Found Sci (2012) 17:205–221
DOI 10.1007/s10699-011-9232-0

Ungrounded Dispositions in Quantum Mechanics

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Published online: 13 July 2011

Abstract General metaphysical arguments have been proposed in favour of the thesis that all dispositions have categorical bases (Armstrong; Prior, Pargetter, Jackson). These arguments have been countered by equally general arguments in support of ungrounded dispositions (Molnar, Mumford). I believe that this controversy cannot be settled purely on the level of abstract metaphysical considerations. Instead, I propose to look for ungrounded dispositions in specific physical theories, such as quantum mechanics. I explain why non-classical properties such as spin are best interpreted as irreducible dispositional properties, and I give reasons why even seemingly classical properties, for instance position or momentum, should receive a similar treatment when interpreted in the quantum realm. Contrary to the conventional wisdom, I argue that quantum dispositions should not be limited to probabilistic dispositions (propensities) by showing reasons why even possession of well-defined values of parameters should qualify as a dispositional property. I finally discuss the issue of the actuality of quantum dispositions, arguing that it may be justified to treat them as potentialities whose being has a lesser degree of reality than that of classical categorical properties, due to the incompatibility relations between non-commuting observables.

Keywords Dispositions · Grounding · Quantum mechanics · Incompatibility

This paper contains an attempt to make connections between some themes in the general metaphysics of properties and philosophy of quantum mechanics. In the past twenty years or so we have witnessed a steady rise of publications taking up the issue of the nature of fundamental properties. One recurrent theme in these discussions has been that the fundamental physical properties may be of a dispositional character, i.e. that they may be characterized as causal powers to do things. Some authors go so far as claiming that those fundamental powers are not reducible to any non-dispositional properties of objects, and that laws of nature

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derive their necessary character from the existence of pure powers.[1] I believe that the metaphysical debate regarding the nature of fundamental properties can benefit from an infusion of ideas and solutions derived from our best scientific theories, including quantum mechanics. In this paper I would like to take some tentative steps towards answering the question whether quantum mechanics can support the claim that fundamental physical properties are irreducible dispositions. The idea of using the notion of dispositions in the context of quantum mechanics is not new, but typically dispositions are invoked in the hope that they may help solve some interpretative problems of quantum mechanics, such as the measurement problem.[2] In my current approach the direction of influence will be from quantum physics to metaphysics rather than the other way around. I will try to extract some metaphysical lessons from quantum mechanics that may be useful for the friends of ungrounded dispositions. But before we can do that, a critical survey of the current state of the debate in the metaphysics of dispositions is in order.

1 Preliminary Distinctions

What are dispositional properties? How are they different from categorical properties? Roughly speaking the underlying distinction is between what an object is actually like now and how it would behave in various possible circumstances. The orthodox view is that ascriptions of dispositions entail certain subjunctive conditionals, whereas categorical ascriptions do not. But an immediate objection can be raised that virtually all property ascriptions entail some conditionals,[3] and thus the proposed categorical/dispositional distinction collapses. Stephen Mumford has made an important suggestion that disposition ascriptions, as opposed to categorical ones, entail appropriate conditionals as a matter of conceptual necessity.[4] This suggestion can be alternatively presented in the form of the requirement that dispositions be properties whose *essence* includes their conditional character. In other words, a disposition ascription is supposed to entail certain subjunctive conditionals in all possible worlds, even if these worlds do not obey our laws of nature.[5]

[1] Among the works in which these claims are discussed are Mumford (1998), Ellis (2001), Molnar (2003), Bird (2007).

[2] See for instance Suárez (2004) as representative of this approach.

[3] This claim is defended in Mellor (1974).

[4] More precisely, Mumford writes that "disposition ascriptions are ascriptions of properties that occupy a particular functional role as a matter of conceptual necessity and have particular shape or structure characterizations only a posteriori" (Mumford 1998, p. 77). He points out that in contrast with this case the functional roles of categorical properties are known through scientific investigations. Mumford concludes that "stronger-than-material conditionals are 'entailed' by both dispositional and categorical ascriptions but in the case of dispositions the relation is a priori as opposed to a posteriori in the case of categorical ascriptions" (*ibid.*, p. 79).

[5] Alexander Bird correctly points out that the existence of necessary entailment between a property attribution and a subjunctive conditional can in some situations be an insufficient criterion of the dispositionality of the property in question. If a given property P happens to co-occur in our world with a particular disposition to M when S (let's denote this disposition by $\mathrm{D}_{(S,M)}$), we can use the description $\mathrm{D}_{(S,M)}$ to refer (non-rigidly) to P in our world. In this case the entailment holds necessarily, but only *de dicto*. For instance, in the actual world the property of roundness is associated with the disposition to roll downhill when unsupported. The ascription "x has the property responsible for rolling downhill when x is unsupported" entails the counterfactual "If x were unsupported, it would roll downhill" but only under the *de dicto* interpretation. In the *de re* case, when the first description is meant as "the property that in our world is responsible for rolling downhill when x is unsupported", the entailment does not have to hold. Bird insists that a proper test of dispositionality should involve only *de re* entailments (Bird 2007, pp. 151–153).

The proposed characteristic of dispositional properties is threatened by a well-known objection. It has been pointed out that there are circumstances in which an object possesses a given disposition, and yet the corresponding counterfactual conditional is not true. Cases of that sort are roughly divided into two types: finks and antidotes. An object possesses a finkish disposition iff it is the case that the stimulation event which is supposed to bring about the manifestation of the disposition destroys the disposition in question before the manifestation event can occur.[6] An antidote, on the other hand, is an interfering event that happens between the stimulus and the manifestation and disrupts the causal chain leading to the manifestation event.[7] Given the possibility of finks and antidotes, it looks like the suggested characterization of dispositions is inadequate, since not even disposition ascriptions necessarily entail appropriate conditionals.

Several responses to this problem have been considered, including the addition of the ceteris paribus clause to the conditionals (Mumford 1998, pp. 84–91). But I believe that finks and antidotes do not threaten directly the categorical/dispositional distinction. They pose an immediate challenge to the adequacy of the conditional analysis of individual disposition ascriptions, but if we are only looking for a general criterion which could differentiate dispositional properties from categorical ones, we may be able to avoid the problem. The suggestion is to characterise dispositional properties with the help of a weaker requirement: P is a dispositional property iff there is at least one situation in which an ascription of P necessarily entails a counterfactual conditional. The meaning of this stipulation can be unpacked in terms of possible worlds as follows. For P to be a dispositional property, there has to be an actual situation s in which P is exemplified by an object x, and in addition there has to be a subjunctive conditional about object x $S(x) \Box\!\!\rightarrow M(x)$ true in all possible worlds which contain an exact copy of s but false in some possible worlds in which x does not possess P. From this condition it follows that just one case of a non-finkish exemplification of a given disposition is sufficient to classify this disposition as such. Barring the improbable case of dispositions whose all occurrences throughout the history of the universe are finkish, this modified condition should be enough to distinguish dispositional properties from categorical ones.

Regarding the antidotes, the problem is that the possibility of an antidote seems to make the conditionals corresponding to a given disposition strictly speaking false in all circumstances. But this objection does not take into account the way counterfactual conditionals work. It may be the case that for each situation in which an object x has a disposition D and its stimulus S occurs, there is a possible world in which an antidote A prevents the manifestation M to happen. But this fact by itself does not make the counterfactual "If it were $S(x)$ then it would be $M(x)$" false. For it to be false, the antidote should occur in all possible worlds that are closest to the actual one, and clearly I can imagine an actual situation such that worlds in which an antidote operates are too far removed from this situation to be treated as the closest stimulus-worlds. So much for the threat from finks and antidotes.

In addition to the general conditional characteristic of dispositional properties, I have to make provisions for some special cases which will be important in later discussions. Firstly, the conditional implied by a disposition ascription may be probabilistic rather than deterministic, meaning that the disposition ensures only that if the stimulus event occurs, the manifestation has a certain chance of occurring. In such a case we should speak about probabilistic dispositions (propensities) rather than deterministic ones. Secondly, we should leave room for an even more special kind of dispositions—spontaneous ones. Spontaneous

[6] Cf. Martin (1994).

[7] Cf. Bird (1998).

dispositions don't require any stimulus event; they are simply unconditional probabilistic dispositions of an object to display a particular manifestation. Technically, their ascriptions don't entail any conditionals, but rather an unconditional statement that the manifestation has a certain chance to occur.

Finally let me explain what I mean by causal bases (grounds) of dispositions. Following the standard approach, I will define a causal base of a given disposition D as a property G satisfying the following requirements:[8]

(1) each time when object x possesses property G, x has disposition D;
(2) G is an intrinsic property of x;
(3) if D is manifested, G is a cause for the occurrence of manifestation M given the stimulus condition S.

This definition as it stands does not prevent the disposition D itself from being its own base. However, the most interesting cases of causal bases are those in which bases are distinct from their dispositions.[9] We will say that if a disposition D has a causal basis G distinct from D, D is grounded in G. The main question that we will have to consider now is whether there can be ungrounded dispositions.

2 Against Ungrounded Dispositions

Several attempts have been made to argue for the Groundedness Thesis, i.e. the thesis that all dispositions are (necessarily) grounded in some properties. Some insist that the causal, categorical basis of a disposition is necessary in order to account for the existence of this disposition when unmanifested, or in order to play the role of a truthmaker for an appropriate conditional.[10] The proponents of ungrounded dispositions can counter this argument by pointing out that there is no reason why the disposition itself cannot account for the truth of the conditional between its manifestations. The most widely considered challenge to the idea of ungrounded dispositions is the extensive argument presented in Prior et al. (1982). Their argument consists of two parts, one dealing with deterministic dispositions and the other with the probabilistic ones. The case of deterministic dispositions seems to be quite straightforward. In the closest possible world in which the stimulus occurs, the manifestation has to happen. The possible world closest to our world should be deterministic, hence there has to be a causally operative condition sufficient for the manifestation to occur there. The causal basis of the disposition is subsequently identified with the property of the bearer which, together with the stimulus condition, jointly constitutes the causally operative sufficient condition.

Having established to their satisfaction the existence of causal bases, PPJ present three further arguments for the thesis that dispositions are always distinct from their causal bases. The first one is just an empirical generalization from the cases of multiple physical realisability of common dispositions such as fragility, and as such it does not exclude the possibility

[8] Mumford generally characterizes the basis of a disposition D as the property, or property-complex, in virtue of which the object has D (Mumford 1998, p. 97). He later admits that a typical relation between dispositions and their bases is the causal relation, but he also notes that another possible relation is when dispositions supervene on their bases. George Molnar, in turn, says that bases (grounds) confer powers on their bearers, which he then explicates directly with the help of the causal relation (Molnar 2003, p. 123).

[9] While it is typically assumed that the bases of dispositions should be categorical properties, some authors (Bird, Mumford) stress that we can form bases of dispositions using complexes of other dispositional properties.

[10] Cf. Armstrong (1968, p. 86ff).

that some dispositions may be identical with their causal bases. The second argument appeals to the situation known from the antidote scenario: it is possible that the manifestation can be prevented from taking place despite the stimulus and the causal basis being present. PPJ take this scenario as a situation in which the causal basis is present but the corresponding disposition is not. However, the fact that the manifestation is blocked by an antidote does not imply that the disposition is not there. PPJ apparently presuppose the simple conditional analysis of disposition ascriptions, but as we pointed out in the first section this analysis is most certainly incorrect, and for that reason the second argument fails. In their third argument PPJ appeal to the fact that both names of the disposition and of its causal basis are rigid designators, and hence if the identity holds, it holds necessarily. But according to PPJ the fact that G is a causal basis of D is contingent: in another possible world D can have a causal basis different from G. Again, I don't see any general arguments in favour of the contingency of the causal grounding of *all* dispositions other than an empirical extrapolation from typical cases such as fragility, and this does not exclude the possibility that some dispositions can possess their bases necessarily, and thus the identity between the disposition and its causal basis is not ruled out.

One standard response to PPJ's argument is that it falls short of establishing that the causally operative sufficient condition for the occurrence of the manifestation (minus the stimulus condition) is an intrinsic property of the bearer of the disposition. The sufficient condition may include extrinsic properties of the bearer, or even properties of objects other than the bearer.[11] But I doubt that this is a very effective strategy of defending ungrounded dispositions. If the only loophole in PPJ's argument was the issue of intrinsicness, the only chance of finding ungrounded dispositions would be among the cases in which the manifestation of a disposition is brought about by the joint operation of the stimulus conditions and some further properties extrinsic to or even external from the bearer of the disposition. But this observation would severely restrict the doctrine of ungrounded dispositions. For instance it seems perfectly legitimate (as acknowledged by the proponents of ungrounded dispositions) to expect that a fundamental disposition of an elementary particle has manifestations which, in given conditions, are brought about by intrinsic features of the particle only (charge, spin, etc.). But in such a case PPJ's argument seems to have full force.

Instead of criticising the part of PPJ's paper which argues for the existence of the causally operative sufficient condition, I suggest focusing on the arguments purporting to establish that this sufficient condition (minus the stimulus) is always distinct from the disposition itself. I have already indicated that none of the three submitted arguments seems to be conclusive. Consequently, we can agree that in most typical cases the bearer of the disposition possesses a property which together with the stimulus condition is the causally operative sufficient condition for the manifestation, but this property may be none other than the disposition itself. Determinism does not necessitate the thesis that all dispositions are reducible to their causal bases.

Nor does indeterminism, in spite of PPJ's claim. In the second part of their argument for the groundedness claim they attempt to formulate a reductio for the thesis that in an indeterministic world there may be dispositions which lack causal bases. If dispositions do not have

[11] This response to PPJ's argument can be found in Molnar (2003, p. 129) as well as Fara (2009). It should be noted that both Molnar and Fara additionally question the assumption that the manifestation has to occur in the closest possible world, the reason being that an antidote can prevent the manifestation from happening while the disposition and the stimulus are still present. I am not entirely convinced by this line of defence against the groundedness thesis. If a given disposition has at least one actual instance in which it is not accompanied by any antidote, the manifestation in the closest possible world in which the stimulus is present has to occur, and the reasoning leading to the existence of a causal sufficient condition for this occurrence seems to be valid.

bases, there might be objects differing only with respect to their particular dispositions, and nothing else. Suppose that we have two such objects *A* and *B* whose all intrinsic properties are the same with the exception of their dispositions to do *M* when *S*: object *A* consistently does *M* when *S* whereas *B* never does *M* when *S*. PPJ argue that because *A* and *B* are qualitatively identical by assumption, in assessing one object's probabilistic disposition to do *M* we ought to take into account the behaviour of the other one. If we do that, it turns out that actually both *A* and *B* have the same probabilistic disposition to do *M* when *S*, which contradicts our initial assumption. PPJ admit that it is hard to imagine that someone would actually reason in such a way, but they think that this is only because of our unrealistic assumption that *A* and *B* are qualitatively indistinguishable. In practice, given that *A* and *B* consistently show radically different dispositions to *M* when *S*, we would normally look for some difference in their other properties to account for this fact.

PPJ's argument seems to me clearly incorrect. From our initial assumptions it neither follows that *A* and *B* actually have the same probabilistic dispositions, nor that it is rational to infer such a conclusion from the available data. No scientifically valid methodology can justify the conclusion that an object which never shows property *M* under the condition *S* actually *possesses* the propensity to *M* when *S*. The only methodologically valid conclusion close to the one PPJ suggest is that if we didn't know whether an object in question is *A* or *B*, it would be rational to expect that there is a fifty-fifty chance that it will *M* when *S*. But this probabilistic statement does not reflect an objective disposition of the object, but rather our ignorance regarding its possessed disposition.

3 The Ungrounded Argument

The thesis that all dispositions are grounded in their causal bases is difficult to establish conclusively due to its universality. On the other hand, it should be relatively easy to prove its negation: all we need is one good counterexample. But some friends of ungrounded dispositions attempt to defend their position in a more general fashion. Mumford presents an argument—the Ungrounded Argument—which purports to demonstrate generally that ungrounded dispositions exist, without actually producing a concrete example of such a disposition.[12] Mumford's argument relies on empirical generalizations, as well as on some assumptions of a more philosophical character. The main empirical premise of the argument is that there are subatomic particles which are simple, i.e. which have no low-level components or properties. A more philosophical premise of the argument, but still with a hint of empirical evidence behind it, states that the properties of subatomic particles are dispositional. And finally there is a premise of an unquestionably metaphysical character stating that the grounds of dispositional properties of an object can be found only among the properties of lower-level components of the object. From these premises it clearly follows that subatomic particles possess dispositions that are ungrounded.

I am not going to contest the first two premises of the argument, although I would like to see some reasons for claiming that properties of fundamental particles are dispositions. But we will return to this question later in the paper. For now let us focus on the third premise. It relies on the micro-reductive programme of explaining dispositional properties of everyday macroscopic objects in terms of their microstructures. But Mumford himself admits that the lower-level grounding is not the only conceivable way of grounding a disposition. He mentions two other types of grounding: self-grounding and ultra-grounding.

[12] This argument has been originally formulated in Mumford (2006) and has been further analysed in (2007).

Self-grounding can be quickly dismissed as equivalent to not being grounded, whereas ultra-grounding (grounding in higher-level properties) has too little justification in scientific practice. But what strikes me is that the list of possible types of grounding given by Mumford seems to be incomplete. Why can't we ground a disposition of an object in a property of the same level as the disposition itself, and yet numerically distinct from it? As a matter of fact, such grounds of everyday dispositions seem to be quite common. Consider for instance the disposition of a ball to roll down the hill when left unsupported. It seems natural to assume that this disposition is grounded in a categorical property of the ball, which is its round shape.[13] No microstructure needs to be invoked in order to make the reduction; indeed we could even assume that the ball has no internal structure at all (unless we accept that simple objects have to be point-like), and still we would be able to claim that the disposition has a causal basis. It seems to me that this example shows that it is too hasty to jump from the premise that an object is simple to the conclusion that its dispositions cannot have distinct causal bases.

I believe that there are genuine ungrounded dispositions of physical objects. But I don't think that we can prove their existence using high-level philosophical assumptions and empirical generalisations. Instead, I propose to look more closely at some particular examples of properties that occur in one of the most fascinating physical theories – quantum mechanics. It turns out that there are good reasons to believe that some of these quantum properties which are of a clearly dispositional character cannot possess any causal, categorical basis.

4 Quantum Dispositions: Spin

Let us consider the property that can be seen as the epitome of a quantum characteristic: spin. It may be useful to briefly sketch the historical development of this concept.[14] Initially the concept of the spin of an electron was conceived in a classical manner as the angular momentum associated with the rotation of the electron about its own axis. Angular momentum is defined classically as the vector whose length equals the product of the body's moment of inertia I (the rotational equivalent of mass) and its angular velocity ω ($L = I\omega$). The vector of angular momentum is parallel to the axis of rotation, and its direction is determined by the right-hand rule. In classical physics rotation of a charged particle gives rise to its magnetic moment, whose value is a function of the angular momentum and the charge. Thus it is expected that electrons should interact with magnetic field the same way classical magnetic dipoles do. This hypothesis was put to the test in the Stern-Gerlach experiment. In this experiment electrons pass through an inhomogeneous magnetic field which creates a deflecting force whose value depends on the orientation of the magnetic moment with respect to the direction of the magnetic field. The deflecting force acting upon an electron is directly proportional to the cosine of the angle between the magnetic moment of the electron and the direction of the magnetic field. In other words, the force is proportional to the length of the component of the magnetic moment along the direction of the field, and thus the force should reach its maximal value for electrons whose magnetic moment is parallel to the field lines,

[13] Clearly the roundness of the ball is not identical with its disposition to roll down the hill. In a possible world in which the law of gravity does not operate objects can be round without having the disposition in question. Interestingly, Mumford himself admits the possibility of reducing dispositions to macrostructural properties in his earlier book (1998, p. 97), using an almost identical example of the disposition of a ball to roll.

[14] For a nice introductory exposition of the experimental roots of the notion of spin see e.g. (Hughes 1989, pp. 1–8)

and its minimal value (equal zero) when the magnetic moment happens to be perpendicular to them.

It should be clear that according to the classical picture of spin we should observe all possible values of deflection from the maximal value "up" through zero to the maximal value "down" in a randomly prepared ensemble of electrons. However, the actual outcome obtained experimentally is radically different from the expected one. Only two discrete values of deflection are observed: up and down. It looks as though the angular momentum of an electron could assume only one of two values in a given direction. This is clearly incompatible with the behaviour predicted on the basis of the classical picture of a rotating sphere, for we can always find a direction along which the angular momentum equals zero (any direction perpendicular to the axis of rotation will do). Moreover, from theoretical calculations it follows that in order to account for the observable value of the magnetic moment of the electron we would have to assume that the speed of the rotation of the electron will exceed the speed of light. Consequently, the classical definition of spin as the angular momentum associated with the rotation of the electron has to be abandoned, which leaves us with the task of finding an alternative physical explication for the notion of spin. Without an underlying mechanism, the only available interpretation seems to be that the spin of an electron in a given direction is identical with the electron's disposition to be deflected either up or down in a non-uniform magnetic field aligned in the selected direction.

Is this spin-disposition grounded in some other physical property of the electron? One possibility of its grounding has been already excluded: spin is definitely not reducible to the property of rotating around the particle's own axis. Incidentally, if this reduction were possible, it would constitute an example of the same-level grounding in a categorical property, as rotation clearly defines a categorical property of the whole particle, and not its lower-level components.[15] But orthodox quantum mechanics does not seem to identify any property which could play the role of the causal basis for spin. However, we should note that such a causal basis can be found in one non-standard interpretation of quantum mechanics, known as the Bohm theory. Without going into technical details we can observe that, according to one popular reading of Bohm's theory,[16] position is the fundamental quantum-mechanical property on which other measurable properties depend. The complete description of a quantum particle, for instance an electron, consists of two elements: its exact spatial location and its wave function (the pilot wave, as it is sometimes called). According to the fundamental equation of motion of Bohm's theory, the velocity of the electron at a given moment is uniquely determined by its wave function at the same moment, hence the trajectory of the electron is fixed by its initial position, the initial form of the wave function, and the physical interactions which make the wave function evolve in accordance with the ordinary Schrödinger equation. The wave function plays two important roles in Bohm's theory: besides acting as a field of force on its associated particle it also contains the information about the probability density of finding the electron in a given location, exactly as in the standard quantum theory.

The measurement of spin by the Stern-Gerlach apparatus amounts to the determination of the position of the electron after having emerged from the magnet. Hence the outcome of a spin measurement in any direction is determined by the position of the electron and its wave function before entering the magnet, but the algorithm which decides what the

[15] The proponents of dispositional monism (or pan-dispositionalism, in Molnar's terminology) would obviously deny the categoricity of rotation, on the basis of the assumption that all (fundamental) properties are essentially dispositional. But a dispositional interpretation of spatiotemporal properties, to which rotation belongs, encounters well-known difficulties. For a discussion of the problem and its possible solutions see Bird (2007, pp. 147–168).

[16] A non-technical introduction to Bohm's theory can be found in Albert (1992, pp. 134–179).

outcome will be is somewhat complicated. If the initial wave function happens to be an eigenfunction of the spin component to be measured, the outcome will always be the same (it will be the eigenvalue corresponding to this eigenfunction) regardless of the exact position of the electron within the wave function. However, the situation changes when the initial wavefunction is a superposition of two eigenfunctions, one associated with the "up" outcome, and the other with the value "down". In accordance with the Schrödinger evolution, the "up" wave function will evolve following the upper path, whereas the "down" wave function will follow the alternative "lower" route. Now the recorded outcome depends on the precise position of the electron within its initial wave function. If the electron happens to be in the upper part of the initial wave function, at a certain moment in the process of the separation of the two components the electron will find itself in an area where the only non-zero value of the entire wave function will come from its "up" component. As a result, from this moment on the electron will be guided by the "up" wave function and it will emerge deflected up rather than down. One interesting consequence of this model of spin measurement is that the recorded outcome depends also on the orientation of the apparatus. To see this, let us suppose that we have turned the magnet upside down without changing the initial location of the electron. This of course means that now electrons deflected upwards will have the value of the spin component "down". However, the rules of dynamics dictate that the electron will yet again follow the upper path, but this time it will be guided by the component of the wave function corresponding to the value "down", and the recorded outcome of the spin will be down.

What property of the electron is spin ultimately reducible to in Bohm's theory? There is no straightforward answer to this question. As we have seen, in the most general case the outcome of spin measurement depends causally on three factors—the electron's position within its wave function, the wave function itself, and the spatial orientation of the apparatus—of which only one can be uncontroversially claimed to be an intrinsic property of the electron (namely, its localisation within the wave function).[17] The ontological status of the electron's wave function is somewhat controversial. In popular expositions of Bohm's theory it is often interpreted as representing a real physical field (following the idea of de Broglie). But this assumption leads to difficulties when we take into account that in order to describe a many-particle system containing n particles we need to write its wave function in a $3n$-dimensional phase space. Moreover, it is unclear to me what the ontological relation of the wave function to its electron is. Does the electron "produce" its wave function the same way it produces the electromagnetic field around itself (in which case the wave function could be interpreted as representing some property of the electron)? If yes, doesn't the guiding postulate imply that the electron is actually causing its own movement through space? One intriguing strategy to avoid these thorny issues has been suggested by Martin Thomson-Jones (unpublished). He proposes to interpret the guiding wave function with the help of a set of irreducible dispositions of the electron to move in a particular direction given its position and the external forces.[18] If we adopted this perspective, ultimately the spin of the electron would be reducible to dispositional, not categorical properties, and the Ungrounded Thesis would be vindicated.

[17] Because the wave function of the electron is considered to be one of its properties, the location of the electron relative to the wave function does not depend on the location of any other object, and therefore can be interpreted as intrinsic. Of course this is not true about location in general: the location of the electron with respect to the measuring apparatus is extrinsic, as it can be changed by merely moving the apparatus. I am grateful to Alexander Bird for alerting me to this problem.

[18] A similar suggestion can be also found in Suárez (2007, p. 436).

5 Quantum Dispositions: Position

Let us now return to the standard quantum theory with no hidden variables. Besides fundamentally non-classical properties such as spin, quantum mechanics also employs well-known old-fashioned properties, for instance position or momentum (velocity). What is their ontological status? Position seems to be a typical non-dispositional property: occupying a given spatial region does not directly involve any powers to do things.[19] Does this classical interpretation carry over to quantum mechanics? It may be argued that actually it doesn't. Even classical properties receive a new interpretation within quantum theory which may be seen as more amenable to dispositional approach. To illustrate this let us consider another famous quantum-mechanical experiment—the double slit experiment. As we clearly see from the appearance of the interference pattern, an individual electron does not seem to possess a well-defined trajectory (passing either through the first or the second slit). Rather, its position at each moment of the passage is characterised with the help of a probability distribution. But this is not to be interpreted as the fact that the electron passes either through the first slit with probability 1/2 or through the second slit with the same probability. We are supposed to interpret this probabilistic description as referring not to the actual state of the electron but rather to its potential position after measurement. Hence the most natural way to interpret the state of the electron when it is in a superposition of different eigenstates of position is in terms of probabilistic dispositions to certain future behaviour. The electron passing through the barrier has the propensity to reveal itself next to the first slit with probability 1/2, and the propensity to be found next to the other slit with the same chance 1/2.

The dispositional interpretation of quantum properties is a direct consequence of the probabilistic character of quantum states. However, in some cases even quantum properties assume (almost) precise values. The spin of an electron deflected upward by a Stern-Gerlach apparatus has the precise value "up". The position of an electron impinged on a photographic plate is well-defined within a narrow margin of error. In such cases it may be tempting to speak about quantum systems possessing categorical properties, as opposed to dispositional ones. Actually, some philosophers of science propose to make the following distinction: when the quantum system is not in an eigenstate for a given operator (and hence the corresponding observable receives a non-trivial probability distribution over its values) it possesses a set of probabilistic dispositions to reveal particular values of the observable. On the other hand, when the system is in an eigenstate of the observable, we can attribute to this system a categorical property.[20] While this interpretation may initially seem to be intuitive, below I present two arguments suggesting that even eigenstates should be interpreted in terms of (deterministic) dispositions rather than categorical properties.

Let us consider a system consisting of two particles prepared in an initial state such that the distance between them is fixed, although none of the particles has a well-defined position (incidentally this is part of the description of the entangled state used in the original EPR

[19] Bird would disagree. See his (2007, pp. 161–168).

[20] I think this is essentially Mauro Dorato's view as expressed in the following passages: "Within QM, it seems natural to replace 'dispositional properties' with 'non-definite properties', i.e. properties that before measurement are objectively and actually 'fuzzy', "The passage from dispositional to non-dispositional is the passage from the indefiniteness to the definiteness of the relevant properties" (Dorato 2007, p. 255). A similar distinction between categorical and dispositional properties in QM seems to be suggested by Mauricio Suárez (2004). Here is how he explains this approach: "A slightly more careful formulation would demand the ascription of two distinct properties: "spin", which would obtain when and only when a value of spin obtains, and—let us call it "spinable"—which would be the dispositional property that obtains regardless. (…) The possession of "spinable" would explain the occurrence of "spin", but the dispositional property would not be reducible to the categorical" (2004, p. 10).

argument). The quantum-mechanical formalism presents this situation as follows: particle number one is not in an eigenstate of its position observable X_1, nor is the other particle in an eigenstate of its position X_2 (for the sake of simplicity we consider the case to be one-dimensional). However, if we introduce now a new observable $X_1 - X_2$ which measures the distance between the two particles, then according to the initial conditions the state of the entire system is an eigenstate of $X_1 - X_2$ corresponding to some precise value d. Now suppose that we interpret this fact as implying that the system as a whole possesses the categorical property of having its components spatially separated by the precise distance d. This translates simply into the statement that particle number one is located at the distance d from the location of particle number two, which can be argued to imply, according to the ordinary semantic rules of natural language, that particle number one is located somewhere. In other words, there is a place at which particle one is located (if you ask what this place is, the answer is: it is the place located d meters from the location of particle two). But this conclusion seems to violate the assumption that the position of neither particle is well-defined.[21]

The "paradox" described above can be solved as follows. I suggest resisting the temptation to interpret the fact that the system is in an eigenstate of the operator $X_1 - X_2$ as implying the existence of the categorical property of the system described above. Instead, my proposal is to treat the fact about the operator $X_1 - X_2$ and its value as the sign of the existence of a particular disposition of the entire system. The system's disposition is such that each time a measurement of the positions of both particles is performed their spatial separation is bound to be equal d regardless of the precise values obtained for each particle separately. This deterministic disposition of the entire complex system is perfectly compatible with the fact that each particle possesses only probabilistic dispositions to reveal particular positions. The key point is that before the measurement the system does not possess any precise value of the distance between the particles, because this value will be revealed only as a manifestation of the disposition in the right circumstances. This is analogous to the familiar case of fragility: we would not say that a vase is broken all the time when it's fragile, but only that it is disposed to break if dropped on a hard surface.

Another argument is based on the observation that if we associate categorical A-properties with every eigenstate of an observable A, we will have to accept that quantum mechanics is strongly non-local, i.e. that it is possible to immediately change a physical property of a distant system by merely selecting a local observable for measurement (this is akin to so-called parameter dependence). Henry P. Stapp has shown that when two spin-half particles are prepared in a certain state known as the Hardy state, the probability of obtaining a particular outcome on one particle is 1 given that the other particle undergoes measurement of a certain observable (regardless of its outcome), while when an alternative selection is made the probability drops to less than 1.[22] Under the categorical interpretation of eigenstates it looks as though a mere selection of a parameter to measure can create a new categorical

[21] This case is just one of many examples of the general situation in which a compound system is in an eigenstate of an operator defined as a function of some observables pertaining to separate components, while none of the components is in an eigenstate of their respective observables (another well-known example is the singlet-spin state of two spin-1/2 particles, where the total spin equals zero while separate spin-components remain indeterminate).

[22] Stapp (1997) contains the original formulation of the proof, while its most recent version can be found in Stapp (2004). Stapp's argument is based on the logic of counterfactual conditionals, where the truth of the statement "If observable A were measured, the outcome would be a" is taken as a counterfactual interpretation of the fact that the probability of the outcome a is one. Stapp claims that his argument proves conclusively that quantum theory is strongly non-local. In my extensive analysis of his claim I show that the argument goes through only if we assume that there is a categorical property of the system which underlies the truth of the aforementioned counterfactual (Bigaj 2010).

property of a distant system. On the other hand the dispositional account of eigenstates may be used to blunt the threat of non-locality thanks to the fact that the notion of a dispositional property is more flexible than that of a categorical property (it may be claimed, for instance, that quantum dispositions of a system do not have to be localized entirely where the system is located).

As we remember, in Bohm's theory position does not admit a dispositional interpretation, as it plays the role of a categorical ground for other dispositional properties, such as spin. It may be worth adding that there is a widely discussed alternative interpretation of quantum mechanics, known as the spontaneous localization theory (or GRW theory), which supports the dispositional character of position in a novel way. According to this theory, each massy particle has a non-zero probability of undergoing a random "hit" which turns its initial wave function no matter how spread it was into an almost perfectly localised one. The probability of an individual particle to undergo such a spontaneous localisation event is assumed to be extremely small, but if the number of particles in a given system is sufficiently big (as is the case for macroscopic objects), it is virtually certain that after a short period of time one particle will get localised somewhere, "dragging" all the remaining ones along. This assumption explains why macroscopic objects are never observed to be in superposed states, and it also accounts for the measurement processes which use macroscopic devices. It seems natural to interpret a spontaneous localisation event as a manifestation of an underlying probabilistic disposition which every particle with mass possesses.[23] Such a disposition doesn't need a stimulus, and hence qualifies as a spontaneous one. It may be claimed that spontaneous dispositions to localise in the GRW theory ground all other properties of quantum systems. For instance, the fact that an electron in the double-slit experiment passing through the screen has one-half chance of being found next to one slit can be reduced to the following rather complex property of the pointer of a position measuring device: the pointer has one-half chance to be localised in a particular position due to the spontaneous localisation of some of its molecules after interacting with the electron.

6 The Reality of Ungrounded Dispositions

The examples of quantum-mechanical dispositions presented so far support the Ungrounded Thesis (barring the case of the Bohmian mechanics). But the existence of "bare" dispositions without causal bases is in itself worrisome. What kind of being do such ethereal entities as ungrounded dispositions possess? An instantiation of a bare disposition does not imply that the disposition is manifested, but only that the manifestation is possible, given the right circumstances. Thus the being of a disposition involves something that is merely possible, not actual. Without a grounding base, an unrealised disposition seems no more than empty space—a "being" with no actuality. To allay these misgivings, Mumford argues that ungrounded dispositions bear all the hallmarks of genuine properties. Dispositions are capable of being instantiated, they retain their identity through each of their instantiation, and, most importantly, dispositions make a difference to the causal role of the objects that possess them (Mumford 2007, p. 75ff.). Bird, on the other hand, meets head-on some metaphysical objections directed against the actuality of ungrounded dispositions (2007, pp. 100–114). One of these objections can be spelled out with the help of the following simple argument. According to dispositional essentialism, ungrounded dispositions are actual properties. More

[23] An extensive argument in favour of the dispositional interpretation of the GRW theory can be found in Dorato and Esfeld (2010).

accurately we should say that the possession of a disposition D by an object x can be an actual state of affairs at t. But the being of disposition D involves some unrealised states of affairs—in particular, an unrealised manifestation M of D by object x at time t. (In fact it can even be claimed that the whole being of D is exhausted in the unrealised possibility of M given the right stimulus S). From these two premises it follows that the *unrealised* manifestation M at t has to be (part of) an *actual* state of affairs, which many would take as bordering on inconsistency.[24]

Bird's reply to this challenge is based on his distinction between the seemingly related notions of being unrealised (unmanifested) and being non-actual. Actuality is explicated as existence in the actual world. According to some approaches (in particular modal realism) unrealised possibilia exist in other possible worlds. But Bird rejects the doctrine of modal realism. For him unrealised possibilia exist in the actual world. In support of his thesis he invokes the Barcan formula, which justifies the transition from the possibility of existence to the existence of possibility. More specifically, Bird insists that unrealised possibilia are contingently abstract objects. If a fragile vase is well protected, its fragility is never realised, and its shattering is a mere abstract object existing in the actual world. But if the vase were dropped, its shattering would become a concrete state of affairs.

One problem with this solution as I see it is that the being of a concrete state of affairs—the possession of fragility by the vase—involves an abstract object (its shattering). But perhaps there isn't much to be worried about: after all, concrete states of affairs routinely involve properties and relations which are abstract objects. However, the case of unrealised possibilities is slightly different. The state of affairs expressed in the proposition "This ball is red" involves an abstract object—the property red—as well as a concrete one. When this state of affairs ceases to be part of the actual world, this does not imply that the property of being red no longer exists, but only that the ball no longer exemplifies it. But if an object loses its disposition—for instance a fragile vase is hardened in a high temperature—the unrealised possibility of its shattering when dropped disappears altogether. It looks like we are capable of destroying an abstract object by merely manipulating concrete things.

Another problematic feature of Bird's analysis is that he postulates the actual existence of the objects of which some seem to be mutually incompatible. It is unquestionable that many possibilities exclude each other: a glass of water can be turned into ice or into water vapour, but it surely can't be both. So in what sense can the possible ice cube and the possible water vapour containing the same molecules exist side by side? One answer may be that the incompatibility in question does not exclude the joint existence of two possibilities (interpreted as abstract objects) but only their joint realisability. This is analogous to the case of universals: the properties of being red and being yellow are incompatible in the sense that they cannot be jointly exemplified (no object can be both completely yellow and completely red), but they can coexist as abstract entities. The dispositions of water to turn into ice and into vapour cannot be jointly realised because they require mutually incompatible stimuli (low and high temperatures, respectively), but it can be claimed that both dispositions coexist peacefully in a given sample of water. However, in the last section we will consider a more troublesome case of incompatibility between certain dispositions, which can cast serious doubts on the strength of their unrealised being.

[24] Bird claims that this conclusion has to be accepted by anyone who rejects both Megarian actualism (the view that the world does not contain any modal features) and modal realism (2007, p. 109).

7 Degrees of Reality and Incompatibility

The problem of the reality of bare dispositions can be approached from a different angle. Without questioning the fundamental fact that ungrounded and unrealised dispositions exist in the actual world, we can ask how "robust" their being is. I suggest that it could be useful to introduce the notion of a degree of being (actuality), for instance on a scale from 0 to 1. Intuitively, this number would give us a measure of how easy it is to "wipe out" a given property. Let me give an example illustrating an extreme case when the degree of reality of a given disposition equals virtually 0. Suppose we have a disposition D with manifestation M and stimulus S, and suppose that as a matter of nomic necessity each occurrence of the stimulus S causes D to disappear. This would be a case of an extremely finkish disposition. You don't have to be a radical empiricist or verificationist to see that in such a bizarre case the disposition D is virtually non-existent, as D has no chance whatsoever of being manifested, being a self-defeating power. On our scale of the degree of being this disposition would receive a value close to zero if not just zero. But I will argue that we can find real examples of dispositions that fall somewhere between 0 and 1. Quantum dispositions will provide such examples.

Suppose that we selected an electron that had been deflected upwards in a Stern-Gerlach apparatus aligned in the z direction. The electron possesses now the deterministic disposition to reveal value up of the spin in the z direction when measured (let's symbolise this by $D(s_z, \text{up})$. But at the same time the electron possesses a set of probabilistic dispositions to reveal different values in all directions other than z. For instance, the electron has a fifty-fifty chance of being deflected up or down in the x direction perpendicular to z. Let us represent these probabilistic disposition as $D_{1/2}(s_x, \text{up})$ and $D_{1/2}(s_x, \text{down})$. In order to make these dispositions manifest we have to perform a measurement M_x, which activates the electron's manifestation, i.e. the objective chance of revealing the value up or the value down. The measurement M_x brings about several changes. First of all, it eliminates the probabilistic dispositions $D_{1/2}(s_x, \text{up})$ and $D_{1/2}(s_x, \text{down})$, replacing them with one deterministic disposition $D(s_x, o)$, where o is the actual outcome obtained in the experiment (either up or down). But this elimination comes sufficiently late not to be counted as a fink—the previously existing probabilistic dispositions had ample time to give rise to appropriate manifestations before they were eliminated. But, more interestingly, the measurement M_x has a direct destructive impact on the disposition $D(s_z, \text{up})$ associated with the z direction. Because different spin components are mutually incompatible (non-commuting), the electron cannot at the same time possess both deterministic dispositions $D(s_z, \text{up})$ and $D(s_x, o)$. In fact, it has been theoretically predicted and empirically verified that measurement M_x eliminates the deterministic disposition $D(\mathrm{s}_z, \text{up})$ and replaces it with appropriate probabilistic dispositions. Here we have a case of "mutual finks": there are two coexisting dispositions such that an attempt to realise one disposition leads inexorably to the destruction of the other one. In such a case one may ask a legitimate question: do these two dispositions really coexist in the fullest sense of the word?

One may suspect that because different spin components look like aspects of one and the same property (which they aren't), these negative correlations can be brushed away as being a consequence of a conceptual dependence between exclusive values of the same quantity. This type of conceptual dependence is responsible for the fact that when we realise one of the many probabilistic dispositions to reveal particular values of the same quantity, all dispositions to give rise to values other than the one actually obtained will disappear. However, the phenomenon of mutual incompatibility is commonplace in quantum mechanics, and often it involves properties that are in no way conceptually related, such as position and momentum.

Again, as in the previous case, any attempt to manifest dispositions related to the momentum of a particle results in destroying the particle's disposition to reveal a precise position. But the incompatibility of descriptions involving precise values of position and momentum is not a result of conceptual necessity, but is rather a nomic feature of the world.

I would like to defend the claim that the existence of incompatibility relations between measurable properties interpreted as dispositions show that the degree of reality of quantum dispositions is lesser than the degree of reality of ordinary, macroscopic dispositions with causal bases. In support of this claim I offer the following observations. The main point I want to make is that exactly analogous cases of conceptually independent dispositions which would stand in the aforementioned incompatibility relation to each other are missing from the world of classical dispositions. The classical situations in which a manifestation of one of two coexisting dispositions entails the destruction of the other one can be reduced to a limited number of special cases, and all these cases are arguably different from the quantum scenario.

One typical case is when two dispositions involve alternative and mutually exclusive possibilities. My ten pound note has the disposition to buy me a lunch, and also a different disposition to pay a parking fee, but once one of its dispositions is realised, sadly the other one is no longer a possibility. But this is obviously a case of conceptual dependence between dispositions. The purchasing power of a currency unit is given by the amount of various goods it can buy, but by definition only one purchase can be made with it (this is similar to the fact that by definition an object can be assigned only one numerical value of its mass at a time, and hence all distinct values are mutually incompatible). Another case of classical incompatibility is when the realisation of one disposition leads to the destruction of its bearer, hence the other disposition is no longer exemplified. The realisation of the vase's fragility destroys its disposition to bring about aesthetical experiences (actually it destroys all of its dispositions, since the vase is no longer there). But clearly this is not what happens with quantum dispositions, where the particle undergoing measurement is not in any way destroyed (we are limiting ourselves to the so-called first type, non-destructive measurements). The classical situation which comes closest to the quantum case is when the stimulus leading to a manifestation of one disposition affects the causal base of the other one. A copper wire has the potential of becoming a superconductor when cooled below a certain critical temperature close to the absolute zero, but obviously such cooling has a dramatic effect on other dispositions of the wire, for instance its malleability. But we can causally explain this effect by pointing out how low temperatures affect the molecular structure of materials such as copper. No similar explanation is available in the quantum case due to the fact that all involved dispositions are ungrounded.

As we have seen, quantum mechanics gives us plenty of examples of apparently ungrounded dispositions of a given system which are in no way conceptually connected, and yet are such that the realisation of one of them eliminates the other one without destroying the system, and in a way that has no obvious causal explanation in terms of some underlying processes. It is not immediately clear how to incorporate this fact into our best metaphysical theory of dispositional properties, but one suggestion is that we should take a second look at the thesis that ungrounded dispositions have the same being as categorical properties (if there are any). Adopting the conceptual framework in which it makes sense to speak about degrees of being we could say that a pair of incompatibility-related dispositions possessed by a quantum system at a given time has a joint degree of being which falls somewhere between the minimal value (non-existence) and the maximal value (full independent existence). This can be expressed perhaps more vividly in terms of possibilities: the alternative possibilities associated with incompatibility-related dispositions can hardly be seen as enjoying a full degree of joint existence, since one possibility exists only as long as we don't attempt to realise the other one. But how can the degree of being for each individual possibility (disposition) be maximal when their joint degree of existence is less than maximal?

The message quantum mechanics sends to the friends of ungrounded dispositions seems to be somewhat ambiguous. On the one hand, there are good reasons to believe that the quantum theory in its standard interpretation (and also in some non-standard interpretations) supports the existence of irreducible fundamental dispositions. On the other hand, it looks as if a complete set of quantum dispositions attributed at a given moment to a particular system might not possess the required degree of independent, actual existence. Jointly incompatible quantum properties give rise to dispositions which are clinched in the mutual-fink relationship, and this fact undermines the belief in the ontological robustness of quantum dispositions without categorical grounds. Perhaps some form of perspectivalism, according to which properties of the worlds depend to a certain extent on the perspective adopted by an observer, could help mitigate this problem, but the cost of this solution may turn out to be unacceptable for many proponents of dispositional ontology due to its anti-realist flavour.

Acknowledgments This paper was presented at the joint Polish-British workshop "Metaphysics of Science" which took place in Warsaw in January of 2010. I would like to thank the organizers and the participants for their critical comments, especially Alexander Bird, Jan Hauska, Stephen Mumford, and Stathis Psillos. I am also indebted to Alexander Bird and Michael Esfeld for reading the manuscript and making useful comments to it. The work on the article was supported by the Marie Curie Intra-European Grant No PIEF-GA-2008-220301.

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