewpoints"* or "perspectives" on the *same* indefinite world, which is in a gigantic state of superposition (Albert and Loewer 1988, Squires 1987).[10]

Note that such a plurality of perspectives in the relational point of view is absent only in appearance, given that in also in Rovelli's interpretation definite physical quantities can actualize only relationally, that is, only once *two* systems are given. It then follows that for any quantum system *Q*, there are many possible "perspectives" that can be associated with it, one for each possible correlation: according to the "perspective" of observer *O*, event *q* has happened, but according to another perspective associated with *O'*, *q* has not happened, and both versions must be consider legitimate. The analogy that Rovelli's interpretation suggests between quantum perspectives on superposed states on the one hand, and special relativistic, 3+1 "perspectives" on the four dimensional reality (Minkowski spacetime) on the other, seems to indicate that – despite the intention of the author – superposition states might be the essential ontological ingredient, and two-systems, quantum correlations mere perspectives on an indefinite reality.

In order to probe the consequences of the many-worlds interpretation for the dispositional or categorical nature of its fundamental properties, let us write the quantum state of the universe as a superposition of various worlds:[11]

$$|\Psi_{\text{Universe}}> = \sum_{\text{i}} c_i \,|\, \Psi_{\text{World-}i}>,$$

$$\sum|c_i|^2 = 1$$

Notice first of all that *each world* behaves like a quasi-classical world of definite properties, in which "fuzzy" properties (i.e., superpositions) are absent. Consequently, relative to each such world, dispositions are reducible (irreducible) *if* they are reducible (irreducible) in the "ordinary" world of semi-classical physics, which is the setting often presupposed by philosophical discussions. From this point of view, the many-worlds interpretation is *neutral vis à vis* the issue of the reducibility of dispositions.

However, since the whole universe is in a global state of superposition, we could as well conclude that, *relatively to the quantum state of the universe*, which is a perfectly definite quantum state from a *mathematical* viewpoint, the *physical* properties of the universe are *really* indefinite. Relatively to the quantum state of the universe, we cannot claim that the moon has a definite position, given that such the definiteness of such a property is only a perspectival matter, depending on, and varying with, different worlds, branches, or minds.[12]

Consequently, there seems to be a sense in which the properties of the quantum universe (say, having a certain density at a certain time) can be understood as being *irreducibly dispositional*, i.e., as being capable of having different definite "manifestations" in different worlds or branches or minds, all of them being actual. That such a dispositional reading of Everett-type interpretations is not so implausible can be gathered also by the notion of a *centered-world* put forward by Vaidman (2002, sect. 2), and by him attributed to

Saunders (1995): if the world is centered on a human being, only perceived states are definite, and non-perceived ones are really superposed. Reality in itself is an entangled mess, and has the ungrounded, irreducible disposition to correlate to our brain states in such a way that we perceive the world as having definite properties. Never an interpretation of a physical theory has put more emphasis on the radical gap between the way the world *is* (reality) and how it *illusorily appears* to us.[13]

7 Dispositions in spontaneous collapse theories (GRW)

In the so-called GRW theories (from the acronym of their main inventors, Gian Carlo Ghirardi, Alberto Rimini and Tullio Weber), the definite, macroscopic world of our experience, threatened to be in a nebulous state by the universal validity of the principle of superposition, is obtained via a modification of the linearity of Schrödinger's equation.[14] In GRW's original model (1985), on which we will focus, the wave function of a system is multiplied by a localization function, which physically represents a *spontaneous localization* in a "limited" region of space of a previously non-localized quantum system. Apart from technicalities, that in this context have no importance, it is essential to note that according to GRW the fundamentally *stochastic* nature of the localization mechanism is not grounded in any categorical property of the quantum system: the theory at present stage is purely "phenomenological", in the sense that no "deeper mechanism" is provided to account for the *causes* of the localization. "Spontaneous", as referred to the localization process, therefore simply means "uncaused".

In the attempt to unify the dynamics of microscopic and macroscopic systems, GRW suppose in other words that all quantum systems have an *irreducibly probabilistic disposition* (a propensity) *to localize* in a region of space whose dimension is approximately 10^{-5} cm, with a frequency *f* given by 10^{-16} sec^{-1}. The probability that such a process occurs is defined as *f* times a second: this is tantamount to assume that a microscopic system (say, a proton) undergoes a localization process, on average, once every 10^{16} seconds (approximately corresponding to once every hundred million years) and this hypothesis explains why isolated quantum systems can typically remain for a very long time in non-localized or superposed state (i.e., they are spread across a very large region of space).

However, since a *macroscopic* system is constituted in average by 10^{23} atomic components, and since the localization of a single particle drives the collapse of all the others, it follows that the components of a macroscopic apparatus that are correlated with the particle that we want to measure will undergo a localization every 10^{-7} seconds. In fact, the average number of particles that will collapse spontaneously in a second is given by $10^{-16} \times 10^{23} = 10^{7}$, which means the macroscopic apparatus remains in a state of indefinite position (i.e., in a superposition of two position states) for no more that 10^{-7} seconds: as Bell put it, Schrödinger's cat remains neither dead nor alive for no more than a split second (1987, p. 44).

For our purposes, it is essential to stress once again that the new uncaused tendency to "swerve" attributed to the atoms by GRW (in Lucretius' *De Rerum Natura* we read of a "*clinamen*" accidentally deviating the vertical fall of the Democritean atoms)[15] is an irreducibly *dispositional property,* that becomes actual or is manifested in ways that could call for – were the new theory prove to be successful in overcoming its present difficulties with a relativistic extension – the introduction of new constants of nature. Furthermore, despite the fact that the irreducibly stochastic *propensity to localize* is not grounded in any *categorical* properties of the quantum system, it is nevertheless strongly *explanatory* of the definiteness of the macroscopic world of our experience. We should therefore change our prejudices concerning ungrounded dispositional properties as being *always* explanatorily empty: the explanatory power of GRW is given by the *unification* that the modified equation accomplishes between the dynamical evolution of quantum systems and the classical evolution of macroscopic systems.[16]

8 QM and the problem of the reducibility of dispositional to categorical properties

Summarizing, we have seen that in *all* of the most important interpretations of QM

(i) dispositional properties – whether probabilistic or deterministic – have a crucial role;

(ii) the only interpretation in which we seem to have reductionism about dispositional, contextual_2 properties is Bohm's.

Before trying to draw our conclusion about these two claims, it is important to recall their relevance for our purpose: if in the most-debated interpretations of QM there are no categorical properties to which one could reduce the dispositional properties, the philosophical thesis that tries to reduce the latter to the former is in serious difficulties, because it is in conflict with the most fundamental theory of matter of our day.

In order to justify the last statement, the three following comments to (i) are appropriate. First: the fact that even the Copenhagen interpretation of QM, that is closest to instrumentalism – and, therefore, closest to a philosophical position that resists from drawing *ontological* lessons from physical theories – is forced to invoke a strong form of contextualism_2, is a strong point in favor of the claim that quantum properties are essentially dispositional.

Second: the fact that, in interpretations as ontologically and methodologically different as the Copenhagen and the hidden variables interpretation, the contextualism_2 of "phenomena" (i.e., their dispositionality) is regarded as fundamental seems to teach us something very deep about the holistic ontology of QM, independently of our philosophical tastes. For Bohr as well as for Bohm, such contextualism refers to the *inseparability of classical apparatuses and the behavior and properties revealed by QM-systems*, in the same sense in which, in the special theory of relativity, one cannot separate space from time except by making a conventional choice of an inertial frame. Despite the big difference between Bohr and Bohm, which lies of course in the latter's postulation of non-contextual, always defined observables (positions of particles), we should be aware as well of the similarities, which have been stressed independently also by Bell.

Third, to the extent that it is not absurd to attribute to an entity realists like Bohr the view that microsystems have dispositional, probabilistic tendencies to display well-defined outcomes in given experimental contexts – whose function is to somehow "extract" "latent aspects" from a real (i.e., mind-independent) entity – Bohr's and Heisenberg's positions appear to be very similar. Unfortunately, claiming that a micro-system *M* has a "real disposition" to show a certain behavior in a measurement context *has little explanatory power*, as it just amounts to saying that if we measure the "fuzzy entity" *M* we get a definite outcome. Bohr's obsession with the language of classical physics as the transcendental condition of possibility to talk about a quantum system may have the unfortunate consequence of preventing us from learning more about the nature of quantum dispositions. In a word, Bohr's and Heisenberg potentialities are as ungrounded as GRW's "hits", but while the latter's dispositions to localize play an extremely important explanatory function, the former types of dispositions don't. So, contrary to the common cliché according to which ungrounded dispositions carry as much explanatory power as the famous *virtutes dormitivae* in Moliere's comedy, it is not the ungroundedness of dispositions that matters, but the particular pragmatic context of the explanation.

Coming now to (ii), and wanting to assess at the same time Clifton and Pagonis's claim that Bohmian dispositions are unremarkable despite their contextuality$_2$, we must avoid possible sources of misunderstandings. We have seen that in Bohm's theory there cannot be any talk of a possessed value of a contextual$_2$ property before measurement and that, in this sense, there cannot be any pre-existing, real property of "having a spin in a certain direction" to be revealed by measurements. Having "no definite spin in a given direction" seems to imply "having no spin at all in that direction", in the same sense in which "having no definite color" implies "having no color at all".

But then a remarkable difference between a quantum and a classical disposition would seem to emerge: on the one hand, it is meaningless to ask what is the possessed value of the spin of the particle independently of a specific measurement context. On the other, at least within a realist view of "classical", macroscopic dispositions, *it is clearly not meaningless to refer to the fragility of a glass independently of, and before of, a "breaking context"*. Isn't this a remarkable difference between macroscopic dispositions and quantum dispositions in Bohmian mechanics? By claiming that Bohmian dispositions are "nothing to write home about", have Clifton and Pagonis (1995) overlooked something? This criticism of Clifton and Pagonis, however, is based on a simple misunderstanding.

It is true that in any minimal realism about dispositions, with which I would agree, the glass possesses the fragility independently of the breaking context, and the disposition "fragility" can be attributed to a glass even if it will never break. Let us agree that there is a real property of "being fragile, or being disposed to break in such and such a context", even before and independently of its manifestation; in monistic views, such a property *exists* precisely because it *is identical* with the micro-structural categorical property of the glass, plus context. Why isn't this different from Bohmian spins, given that there is no way for us to refer to a non-contextually$_2$ possessed value of spin before the measurement context?

What we should say to defend the perfect analogy between a Bohmian "spin in a given direction" and classical dispositions like fragility is that the latter's "propensity to break in a certain context" corresponds to "*the propensity to show a definite spin* in a certain measurement context", which is clearly possessed by Bohmian particles also before measurement, and independently of it. In the Bohmian case, the correct analogy with the classical disposition "fragility" is not given by "having a definite spin" but by "the disposition to have a definite spin". It follows that the manifestation of the two dispositions is, respectively, the breaking event in one case and the acquisition of a definite spin in the other. Accordingly, and even from the viewpoint of a realist position about dispositions, Clifton and Pagonis are correct in holding that the contextualism of values in Bohm's theory is not remarkably different from the dispositionality of ordinary classical properties.

Coming now to the reducibility thesis in the Bohmian theory, we should ask whether the property "being disposed to have a certain definite value of spin" is identical to the categorical basis, given by the non-contextual position of the particle whose spin is to be measured, plus a specific measurement context (a certain orientation of a Stern-Gerlach apparatus).

Given the deterministic nature of the theory, however, it seems at first appropriate to claim that the measurement context, together with the non-contextual observable *and* the propensity to manifest a certain spin in a given direction, *cause* the particle to have such and such a spin. This move seems to make room for a dualistic theory of a Placean kind, to the extent that the latter is committed to the view that the categorical base causes (and is not identical with) the disposition, and the latter in its turn, together with the context, causes the manifestation. According to Place, the fragility is caused and explained by the molecular structure of the glass, and it is the fragility that causes and explains the breaking of the glass by a stone. If this causal analysis were correct, the reducibility which Clifton and Pagonis defend would not follow.

However, Place's account of dispositional properties seems to multiply causes without necessity. The stone is certainly a cause of the breaking, together with the molecular structure of the window glass: if the structure of the window had been different, the stone would have not broken it. But claiming that fragility, referred to the glass as macroscopic entity, is an additional cause of the breaking introduces an unnecessary link in the narrative: as we have seen in the previous chapter, the predicate "fragile" has a predictive function that refers to certain contexts, but the cause of the breaking and its true explanation lies in the microscopic structure of the glass. Fragility by itself can provide only very fragile explanations.

The case seems perfectly analogous for quantum, bohmian dispositions. The quantum dispositional property "propensity to show a certain spin" should be regarded as identical with a complex state of affair, constituted by the possessed position and other purely contextual_1 properties of the particle. Note that we cannot claim that the categorical property (position) is a sufficient cause for the manifestation of the disposition in the same sense in which the microstructure of glass is not sufficient for the breaking event

9 Conclusions

Since only bohmian dispositions are reducible to context and non-contextual variables, the possibility of considering dispositions as reducible seem to depend on the prospect of success for the Bohmian interpretation of QM. The fact that the non-local contextuality of the fundamental physical observables is so widespread a feature of various interpretation of QM confirms that the quantum world cannot be conceived of as inhabited by entities whose identity is given by intrinsically possessed properties. The relational aspect of such entities is much more important to understand what these entities really are.

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[2] The first position he discusses is the Copenhagen interpretation, while the third is associated with a “property realism” of Bohm’s type. For these interpretations, see below.

[3] The interested reader could look at Dorato (1995).

[4] The case of the direction of spin, rather than its magnitude, will be discussed below.

[5] Mumford’s proposal to distinguish dispositional from non-dispositional properties in terms of functional roles and specification of that role respectively is not too dissimilar from the approach followed here: «to give a disposition ascription is to say something about what a thing can do but to say nothing about how it does what it does…With a categorical property ascription, nothing is entailed, purely conceptually, about what causal or functional role such a shape, state, structure, or property will play in its interactions with other things. Hence it is not possible to derive anything about the causal role of a property, analytically, from the meaning of a categorical property ascription…(1998, pp. 76-77).

[6] Here the superposition in question corresponds to the property of having gone through the first and the second slit. In general, a superposition of states corresponds to the *sum* of two or more states, and in our context is

roughly synonymous with a formally well-defined state that at a macroscopic level would refer to an indefinite property.

[7] The theory is described by *two* equations, the familiar Schrödinger's equation and a guide equation relating the velocity of the k-th particle to the gradient of the ψ-function with respect to the k-coordinate of the particle.

[8] For a readable account of Bohmian mechanics, see Goldstein (2001).

[9] Furthermore, the assumption that the observable *A* has a definite, possessed value that – in being independent of the measurement context – is non-contextual$_2$, would lead to a contradiction with a well-known "no-go theorem", prohibiting a non-contextual$_2$, simultaneous assignment of a definite value to all the observables of a system (Kochen and Specker 1967).

[10] This second reading seems to be closer to the original view proposed by Everett (1957).

[11] Here I follow Lev Vaidman's notation (2002)

[12] Replace "worlds" with "minds in a single individual" and you get the many-minds view.

[13] For the problem of the empirical coherence of Everett's type views of QM, see Barrett (1999).

[14] A recent, readable survey of collapse theories and relative references is given in Ghirardi (2002)

[15] This historical parallel is due to Van Fraassen (see Ghirardi 1997, pp. 379-381)

[16] Friedman (1974) and Kitcher (1976) have both proposed a theory of explanation according to which to explain means to unify.