Powerful properties and the causal basis of dispositions

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1. Introduction

Many predicates are dispositional. Some show this by a suffix like "-ible", -uble", or "-able": sugar is *soluble* in water, gasoline is *flammable*. Others have no such suffix and don't wear their dispositionality on their sleeves. Yet part of what it is to be solid is to be disposed to resist deformation, and part of what it is to be red is to appear red to normal human observers in normal lighting conditions.

However, there is no agreement as to whether dispositional predicates may be given a realist interpretation. For many authors, propositions containing them are made true by states of affairs (or facts) containing categorical, rather than dispositional properties. Many also claim that the states of affairs that make true attributions of dispositions to macroscopic objects are microscopic states of affairs concerning their parts. For example, what makes a vase fragile is the microscopic structure of its molecular constituents, which is what makes the vase break when it falls.

Against these claims, I will argue that what makes a dispositional predicate apply to an object, whether macroscopic or microscopic, whether in common sense or science, is the object's having what I will call a powerful property. If the object is macroscopic, it is another matter whether the property is microreducible. My reasons for supposing that these powerful properties exist are those for postulating theoretical properties generally: they unify existing explanations and suggest new ones.

My plan is as follows. I will begin with a brief sketch of the debate between what I call the reductionist and the realist doctrines about dispositions. Then I will argue that there are many so-called multi-track dispositions, both in common sense and in science, and that accounting for them requires a distinction between the concepts of powerful property and disposition. I will give three examples of multi-track dispositions, one from common sense, one from physics and one from cognitive psychology. In each case in which an object has a multi-track disposition, it has a powerful property that contributes causally to bring about the manifestations of the disposition. The distinction between powerful properties and dispositions makes realism and reductionism compatible: Realism is justified with respect to powerful properties, whereas the ascription of a disposition is reducible: it is made true by the fact that the object has a powerful property, together with laws of nature. I will then justify the existence of real powerful properties against several arguments: that such properties are pseudo-properties having only verbal existence, that only their reduction base is causally efficacious and therefore real, that some dispositions need no such causal basis, and that there are no irreducible multi-track dispositions in the first place.

2. Reductionism and Realism

Take a truthful attribution of the dispositional predicate "is elastic" to a rubber ball.

(1) "This rubber ball is elastic".

Reductionists hold that such attributions of dispositions can be analysed in non-dispositional terms. Carnap (1936/7) has shown that it is impossible to analyse them within standard first order logic, using in particular the material conditional. Goodman's (1955) thesis that they can be analysed in terms of counterfactual conditionals instead, has launched a rich debate, which I will not go into here[1].

Rather, I will consider the thesis, put forward by Quine (1971) and Armstrong (1973), that attributions of dispositions can be reduced in another sense, i.e. in the sense of the reduction between theories. According to Quine, the role and utility of attributions of dispositions is to "refer to a hypothetical state or mechanism that we do not yet understand" (Quine 1971, p. 10). In Armstrong's words, "dispositional concepts leave us in ignorance concerning the properties of the disposed object which give it that disposition" (Armstrong 1973, p. 417). If the attribution of a dispositional predicate to an object is true, there must be some state of affairs involving the object that makes the attribution true[2]. Armstrong suggests that these truthmakers are microscopic: In the case of brittleness, the underlying microscopic state is "a certain sort of bonding of the molecules of the brittle object" (Armstrong 1973, p. 417). Scientific research leads to a "contingent identification" (Armstrong 1973, p. 420) of the disposition with the microstate. The difference between the disposition and its microscopic reduction basis is epistemic. Ontologically speaking, the disposition just *is* the reduction base, vaguely or incompletely conceived.

Prior, Pargetter, and Jackson (1982) who share the reductionist approach to dispositions, deny that dispositions are identical to their reduction basis. They agree with Quine and Armstrong that if an object can truly be said to have disposition D, then it must have a first-order state L that is causally responsible for the manifestations E, which are characteristic of D in appropriate triggering circumstances T. But they argue that the disposition D cannot be identical with this first-order state L, which they call D's "causal basis" because D has, or at least can have, different causal bases in different objects.

In spite of this difference, all reductionist accounts we have mentioned share the idea that every true attribution of a disposition has a non-dispositional truthmaker: a state of affairs, generally taken to be microscopic, or microstructural, involving a categorical property.

I will call "realist" those account of dispositions, which deny that attributions of dispositions must have categorical truthmakers[3]. Realists argue that at least some attributions of dispositions have truthmakers that contain a dispositional, rather than a categorical property. For realists, dispositions are properties in their own right, which can exist without a so-called "categorical basis". Realists typically defend the following theses:

1. Attributions of dispositions cannot be analysed in non-dispositional terms. What makes true the proposition that this ball is elastic is the fact that the ball has a real powerful property of elasticity.
2. Even if some dispositions actually have a basis, they need not have one. It is an empirical issue whether macroscopic powerful properties such as elasticity can be reductively explained in terms of the properties of the microscopic parts of elastic objects. The existence of the macroscopic disposition does not depend on the possibility of such a reduction.
3. Some powerful properties have a reductive basis that is itself dispositional.

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[1] See Mumford (1998), Gnassounou and Kistler (2007).

[2] The theory of truthmaking is developed in Armstrong (2004).

[3] Realist accounts have been put forward by Harré and Madden (1975), Mumford (1998), Ellis (2001), Molnar (2003), Bird (2007). Mellor's (2000) account does not fit in this classification. He takes temperature to be a "real disposition" that causes the manifestations of temperature, but not fragility, because different properties cause the manifestations of fragility in different things.

4. Attributions of dispositions to elementary particles cannot be reductively explained. If there are true attributions of dispositions to elementary particles, their truthmaker must contain a fundamental powerful property that has no basis.

One important thesis of this paper is that the reductionist and realist positions are only incompatible insofar as one conflates two concepts: *powerful properties* (PP) and *dispositions*. My argument will be based on the analysis of so-called "multi-track" dispositions. The distinction between powerful properties and dispositions is required to account for multi-track dispositions such as elasticity. In light of this distinction, it appears that realism and reductionism can be reconciled: Realism is right about powerful properties, whereas reductionism is right about dispositions[4]. The distinction between powerful properties and dispositions requires the notion of a law of nature. Each law in which a given powerful property plays a role, corresponds to a disposition of the objects possessing the powerful property[5].

3. Multi-track dispositions

Gilbert Ryle has observed that many dispositional predicates are tied to a whole set of triggering-manifestation pairs. Such dispositions are often called "multi-track" dispositions. Being elastic is a traditional example of a common sense dispositional predicate whose meaning is related to several manifestations. "We can say that something is elastic, but when required to say in what actual events this potentiality is realized, we have to […] say that the object is contracting after being stretched, is just going to expand after being compressed, or recently bounced on sudden impact." (Ryle 1949, p. 113) Common sense treats elasticity as one property, not several. However, to be elastic entails having several dispositions, in the sense that several conditionals are true of every elastic object; and these conditionals are typically irreducible to one another. If an object o is elastic, then 1) if o is stretched, then o will retract once released; and 2) if o is compressed, o will expand once released, etc. As Mumford remarks, "an ability to bounce (when dropped) is different from an ability to bend (when pressured) though both might reasonably be thought dispositions of something that is elastic, in virtue of its elasticity." (Mumford 2004, p. 172)

Scientific dispositional predicates too are semantically linked to several triggering-manifestation conditionals. Consider electrical conductivity σ. The concept of electrical conductivity is introduced to account for the fact that different materials react with electrical current of different intensity to a given electric field. The conductivity of a given piece of copper can manifest itself in infinitely many ways: by giving rise to electric current of density J_1 in a situation with electric field E_1, to J_2 in the context of electric field E_2, etc. All these dispositions to manifest by current densities J_i, given field E_i, can be expressed by a single law stating that J is proportional to E, $J=\sigma E$. However, electrical conductivity is not just shorthand for the ratio J/E. Rather, it is a theoretical property. It figures in laws relating it to other properties. As with other theoretical properties, postulating its reality allows explaining the links between σ and various other properties. According to one of these laws, the Wiedemann-Franz law, the thermal conductivity λ of metals is proportional to the electrical conductivity σ.

$$\lambda = \sigma \frac{1}{3}\left(\frac{\pi k_B}{q}\right)T$$

[4] As Shoemaker (1980) and Mellor (2000) have shown, the dispositional-categorical distinction applies strictly speaking to predicates not properties. Cf. Kistler (2007). See below, section 6.3.

[5] It is noteworthy that, if it is correct that powerful properties must be distinguished from dispositions, we have a reason to believe that there are laws, against Mumford's (2004) claim that dispositions make laws metaphysically superfluous.

with T: temperature, k_B: Boltzmann's constant, *q*: unit charge.

All metals possessing electrical conductivity σ have thermal conductivity λ. Thermal conductivity is itself a powerful property that gives conductive substances such as copper different dispositions to manifest in different triggering circumstances. Given that σ is lawfully linked to λ, the fact that an object has σ gives it indirectly all the dispositions of λ. σ manifests itself also in the manifestations of λ; in particular, σ can be measured by the manifestations of λ. In this way, the manifestations of σ are multiplied by the laws which link σ to other properties F, and then again by the laws which link these F to still other properties, and so on. Each of these manifestations corresponds to a different disposition that can be truthfully ascribed to an object by virtue of its possessing σ.

A person's iconic memory of a stimulus is a cognitive multi-track disposition. Iconic memory is a form of short-term memory - it decays rapidly, lasting for approximately 1 sec - that has been postulated by Sperling (1960) to account for a surprising phenomenon connected to a set of behavioral dispositions.

7	1	V	F
X	L	5	3
B	4	W	7

Fig. 1 Stimulus of one of Sperling's experiments (from Sperling 1960, p. 3)

In Sperling's "partial report condition", subjects are trained to report selectively the content of the upper, lower or middle row of the array, according to whether they hear, immediately after the presentation of the stimulus, a high- middle- or low-pitched tone. Immediately after the end of the exposition to the stimulus, subjects are capable to report on average three items from each of the three rows, although they cannot report them all in the same trial. This capacity can be explained by postulating the existence of iconic memory, in which subjects retain, for about 1 sec., about 9 characters from a 12-character array.

Having a given content in one's iconic memory is a powerful property. It is not directly observable; however, the existence of a memory state containing 9 items explains three dispositions the subject has immediately after exposition to the stimulus, such as: If she hears a high frequency tone, she reports on average three items of the top row.

Both common sense and scientific discourse provide cases where having a powerful property (being elastic, having an electrical conductivity of 60×10^6 Siemens/meter, having stored 9 letters in iconic memory) entails having several dispositions. However, as long as "powerful property" and "disposition" are not distinguished, we seem to be caught in the paradox of having to say of the same property instance that it is both one and several. Consider an elastic rubber ball *b* and suppose we have only one concept of disposition. The following three statements are true of *b*.

1. *b* has the disposition of elasticity.
2. *b* has the disposition to expand after having been compressed.
3. *b* has the disposition to retract after having been stretched.

(1), (2), and (3) all seem to ascribe the same disposition: elasticity, as opposed to, say, opacity or inflammability. However, (2) and (3) cannot attribute the same disposition. (2)

attributes to *b* the disposition to expand (after having been compressed) and (3) the disposition to retract (after having been stretched). A disposition to get longer cannot be identical with a disposition to get shorter.

Distinguishing between powerful properties and dispositions yields a straightforward way to avoid the paradox. A disposition is defined by a specific conditional linking a triggering condition to a manifestation. The disposition P_1 to retract (manifestation M_1) when released after having being stretched (triggering condition T_1) is different from the disposition P_2 to expand (manifestation M_2) when released after having been compressed (triggering condition T_2), and also different from the disposition P_3 to bounce (M_3) when dropped (T_3). Elasticity is the powerful property that gives r its dispositions P_1, P_2, P_3. Now, what exactly does "give" mean in this context? What is the relation between the property of being elastic and the different dispositions D_i it gives its bearers?

The simplest hypothesis is that D is identical to D_i, for all i. But this cannot be correct, because the dispositions D_i are not identical with each other. Another hypothesis is that D is identical to one specific disposition D_j, but not to the others. This does not fit our case, because elasticity is not linked more closely to one of these dispositions than to the others.

Ryle's thesis is that the relation between a predicate expressing a multi-track disposition such as elasticity and a predicate expressing a single disposition is equivalent to the difference between a *determinable* predicate and one of its *determinates*. "Some dispositional words are highly generic or determinable, while others are highly specific or determinate." (Ryle 1949, p. 114) The predicate "x is a baker" is determinate in the sense that it names a disposition with a unique manifestation, the activity of baking. "x is a grocer" is less determinate, in other words, a determinable. The dispositions to act of someone satisfying this predicate are expressed by the determinates of this determinable: "x is selling sugar now", x is weighing tea now", "x is wrapping butter now" (Ryle 1949, p. 114).

However, the distinction between determinable and determinate is not the same as the distinction between a powerful property and the dispositions it gives its bearers. All properties that are determinates of a given determinable are of the same type: Either they are all intrinsic, or they are all relational. However, a powerful property and the dispositions it gives its bearer do not belong to the same category in this respect. A powerful property is an intrinsic property, whereas a disposition is relational: The identity conditions of a disposition depend in an essential way on circumstances which are in part external to the object that has the power, and in particular on the laws of nature. In general, neither the triggering circumstances T nor the manifestation M are intrinsic properties of the powerful object. That a determinable and its determinates are properties of the same type is a consequence of a general constraint on the relation between them. As Funkhouser (2006) explains, the determinates of a given determinable determine it according to a limited number of "determination dimensions". For colours, there are e.g. three such dimensions, hue, brightness and saturation, so that a given colour C corresponds to a subspace S of the three-dimensional colour space. Determinates of C correspond in turn to subspaces of S. A relational property such as a disposition cannot correspond to a subspace of the space corresponding to an intrinsic property, such as a powerful property.

Here is my hypothesis about the relation between a powerful property and the dispositions D_i it gives its bearers. Ascribing disposition D_i to object *b* is equivalent to asserting the counterfactual conditional "if *b* were in conditions T_i, then ceteris paribus, *b* would manifest M_i"[6]. It is justified to ascribe D_i to the object *b*, rather than to the circumstances T_i, if and only if there are intrinsic properties of *b* by virtue of which *b* contributes causally to the production of M_i. Let us call the "causal basis" in *b*, of the

[6] The ceteris paribus clause is required to account for exceptional circumstances, such as the presence of masks or antidotes. Cf. Johnston (1992), Molnar (1999), Bird (1998).

disposition D_i to manifest M_i, the set B_i of those intrinsic properties of *b* that intervene causally in the production of M_i, alongside the triggering circumstances T_i and other background conditions. In general, each D_i will have its own causal basis B_i. A given set of dispositions D_i is grounded on a unique common powerful property if and only if the intersection $I= \cap B_i$ is not empty. In that case, the powerful property underlying a given set of dispositions D_i is the conjunction of the properties belonging to I. In sum, the powerful property underlying a set of dispositions D_i is the conjunction of those intrinsic properties of the object to which the dispositions D_i are truthfully ascribed, which contribute causally to bring about all of their manifestations M_i. There is, e.g., a real property of elasticity belonging to the rubber ball *b* if and only if there is a set of intrinsic properties of *b*, which contribute causally to the manifestations of all the dispositions associated with elasticity: bouncing after being dropped, retracting after having been stretched, etc. Conceived in this way, powerful properties have the status of theoretical properties, in the sense that the postulate of their existence is fallible, and has to be justified by the usual criteria of theory construction: It must enhance the simplicity of explanations and predictions in general and causal explanations in particular and it must be fruitful, in the sense of suggesting new explanations and predictions.

If single-track dispositions exist, they are a special case of multi-track dispositions, in which the causal basis of a given disposition has no elements in common with the causal bases of any other dispositions.

4. Arguments for powerful properties

The hypothesis that there is a real powerful property underlying a set of dispositions D_i, has the form of an inference to the best explanation. If there is a unique powerful property that is the causal basis of a set of dispositions D_i, it provides a unique, and unifying explanation of their manifestations M_i.

In electric fields E_i of various strengths a copper wire *w* manifests different dispositions to produce different current densities J_i. Electrical conductivity σ is postulated as an intrinsic property of *w* that contributes causally to bring about the different J_i in different fields E_i. The existence of this common causal basis makes it possible to express the relation between the different E_i to the J_i in a single equation.

As a theoretical property, a powerful property may lead to explanatory unification at a larger scale. σ figures in various theoretical laws, such as the Wiedemann-Franz law. These laws express relations between σ and other theoretical properties, which figure themselves in still other laws. Thus σ mediates, and helps explaining, relations between other theoretical properties to which σ is linked, directly or indirectly, by laws. Electrical conductivity being linked both to thermal conductivity (by the Wiedemann-Franz law) and the magnetic field B (via the law linking J_i to E_i, and the laws linking E to B, such as Ampere's law and the Maxwell-Faraday equation), it can explain systematic correlations between λ and B, which might have appeared mysterious without σ. In a similar way, the content of the iconic memory of Sperling's experimental subject is a theoretical property that explains in a simple and unified way, several of her dispositions to behave in the different partial report conditions.

A second reason for postulating powerful properties is, as for other theoretical properties, their fruitfulness. The postulate is justified if it suggests new experimental hypotheses. This seems to be the case for iconic memory. It has been introduced to account for the performance of subjects in the partial report condition for different lines of the array. However, iconic memory suggests new testable hypotheses about performance in yet unexplored partial report conditions: Subjects should have dispositions to report columns and diagonals of the array.

5. Arguments against efficacious powerful properties

5.1. Powerful properties are pseudo-properties

Reductionists will object that the concept of a property that is both dispositional and a causal basis, and thus causally efficacious, is contradictory. According to one traditional argument, dispositions are not real because they are not causally efficacious. Dispositions, so the argument goes, are like the famous "dormitive virtue" mentioned in Molière's play "The Imaginary Invalid" (also called "The Hypochondriac"). When asked for the cause of opium smokers' sleepiness, Molière's candidate (for becoming a medical doctor), mentions the dormitive virtue of opium. This is supposed to ridicule pseudo-explanations in scholastic style. Indeed, the bachelor's answer seems to be a tautology rather than an explanation. If we mentioned dormitive virtue to explain sleep we would "expose ourselves to Moliere's ridicule, and, if we did nothing further, we would deserve it." (Armstrong 1973, p. 419) The reason is that the expression "dormitive virtue" is analytically linked to sleep, meaning nothing more than "property that causes sleep". Now it can be argued that this shows that dormitive virtue cannot cause sleep, for causation is contingent.

However, such an argument is fallacious because it fails to distinguish between a property and the descriptions of a property. The "dormitive virtue" argument against the efficacy of powerful properties can be criticized in a way analogous to Davidson's rebuttal of an argument against the thesis that our actions are caused by our reasons. Davidson (1963, p. 14) points out that if *c* is cause of *e*, then we can truthfully name *c* "the cause of *e*". The statement "the cause of *e* caused *e*" is certainly tautological, but it would be mistaken to take this to show that the cause of *e*, i.e. *c*, didn't cause *e*. "The cause of *e* causes *e*" (for an event *e*) is true even though cause and effect are described in such a way that the resulting statement is analytic.

Here is the analogous reasoning concerning the efficacy of properties. Assume it is true that "the property of bearing electric charge *q* creates, at distance *d*, an electric field of strength E". Replacing the expression "property of bearing electric charge *q*" by the description "property that creates, at distance *d*, an electric field of strength E" makes the statement analytic: "the property that creates, at distance *d*, an electric field of strength E, creates, at distance *d*, an electric field of strength E". However, this does not deprive the property of bearing electric charge *q* of its causal efficacy. The same fallacy seems to be operative in the case of the dormitive virtue of opium. The property of opium that is efficacious in bringing about sleep when absorbed in the way X can truthfully be named "the property that (ceteris paribus) brings about sleep when absorbed in the way X". The fact that we produce an analytical statement by calling it that way when stating the cause of sleep, does not deprive this property of opium of its efficacy in bringing about sleep.

Opium is not a placebo[7]. The problem stems from the functional meaning of the expression "dormitive virtue". It determines the identity of the property only indirectly, by its typical effect. This does nothing to put in doubt its reality or causal efficacy.

5.2. Macroscopic dispositions are not real, only their microbase is.

Another influential argument against real efficacious powerful properties has already been mentioned above. Prior, Pargetter, and Jackson (1982) argue that 1) all dispositions have a causal basis, 2) this basis is distinct from the disposition itself and 3) all causal efficacy erroneously attributed to the disposition really belongs to the basis.

[7] We shall return to placebos below, in section 6.1.

Contrary to Armstrong and Quine, Prior, Pargetter, and Jackson refrain from arguing that the causal basis must be categorical[8]. However, they identify the *causal* basis of a macroscopic disposition, i.e. the intrinsic property by which the bearer of the disposition contributes to bring about the manifestation, with its microscopic *reduction* basis[9]. Typically, the reduction base consists of some microscopic property such as "having molecular bonding *a*", or "having crystalline structure *b*" (Prior, Pargetter, and Jackson 1982, p. 253). From the premises that (1) the causal basis is the microscopic reduction basis and that (2) it is distinct from the macroscopic disposition, they conclude that the macroscopic disposition is not real, i.e. not efficacious. Armstrong and Quine come to the same conclusion: For them, the disposition is identical with the basis, but the basis is categorical, and a property cannot be both categorical and dispositional. Therefore, there is no real macroscopic disposition.

These arguments against the reality of macroscopic dispositions share the same weakness: they do not justify the implicit presupposition that the causal basis is necessarily identical with the microscopic reduction basis. If this presupposition is false, Armstrong's, Quine's and Prior, Pargetter, and Jackson's arguments do not refute the thesis that macroscopic powerful properties such as electrical conductivity, the iconic memory of a stimulus, and even fragility can be the causal basis of their manifestations.

I cannot pretend to establish here that macroproperties can be causally efficacious, whether or not they are microreducible. But I can make this claim plausible by looking at a simple example of the microreduction of one paradigmatic dispositional macroproperty, i.e. electrical conductivity. The analysis of this case shows that the reasons to think that microscopic reduction base is more apt as a causal basis are ill founded. Indeed, the reasons for this conviction are the hypothesis that the properties in the reduction base are 1) purely categorical and 2) purely microscopic. However, as we will see, the properties to which electrical conductivity is reduced are neither purely categorical nor purely microscopic.

Electrical conductivity of metals can be reductively explained in a simple model due to Drude (1900). Although it is classical and does not take into account the quantum mechanical structure of metals[10], the Drude model provides a good approximation in a large range of common circumstances. The model is built on the hypothesis that electrical current is due to the motion of "free" electrons, i.e. electrons moving freely through the crystal grid constituting the metal, and to the electric charge carried by these free electrons. The macroscopic electrical conductivity of metals is explained in terms of the following properties of the microscopic constituents of metals: the number of free electrons per cubic centimetre n, the charge of an individual charge carrier q, the so-called relaxation time or mean free time of the free electrons, i.e. the average time interval between two collisions, τ, and the mass of an electron m.

The bridge law (1) expresses the core of the reduction.

$$(1)\ \frac{nq^2\tau}{m} = \sigma$$

[8] "We have not here argued that the causal basis is categorical or intrinsic, only that it exists." (Prior, Pargetter, and Jackson 1982, p. 253).

[9] Armstrong and Quine do not claim that the causal basis of a macroscopic disposition is necessarily microscopic, but they suggest that this is at least the typical case. When we attribute a disposition to *x*, says Quine, "we are attributing to *x* some theoretical explanatory trait or cluster of traits. Typically these would be traits of microscopic structure or substance." (Quine 1966, p. 73) For Armstrong, "attribution of a disposition to an object entails that the object is in a certain state. What is the concrete nature of this state? […] In the case of brittleness, for instance, the state will be a certain sort of bonding of the molecules of the brittle object" (Armstrong 1973, p. 417).

[10] Quantum mechanical models of conductivity are required to explain phenomena occurring in extreme conditions, such as supraconductivity.

(1) shows that the reductive basis of σ lies in microproperties of the metal's free electrons. Now, the microproperties mentioned in the reduction of conductivity are neither purely categorical nor purely microscopic. Here is why they are not purely categorical. The expression on the left hand side of equation (1) is equivalent to the product of the mobility μ of an individual electron with its charge *q* and the number *n* of electrons per unit volume.

$nq\mu = \sigma$

The dispositional character of the mobility μ of electrons is apparent in its name. It is the disposition to move with speed *v* in external field E. This shows that the mere fact that a property is microscopic, and used in a reductive explanation of a macroproperty, is not sufficient to establish that this property is categorical. Moreover, as several authors[11] have argued, the properties of having elementary charge *q*, mass *m*, and mean free time τ, also have a dispositional essence, although this is not apparent in their name. To bear charge *q* just is to have a set of dispositions, such as the dispositions to attract charges of opposite sign, to repel charges of equal sign, and to accelerate along external fields. Similarly, to have mean free time τ is to have the disposition to move without collision for a mean time of τ seconds.

Paradoxical as it may sound, some of the properties in the basis of the microreduction of conductivity are also not purely microscopic. Properties such as mobility μ and mean free time τ are microscopic insofar as they are truly attributed to microscopic particles, i.e. electrons; however, they are not purely microscopic in the sense that they are dependent on, and determined by, macroscopic properties of the crystal.

6. Need dispositions have a causal basis?

6.1. Intrinsicality

One of our premises has been that dispositions must have a causal basis. If an object *b* has the disposition D to manifest M in circumstances T, the causal basis of D in *b* consists of those intrinsic properties of *b*, which contribute causally to bring about M. It would be a mistake to define the causal basis, as Prior, Pargetter and Jackson (1982), "to be the property or property-complex of the object that, together with […] [the triggering condition, M.K.] is the causally operative sufficient condition for the manifestation" (Prior, Pargetter, and Jackson, p. 251). As Molnar (2003, p. 129) points out, the cause of the manifestation of a disposition is not always exclusively composed of the triggering condition and intrinsic properties of the object to which the disposition is attributed. In many cases, part of the cause of the manifestation M belongs to the circumstances[12]. A match has the disposition to light, but its property of being covered with a layer of potassium chlorate, is only part of the cause of the match's lighting. Oxygen is another part, which is not an intrinsic property of the match. This refutes the claim that every disposition has a causal base *as it is defined by Prior, Pargetter, and Jackson*. But it doesn't refute this claim according to our definition of the concept. If the cause of the manifestation is "a mixture of circumstances, including some that are intrinsic to the bearer of the disposition and some that are extrinsic to the bearer" (Molnar 2003, p. 129), there is a causal basis in our sense: the set of intrinsic properties that contribute to cause the manifestation.

However, one might think there are also more extreme cases: dispositions that do not even have a causal basis in our sense. An object *b* with disposition D, such that *none* of its intrinsic properties contributes causally to a manifestation M of D, would indeed refute our thesis of the necessity of a causal basis. Consider the famous chess playing machine built in

[11] Popper (1957), Mumford (1998), Ellis (2001), Molnar (2003), Bird (2007).

[12] McKitrick's (2003a) "extrinsic dispositions" belong to this category: the causes of their manifestations are in part extrinsic to the object to which the disposition is ascribed.

1769 to amuse the Austrian Queen Maria Theresia. The machine seemed to have the disposition of playing chess, but in fact it was a dwarf, a human chess player hidden in the machine, who produced the moves on the chess board. Had this machine the disposition to play chess? Whether it is correct or incorrect to attribute this disposition to the robot depends on how exactly one conceives it. Either the robot is taken to be the mechanical device excluding the dwarf. Then it is certainly wrong to attribute any chess playing dispositions to it. However, if the robot is taken to include the dwarf as a part, the attribution is correct. Both possibilities are compatible with our thesis. If the dwarf is no part of the robot, no intrinsic property of the robot contributes to cause the chess moves. But then the robot has no chess playing dispositions in the first place, and there is no reason to postulate any powerful property underlying such dispositions. If the dwarf is taken to be part of the robot, it has chess playing dispositions. But the so conceived robot has intrinsic properties (which are really properties of the dwarf) that contribute causally to the chess moves.

Placebos also seem to have dispositions without any causal basis. Placebo pills can be powerful remedies, yet by definition of a placebo, none of their intrinsic properties contribute anything to cure the patient. Therefore, the pill's disposition to cure the patient does not have any causal basis in our sense. The cases of the placebo pill and of the chess machine share the same structure. To the extent that no intrinsic property of the pill contributes causally to curing the patient it is simply wrong to attribute a disposition to cure to *the pill*. Indeed, it is not really the placebo pill that has the disposition of curing, but the fact that the doctor prescribes it. The causal basis of the curing is in the doctor's act, which cures via the patient's belief that she will be cured.

6.2. Masking

Prior, Pargetter, and Jackson's definition of the notion of a causal basis has another important defect. They take the causal basis of a disposition D to be "the causally operative sufficient condition for the manifestation" (Prior, Pargetter, and Jackson 1982, p. 251), at least in the case of what they call "'surefire' dispositions", whose manifestations are produced according to deterministic laws. Let us disregard irreducibly probabilistic dispositions, such as radioactive atoms' disposition to decay spontaneously.

It is well known that dispositions can be "masked" (Johnston 1992, Molnar 1999) or counteracted by an "antidote" (Bird 1998) without thereby ceasing to exist. "If we carefully package a fragile vase, thereby masking its fragility" (Molnar 2003, p. 130) the vase will not break even in circumstances that normally trigger this manifestation of its fragility, such as falling from high on hard ground. The packaged vase is fragile although its properties are not *sufficient* for its breaking when it falls from high on hard ground. Similarly, the poison does not manifest its toxicity if an antidote has also been ingested. Masks and antidotes show that the possession of a disposition is not sufficient to guarantee a manifestation in its triggering condition. Therefore, as Molnar points out, no disposition that can be masked (or for which there exist antidotes) has a causal base *in Prior, Pargetter, and Jackson's sense*.

However, the vase's fragility and the poison's toxicity both have a causal basis *in our sense*. If the vase the fragile, it must be *possible* that its fragility is unmasked. The causal basis is defined with respect to such (normal) circumstances in which the disposition is triggered and manifests itself. The causal basis consists of those intrinsic properties of the object that contribute to the manifestations in these normal circumstances. There cannot be any disposition that is *necessarily* masked (or necessarily accompanied by an antidote): if property P is necessarily accompanied by a mask that prevents manifestation M in triggering circumstances T, then objects having P do *not* have the disposition to M in situations of type T.

6.3. The "missing base" of fundamental dispositions

Several authors have argued that dispositions of fundamental elementary particles may be "bare" or "ungrounded". This can mean different things. Blackburn suggests that fundamental dispositions may lack "categorical ground" (Blackburn 1990, p. 64). Ellis (2001, p. 114f.) argues that powerful properties do not need "categorical bases". McKitrick claims that they may be "bare dispositions", which she defines as dispositions that have no "causal basis" (McKitrick 2003, p. 355) distinct from themselves. For Molnar, "no causal bases can be found at all" (Molnar 1999, p. 9; 2003, p. 132) for dispositions of simple subatomic particles. Mumford (2006) argues that basic dispositions may be "ungrounded", i.e. not grounded in some property other than themselves.

Although these claims all express the idea that there are at least some dispositions that are ontologically fundamental, they are not otherwise equivalent. Molnar's argument for his thesis that some dispositions have no basis shows that what he means by a "basis" is a reduction base. "Traditionally, to find causal bases we look to the relations between the powers of a whole and the powers and other properties of its parts" (Molnar 2003, p. 131). Similarly, when Mumford argues that powerful properties of fundamental properties refute the thesis of "global groundedness", according to which "every powerful property is grounded in some property other than itself" (Mumford 2006, p. 471), he defines "ground" as meaning "reduction base": "The grounds of a powerful property can be found only among the lower-level components or properties of that of which it is a property" (Mumford 2006, p. 477).

What is distinctive about fundamental particles is indeed their lack of a "base" for micro-reducing their properties. Such properties of elementary particles as mass, charge, or spin, are the objects of a fundamental scientific theory. At the present state of science, there is no more fundamental science to which that theory might be reduced. Does the absence of any "reduction base" to which the dispositions of elementary particles might be reduced imply that they do not have any "categorical ground"? Answering this question presupposes clarifying the conceptual distinction between the dispositional and the categorical. This is a hotly debated issue. Most authors take it to be an ontological distinction between two sorts of properties. However, a minority[13] interprets it as a distinction between two types of concepts or predicates. According to this interpretation, one can conceive of a given property in two ways: either categorically, in terms of what it is, or dispositionally, in terms of which dispositions it gives its bearer. I will adopt the following version of the view that the distinction is conceptual, although I cannot defend it here[14]. A concept or predicate P is dispositional if the truth of the proposition "*b* is P", for some object *b*, entails, a priori (by virtue of the meaning of P), a counterfactual conditional of the form: "if *b* was in triggering condition T then ceteris paribus it would produce manifestation M". A predicate is categorical if and only if it does not, by its very meaning, a priori entail such a counterfactual linking a triggering condition to a manifestation.

In this framework, the relation between a powerful property and the dispositions it gives its bearer can be expressed in the following way. The powerful property, which is the causal basis of (one or several) dispositions to M_i in conditions T_i, appears as categorical if it is conceived as an intrinsic property, and as dispositional if it is conceived indirectly, through the dispositions to M_i in T_i. The charge of an elementary particle is a powerful property, which is the causal basis of its various dispositions to manifest M_i in conditions T_i. This powerful property can be conceived in a dispositional way because it is part of its essence is

[13] Shoemaker (1980), Mellor (2000).
[14] For a defense, see Kistler (2007).

to give its bearer dispositions to M_i in conditions T_i. However, it can also be conceived as intrinsic and categorical.

Does the fact that the dispositions of elementary particles cannot, for lack of parts or internal structure, be micro-reduced in terms of properties of their parts, imply that they do not have any "causal basis"? It does not: such particles have powerful properties that are the causal basis of the manifestations of these dispositions. McKitrick expresses a similar idea by saying that dispositions may be "their own causal basis". "If fragility turns out to be causally relevant to breaking, then fragility is its own causal basis." (McKitrick 2003, p. 353) However, there is an air of paradox about McKitrick's expression: as a disposition, the fact that vase *b* is fragile is *a priori* linked to the counterfactual that if *b* fell from high on hard ground then, ceteris paribus, *b* would break. However, it can only be discovered *empirically* whether the vase has such a property as fragility that contributes causally to its breaking in appropriate circumstances. What causes what can only be discovered empirically. This apparent paradox can be avoided by distinguishing, as I have suggested, between the disposition expressed by the counterfactual "if the vase fell it would break" and the powerful property fragility, which is the causal basis of the disposition.

7. Are there irreducibly multi-track dispositions?

My argument for the distinction between powerful properties and dispositions has made heavy use of the fact that many dispositions are multi-track. However, the existence of irreducibly multi-track powerful properties has been questioned by Bird (2007) who argues that dispositions that appear to be multi-track are always equivalent to conjunctions of single-track dispositions; furthermore, they are never fundamental. His argument rests on a distinction between "pure" and "impure" dispositions. A pure disposition P can be characterized by a single conditional linking a triggering condition T to a manifestation M. If object b with pure disposition D were in triggering condition T, it would manifest M.

(Db and Tb) $\Box\!\!\rightarrow$ Mb.=

What appear to be "multi-track" dispositions are "impure" insofar as they cannot be so characterized. Impure dispositions are linked to many conditionals: There is a whole set of pairs of triggering conditions T_i and manifestations M_i, such that an object b with an impure disposition I would manifest M_i if it were in condition T_i.

For all i [(Ib and T_ib) $\Box\!\!\rightarrow$ M_ib].

Bird holds the following two theses.

(T1) All impure dispositions are conjunctions of pure dispositions, and

(T2) "All impure dispositions are non-fundamental." (Bird 2007, p. 22)

Take our example of conductivity σ. It seems to be an impure disposition, insofar as it is characterized by a whole set of counterfactual conditionals. For each value of electric field E_i, the current density is $J_i=\sigma E_i$. Application of (T1) yields the claim that attributing σ to an object is equivalent to attributing to it the conjunction of dispositions

(CD) For all i [(E_i) $\Box\!\!\rightarrow$ J_i].

Thesis T1 quite naturally leads to thesis T2 according to which all impure dispositions are non-fundamental. Indeed, Bird argues, there cannot be an impure fundamental disposition, because 1) given thesis T1, impure dispositions are conjunctions of pure dispositions, and 2) conjunction of dispositions cannot be fundamental, since a conjunction is less fundamental than its conjuncts.

Here are two arguments against Bird's first thesis. The first uses Bird's (implicit) distinction between two types of "impure" dispositions:

Type A: properties such as electrical conductivity, which figure in several deterministic functional laws relating variables with infinitely many values.

Type B: propensities, which are dispositions with probabilistic manifestations, such as dispositions for different types of radioactive decay.

Bird allows, although somewhat tentatively, that properties of type B may be irreducibly multi-track. Let us suppose that particles of type P, when triggered by condition T, either decay in the A-cascade or in the B-cascade, each with its intrinsic probability. For such a particle *x*, if *x* is triggered by T, then either, with probability α, it decays in the A-cascade, or with probability β, it decays in the B-cascade. Is this disposition equivalent to the conjunction of the disposition to decay in the A-cascade and the disposition to decay in the B-cascade? It is not, because there is no ground for distinguishing two dispositions here: necessarily, something has one if and only if it has the other. In such a case, Bird admits, "we would not wish to ascribe different intrinsic dispositions", and concludes that "such cases are best assimilated to propensities" (Bird 2007, p. 23, note 18). Contrary to (T1), propensities seem to be impure dispositions that are not equivalent to conjunctions of pure dispositions[15]. The propensity of the P particle seems to be equivalent to a powerful property and distinct from both from the (pure) disposition to decay in the A-cascade and the (pure) disposition to decay in the B-cascade. Now, if our distinction is needed to account for propensities, it is more ontologically parsimonious to make the hypothesis that it applies to all multi-track dispositions.

My second argument bears directly on the controversial powerful properties of type A. The reasons for postulating powerful properties are the same as the reasons for postulating theoretical properties, over and above the conjunction of their test sentences, which are conditionals associating triggering conditions to manifestations.

Take any law, such as $J_i=\sigma E_i$, that expresses in a single formula the dependence of the values of J, on circumstances E. According to (T1), attributing σ to an object is equivalent to attributing it the conjunction (CD). However, as I have argued above, the explanatory power of a theoretical property such as σ goes beyond the conjunction of its test conditionals. The attribution of σ to an object is the first step towards a unifying explanation of all these counterfactuals. Rather than just abbreviating them, it indicates their common truthmaker.

A simple fact that the attribution of σ can explain, and the mere conjunction of conditionals cannot, is why there could not be an object that has just *part* of the conjuncts of (CD). If the conjunction were a brute fact, this would be possible. However, if all the conjuncts are consequences of the object's having the powerful property σ, one of these conditionals can only be true of a given object if the whole set of them is also true of it.

There is also a more scientifically fruitful sense in which the content of the attribution of a theoretical property goes beyond the mere attribution of the conjunction of its triggering-manifestation conditionals. Compare the conditionals associated with the electrical conductivity σ and with the thermal conductivity λ.

(CD-σ) For all i $[(E_i) \Box\!\!\rightarrow J_i]$.

(CD-λ) For all i $[(\Delta T_i) \Box\!\!\rightarrow Q_i]$,

Only if one postulates the existence of properties σ underlying the conjuncts of (CD-σ) and λ underlying the conjuncts of (CD-λ), does it become possible to state a link between them: the Wiedemann-Franz law, and to explain that link: by reducing the law.

According Bird's (T2), there are no fundamental impure dispositions. However, the same reasoning applies to fundamental dispositions as to non-fundamental dispositions. Even for fundamental properties, the powerful property is more fundamental than 1) each individual

[15] Fundamental propensities also refute (T2).

disposition it gives its bearer, and 2) the conjunction of these dispositions. The reason is that it explains and unifies all these dispositions. The difference between fundamental and non-fundamental depends on whether or not a powerful property has a reduction base. However, this difference is independent of the relation between powerful properties and dispositions.

8. Conclusion

I have argued that multi-track dispositions can best be understood if we distinguish the *powerful property* that makes it *one* multi-track disposition, from the various *dispositions* that correspond to its different manifestations in different circumstances. Powerful properties are real properties insofar as they efficacious. Indeed, we have defined them as those intrinsic properties of an object possessing a multi-track disposition, which contribute causally to all of its manifestations. The reasons for taking powerful properties to be real are the same as for other theoretical properties. They provide explanatory simplification and unification, insofar as they constitute the common ground of the various dispositions associated with a multi-track disposition. The fact that elasticity underlies, among other manifestations, retracting, expanding and bouncing of rubber balls in different circumstances, explains why it is no accident that objects having one of these dispositions in general also have the others. Much confusion in this debate results from the failure to distinguish the causal basis from the reduction basis. Indeed, the fact that fundamental dispositions have no reduction basis is no reason to deny that they have a causal basis. Insofar as they have typical manifestations, all dispositions have causal bases: powerful properties. Whether a powerful property is fundamental or not, and in the latter case, whether it is reducible or not, is independent of the question of its efficacy in contributing to bring about the manifestations of the dispositions it underlies[16].

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