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Natural Kinds, Causal Profile and Multiple Constitution

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Abstract: The identity of a natural kind can be construed in terms of its causal profile. This conception is more appropriate to science than two alternatives. The identity of a natural kind is not determined by one causal role because one natural kind can have many causal roles and several functions and because some functions are shared by different kinds. Furthermore, the microstructuralist thesis is wrong: The identity of certain natural kinds is not determined by their microstructure. It is true that if A and B have the same microstructural composition then a sample of a chemical substance A is of the same chemical substance as a sample of B. However, the reverse does not hold. It is not the case that if a sample of a chemical substance A is of the same chemical substance as a sample of B then A and B have the same microstructural composition. This is because a macroscopic NK can be “multiconstituted” by different microstructures.

Keywords: natural kind, causal profile, microstructuralism, constitution, multiconstituted, function, causal role, chemistry, substance

Introduction

Natural kinds (NK) are types of objects, events, or substances that exist independently of human categories (conventional or not).¹ There are intuitively clear

¹ I construe natural kinds as sets or classes of objects rather than as universals (in the vein of Aristotle’s secondary substances), for the greater ontological parcimony of this conception. To anticipate on an example that will be introduced in a moment, the thesis that gold is a natural kind can be interpreted in two ways. According to the first – which I will choose here – the natural kind gold consists of the set of atoms and macroscopic samples of gold, independently of when or where they exist. According to the second, gold is a universal of which individual atoms and samples are instances. These two conceptions of natural kinds are analog to conceptions of natural properties as sets of resembling objects and as universals of which the

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cases of both natural and non natural kinds. The concept T of earthquakes of strength between 4 and 4.9 that occurred in 2014 does not pick out any natural kind because events in set E falling under this concept share no objective feature that (1) is independent of the human concept T and (2) that they do not also share with events outside E. One way of expressing this is by saying that, if there were no human concept T or if there were no humans, the events in E would not resemble each other more than they resemble events outside E. By contrast, gold is a natural kind because there are some respects in which all atoms and samples of gold resemble each other more than they resemble other objects. However, even if the judgments about gold being a NK and E not being a NK are uncontroversial, the task of finding a philosophical theory that justifies these intuitive judgments and provides grounds for judging less paradigmatic cases is difficult. Gold is a paradigmatic NK because there is a simple necessary and sufficient condition for belonging to the set of atoms and samples of gold: an object is gold if and only if it is an atom with atomic number (the number of protons in its nucleus) 79 or if it is composed (almost²) exclusively of such atoms. The aim of this paper is to contribute to the philosophical debate about what NK are and what determines their identity, i. e. what determines whether two objects or samples belong to the same NK.

There are two ways of conceiving of the project of providing a philosophical analysis of what natural kinds are and what determines their identity. One way is to conceive the task as part of “descriptive metaphysics” in Strawson’s (1959) sense. Its aim is to make explicit the structure of the concept of natural kind that is part of common sense and finds its expression in ordinary language. A large part of the philosophical literature on natural kinds belongs to this research tradition, in particular the analysis of the semantics of NK terms of natural languages. The aim of such an analysis is to find out how the competent speaker of a natural language conceives of the reference/extension of the natural kind terms she uses. Descriptive metaphysics so understood has traditionally been conceived and pursued as “armchair” philosophy (Jackson 1998), using the method of analyzing the intuitions of the philosopher herself. However, descriptive metaphysics can be naturalized by cognitive science.³ Common sense

objects in those sets are instances (Bird 2015). The distinction between these two construals of the concept of natural kinds is independent of the theses and arguments that will be examined in what follows.

² The NK concept used both in common sense and in chemistry allows for impurities, which makes its extension vague (Abbott 1997; Hendry 2006).

³ Experimental philosophy has an intermediate status (Knobe and Nichols 2008). It explores the structure of common sense by analyzing the intuitions of a large number of subjects.

concepts can be naturalized by reconstructing them in scientific terms. Attempts at naturalizing a concept can lead to different results. One is the discovery that certain intuitions are determined or at least influenced by the culture to which a person belongs. Others can turn out to be idiosyncratic in the sense of being determined by an individual's life history. However, and that is what seems to be the case of intuitions concerning natural kinds, it can also turn out that some intuitions are shared by all humans, which could be explained by their innate character. Naturalizing an intuition allows to discover the status of an intuition, which remains indeterminate in armchair metaphysics. The natural kind concept implicit in common sense is the object of research in cognitive psychology (Ahn et al. 2001; Gelman 2003) and anthropology (Sousa, Atran, and Medin 2002). This research seems to confirm the thesis that common sense postulates a hidden essence that determines the identity of natural kinds. An "essence" is a criterion for what belongs to a kind that extends beyond actuality to other possible worlds. Postulating such essences allows to explain the fact that we have intuitions on what is possible even if it is not the case in the actual world.⁴ The naturalization of common sense by cognitive science seems to show that some concepts of NK are themselves NK. However, the *concept* of a NK remains of course different from the NK it represents. According to one hypothesis, all human infants develop, at a certain step in their cognitive development, the concept of an animal (Setoh et al. 2013). Whether or not the concept of an animal is a cognitive natural kind, the existence of that concept is independent of the existence of a NK of animals. The former would be a psychological kind, the latter a biological kind whose existence could only be justified by biology and not by cognitive science.

I have mentioned descriptive metaphysics as a first way of conceiving the task of a philosophical analysis of the concept of a natural kind only to distinguish it from a second way according to which the task belongs to the metaphysics of science. With respect to NK, the aim of metaphysics of science is to find out what NK really are in light of what science tells us about them. Scientific concepts are often different from the concepts discovered by the naturalization of common sense concepts. Common sense presupposes e.g. that all animals of a given species share some intrinsic feature that provides a necessary and sufficient condition for belonging to the kind. Contemporary biology, which is relevant for the metaphysics of natural kinds, does not warrant the idea that the animals belonging to a biological species share any intrinsic property. The concept of a biological kind can nevertheless be defined without

⁴ To the extent that the present paper bears on natural kinds as they are construed in science rather than common sense, I will not say anything about essences in what follows.

any such universally shared properties, e. g. by virtue of common ancestry, which is an extrinsic criterion (Okasha 2002).

Existence and Identity of Natural Properties

Metaphysics is concerned with the existence and identity of fundamental types of entities. To develop metaphysics in the light of science, we must find scientific criteria of existence and identity. The most straightforward scientific criterion of the existence of an entity of whatever kind – be it a property, a kind of substance or a kind of events or individuals – is the fact that the entity plays a central role in some science.

(EX) An entity X (property, kind of substance, kind of individual) exists if and only if there is some science that makes reference to X in the laws or models it uses to produce explanations and predictions.

This criterion is suggested as a working hypothesis. It is controversial, given that the possibility of metaphysics of science is itself the object of a vivid debate.⁵ Here are some remarks on the criterion (EX).

1. The criterion of being part of a law of nature is weaker than Quine's. According to Quine, the ontology of a theory consists in the set of entities towards which the theory is "ontologically committed", i. e. the entities that exist if the theory is true. Quine takes quantification as his criterion of ontological commitment: A theory is ontologically committed to the existence of a given sort of entities if and only if these objects belong to the domain in which the bound variables in the axioms and theorems of the theory take their values.⁶ One reason for thinking that Quine's criterion is too strong is that it cannot be applied to theories with different formalizations, such as classical mechanics (Vorms 2011) or to theories which have

⁵ I cannot here do justice to the complexity of the debate on the possibility of doing metaphysics in a way compatible with present day scientific knowledge. One question that structures the debate is whether metaphysical knowledge can at least partly be a priori, as Jackson (1998) and Lowe (2001) argue, or whether it must be entirely derived from scientific theories, which implies that the metaphysics of science has the same status of a posteriori knowledge as those theories themselves. Following Ladyman and Ross (2007), Maudlin (2007) and Callender (2011), I adopt the latter doctrine.

⁶ "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 1939a, 199; italics in the text). Cf. also Quine (1939b). "We are convicted of a particular ontological presupposition if, and only if, the alleged presuppositum has to be reckoned among the entities over which our variables range in order to render one of our affirmations true" (Quine 1948, 13).

several interpretations such as quantum mechanics. I will rather follow Armstrong's (2004) proposal. According to his hypothesis of truth-makers, the ontological commitments of a scientific theory also includes properties expressed by predicates that are not the object of higher-order generalizations. In this sense, (EX) expresses the hypothesis that the formulas expressing scientific laws give us reason to believe in the existence of *all* properties that are represented by the predicates contained in these formula, with the exception of mathematical predicates, not only in the existence of the values of the variables in the scope of a quantifier.⁷

2. The justification of the existence of X by the presence of a predicate representing X in a law statement is independent of the reducibility of the law. It is possible that electric charge is a fundamental property in the sense that some laws about charge are irreducible. However, anticipating an example I will introduce in a moment, the conductivity g_K of cellular membranes of muscle fibers for K^+ ions is certainly not irreducible: It is plausible that there is a reductive explanation of all laws about g_K . This point is important⁸ insofar as there is an important controversy over the ontological implications of "special sciences", i. e. all sciences except fundamental physics. According to the eliminativist argumentative strategy, the fact that the hypotheses of a theory T are neither directly nor indirectly reducible to fundamental physics is a reason to consider that T has no ontological significance, in other words, that the theoretical terms of T do not refer to real properties. Paul and Patricia Churchland have applied such an argument to an important part of common sense psychology, construed as a (folk) theory (Churchland 1979; 1986; see also Kim 1998; Bickle 2003). Others

⁷ Mellor (1991; 2012) provides other arguments for believing that we have as much reason to believe that properties exist as we have to believe that particular objects exist. Mellor suggests replacing Quine's criterion of ontological commitment by what he calls the "Ramsey test". If we collect all laws in a unique "Ramsey sentence", the properties that exist (i. e. those to which science is "ontologically committed") are the values of the (second order) variables that are in the scope of the quantifiers of this Ramsey sentence. This conception leads Mellor to deny that there are properties corresponding to predicates of non fundamental laws, such as the laws of chemistry, e. g. the property of being a potassium atom. According to the Ramsey test only the properties of being specific isotopes of potassium exist because the Ramsey sentence quantifies only over predicates expressing the latter and not over the disjunctive predicate expressing the property of belonging to one or the other isotope of potassium (Mellor 2012, 399). Another problem with Mellor's account is that, as Mills (2014) shows, we have no reason to believe there is only one Ramsey sentence, which means that such a Ramsey sentence is not sufficient for playing the role (of our (EX)) of providing a necessary and sufficient criterion for being a natural kind.

⁸ and deserves to be justified (Kistler 2004; Kistler 2007; Kistler 2012; Kistler 2016).

have argued that, on the contrary, the fact that T is not reducible to more fundamental sciences justifies the (non redundant) existence of a special science T, and thus indirectly the ontological implications one can draw from applying criterion (EX) to its hypotheses (Fodor 1974).

3. (EX) can be justified in a naturalistic framework. Naturalism considers that the best and most fundamental justifications are scientific. In a naturalist framework, the best reason to believe in the existence of X is the fact that science postulates X, which can be inferred from the scientific use of formulas representing laws⁹ that contain a predicate representing X. The fact that X appears in laws reflects the fact that science postulates X because laws play a central role in science. Laws are used to explain and predict phenomena and to justify counterfactual conditionals. True, history gives us reason to expect that the theories and models of present-day science are not definitive, in other words that these theories and models will eventually be modified or replaced. Adopting criterion (EX) makes metaphysics dependent on science, in particular with respect to its change in the course of history. The epistemic status of the metaphysical structures and entities whose existence is justified by (EX) is at least as fallible as the theories from which they are derived. The justification of the metaphysical conception of a part of the world that derives from a scientific theory cannot be stronger than the justification of that theory itself. Metaphysics of science thus construed is necessarily at least as provisional, hypothetical and subject to historical change as scientific theories.
4. According to the conception of metaphysics of science that is based on the application of (EX), its results depend on the scientific theories to which (EX) is applied. (EX) contains the idea that laws and models play the same role with respect to the ontological commitments of a theory. This may seem surprising given the difference between laws and models: Laws correspond to confirmed hypotheses that have been conceived with the intention of being capable of a realistic interpretation. Models are by contrast often conceived as fictions that are not capable of such a realist interpretation (Barberousse and Ludwig 2008). This distinction must be understood in the context of the issue of scientific realism, i. e. the question whether scientific theories aim at representing reality. All hypotheses are fallible; even those that are well confirmed can only be provisional attempts to represent real

⁹ The semantic conception analyzes scientific theories in terms of their models, i. e. interpretations in which the theory is true, rather than in terms of laws, represented by nomological statements. (EX) is independent of this difference in the formal tools for analyzing scientific theories.

entities, properties or processes. The difference between structures introduced as models – and thus as fictions – and structures introduced with the aim of representing laws is a difference of degree. The possibility of interpreting a theory realistically, depends on its integration within the rest of science. To take a standard example, Bohr introduced his model of the atom as a model and thus as a fiction because that model postulates entities with properties that are incompatible with extremely well confirmed physical hypotheses. Bohr’s model contains, e. g., electrons moving on stationary closed orbits without emitting any radiation. Such electrons were introduced as fictions because well confirmed hypothesis of physics prevented them from being interpreted realistically. It is on the ground of this incompatibility that Bohr’s model was taken only a step towards a more coherent and thus more satisfactory theory. In general, the existence of contradictions between different theories and the existence of phenomena that no theory can explain stresses the hypothetical and fallible status of the structures to which these theories are ontologically committed and which are the object of metaphysics of science.

I will now use (EX) to find a principle that makes explicit the way science determines the identity of a natural property X. Then I will argue that a concept of natural kind that fits science can be construed by generalizing from the concept of a natural property. In advanced sciences using a mathematical formalism and representing lawful generalizations in the form of equations, the symbols that do not represent numbers or logical or mathematical relations typically represent natural properties. According to (EX), the presence of the symbol “m” in equations representing laws of nature justifies the existence of the natural property of having a determinate mass (and the determinable property of having some mass or other, i. e. of being massive). One such law is

$$W_p = mgh$$

It specifies the potential energy W_p a body with mass m gains when it is lifted to height h starting from the surface of the Earth, where “g” represents the acceleration of free falling bodies near the surface of the Earth.

Here is a second example of a much more specific natural property whose existence can be justified by (EX). Cellular membranes of muscle fibers have a certain conductivity for K^+ ions, i. e. such membranes are permeable, under certain conditions and to a certain degree, for K^+ ions. The application of (EX) justifies the belief in the existence of a natural property g_K of cellular membranes of muscle fibers of having conductivity for K^+ ions because there are laws

of biophysics (Morris and Lecar 1981) containing a symbol g_K representing this property.

$$I = C\dot{V} + g_L(V_L) + g_{Ca}M(V - V_{Ca}) + g_KN(V - V_K)$$

containing the following symbols:

I = applied current (mA/cm²)

C = membrane capacitance (mF/cm²)

V = membrane potential, V_L , V_{Ca} , V_K = equilibrium potentials corresponding to conductance g_L , g_{Ca} , g_K .

\dot{V} = derivative of the potential V with respect to time, representing its rate of change.

g_L , g_{Ca} , g_K = conductance for leak, Ca⁺⁺ and K⁺ ions (mSiemens/cm²)

M , N = fraction of open Ca⁺⁺ and K⁺ channels

The law expresses the fact that if a current I is applied to such a membrane, the current can be represented as divided in four components: a part proportional to the capacitance C of the membrane is stored as electrons in the membrane. The other three parts correspond to charges crossing the membrane in the form of ions: one fraction proportional to the density of open channels permeable to calcium ions (Ca⁺⁺) and to the conductivity of the membrane to these ions corresponds to the flux of Ca⁺⁺ ions through these channels; another corresponds to the flux of K⁺ ions crossing the membrane through ionic channels specific for these ions; a third part (“leak”) corresponds to the net flux of all other types of ions through other types of ionic channels.

The naturalistic strategy for finding a criterion of *existence* for natural properties (EX) can also be employed for finding a criterion for the *identity* of natural properties, i. e. a criterion that determines whether two property symbols represent the same or different properties. What is the scientific justification for judging that properties F and G are distinct? To show that $F \neq G$, it is necessary and sufficient to find at least one situation in which an object x with G behaves differently from an object y with F . If only deterministic laws are at play, this requires that there is at least one law in which F figures but not G (or vice versa), or a law in which F occupies a different position with respect to G . Taking statistical laws into account, it is necessary and sufficient for showing that $F \neq G$ that there is at least one type of situation in which the evolution and interactions of objects with G differ statistically from those of objects with F . In other words, F figures in the same laws as G , occupying the same structural position as G , if and only if $F = G$. This suggests the following naturalistic criterion of the identity of natural properties.

(ID) The identity of a property P is determined by the set of laws featuring P and the structural role P occupies in those laws.

In other words, the laws featuring a property P make P what it is. This metaphysical thesis must be distinguished from the epistemic claim that a property P is known to the extent that the laws featuring it are known. According to the metaphysical thesis (Shoemaker 1980; Kistler 2002), the laws in which P figures determine P 's identity.¹⁰

Natural properties postulated in science always feature in more than just one law. Here are three laws containing the elementary electric charge q .

1. $\mathbf{F} = q\mathbf{E}$. (variables in boldface represent vectors; other variables are scalars.)
An object bearing elementary electric charge q that is located at a point in space that contains an electric field \mathbf{E} undergoes a force \mathbf{F} of strength and direction $q\mathbf{E}$.
2. $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$. According to the law of the Lorentz force, an object bearing elementary electric charge q that is moving with velocity \mathbf{v} in a magnetic field \mathbf{B} undergoes a force $q\mathbf{v} \times \mathbf{B}$.
3. $\boldsymbol{\mu} = \frac{1}{2} q\mathbf{r} \times \mathbf{v}$. An object charged with q rotating with speed \mathbf{v} around a circle with radius \mathbf{r} , creates a magnetic moment $\boldsymbol{\mu} = \frac{1}{2} q\mathbf{r} \times \mathbf{v}$.

Each law featuring the elementary charge q determines a disposition shared by all objects that bear q . A dispositional predicate can be characterized by a counterfactual conditional, $T\Box \rightarrow M$, where $\Box \rightarrow$ represents the counterfactual connective, T is the characteristic triggering condition and M the characteristic manifestation condition. By virtue of the law $\mathbf{F} = q\mathbf{E}$, objects with q have the following disposition: If an object with q were in \mathbf{E} , it would undergo a force $q\mathbf{E}$. (T : being in \mathbf{E} ; M : undergo a force $q\mathbf{E}$). By virtue of the law $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$, objects with q have the following disposition: If an object bearing the elementary charge q moved with velocity \mathbf{v} through magnetic field \mathbf{B} , it would undergo a Lorentz force $q\mathbf{v} \times \mathbf{B}$.

The appearance of q in each of these laws suffices, according to (EX) to postulate the existence of the property of bearing the elementary electric charge. As we have seen, each of these laws grounds a disposition that objects have by virtue of having q . From the premise that all the laws featuring q are inseparable of q (in the sense that q could not exist without these laws) and the premise that

¹⁰ This thesis has modal consequences. In every world in which P exists, all the laws containing P exist. If there is some possible world w containing a property P^* , such that P^* does not in w obey to one of the laws that P obeys to in the actual world, then P^* is not P . A property that makes objects having it attract (or repel) other charges with $1/r^3$ rather than with $1/r^2$ is not electrical charge, i. e. it is not the same property of electrical charge that exists in the actual world, because the identity of the property of being electrically charged is determined by (among other facts) the fact that charged objects attract (or repel) other charged objects with $1/r^2$. A property such as P^* is a metaphysical possibility: it exists in possible worlds w , in which there is a property that makes things attract or repel other objects with a force proportional to $1/r^3$.

each of these laws grounds a disposition of objects having q , it follows that all these dispositions are inseparable from the property of having q . The possession of q is necessary and sufficient for having all those dispositions. The theses that 1) laws and dispositions are inseparable and that 2) the laws bearing on P determine P 's identity lead to the dispositional account of the identity of natural properties (Shoemaker 1980). The identity of a property is determined by the set of dispositions it gives objects having it, in other words, by its causal profile.

If property P is inseparable from the set of laws featuring P and if each law is inseparable from a disposition then the dispositions corresponding to the possession of P are also inseparable from each other. If an object has one of these dispositions, it must have them all. If the inseparability of a set of dispositions is the consequence of the existence of a natural property, then this inseparability, which is a fact observed by science, can be used as a premise in an inference to the best explanation to justify the existence of the natural property. The existence of P , present in several laws, provides an explanation of the systematic association of the set of dispositions. The three dispositions corresponding to the three laws mentioned above always come together. No object possesses only one or two of them. The postulate of the property of being charged with q that underlies the three dispositions explains why these dispositions are inseparable, which would otherwise remain a brute fact.

The natural property is the *common ground* of all these dispositions. This ground is what Prior, Pargetter, and Jackson (1982) call a disposition's "causal basis": It is the set of intrinsic properties that contribute, together with the triggering condition of the disposition, to causally bring about its manifestation. According to this conception of natural properties, they are what have often been called "multi-track dispositions" (Kistler 2012), in other words, dispositions with multiple manifestations. They are properties that manifest themselves in different ways in different circumstances. Bird (2007) argues that such properties cannot be fundamental. In Bird's vocabulary, a disposition is "pure" if it manifests itself in only one way. Object b has the pure disposition D if its possession gives rise to just one disposition to manifest M in triggering conditions T :

$$(D_b \text{ and } T_b) \square \rightarrow M_b.$$

According to Bird, "we do not need to posit fundamental multi-track dispositions" (Bird 2007, 24) whose possession gives rise to a whole set of conditionals:

$$\text{For all } i [(I_b \text{ and } T_i b) \square \rightarrow M_i b].$$

because all impure dispositions are equivalent to conjunctions of pure (“single-track”) dispositions (Bird 2007, 23).

Two points in reply. 1. The fact that a property appears in more than one law guarantees that it gives its possessors more than one disposition. Therefore, the existence of pure dispositions is doubtful. A property can only ground a pure disposition if it appears in no more than one law. However, the postulate of such a property would be superfluous. If m figured only in the law $F = ma$, we might consider m as defined by F/a . It is essential for theoretical properties that their identity is not exhausted by any one law taken in isolation (Hempel 1965, 116).

2. A theoretical¹¹ natural property such as electric charge does not reduce to the set of its characteristic dispositions (one for each known law in which it figures). A theoretical property provides a unifying explanation of why the dispositions in the set always come together. The postulate of the existence of the property of being charged with q explains why the dispositions associated to that property by the laws featuring it are inseparable. It is impossible that the object possessing q follows only a part of the laws featuring q but not all because “ q ” represents one property the object has or does not have but which it is impossible to have only “partially”.

The Causal Profile of Natural Kinds

The metaphysical category of natural kinds can be construed in analogy to natural properties. A natural kind of objects such as electrons, K^+ -ions or ionic channels in the membrane of muscle fibers that are permeable to K^+ -ions, is a set of objects or samples of substances resembling each other in certain respects, in other words, sharing certain natural properties, more than they resemble objects outside that set.¹² In the case of fundamental kinds such as electrons, the members of the kind resemble each other perfectly, i. e. they share all their intrinsic properties. For non-fundamental kinds, the resemblance is in general not perfect. K^+ ions can belong to different isotopes, such as ^{39}K and ^{40}K . K^+ ions of different isotopes belong to the same natural kind by virtue of sharing the number of protons in their nucleus and their electronic configuration, but they

¹¹ The argument relies on laws and thus only applies to properties featuring in laws, in other words theoretical properties. One might speculate that the conception justified in this way also applies more widely to other properties that are not (yet) the object of scientific theories. However, it is more cautious to limit the scope of the argument to theoretical properties.

¹² In analogy to natural properties, there are two ways of conceiving natural kinds, as sets of objects (or samples) or as universals.

differ with respect to the number of neutrons: both ^{39}K and ^{40}K have 19 protons, but ^{39}K has 20 neutrons whereas ^{40}K has 21. It is atomic number (the number of protons) that determines membership in the natural kind K of potassium, rather than mass (itself determined by the sum of protons and neutrons) because potassium is a chemical kind. From the point of view of chemistry, the evolution and interactions of atoms, in particular their reactivity and capacity to form molecules, are determined by their electronic structure, which is itself determined by the number of electrons corresponding to the number of protons in the nucleus of the electrically neutral atom.

In both cases, fundamental and non-fundamental kinds, a natural kind can be characterized by a set of properties that are systematically associated. Such a set of properties forms what Boyd (1991) has called a homostatic property cluster (HPC), and Slater (2015) a “stable property cluster” (SPC). Natural properties are “systematically ‘sociable’ in various ways. They ‘like’ each other’s company” (Chakravartty 2007, 170).¹³

Explanations that make reference to natural kinds exploit that systematic association. Biochemical explanations that make reference to K^+ -ions depend on the fact that K^+ -ions have several properties. Their positive charge alone is not sufficient to explain the contribution of K^+ -ions to a mechanism such as the propagation of action potentials. This can be seen from the fact that equally positively charged Na^+ -ions play a completely different role in the same mechanism. Proteins that are fundamental for biochemical mechanisms play their role by virtue of many more properties. Not only net charge and mass but charge distribution and spatial conformation are indispensable for their contribution to these mechanisms.

Now, it might seem that it is not necessary to postulate the existence of a natural kind over and above the set of properties shared by all members of the kind. Recall Bird’s thesis that a property giving its possessors many dispositions can be analyzed in terms of a conjunction of properties corresponding each to a simple (or “pure”) disposition. In a similar vein, authors such as Armstrong (1997), Bird (2007) and Tobin (2013) suggest that NK can be analyzed as being equivalent to sets of (1) several properties and (2) laws or mechanisms that hold

¹³ Properties are sociable “in different ways”, in the sense that certain kinds, which Chakravartty calls “essence kinds”, but not all are characterized by the fact that their members share *all* their intrinsic properties. Electrons are such an essence kind because they share all their intrinsic properties such as rest mass, electric charge and spin. In the case of other natural kinds, which Chakravartty calls “cluster kinds”, only part of their properties is shared by all members of the kind. All atoms of potassium have 19 protons in their nucleus but some have 20 neutrons whereas others have 21.

these properties together. Parsimony requires refraining from postulating entities that are not strictly indispensable for making sense of science. “Natural kinds are a superfluous ontological addition. An ontology of properties alone will suffice to determine natural classifications” (Tobin 2013, 175). If it is in principle always possible to provide a reductive explanation of the systematic coexistence of the set of properties characteristic of a given kind, why postulate the existence of the NK as an entity over and above the properties, laws and mechanisms mentioned in that reductive explanation? It may seem superfluous to postulate the existence of the natural kind of potassium ions K^+ , over and above the properties of being an atom with 19 protons in its nucleus and the electronic configuration characteristic of 18 electrons. Once the reductive explanation is known, talk of K^+ -ions can in principle be eliminated in favor of propositions mentioning a structural description featuring the properties in the reduction base, together with the laws and mechanisms holding them together.

To evaluate that hypothesis, we should first distinguish between laws and mechanisms. Natural kinds are not in general equivalent to sets of properties whose systematic association is explained by a mechanism. Fundamental natural kinds of objects cannot be analyzed in terms of mechanisms because these objects have no parts. Take electrons. The mass, charge, and spin characteristic of electrons are systematically associated and thus form a stable cluster. However, given that electrons are a fundamental kind, the coexistence of this set of properties cannot be explained mechanistically. A mechanistic explanation requires an object or system to be complex. It is essential for a mechanistic explanation to make reference to the parts of the object or system to be explained, as well as to the properties and interactions of these parts. Fundamental natural kinds such as electrons have no such parts. Therefore, there cannot be any mechanistic explanation of the fact that the charge, mass and spin of electrons are inseparable. Postulating the existence of the electron as a fundamental natural kind provides a metaphysical framework for explaining that inseparability. That framework can later be completed by a scientific explanation.

However, nothing seems to stand in the way of the possibility of reducing fundamental natural kinds to the set of their properties together with the laws that guarantee their association.¹⁴ In many cases, we ignore how to produce

¹⁴ This is an even more so for non-fundamental kinds, i. e. types of objects or substances that are composed of more fundamental objects or substances. K^+ -ions are composed of protons, neutrons, and electrons. To the extent that the composition is known, it is in principle possible to replace expressions making reference to K^+ -ions by the complete structural description corresponding to the reduction of K^+ -ions to their components and the relations among them.

such a reductive explanation. If all natural kinds are reducible in principle, the concept of natural kind is not metaphysically primitive. However, to the extent that we ignore the complete reduction of all fundamental natural kinds, the concept of natural kind remains epistemically indispensable. Moreover, to the extent that our knowledge of properties and laws constitutive of a natural kind is partial,¹⁵ the set of properties that are known at a given moment in history does not constitute a necessary and sufficient condition for belonging to that kind.

Functional Kinds in Biochemistry?

If the identity of a natural kind is determined by a set of natural properties and if the identity of a natural property is determined by a set of dispositions, in other words by a causal profile, the identity of a natural kind is also determined by a causal profile. With respect to natural kinds playing a role in biology, in particular biochemical kinds, this conclusion seems to justify the thesis that the identity of a natural kind is determined in terms of a functional role (Manafu 2014). In what follows I will examine this thesis. The relation between kinds and functional roles is complex for two complementary reasons. First, one natural kind can in principle have many functions, and second, different kinds can in principle share a function.

So-called “moonlighting proteins” belong to the first category. They are named metaphorically after people with a second job, done at night by “moonlight”. Crystallins are one type of biological molecules that have several functions. In the lens of vertebral eyes they play the structural function of guaranteeing refractive properties and transparency. However, these proteins also serve entirely different functions. The α B-crystallin has, beyond its function as a lens protein, the function of protecting cells from elevated temperatures, serving as a “small heat shock protein” (De Jong, Leunissen, and Voorter 1993), whose synthesis is induced by heat and other forms of physiological stress. Moreover, crystallins play the role of “molecular chaperones”, acting as

¹⁵ This is well illustrated by the case of water. Although the structure of water is simple comparatively to other non fundamental kinds such as organic molecules, new properties of water are regularly discovered (Chaplin 2016). In this sense, Mill explains that it is essential to the concept of a natural kind that it has more properties than those with the help of which we determine the reference of the terms we use to designate it. Natural kinds are “classes, distinguished by unknown multitudes of properties, and not solely by a few determinate ones” (Mill 1843, I, 7, § 4, 80).

enzymes in various aspects of translocation and folding of polypeptides and in the assemblage of protein complexes (Saibil 2013).

Far from putting into doubt their reality, the fact that crystallins play different functions in different circumstances is on the contrary the best justification for their existence as a natural kind. If a molecule played exactly one function, it would be more parcimonious to postulate just a dispositional property. If it played a determinate number of functions, we might avoid the postulate of the kind by referring to a cluster of dispositional properties instead. However, for the same reason as in the case of natural properties, the postulate of a NK underlying different functions provides the metaphysical framework for a unifying explanation of why the dispositions for these various functions always go together. Moreover, the number of functions of a given biological NK is not fixed at any moment of time. In the process of evolution, the same protein can acquire new functions, and lose old ones. Taking account of the possibility that a protein acquires new functions requires postulating an entity that is logically independent of any finite set of functions.

This suggests construing NK as powerful entities¹⁶: all objects belonging to a NK have a certain number of dispositions to behave and interact in various circumstances. Some of them correspond to biological functions. Only part of these dispositions is actually manifested at any given moment, and only a part of those that are manifested is known. The NK underlies and determines the set of dispositions. Each function of a biological molecule can be interpreted as a manifestation corresponding to one of its dispositions.

There are different mechanisms that allow moonlighting proteins to assume different functions in different circumstances. However, in all these mechanisms “a change in the molecular environment” (Tompa et al. 2005, 484) is “responsible for the fact that the protein performs different functions in different situations” (Goodwin 2011, 542). In the metaphysical framework of powers and dispositions, a protein molecule is interpreted as a powerful object P, such that, for each T_i in a set of triggering situations, P and T_i together cause a

¹⁶ The conception of natural kinds as powerful entities bears some similarity to Dumsday's (2013) who also holds that natural kinds provide a metaphysical explanation for why certain properties always come together. “The natural kind essence of an object is irreducible to the properties associated with that essence, such that the kind ‘electron’ is something over and above its mass, charge etc., and serves to ground them.” (Dumsday 2013, 874). However, Dumsday stresses the metaphysical argument in favor of such an “essence”, which makes it sound as if natural kinds had to be postulated by metaphysicians not scientists. On the contrary, natural kinds are postulated in science itself, because their existence provides a theoretical but empirically justifiable explanation of the fact that certain dispositions always come together.

specific functional behavior M_i . Just as natural properties are “multi-track” in determining different dispositions of their bearers (one for each law featuring the property; see above), so NK are multi-track and determine many functions corresponding to their manifestations in various circumstances. The fact that P determines a whole set of dispositions (the relation thus being one-many) explains why “there is no one-one correlation between the tertiary structure of a protein and its biological function” (Goodwin 2011, 542).

The multi-functional profile of a NK shows that its identity is not determined by a single function. The identity of a NK is not determined by a unique *set* of dispositions/functions either, as it is actually manifested or known at some moment. However, it would be wrong to conclude from this that NK are not “functional kinds”. Rather, the fact that a NK has various dispositions and functions suggests a conception of NK as what underlies and determines a set of inseparable dispositions. The set of these dispositions constitutes the NK’s causal profile; the known part of this profile constitutes our inductive basis for postulating it. However, the NK itself is not logically equivalent to the set of functions actually exercised at some moment, because it is essential, at least in the case of proteins, that they can acquire new functions.¹⁷

There is a second and complementary reason for which there is no 1:1 relation between biomolecules and functions. The first was that a given type of molecule can have several functions. The second reason is several molecules can share a function. There are many examples of shared biological functions. In evolutionary terms, this is explained by “convergent evolution”, or more precisely “functional convergence” (Buller and Townsend 2013). Oxygen transport molecules provide a clear case. At least three types of molecules have evolved to play the role of transporting oxygen through a circulatory system to the various tissues in an animal’s body.¹⁸ The most well known consists of hemoglobins, which occupy this function in vertebrates and various invertebrate phyla. In other invertebrate phyla, the function of transporting oxygen is played by molecules of two other types: hemerythrins and hemocyanins. Each of these types includes a huge variety of different molecules (van Holde and Miller 1995).

¹⁷ There are two mistakes in Tobin’s (2010) analysis of moonlighting proteins. First, it is wrong to infer from the “functional promiscuity” (Tobin 2010, 52) of such proteins that molecules with different functions are necessarily “distinct macromolecular kinds” (*ibid.*). The same type of molecule can have different functions. Second, the fact that moonlighting proteins have several functions does not refute the microstructuralist thesis that their functional profile is completely determined by their microstructure.

¹⁸ Other examples are wings, eyes, opsins (Aizawa and Gillett 2011; Aizawa 2018), protein kinase A in the mechanism of memory consolidation (LTP) (Bickel 2003, 144, Kistler 2004, 323; Aizawa 2007; Aizawa and Gillett 2009, 198).

The Multiple Constitution of Natural Kinds

The causal profile of a NK is only partly actualized and only partially known. So far, we have suggested that NK are postulated as the common basis of a set of inseparable dispositions. Some authors have suggested a more explicit and less metaphysically obscure way of characterizing the identity of a NK. Hendry defines microstructuralism with respect to a natural kind as “the thesis that membership of that kind is conferred by microstructural properties” (Hendry 2006, 865) and argues that it is plausible at least for chemical elements but also for complex substances such as water.

Couldn't we identify the NK that underlies the causal profile of a protein simply with the microscopic structure of the protein, i. e. the set of its atomic components and their structural arrangement? Here is how Tahko expresses this hypothesis.

“(IDENT) Necessarily, a sample of a chemical substance A is of the same chemical substance as B if and only if A and B have the same microstructural composition.” (Tahko 2015, 804)¹⁹

I have suggested that a NK is postulated in science as something that underlies a set of inseparable dispositions. Isn't it the microstructural composition of a molecule that determines the set of its dispositions and functions? No doubt, the causal profile is determined by microstructure. This follows from physicalism and from the supervenience of higher-level properties of complex objects on the lower-level properties of their constituents. In the case of proteins, this means that the tertiary (and quaternary) structure of a protein (and thus its causal profile, i. e. the set of its dispositions) is a consequence of its primary structure. However, (IDENT) is a biconditional. What follows from physicalism is one direction, i. e.: If A and B are samples of chemical substances that share their microstructural composition then A belongs to the same kind of chemical substance as B.

What makes (IDENT) controversial is the other direction of the biconditional, according to which, if a sample of a chemical substance A belongs to the same kind of chemical substance as B then A and B have the same microstructural composition. In other terms, what is controversial is whether there is a one-one relation between NK and in particular biochemical kinds such as proteins,

¹⁹ (IDENT) can be interpreted either as a thesis in descriptive metaphysics or as a thesis in the metaphysics of science. According to the first interpretation, it says what common sense intuition takes NK to be, i. e. what determines their identity according to common sense. According to the second interpretation, it says what NK are according to science. We will take it in the latter sense.

identified by their causal profile (partly actual and partly known) and their primary structure, i. e. their atomic structure.

In order to compare the level of the whole molecule with the level of its atomic constituents, let me adopt the convention of calling the former “macroscopic” in relation to the latter. There are two reasons for denying that there is a 1:1 correspondence between a property characterizing the set of microscopic constituents, together with structural relations between them, and the property at the level of the whole molecule that underlies the molecule’s functional profile.

Here is Tahko’s formulation of this thesis:

“(INST) Necessarily, there is a 1:1 correlation between (all of) the chemical properties of a chemical substance and the microstructure of that substance.” (Tahko 2015, 804).

In what follows, I will argue that (INST) is not correct in general because it is possible that different microstructures give rise to the same macroscopic NK, conceived as what underlies and unifies a set of dispositions. One macrostructure can be determined by many different microstructures.

It may be useful to show first that the opposite is not true. It might at first sight seem as if the relation between the set of atomic constituents of a molecule and its chemical type is sometimes one-many, i. e. that the same microscopic structure can give rise to different types of molecules. This might seem to be the case for isomers such as butane and isobutane, because these are different molecules that have exactly the same constituents. However, the case of isomers just shows that there is more to structure than the set of constituents. Structure also includes the relations between the constituents. However, if one includes in the structure, as one certainly should, both the set of constituents *and the set of bonds among them*, isomers are not any more counterexamples to the thesis that the microscopic structure of a molecule determines its chemical type.

We have no reason to doubt the physicalist thesis that if A and B are samples that share their microstructural composition then A belongs to the same chemical substance as B. However, the microstructuralist thesis is wrong because the other direction of the biconditional (INST) fails. “Multiconstitutability” (or “multiple constitutability”) shows that it is not true that if sample A is of the same chemical substance as sample B then A and B have the same microstructural composition.

If a chemical substance is “multiconstituted”, there are two or more microscopic structures that give rise to the same substance.²⁰ Hemoglobin

²⁰ Multiple constitution is analyzed in Aizawa and Gillett (2009). It may be misleading to conceive multiple constitution as (a form of) multiple “realization”. Part of the disagreement between defenders of multiple constitution and advocates of what Gillett (2003) calls the “flat view” of realization (Shapiro 2004) might be overcome by acknowledging (with the

is a case in point. There is a huge variety of hemoglobins even within the human species (Huisman, Carver, and Efremov 1996). However, only a part of the diversity at the microstructural level has effects at the level of the chemical and biological dispositions of hemoglobin. What makes hemoglobin what it is, i. e. what underlies its functional profile, is determined by a very specific part of the microscopic structure. Only 9 of the amino acids that make up the primary structure of hemoglobin molecules are present in all functional hemoglobin molecules. They are the “highly conserved amino acid residues in hemoglobins” (Anandhi 2014, 3–34). Variations at any sites other than those 9 do not alter the functional profile of the molecule (Ota et al. 1997).

For such proteins as hemoglobin there is a many-one relation between their microstructure (the sequence of amino acids that constitutes their primary structure) and the tertiary and quaternary structure that determines their causal profile. This multiconstitutability refutes the microstructuralist thesis according to which there is a 1:1 relation between the identity of a chemical substance at the level of the type of the whole molecule and its microstructure, i. e. the set of its constituents together with their relations. Different microstructures can give rise to a unique type of molecule, in the sense in which the identity of the type of a molecule is determined by its causal profile.

The distinction between the two directions of the biconditional that defines microstructuralism shows a weakness in Goodwin’s defense of microstructuralism. The fact that “the space of conformations, and thus the capacity to react in various ways, is determined by microstructure (Goodwin 2011, 540) corresponds to the physicalist direction of the biconditional. Goodwin’s “space of

latter) that “realization” designates the relation between a role-filler and a role, or in other words, a relation between a concept picked out by a first order predicate (describing the role filler) and a concept picked out by a second order predicate (describing the role). In the case of hemoglobin (which is one type of molecule that fills – or “realizes” – the role of transporting oxygen in the body of animals), the role-filler is multi-constituted: Many microstructures determine what is the same kind of role-filler in terms of its functional profile. It may be misleading to call this relation of constitution a form of “realization”. Let me explain why in terms of the distinction between levels and orders. *Levels* are defined with respect to a hierarchy of parts and wholes. The whole and its properties are at a higher level than its parts and their properties. *Orders* are linguistic and conceptual: A second-order predicate is a predicate defined with an existential quantifier ranging over first-order predicates. Constitution is a relation between properties at different levels: properties of a complex object and properties of its parts, whereas “realization” is more naturally used to designate a relation between properties *at the same level* that correspond to predicates of *different orders*: A functional role is defined by a second-order predicate, the role filler by a first-order predicate.

conformations” can be interpreted as corresponding to the set of dispositions, characteristic of a given chemical type, to manifest M_i in circumstances T_i . According to the hypothesis defended in this paper, this set of dispositions is determined by a power at the level of the molecule. According to physicalism, this macroscopic power itself is determined by microstructure. However, this does not justify “structural monism about protein classification” (Goodwin 2011, 543) because this would require that the other direction of the microstructuralist biconditional is correct as well. In fact, the determination of the macroscopic powers by the microstructure is often many-one, in the sense that many different primary structures determine the same tertiary (or quaternary) structure, which itself determines the set of dispositions and possible functions a protein can have.

Conclusion

Natural kinds are theoretical postulates that provide a framework for the scientific explanation of why certain properties and dispositions systematically go together. The identity of a natural kind is determined by a set of dispositions that constitutes its causal profile. In the case of biochemical kinds, some of their dispositions correspond to functions. This conception of NK makes sense of the fact that some biological kinds have more than one function and that different kinds can share a function. I have distinguished two theses that are often run together as “microstructuralism”, one correct and one incorrect. The correct part is the physicalist thesis that if two samples A and B share their microstructure, then A and B belong to the same kind. The incorrect part is the reverse conditional. It is not correct that if A and B belong to the same chemical kind, they share their microstructure. Biochemical kinds such as proteins are “multiconstituted”, in the sense that two molecules with different microstructures can belong to the same chemical kind.

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