Powers, dispositions and laws of nature

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Abstract Metaphysics should follow science in postulating laws alongside properties. I defend this claim against the claim that natural properties conceived as powers make laws of nature redundant. Natural properties can be construed in a "thin" or a "thick" way. If one attributes a property in the *thin* sense to an object, this attribution does not conceptually determine which other properties the object possesses. The thin construal is underlying the scientific strategy for understanding nature piecemeal. Science explains phenomena by cutting reality conceptually in properties attributed to space-time points, where these properties are conceived of independently of each other, to explore then, in a separate step, how the properties are related to each other; those determination relations between properties are laws. This is compatible with the thesis that laws are metaphysically necessary. According to the *thick* conception, a property *contains* all its dependency relations to other properties. The dependency relationships between properties (which appear as laws in the thin conception) are *parts* of the properties they relate. There are several reasons to resist the thick conception of properties. It makes simple properties "holistic", in the sense that each property contains many other properties as parts. It cannot account for the fact that properties constrain each other's identity; it can neither explain why natural properties are linked to a unique set of dispositions, nor why and how this set is structured nor why the truth-maker of many disposition attributions is relational although the disposition is grounded on a monadic property.

Keywords Law of nature; Property; Natural property; Power; Disposition; Metaphysics; Necessity; Natural necessity; Determination

Introduction

Many sciences seem to discover laws. Physics is full of examples: Galileo's law of free fall, Kepler's laws, Newton's laws, Ohm's law, Maxwell's laws. Of course, the fact that certain generalizations or mathematical equations are called "laws" does not establish that they really express laws. Some generalizations, such as the Titius-Bode law are called "laws" although everyone agrees that they do not really express a law, but only an accidental regularity. According to a widely shared conviction, statements such as Ohm's law express laws because they satisfy a certain number of conditions that

set them apart from accidental universal statements. Let us accept as a working hypothesis that laws are expressed by equations or universal generalizations that can be used to explain and predict phenomena (or other laws that can themselves be thus used) and to justify counterfactual conditionals[1].

Until fairly recently, the main philosophical debate on laws of nature opposed empiricists and nomological realists. For empiricists, laws are a special sort of regularities concerning events or facts, or supervene on such regularities. According to Lewis' version of the so-called Mill-Ramsey-Lewis account of laws of nature, "a contingent generalization is a *law of nature* if and only if it appears as a theorem (or axiom) in each of the true deductive systems that achieves a best combination of simplicity and strength" [Lewis 1973, 73; italics Lewis'][2]. According to the main opposite view, nomological realism, laws are objective features of reality. Their existence depends neither on the existence of theories nor on the existence of scientists and subjects asking for explanations and predictions. According to the most influential traditional version of nomological realism, developed by Dretske, Tooley and Armstrong (DTA), laws are necessitation relations between universals. On both traditional accounts, laws are contingent. This fits well with the intuition that the laws could have been different from what they are. However, such intuitions are not always trustworthy. It might well be that the contingency of laws seems intuitively convincing only to someone who confuses the fact that laws are discovered a posteriori (or are "epistemically contingent") with the fact that they are metaphysically contingent. Shoemaker (1980; 1998) and others have made a case for the opposite thesis, according to which laws are metaphysically necessary[3]. As I will show later, Shoemaker's reasoning leads to the result that laws are *conditionally* necessary, in the sense that all the laws in which a property P figures exist in every world in which P exists.

Against this, Mumford (2004) has argued that the premises of the argument for the (conditional) necessity of laws (that a property cannot exist in a given world without all the laws that hold of that property in the actual world) rather yield the conclusion that there are no laws at all[4].

In this paper, I defend the idea that laws have the same metaphysical status as natural properties. Science requires postulating both. I take it that the best justification for metaphysical theses is that their truth is the best way to make sense of science. Quine's criterion for existence, in terms of being the value of a quantified variable in some scientific statement, is too narrow[5]. The mere fact that a variable figures in a well-confirmed law warrants the metaphysical claim that the variable corresponds to a real

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[1] It is notoriously difficult to provide a non-circular analysis of the difference between laws and accidental generalizations. Cf. Goodman (1955). There are many proposals for adding more necessary conditions to those mentioned in the text, but they are all controversial. Bird (2006, p. 451) suggests, e.g., that laws must have some degree of fundamentality and must correspond to a new discovery, i.e. not be deducible from already known laws. This is not the place to enter the debate about what exactly is the set of necessary (and jointly sufficient) condition for a generalization to express a law.

[2] See also Lewis (1999: 41-43), Lewis (1999: 233-44).

[3] Kistler (2002).

[4] Bird (2007) argues that they lead to a weaker conclusion: Laws supervene on natural properties, in such a way that knowledge of laws can be derived from knowledge of properties.

[5] "We may be said to countenance such and such an entity if and only if we regard the range of our variables as including such an entity. To *be* is to be a value of a variable." (Quine 1939/1976, p. 199; italics Quine's).

property. Contrary to Quine's criterion, it is not necessary that there be scientific statements that quantify over the variable. Why do we believe that there is a property of having mass? The following justification seems sufficient. Mass is expressed by a variable that figures in well-confirmed laws such as F=gMM*/r2. This reasoning applies to properties and laws at all levels and in all sciences. In biophysics, e.g., it has been discovered that muscle fibers exhibit voltage oscillations that can be mathematically modeled by differential equations (Morris and Lecar 1981). To the extent that these models correctly approximate the behaviour of real muscle fibres, e.g. the giant muscle fibres of the barnacle (a marine arthropod), we may suppose that there are laws relating the properties that are represented by the variables featuring in the equations of the model. Thus, the fact that these equations contain (among many other variables) a variable that represents the conductance g_K of the muscle fibre's membrane for potassium ions gives us a reason for taking the property of having conductance g_K to be a real property of such membranes.

Being metaphysical theses, both the existence of properties and the existence of laws are controversial. My aim in this paper is to defend the existence of laws against recent arguments that the existence of properties is more fundamental, so that laws have either only a derivative status or do not exist at all in addition to properties. My main thesis is that our belief in the existence of laws, such as Newton's law of gravitation or the laws governing voltage oscillations of muscle fibres, is warranted by a reasoning of the same sort and of the same strength as our belief in the existence of natural properties, such as the property of having mass (of a certain quantity) M or the property of cell membranes of having conductance g_K for potassium ions.

1. The distinction between powers and dispositions

My argument for the thesis that laws are required to make sense of science, even within a metaphysical conception of natural properties, has two steps.

I argue first that the truth-maker of disposition attributions contains natural properties or, in other words, powers. This argument relies on the thesis that 1) the distinction between the dispositional and the categorical is a distinction between concepts and predicates, not properties, and on the thesis that 2) natural[6] properties, conceived as powers, are distinct from dispositions: For typical scientific properties, the same power figures in the truth-maker of many disposition attributions. In a second step, I argue that laws are required over and above powers, as constituents of the truth-makers of disposition attributions.

I shall take it for granted that 1) there is a conceptual link between the attribution of a disposition and the truth of a counterfactual conditional and 2) that there can be no explicit analysis of the attribution of a disposition in terms of a counterfactual conditional. According to the first of these theses, attributing to an object b the common sense disposition of being fragile means that, if b were sharply struck or subjected to appropriate stress, then, under otherwise normal circumstances, it would break. In the same way, attributing to a massive object b the disposition to fall with constant acceleration near the surface of the Earth means that, if b were dropped above but near

[6] I will henceforth drop the qualifier "natural". It should be understood that what I say does not apply to "abundant" (Lewis 1983) properties, in the sense in which there is an abundant property for any arbitrary predicate, even for negative, disjunctive or "gerrymandered" predicates such as "grue".

the surface of the Earth, then it would, if no forces other than gravitational attraction acted on it, fall with constant acceleration in the direction of the centre of the Earth.

The escape (or "ceteris paribus") clauses "under otherwise normal circumstances" and "if no forces other than gravitational attraction acted on it" threaten to make these conditionals tautological[7], because they tend to make the meaning of the attribution of a disposition equivalent to a statement such as: "if b were sharply struck or subjected to appropriate stress, then it would break or it would not". Conditionals with such ceteris paribus clauses cannot pretend to provide a (non-circular) analysis of disposition attributions. However, such a clause is indispensable for without it, the truth of the counterfactual would be neither necessary nor sufficient for the truth of the attribution of the disposition. This has been shown with the help of thought experiments with so-called finks (Martin 1994). A fink is a mechanism that destroys a disposition as soon as it is triggered. Martin's "electro-fink" is a circuit breaker mechanism connected to a wire. The wire's being live is a dispositional property that corresponds in ordinary circumstances to the truth of the counterfactual "if someone touched the wire, she would get an electric shock". Once the wire is connected to the circuit breaker, each time the live wire is exposed to the triggering condition, the circuit breaker will remove the basis of the disposition[8].

David Lewis has made an important suggestion for an analysis of disposition attributions in terms of counterfactuals, which excludes the possibility of such finks. Lewis takes up the thesis (Prior, Pargetter and Jackson 1982) that every disposition requires a "causal basis". If an object x has a disposition D to manifest M in triggering situations T, x must have intrinsic properties B that contribute causally, together with the triggering circumstances T, to bring about the manifestation M. Lewis suggests that the possibility of finks can be excluded by requiring that the object to which the disposition is attributed has such an intrinsic property B, which is the causal basis of the disposition, and that the object keeps this property for some time after it has been triggered, long enough to guarantee that the triggering condition T together with B cause the manifestation. Here is Lewis' analysis:

"Something x is disposed at time t to give response r to stimulus s iff, for some intrinsic property B that x has at t, for some time t' after t, if x were to undergo stimulus s at time t and retain property B until t', s and x's having of B would jointly be an x-complete cause of x's giving response r" (Lewis 2000, p. 157)

However, it has turned out that this does not provide a correct analysis of the truth conditions of disposition attributions. The satisfaction of the right-hand clause of Lewis' equivalence is in fact not necessary for the truth of a disposition attribution. This can be shown by reflection on so-called "antidotes" (Bird 1998). The presence of an antidote to a disposition does not remove its causal basis and thus does not remove the disposition. Yet even if the disposition is present and remains present after triggering (thus excluding the presence of a finkish mechanism), the antidote may make it the case that the triggering is not followed by the manifestation characteristic of the disposition. For this reason, the equivalence between having the disposition (and its causal basis) and

[7] See Lipton (1999).

[8] Martin also describes a second sort of fink, which is a mechanism doing the opposite: it gives an object a certain disposition if and only if the object is put to the test by the triggering condition.

the truth of the counterfactual can only be said to hold *ceteris paribus*, i.e. insofar as no antidote is present at the time of triggering.

There seems to be no way to replace the ceteris paribus clause with an empirical description of the circumstances in which the manifestation occurs, given the triggering condition. Therefore, the ceteris paribus clause is not just an abbreviation for such a condition. A counterfactual with a ceteris paribus clause cannot provide a non-circular analysis of the truth conditions of dispositions attributions. Lacking such an analysis, we will have to be content with the equivalence of the attribution of disposition D to object b and a counterfactual conditional of the form "if b were in (triggering) circumstances T, then ceteris paribus, b would manifest M".

Crucial for our argument is the fact that the truth of the attribution of a disposition to an object x requires that the object has an intrinsic property B, which is called the causal basis of the disposition (Prior, Pargetter, Jackson 1982). The causal basis is a property in virtue of which x itself contributes, together with the triggering situation, to cause the manifestation. It is true to say that x has the disposition to M if triggered by T only if x has some intrinsic property B that contributes causally, together with T, to bring about M. In other words, the truth-maker of the attribution of the disposition D to x at t contains the fact that x has B at t and for some sufficiently extended period after t. It is crucial that the ascription of disposition D to object b requires that there is something about the object b itself that contributes to bringing about the manifestation M. Indeed, if no intrinsic property of b contributes to M, it is not correct to ascribe the disposition to b. It is, e.g., not the placebo pill that can properly be said to have the disposition to heal; rather, what has that disposition is the doctor's act of prescribing it.

This seems to be the case with the force on an electrically charged object in an electric field: the triggering condition (i.e. the presence of the electric field E) is not in itself causally sufficient to bring about the force; it is the interaction of the property of being charged with the field that produces the force.

Let (Bi) be the set of those intrinsic properties of *b* that contribute causally to Mi, along with triggering circumstances Ti and background conditions. Then (Bi) is the causal basis, in the object b, of the disposition D to manifest M in conditions T. I suggest to call this causal basis, which is an intrinsic property, the "power" underlying the disposition[9].

The dispositional-categorical distinction can either be interpreted as an ontological distinction between sorts of properties or as a semantic distinction between sorts of concepts or predicates. I will here accept the latter conception according to which it corresponds to a distinction between two ways of conceiving of a given property:

A dispositional concept (or predicate[10]) is a concept such that its attribution to some object *a priori* entails a certain counterfactual conditional. "A priori" means that the entailment is guaranteed by the content of the concept (the meaning of the predicate), so that it is (at least implicitly) known be every competent speaker, without any need for empirical enquiry and information. This distinguishes them from

[9] Many authors also take for granted that the causal basis of the attribution of a macroscopic disposition to a macroscopic object must be microscopic, or "microstructural" (Quine 1971, Armstrong 1973, Prior, Pargetter, Jackson 1982). However, it is really an independent issue whether the causal basis is microreducible or not. See Kistler (2012).

[10] In what follows, it should be understood that what I say about concepts is also supposed to apply to predicates.

categorical concepts. A concept is categorical insofar as its attribution to an objet does not a priori entail any counterfactual conditional.

The property of bearing elementary electric charge can be conceived in a categorical way as a fundamental natural property, or in a dispositional way: in this sense, attributing to an electron b the property of having elementary electric charge is equivalent to the counterfactual: if b were placed in an electric field of strength E (triggering condition T), b would be subject to a force F=Eq (manifestation M).

This gives us a simple reason for distinguishing between dispositions and powers: "power" is an ontological category that picks out natural properties, whereas "disposition" is a semantic category that picks out a certain way of conceiving and describing natural properties. All powers, i.e. natural properties, can in principle be conceived both in a categorical way as intrinsic properties of objects, or in a dispositional way, by way of the manifestations they would bring about if an object having them were in a certain triggering condition.

The thesis that all natural properties can be conceived both in a categorical and in a dispositional way bears some resemblance to the view that properties have a "dual nature" (Martin 1996; Heil 1998). "Every property … endows its possessor with both a particular disposition or 'causal power' and a particular quality*"* (Heil 1998, p. 181). Here, the distinction between "disposition" and "quality" is taken to be ontological. However, this "dual aspect" theory does not explain how the dispositional and the qualitative aspect of a property can coexist within a property although they seem to be incompatible. This problem is solved if the distinction is taken to be semantic. Dispositional and categorical predicates can make reference to the same property although they have, as predicates, incompatible properties: dispositional predicates a priori entail a ceteris paribus counterfactual, whereas categorical predicates do not. The dual nature account has a second problem: If every property has a dual nature, then all properties are dispositional (Popper 1957). If "dispositional" is taken to be a metaphysical concept, it doesn't satisfy a necessary condition on concepts: partition its domain of application in objects falling in its extension and objects that do not. I take this to be a reason for taking "disposition" to be a semantic not metaphysical concept.

Do we really need both concepts of power and disposition, instead of just one? In other words, couldn't we simply say that a disposition is a power, and that a power is its own causal basis? The reason for which the distinction between power and disposition is indispensable is that many powers are "multi-track", i.e. contribute to make true different disposition attributions.

Let us take electric charge. The fact that an object x possesses the elementary electric charge q contributes to making true many disposition attributions to that object. Here are four of them.

1. The disposition of x to undergo a force **F**=q**E** if x was in electric field **E**.

2. The disposition of x to attract a second object with charge q* and at distance r with force

$$F = k_e \cdot \frac{q \cdot q^*}{r^2}$$

(Coulomb force).

3. The disposition of x to undergo a force **F**= q**v** x **B** (Lorentz force) if x was moving with **v** in **B**.

4. The disposition of x to bear a magnetic moment **m**= ½ q**r** x **v** if x was in rotation with speed **v** on radius **r**.

The four dispositions mentioned are not identical: it is not the same thing for x to be disposed to undergo a force **F**=q**E** (manifestation M1) when it is placed in an electric field **E** (triggering condition T1), for x to be disposed, at a distance r from of a second object that is charged with charge q* of the opposite sign (triggering condition T2), to exert on this object a force

$$F = k_e \cdot \frac{q \cdot q^*}{r^2}$$

(manifestation M2), and or for x to be disposed to undergo a force **F**= q**v** x **B** (manifestation M3) when x moves with v through a magnetic field **B** (triggering condition T3).

The very fact that these dispositions are different may seem paradoxical because, although they are different, they are all dispositions of electric charge, and electric charge seems to be just one power, not many. As long as we have only one concept of disposition/power, charge seems to be both one power and many powers.

A way of avoiding this paradox is suggested by the fact that these dispositions always go together or, in other words, that it does not seem to be possible that something has just one (or just two) of these dispositions without also having all the others. This indicates that something unites this set of dispositions.

What is the relation between the property of bearing electric charge and the different dispositions Di it gives its bearers? Being charged cannot be identical to all dispositions Di, because the Di are not identical with each other. Being charged cannot be identical to one of the Di (but not the others either), because it is not linked more tightly to one of the Di than to the others.

Here is a way of avoiding the paradox that charge is both one and many powers/dispositions. It consists in making the hypothesis that there is an element of reality, the natural property of being charged, which is both distinct from each of the dispositions in the set and nevertheless explains the fact that they are always present together. Charge is a powerful property, or simply "a power", which is not identical to the dispositions in the set. What is the link between the power and the dispositions? Power is a metaphysical concept, whereas disposition is a semantic concept. What is it in reality that makes the attribution of the different dispositions Di to a given object x true? My hypothesis is that what unites the set of dispositions corresponding to electrical charge is that the truth-makers of the Di have a common element.

As I have argued above, some intrinsic properties of x must contribute to make the attribution of a disposition to x true. The object b has Di if and only if there are intrinsic properties B of *b* by virtue of which *b* contributes causally to the production of Mi. Let us call the "causal basis" in *b*, of the disposition Di to manifest Mi, the set Bi of those intrinsic properties of *b* that contribute causally to Mi, along with triggering circumstances Ti and background conditions.

In general, if several dispositions Di can truthfully be attributed to an object x, each Di will have its own causal basis Bi. However, a simple hypothesis can explain why the different dispositions linked to electric charge we have mentioned above always come together. The attribution of all the dispositions in a set (Di) to a given object always has the same truth value – in the sense that if one is true, all the others are

true and if one is false all the others are false – if all the dispositions in (Di) have the same causal basis. The simplest hypothesis for explaining why they are tied together is that the powerful property of being charged is a common part of the truth-makers of the attribution of all these dispositions.

Object *b* has the power of being charged if and only if there is an intrinsic property of *b* that contributes causally to the manifestations of all the dispositions associated with being charged: attracting other charged bodies, interacting with a magnetic field if in motion, etc. This power is the common causal basis of all these dispositions. If single-track dispositions exist, they are a special case of multi-track dispositions. A single-track disposition would be a disposition that is not lawfully linked to other dispositions. This seems never to be the case for scientific dispositions: laws of nature link different natural properties[11].

Powers are theoretical properties. This implies that the postulate of their existence is fallible, and is justified by the usual criteria of theory construction. The two main reasons for postulating a theoretical property is that its existence provides the best unifying explanation of phenomena and that it is fruitful in suggesting new hypotheses.

The reason to postulate the existence of electrical charge q is that the hypothesis of the existence of this intrinsic property provides the best unifying explanation of why the different dispositions (1) to (4) mentioned above always come together. It is because this property is the common truth-maker of these dispositions that every object that has one of them has them all: to have one of these dispositions, it is necessary to have the intrinsic powerful property of being electrically charged; and having the power of being electrically charged is sufficient for having all the other dispositions in the set (Di).

It is important to distinguish the concepts of causal basis and reduction basis. Insofar as all dispositions have manifestations, all dispositions have causal bases, which are powers. The causal basis of x's disposition to exhibit manifestation Mi in triggering situation Ti is, among x's intrinsic properties, that which contributes causally, together with Ti, to bring about Mi. This intrinsic property, the causal basis of the disposition to Mi in condition Ti, need not be microscopic relative to the level of description of Ti and Mi. The causal basis of a macroscopic disposition is in general itself macroscopic. The disposition of a macroscopic object x to exert, in the vicinity of a second macroscopic object y that is electrically charged, a force on y, has a macroscopic causal basis: the property of x to be electrically charged. True, the macroscopic property of being charged can be reductively explained in terms of microscopic properties of the microscopic parts of x. But this need not be the case. Fundamental dispositions have no reduction basis, but they have a causal basis[12]. The causal basis of the disposition of an electron to repel a second electron is the first electron's intrinsic property of bearing the elementary electric charge. Being elementary, it cannot be reduced to properties of the electron's parts, for there are no such parts. This shows that the causal basis of a disposition need not be microreducible. So we can generalize to macroscopic dispositions and their macroscopic causal bases: the micro-reducibility of a macroscopic causal basis is not required for the truth of the disposition attribution. The reality and causal efficacy of the causal basis is independent of its reducibility.

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[11] We shall come back later to the significance of this fact for the metaphysical status of laws.

[12] Mumford (2006), Molnar (1999, 2003, chap. 8).

Many authors take multi-track powers to be a superficial phenomenon that should not be taken to play any fundamental role in the metaphysical theory of powers and dispositions. The reason is that, if multi-track powers can always be analysed in terms of single-track powers. Therefore, only the latter should play a fundamental metaphysical role. Bird claims that "we do not need to posit fundamental multi-track dispositions" (Bird 2007, p. 24). His argument proceeds through two theses I will mention in a moment. What Bird calls "pure" and "impure" dispositions are equivalent to our "single-track" and "multi-track" powers. Attributing to object b the *pure* disposition D is equivalent to a single counterfactual conditional

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

If b, which has disposition D, were in triggering situation Tb, it would manifest Mb[13]. By contrast, attributing to object b the *impure* disposition I is equivalent to a whole set of conditionals:

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

In this vocabulary, Bird's first thesis is that

(T1) All impure dispositions are conjunctions of pure dispositions.

In our vocabulary, (T1) says that it is equivalent to attribute an object a multitrack disposition and to attribute it a conjunction of single-track dispositions.

We have already seen a reason to deny (T1). A theoretical power such as electric charge is not identical to the conjunction of is characteristic dispositions. We have chosen a set of four such dispositions that are characteristic of electrical charge. However, as I shall argue later, the list is actually much longer.

Here are three reasons for thinking that the attribution of a multitrack power such as electrical charge has a content that goes beyond the attribution of a determinate set of dispositions, each of which is defined by a (ceteris paribus) counterfactual conditional linking one triggering condition to one manifestation.

1. Multitrack powers are theoretical properties, which provide a unifying explanation of a set of dispositions. The property of an object b of being charged is not equivalent to a set of dispositions because the property can explain why these dispositions always come together. If the multi-track (or impure) disposition were just equivalent to a certain conjunction of dispositions in a set (Di), the fact that the dispositions belonging to (Di) always come together would be a brute fact. However, the postulate of a multi-track power can explain why all the dispositions in (Di) always comes together, in the sense that nothing can have one of them without also having all the others.

2. The conception according to which a multitrack power is part of the truthmaker of the dispositions in a set (Di), rather than being equivalent to the conjunction of these dispositions, allows to make sense of scientific discoveries. It may be discovered after the multitrack power has been introduced (on the basis of set (Di)) that there is a larger set (Di*) that contains (Di) as a subset, such that all dispositions in Di* always come together. This could have happened if electrical charge was first introduced to provide a unifying explanation for why dispositions (1), (2) and (3) always come together, and if subsequently it was discovered that there is a larger set (Di*) that contains, over and above the dispositions (1), (2) and (3), a fourth disposition (4) to give rise to a magnetic moment, that is also always associated to each of the dispositions in set (Di). This

[13] We shall here follow Bird in omitting the ceteris paribus qualifier, which must strictly speaking be inserted into the consequent of the counterfactual, in order to take account of the possibility of antidotes.

possibility shows that the power is not equivalent to any finite set of dispositions, such as (Di) or (Di*). It is characteristic of theoretical properties that it remains always possible that new observable consequences are discovered.

Bird's second reason for not taking impure dispositions metaphysically seriously is that (T2) "All impure dispositions are non-fundamental." (Bird 2007, p. 22). If it were correct that all impure (or multitrack) dispositions are non-fundamental, they would be micro-reducible in terms of fundamental dispositions, which are pure (or single-track). However, as I have argued above, the issue of micro-reducibility is independent of the issue of the possibility of a unifying explanation of a set of dispositions. The postulate of a powerful property is justified by the fact that it can explain why the dispositions in a given set always come together; this criterion is independent of whether the powerful property is fundamental or micro-reducible.

2. Laws as parts of the truth-makers of disposition attributions.

We are now in a position to draw the implications of the conceptions of powers and dispositions developed so far, on the issue of the metaphysical status of laws. Laws are indispensable to make sense of what science tells us about dispositions, for two reasons.

The first reason is that laws are required to explain the structure of the dispositions corresponding to one property. The second reason is that dispositional concepts and predicates are relational, whereas powers are typically monadic. The truthmaker of disposition attributions must contain a relational part over and above powerful properties, which are monadic. The relational part of the truth-makers are laws.

I will argue for the existence of laws alongside powerful properties, by showing that the rival thesis, according to which laws do not exist (Mumford) or have only derivative existence (Bird) leads to inacceptable consequences.

Bird (2007) argues that the metaphysical status of laws is derivative relative to natural properties, on the basis of the following three theses. First, natural properties are powers, in the sense that the possession of such a property necessarily entails the possession of a disposition. Second, at least some laws are metaphysically necessary[14], in the sense of holding in all possible worlds in which the properties figuring in them exist. Third, these laws are entailed by the properties. From these premises, Bird draws the conclusion that a universal generalisation holding for objects possessing a property P, which is equivalent to a law, can be "derived from a claim about the essence of P" (Bird 2007, p. 46). He concludes that laws have only a derivative status with respect to properties. Once powerful properties have been postulated, there is no need to postulate laws in addition.

Mumford (2004) argues for a "lawless" metaphysics. From a metaphysical point of view, there are no laws. The role that has been attributed to laws by nomological realists, such as making true scientific explanations and predictions and justifying counterfactuals, is played by natural properties[15]. The natural properties postulated by

[14] "Some laws must be held to be necessary whether one is a categoricalist or a dispositional essentialist" (Bird 2007, p. 177).

[15] True, this is not how Mumford himself would present his thesis. He claims: "I am not making properties serve the role of laws" because "the world leaves no such role to be filled by anything" (2004, p. 204). However, this is intended to be true of laws conceived as "governing", from the

scientific hypotheses and theories can play this role because they are "modally involved" in the sense that they contain necessary relations to other properties. Thus, at every occasion in which such a property is instantiated, the object possessing the property stands in a necessary relation to other properties. From these premises, Mumford draws the conclusion that it is a mistake to postulate laws over and above natural properties, for properties alone, conceived as powers, can do all the metaphysical work that is needed: explain what makes scientific explanations and predictions true and what justifies counterfactuals.

However, in a lawless metaphysics, it is not possible to account for the relation between properties and dispositions. Mumford considers two ways of conceiving the relation between a property P and the dispositions P gives an object.

1) According to the first conception, properties are sets of dispositions[16]. In other words, dispositions are *elements* of properties. To evaluate this thesis, it will be useful to translate Mumford's vocabulary into the vocabulary used in this paper. What Mumford calls "properties" are our powers (or powerful properties): these are terminological variants both expressing the metaphysical concept of what it is about an object that makes true the attribution of a disposition or a counterfactual linking a triggering condition to a manifestation condition. Mumford's powers are our dispositions: each power (disposition) corresponds to exactly one counterfactual linking a triggering condition to a manifestation. In our vocabulary, the thesis that "properties are sets of instantiated powers" becomes the thesis that "powerful properties are sets of dispositions".

2) Mumford considers a second way of conceiving the relation between a property P and the dispositions Di. According to this conception, properties are "mereological sums of" (Mumford 2004, p. 171) powers. In our vocabulary, powerful properties are mereological sums of dispositions.

If one of these conceptions is correct, it follows indeed that no law is required for making true the attribution of a disposition. The mere possession by an object x of P is sufficient to make true the attribution to x of every disposition that is an element (conception 1) or a part (conception 2) of P; the mere possession of P by x is also sufficient to make true the counterfactual "if x were in condition T, it would manifest M".

I will call the conception of properties according to which a property *contains* all the dispositions (either as elements or as parts) it gives every object possessing it, the *thick conception of properties*.

According to this thick conception of properties,

1) a property P *contains* all/some of the dispositions Di that P gives its bearers. An object x's property of being electrically charged, e.g., contains x's disposition to undergo a force $\mathbf{F}=q\mathbf{E}$ if x was in electric field $\mathbf{E}$.
2) The electric field $\mathbf{E}$ and the force $\mathbf{F}$ are in some sense "contained" in P.

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outside as it were, properties that would otherwise, if it were not for the laws, be inert. When I nevertheless attribute to Mumford the thesis that powerful properties fill the role that has traditionally been attributed to laws, I mean the role of justifying counterfactuals and to make possible scientific explanation and prediction of phenomena.

[16] "Perhaps properties are sets of instantiated powers" (Mumford 2004, p. 171).

3) If we accept the view that properties are internally related (I will say that these internal relations are laws[17]) then it seems to follow that P also contains these internal relations to other properties such as **E** and **F**.

We would have a strong argument for the thick conception of properties if it followed from the thesis that laws of nature are conditionally necessary. Let me sketch the reasoning that leads to adopting this thesis. It will turn out that it does not favor the thick conception over the alternative "thin" conception, according to which natural properties contain neither the laws featuring them nor the dispositions they give objects having them. The thesis that laws of nature are conditionally necessary is a consequence of the following reasoning about what determines the nature of a natural property. Nothing else than the laws a property figures in can determine the nature of a property. What is it to be electrically charged? Insofar as being electrically charged is a property that has been introduced on theoretical grounds we know exactly as much about this property as we know laws in which it figures. Scientific hypotheses being fallible, the laws that we take to be true may turn out to be incorrect; and there are certainly laws featuring electrical charge that have not yet be discovered. So let us say that the laws we take to be true of charge today are an approximation of a subset of the laws that really hold of electrical charge. However, our partial ignorance notwithstanding, insofar as the law of the Lorentz force is approximately true, this law expresses part of what it is to be electrically charged: It is to undergo a force F=qE if placed in an electric field E. The same holds for the other laws featuring electrical charge. Part of what it is to be electrically charged with charge q is to attract (or repel) other objects at distance d that are charged with q* with F=keqq*/r2.

If there is a possible world in which there is a quantitative property q+ such that objects possessing q+ repel each other with a force proportional to the product of their quantities of q+ and to the inverse *cube* of their distance, then q+ is not the property of being electrically charged. Similarly for all other natural properties: It is part of what it is to have a mass of M to attract other objects having mass according to the law of universal gravitation F=gM1M2/r2. Thus, if some possible world contains a property M+ such that two objects having respectively quantities M1+ and M2+ of this property M *repel* each other with a force proportional to (the product of their quantities of M+ and) the inverse of the square of their distance, then M+ is not the property of having mass M. The same reasoning holds for all properties M++ featuring in laws that do not have *exactly* the same form as the law of universal gravitation F=gM1M2/r2. In other words, in all possible worlds in which the property of having mass M exists, it is such that pairs of objects having M *attract* each other with a force proportional to (the product of their quantities of M and) the inverse of the square of their distance. It is important to stress that this argument only leads to the consequence that laws are *conditionally* necessary: For all possible worlds w, *if* the property of having mass M exists in world w, then all objects possessing this property obey to the inverse square law of gravitational attraction. The law is not absolutely necessary because there may well be worlds in which there is no such property at all. In a world in which M does not exist, all universal conditional statements whose antecedent attributes M are trivially true. Thus, from an empiricist point of view, in which laws are statements, one might want to say that laws bearing on M are trivially true in all worlds in which there is no

[17] I will come back to the concept of an internal relation in a moment.

property of having mass M. However, from a realist point of view, a law is a relation between properties. If one of the properties does not exist in a given world, the law itself does not exist there either.

It follows from this conception of laws as conditionally necessary that in every world with P, all laws involving P hold; therefore all properties lawfully linked to P exist. It further follows that laws form a network that is characteristic of the actual world w_0. Natural properties come in a package; for all possible worlds w, either w contains *all* the natural properties of the actual world w_0 or *none*.

It also follows that laws are internal relations between properties. An internal relation R between b and c is such that b and c could not exist without being related by R(b,c). In other words, in every possible world in which b and c exist, they are related by R. Take two properties P and Q that exist at world w. If there is a law L relating P and Q in w, then this law exists in every world in which P and Q exist. This implies that P and Q are internally related by L.

However, it does not follow that any property Q ≠ P, even if is lawfully linked to P, is *part* of property P. Even if Q is necessarily linked to P (because Q exists in every world in which P exists, because every world in which P exists contains a law linking it to Q), it does not follow that Q is *part of* P or somehow *contained in* P.

We are now ready for four arguments for thinking that properties are not just sets, clusters or mereological sums of dispositions, and for postulating the existence of laws. Here is the first. Laws explain the structure of the dispositions whose attribution is made true by property P. Such a structure cannot be explained in the framework of a conception according to which properties are just sets (or mereological sums) of dispositions.

Recall that the possession of a natural property such as having electrical charge q makes true attributions of a whole set of dispositions:

1) if an object with q were in E, it would undergo F=qE.

2) If an object with q was moving with v in a magnetic field B, it would undergo a force F = qv x B.

3) If in rotation with speed v on radius r, creates magnetic moment m= ½ qr x v….

These dispositions, which correspond to the laws in which q explicitly figures, are only the tip of an iceberg of dispositions whose attribution is made true by the possession of property q. The reason is that that there are many dispositions whose attribution to an object x is made true by the conjunction of several laws: one law in which q itself figures, together with other properties such as R, and one or several other laws that contain R.

As an example, the attribution to electrons of the disposition to create a magnetic field if they are in motion as electric current I (Ampere's law) is directly made true by the property of the electrons of being electrically charged. The truth-maker of the attribution of this disposition has two parts: 1) the possession of charge by the electrons and 2) Ampere's law that links the movement of electric charge (electric current) to the existence of a magnetic field.

But the same property of having electric charge also contributes to make true, in a more indirect way, the attribution to electrons (moving as electric current) of the disposition to exercise a force on a second wire. This disposition has a more complex truth-maker that is composed of 1) the property of the electrons of having electric

charge and two laws : 2) Ampere's law linking I to B, and 3) the law of the Laplace force F= Il x B, linking B, together with a second current I, to a force F (with l = the length of the wire conducting the second current situated in field B).

By virtue of the laws featuring B, such as the law of the Laplace force, electrons have more dispositions than just those corresponding to the laws in which charge figures directly itself. Electrons have the disposition to create B, which itself has the disposition to create a force on a wire with a second current. So, indirectly, moving electrons have the disposition to create a force on other charges.

So here is my first argument against the thesis that P is a cluster of dispositions. A cluster is *unstructured*. Therefore, it cannot account for the fact that some dispositions are more directly linked to a property than others.

In our example, the property of bearing electrical charge gives a charged object *directly* the disposition to attract other charges, but only *indirectly* the disposition to exercise the Lorentz force on other wires with electric current.

Laws are required to explain the difference between dispositions that are directly made true by a powerful property P and dispositions that are only indirectly made true by P.

Disposition attributions are directly made true by P if they are determined by 1) power P and 2) a law that explicitly contains P. This is the case of the disposition of electric current to create magnetic field B corresponding to Ampere's law. The set of laws directly containing property P make true a first set S1 of dispositions. This set can be compared to a first "shell of an onion centred on q".

A second set S2 (of which S1 is a subset) of dispositions are more indirectly made true by property P. This "second onion shell" contains dispositions whose attribution to an object x is made true by P and two laws: a law L1 directly containing P and a law L2 containing another property contained in L1.

In our example, the powerful property of carrying electric current is lawfully linked to magnetic field B (Ampere's law plays here the role of L1), whereas B is linked to force F=Il x B by the law of the Lorentz force. Thus the second set S2 contains a disposition whose attribution to a wire w is made true by 1) the fact that electric current flows through w 2), Ampere's law linking current to field B, and 3) the law of the Lorentz force linking B to a force on a second wire with electric current I*.

There is in principle no end to conceiving more sets of dispositions S3, S4 etc. linked even more indirectly to the possession of some powerful property, by three or more laws in addition to the possession of a given powerful property.

Here is a second argument against the thesis that a powerful property P is just a set of dispositions. This doctrine cannot explain why there are no properties corresponding to *subsets* of these sets. Why is there a cluster containing D1 "if E then F=qE", D2 "if v and B, then F=vq x B", and D3 "if v around circle r, then m=qr x v", but no cluster containing, say, only the first two of these three dispositions? Why isn't there a property Q that gives its bearer the dispositions to undergo F=qE if in electric field E and the disposition to undergo F=vq X B if moving with v through field B, but that does not give its bearer the disposition to give rise to magnetic moment m=qr x v if rotating with speed v and radius r ? Postulating laws makes it possible to answer this question: The set of laws containing the property P exactly determines the set of dispositions whose attribution is made true by P. A property such as Q cannot exist: an object can have D1 only if it has q and if the law F=qE holds. But, if laws are conditionally necessary, every world in which q exists contains *all* the laws containing

q. It contains in particular the law by which circulating charges create magnetic moment m=qr x v. So every object that has disposition D1 because it has q (and because the law F=qE holds) must also have D3 because it has q and because the law of magetic moment holds in all worlds containing q.

At one point, Mumford seems to acknowledge that a property isn't just a set or a cluster because there are "real and important connections" (Mumford 2004, p. 173) between the dispositions in a cluster. However, he argues that these connections do not correspond to laws, because laws would have to be external relations. This argument has no force against our view that laws are internal relations between properties.

A third argument against taking properties P to be clusters of dispositions (and against denying the role of laws in determining dispositions) is that it does not seem to be possible, without laws, to make sense of systematic relations between different properties/clusters.

Suppose, for the sake of the argument, that properties are clusters of dispositions. Then it is systematically the case that the same disposition belongs to several clusters Both the cluster of v (speed) and the cluster of B (magnetic field) contain, e.g., the disposition to produce a force on moving charged objects proportional to their charge and speed. In the cluster conception, these dispositions are parts of different properties, v and B.

If properties were clusters, one such cluster, say the cluster of v, should put no constraints on other clusters, such as the cluster of B. However, dispositions belonging to different clusters constrain each other. Given that v gives a charged object the disposition to undergo F=qv x B if in B, the disposition of B to exert a force on charges moving with speed v must be the disposition to produce F=qv x B. B could not contain, say, the disposition to produce F= q^2v x B.

If we take properties to be thin, and to be related to other properties by laws, we can explain these constraints as nomological. Dispositions figuring in different clusters can be constrained by each other because they are determined by the same law. The attribution to an object moving with speed v of the disposition to undergo Lorentz force (F = qv x B) is made true by the objects' property of having speed v and by the law of Lorentz force. The attribution to field B of the disposition to exert force F = qv x B on particles with charge q and speed v is made true by B and *the same law* of Lorentz force (F = qv x B). The fact that the same law contributes to make true both disposition attributions explains why these dispositions are not independent of each other.

Here is a fourth and last argument for taking laws to be part of the truth-maker of disposition attributions (over and above powers): The truth-maker must be in part relational because the disposition is relational, whereas the relevant powerful property is monadic. At least some dispositions have relational triggering and manifestation conditions. In the case of the property of being charged, the triggering condition of the disposition, attributed to an object x bearing charge q, to attract other objects, is a relational fact about x: the fact that x is at distance r from a second object y with electric charge q*. The manifestation condition is also a relational fact: the fact that x exercises a Coulomb force F=keqq*/r2 on y. The truth-maker of the attribution of this disposition to x cannot be entirely monadic because the triggering and manifestation conditions of the disposition are not monadic but relational. Part of the truth-maker is the powerful property of bearing electrical charge, which is a monadic property. But the truth-maker must also have a relational part. If there are laws, we can conceive of the truth-maker as composite, having a monadic part, which is the powerful property P and a relational

part, which is the law relating the power P and the triggering condition to the manifestation condition.

Conclusion

I have sketched a metaphysical framework in which powers and laws together play the metaphysical role of making true disposition attributions. This framework explains why dispositions are systematically correlated with each other. Natural properties that figure in several laws are a common truth-maker for dispositions that always go together. Such properties are powerful properties that correspond to the traditional concept of a multi-track disposition, which we have reinterpreted as consisting of a set of disposition attributions whose truth-makers have a common part. The common part of their truth-makers is a powerful property that is the causal basis of each of the dispositions: it is an intrinsic property of the object to which the disposition is truthfully attributed, which causally contributes, together with any of the triggering conditions, to bringing about the corresponding manifestation.

The reasons for postulating such powerful properties are same as the reasons for postulating theoretical properties in general: Such a postulate is justified insofar as it is the best unifying explanation of the fact that certain disposition attributions are always true together, and insofar as it is fruitful in suggesting new and yet unknown dispositions.

Disposition attributions have composite truth-makers. What makes it true that object x has the disposition to M in triggering situation T, is 1) a monadic powerful property P possessed by the object, which is the causal basis of the disposition, and 2) one or several laws relating T and P to M. Powers are natural properties which are represented by the variables figuring in scientific laws. Against the thesis that laws are not needed over and above powerful properties to make sense of the scientific explanation, we have argued for the following theses. Laws are internal relation between properties. Natural properties make true disposition attributions only together with laws. Natural properties neither contain (as parts or as elements) the laws that link them to other properties nor those other properties[18].

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