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WHY WATER MAY NOT BE A NATURAL KIND AFTER ALL: ENRICHING THE DISCUSSION AROUND CHEMICAL KINDS*

Por qué el agua podría no ser una clase natural después de todo: Enriqueciendo la discusión en torno a las clases químicas

Vanessa A. Seifert [a, b]
https://orcid.org/0000-0002-5391-0791
seifertvan@phs.uoa.gr

[a] University of Athens, Athens, Greece.
[b] University of Bristol, Bristol, United Kingdom.

Abstract

I present an argument that undermines the standardly held view that chemical substances are natural kinds. This argument is based on examining the properties required to pick out members of these purported kinds. In particular, for a sample to be identified as —say— a member of the kind-water, it has to be stable in the chemical sense of stability. However, the property of stability is artificially determined within chemical practice. This undermines the kindhood of substances as they fail to satisfy one of two key requirements: namely that they are picked out by (some) natural properties and that they are categorically distinct. This is a problem specifically for the natural realist interpretation of kinds. I discuss whether there are other ways to conceive of kinds in order to overcome it.

Key words: Chemical Substances; Natural Kinds; Chemical Stability; Metaphysics of Chemistry.

Resumen

Presento un argumento que socava la visión estándar de que las sustancias químicas son clases naturales. Este argumento se basa en el examen de las propiedades requeridas para seleccionar a los miembros de estas supuestas clases. En particular, para que una muestra sea identificada —por ejemplo— como miembro de la *clase agua*, tiene que ser estable en el sentido químico de estabilidad. Sin embargo, la propiedad de estabilidad se determina artificialmente dentro de la práctica química. Esto socava la naturaleza de clase de las sustancias, ya que no satisfacen uno de los dos requisitos clave: que son seleccionadas por (algunas) propiedades naturales y que son categóricamente distintas. Este es un problema específicamente para la interpretación realista natural de las clases. Discuto si hay otras formas de concebir las clases para superarlo.

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Palabras clave: Sustancias químicas; Clases naturales; Estabilidad química; Metafísica de la química.

1. Introduction

Chemical substances may not be natural kinds after all. This is not because —as one might think— they are eliminated by their physical basis. Nor because there are no essential properties which uniquely pick out members of these classes.[1] Instead, there is a different —and so far, unheard of— reason for questioning their kindhood. This reason, in short, lies in their stability and how chemists determine it.

In this article, I formulate a novel argument that undermines the natural kindhood of substances such as water. This argument is based on the analysis of what it means in chemistry for a substance to be stable. I show that stability is a property which is determined by chemists to hold under some set of conditions. This warrants us to question the metaphysical import assigned to the relevant chemical classifications. This is because two key requirements are undermined as a consequence of this feature of stability. The first is that for any classification to be regarded a natural kind, its properties (by which its members are picked out) have to be natural. The second is that natural kinds need to be categorically distinct. Due to chemical stability, this is not the case for substances.

I only focus on substances and not on other chemical entities which have been discussed as candidate natural kinds in the literature (such as elements or acids). I follow IUPAC's definition of substances. By substance, chemists refer to "(m)atter of constant composition best characterized by the entities (molecules, formula units, atoms) it is composed of." (IUPAC, 2014, p. 265).

Section 2 briefly presents what has been discussed about substances vis-a-vis their natural kindhood so far. Section 3 spells out how chemical stability undermines substances as candidate natural kinds. Section 4 discusses the implications of this argument, including ways it could be circumvented. Section 5 concludes.

2. On Chemical Kinds So Far

Several case studies from chemistry have drawn the attention of philosophers who are interested in natural kinds, including elements,

[1] I leave open that one could formulate arguments on these two bases. I don't consider this here.

substances, mixtures, macromolecules and acids (see Seifert, 2023 for an overview). However, the discussion of chemical kinds has been somewhat one-sided. Most debates revolve around identifying which properties are necessary and/or sufficient to pick out members of these kinds. Whether we have good reasons to think of these cases as natural kinds in the first place has not been debated (at least explicitly). Admittedly, being able to identify which properties are essential to picking members of a classification brings one half way to establishing that this classification corresponds to a natural kind. Nevertheless, as the general literature illustrates there are other criteria to natural kindhood that extend being able to identify which properties are essential to a kind.

Before focusing on two such criteria, this section briefly presents how the discussion of substances as kinds has unfolded so far.

Which properties unify the members of a chemical kind, such as of the kind-oxygen, the kind-water, the kind-hydrochloric acid, and so on? The received view on this question is microstructural essentialism, which takes microstructural properties to correctly pick out the members of these kinds. Chemical elements and compounds have been discussed more extensively, though philosophers have also extended their analysis to acids and macromolecules. For example, in the case of water, discussed most famously by Kripke (1972) and Putnam (1975), microstructural essentialism takes that it is the structure of the constitutive atoms of water (namely of oxygen and hydrogen) that are essential to all members of the kind-water (e.g. Ellis, 2001; Harré, 2005; Havstad, 2018; Hendry, 2006; and Hoefer & Martí, 2019).[2] The property which is taken to confer the (micro) structure of atoms is atomic number, namely the 'number of protons in the atomic nucleus' (IUPAC, 2014, p. 123). What it means for these properties to be essential is not entirely uncontroversial, as some take it to mean that essential properties have to be both necessary and sufficient, while others require them to only be necessary.

The main objection that has been raised against microstructural essentialism is that specifying microstructure is not sufficient to correctly pick members of substance-kinds, such as water.[3] First, this is because there are examples of substances that —if their members were unified only in terms of their microstructure— would include in their class substances with remarkably different macroscopic properties. The main example offered is that of water and heavy water (i.e. deuterium oxide). Heavy water

[2] Hence the famous phrase 'Water = H_2O'.

[3] This objection holds weight only under the assumption that essential properties are both necessary and sufficient to picking members of a kind.

consists of isotopic variants of oxygen and hydrogen which in turn account for its high toxicity (the chemical formula for heavy water is D_2O). By following microstructural essentialism, one would have to admit deuterium oxide as a member of the kind-water, which may be problematic if we want to retain the idea that water is (always and essentially) a drinkable non-toxic substance.[4]

The same point is illustrated by the case of isomers. Isomers are "(o)ne of several species (or molecular entities) that have the same atomic composition [...] but different line formulae or different stereochemical formulae and hence different physical and/or chemical properties" (IUPAC, 2014, p. 784). A microstructural essentialist does not differentiate between different isomers: ethanol and methoxymethane for example are both considered members of the same substance-kind because they have the same number and type of atoms (Hendry, 2006, p. 869). This is problematic not only because substances with starkly different observable properties are not distinguished as different kinds, but also because it goes against chemical practice which does differentiate and identify them as different kinds of substances. [5]

Interestingly, there is a way to circumvent both these problems without having to reject microstructural essentialism. This is done by enriching the notion of microstructure to include not only the specification of the atomic number of the relevant atoms, but also their proton number and the ways in which these atoms are connected to each other. If one incorporates such information to the idea of microstructure then the objection raised by the cases of isotopes and isomers could be overcome.[6]

The problems for microstructural essentialism do not end here however. Needham (2011, p. 9) and Häggqvist (2022) have argued that there is no single unique microstructure to a substance-kind by which one could

[4] To my knowledge, this objection is a consequence of a similar objection raised against element-kinds and their isotopic variants. Isotopes are "(n)uclides having the same atomic number but different mass numbers", meaning that different isotopes of an element share the same number of protons but have different numbers of neutrons (IUPAC, 2014, p. 794). Robin Hendry discusses this objection for the case of compound-kinds and rejects it for both elements and compounds (Hendry, 2012, pp. 62-63).

[5] Needham (2011) raises a similar worry for the case of mixtures: microstructural essentialism cannot distinguish between certain compounds and mixtures. A mixture refers to a "portion of matter consisting of two or more chemical substances" (IUPAC, 2014, p. 941). For example, a microstructural essentialist cannot differentiate (as kinds) between a homogeneous mixture of hydrogen and oxygen (of specific proportion) and water (which similarly consists of these types of atoms).

[6] Havstad (2018) offers a very nuanced and interesting analysis of how such challenges can (to an extent) be overcome.

unify its members. This is because the thermodynamic conditions (i.e. the temperature and pressure) in which substances are found influence their microstructure in significant ways. Returning to the example of water, its microstructure is quite different when found in its liquid, solid or gaseous phase. Bond lengths and bond angles differ and so does the concentration of ions of H_3O^+ and OH^- to which H_2O molecules dynamically transform within the substance. So, water exhibits variations of microstructures which are determined by the macroscopic conditions in which water is found.

A final problem raised against microstructural essentialism is that microstructural properties are not necessary to pick out members of substances-kinds.[7] Indeed, Needham formulates such an argument, claiming that the specification of the thermodynamic properties of substance-kinds are sufficient to picking their members (Needham, 2011, p. 8). He argues that the unique triple point of substances theoretically distinguishes between different substance-kinds. In addition, the use of the Gibbs phase rule in thermodynamics successfully distinguishes distinct substances in a mixture. Thus one needs not to invoke microstructure to pick out members of substance-kinds.

This is how the discussion of chemical kinds has developed so far with respect to substances (but also to an extent, chemical elements). There are also some interesting discussions around acids, where Chang (2012; 2015) has denied their kindhood on the grounds that there is no set of properties which acids have in common and according to which they could be grouped together (see Scerri, 2002 and Thyssen, 2023 for a recent response). In the interface with biology, chemical kinds have also drawn attention, with philosophers focusing on whether biological functions should be included in the identification of biochemical kinds (e.g. Bartol, 2016; Bellazzi, 2022; Goodwin, 2011; Tahko, 2020; Tobin, 2010).

Returning to the case of substance-kinds, no one (to my knowledge at least) has argued against them being natural kinds. Everyone agrees that water is a kind and existing disagreements almost exclusively revolve around which properties are necessary and/or sufficient to picking out its members.[8] While this has offered great insight into the nature of chemical substances (and of water more specifically), it has overlooked the extensive body of knowledge around natural kinds found in the general philosophical literature. Section 3 enriches the discussion of substance-kinds (and thus

[7] Note that this is a problem under both interpretations of what it means to be an essential property (see above).

[8] The only case for which there is a debate about whether it corresponds to a natural kind is that of acids (e.g. see Chang, 2012; 2015, Thyssen, 2023, Scerri, 2022)

chemical kinds more generally) by offering a new perspective through which to examine them.

3. A New Dimension to the Discussion: Naturalness & Distinctness

In the *Stanford Encyclopaedia of Philosophy*, Bird and Tobin (2024) list six criteria that more or less should be fulfilled for a classification to be admitted as a natural kind.[9] These are:

(I) "Members of a natural kind should have some (natural) properties in common."
(II) "Natural kinds should permit inductive inferences."
(III) "Natural kinds should participate in laws of nature."
(IV) "Members of a natural kind should form a kind."
(V) "Natural kinds should form a hierarchy."
(VI) "Natural kinds should be categorically distinct."

I claim that criteria I and VI are not fulfilled for the case of chemical substances, thus undermining the standard realist interpretation of natural kindhood, namely what Bird and Tobin call 'naturalism about kinds'. This is the standard realist view of natural kinds which takes that scientific classifications have metaphysical import and should be regarded as real because they carve nature at its joints.[10] Note that I do not reject substances as kinds tout court, but rather offer an argument that undermines a specific realist interpretation of natural kinds when applied to substances. Specifically, in this section I show that there are grounds to entertain the idea that substance-kinds such as water are not kinds as per the natural realist. These grounds are based on the analysis of a necessary property of substances, namely stability.

For any chunk of matter to be admitted as a substance, it has to be stable. Stability is defined by the International Union of Pure and Applied Chemistry (IUPAC) which is the authority for chemical nomenclature as follows:

[9] As they point out, these criteria are set under the naturalistic reading of natural kindhood and not under conventionalist or pluralist interpretations (Bird & Tobin, 2024, Section 1.1). For the time being, I only focus on the former reading and in section 4 I discuss alternative interpretations of natural kindhood as a way to circumvent the problem I present.

[10] This is not a general criticism against the realist interpretation of natural kinds, but against viewing substance-kinds as per this interpretation. Nevertheless, as I mention in section 4, one way to respond to this criticism is by rejecting this interpretation altogether.

> As applied to chemical species, the term [stable] expresses a thermodynamic property, which is quantitatively measured by relative molar standard Gibbs energies. A chemical species A is more stable than its isomer B if $\Delta_r G^o > 0$ for the (real or hypothetical) reaction A→B under standard conditions. If for the two reactions: P→X+Y ($\Delta_r G^o{}_1$), Q→X+Z ($\Delta_r G^o{}_2$), P is more stable relative to the product Y than is Q relative to Z. Both in qualitative and quantitative usage the term stable is therefore always used in reference to some explicitly stated or implicitly assumed standard. (IUPAC, 2014, p. 1432)

Stability is a necessary property of any and all members of a (purported) substance-kind. There is no member of a purported substance-kind which is not stable. This is to be expected as for any substance to be empirically identifiable (by some measurement), it must be stable. Achieving stability is crucial to manipulate a substance, study it, and observe its chemical and physical properties. If there are no manageable conditions under which to study a substance there is not really any use of it; more than that, one cannot sensibly identify it as a distinct entity.

Given this, it follows that stability needs to fulfil the criteria listed by Bird and Tobin if we want to admit substances as kinds according to the natural realist interpretation. Following criterion (I), being a natural property is among those criteria.[11]

Most discussion on this criterion revolves around what one means by natural properties: if they need to be intrinsic, and if any sort of natural property will do to fulfil it. In general, a lot has been said about what one means by natural and unnatural properties; I cannot do justice to the extensive literature dedicated to this distinction (see Dorr, 2024 for an overview). For present purposes, I assume that however one understands naturalness, there is one feature to it which is uncontroversial, namely that natural properties are not artificial.[12]

There are different ways in which a property may be thought of as artificial but here I spell it out in terms of mind-dependence. That is, a property is artificial (and thus unnatural) if it is mind-dependent. A classic example of an artificial property is the value we assign to money. The

[11] I do not consider whether natural properties are distinct from kinds (e.g. Tobin, 2013).

[12] I assume that if something is artificial then it is unnatural, but I leave open that the opposite may not be the case (namely that an unnatural property, entity, etc. is artificial). Given that my argument hinges on pointing out the existence of an artificial property when picking substance-kinds (namely of stability), this allows me to refer to this specific property as an unnatural one.

property of certain green papers having the value of 5 dollars is artificial: it is something people have come up with. In general, for any ontological category to be regarded mind-independent it must be the case that it does not depend causally and intentionally on us humans (e.g. Brock & Mares, 2007). Put crudely, an entity or property is mind-independent if it can exist independently of us and how we conceive it. As Brock and Mares put it using as example the economy:

> Objective existence [...] has nothing to do with impartiality. An official government inquiry into the state of the economy may be unbiased and disinterested, and so objective in one perfectly respectable sense, but this is not enough to secure any sort of realism about the economy. It must also be shown that the economy exists independently of us: independently of our minds and our mental states (2007, p. 34).

Brock and Mares point out that there are different ways something can depend on our minds, leading to different forms of antirealism (such as social constructivism).[13] Two forms of mind-dependence are of interest in the present context: causal and intentional dependence. Brock and Mares define causal dependence as follows:

> A domain of Fs causally depends on us if and only if we play an essential causal role in bringing the Fs into existence; that is, the Fs would not have come into existence in the first place had human beings, and our concomitant actions, intentions and mental states not existed (2007, p. 38).

This is not a particularly strong form of dependence as it does not necessarily imply that the relevant F is not objective. Consider for example the Acropolis: it causally depends on humans in the sense that —if there were no human to construct it 2000 years ago— it would not have existed. But the monument is well enough independent of our continuous existence: whether or not humans disappear from Athens will have no effect on its existence (they are, as Brock and Mares would put it, metaphysically independent).[14] The second form of dependence is more pressing and it is

[13] I am not currently interested on how this affects discussions around realism-antirealism, though the connection of natural kinds with the realism debate is fairly evident.

[14] This is defined as follows: "A domain of Fs metaphysically depends on us if and only if the continued existence of our minds is required for the continued existence of the Fs" (Brock & Mares, 2007, p. 39).

this form which is relevant to the property of chemical stability; namely intentional dependence.[15] As Brock and Mares put it "(t)heir continued existence requires that we have an appropriate intention: an intention that they continue to exist" (2007, pp. 41- 42).

More precisely, IUPAC's definition shows that chemical stability intentionally (and hence causally) depends on the scientists' choices. Recall the last sentence of its definition: "Both in qualitative and quantitative usage the term stable is therefore always used in reference to some explicitly stated or implicitly assumed standard" (IUPAC, 2014, p. 1432). This suggests that determining the stability of a chemical entity depends on the specific thermodynamic conditions in which it is considered, which in turn depends —causally and intentionally— on the scientists who chose those conditions.

Usually, these conditions are the so-called standard thermodynamic conditions. These are specified in terms of standard pressure, standard concentration or standard molality.[16] What precise value these conditions take depends on the phase of the examined system (i.e. whether it is a liquid, solid or gas).[17] Moreover, the value of standard conditions can change over time. For example, the standard pressure nowadays corresponds to the value 10^5 Pa, but prior to 1982 it corresponded to 101 3215 Pa (i.e. 1 atm) (IUPAC, 2014, 1437).

Not all entities are considered under standard conditions. For example, pure liquid acrylonitrile is admitted as a stable substance even though is not naturally found under normal thermodynamic conditions and only achieves stability at temperatures over 100 °C. This example also shows that there is no mind-independent difference between different thermodynamic conditions. In principle, any set of conditions can be admitted as the appropriate context in which some chemical entity is

[15] Intentional dependence implies causal dependence but not vice versa: not all causally dependent things are intentionally dependent but all intentionally dependent things are causally dependent.

[16] Standard concentration is "*usually* equal to 1 mol dm^{-3}" and standard molality is "*usually* equal to 1 mol kg^{-1}" (italics added here) (IUPAC, 2014, pp. 1434, 1437).

[17] As IUPAC states, "(t)hree standard states are recognized: For a gas phase it is the (hypothetical) state of the pure substance in the gaseous phase at the standard pressure $p=p^o$, assuming ideal behaviour. For a pure phase, or a mixture, or a solvent in the liquid or solid state it is the state of the pure substance in the liquid or solid phase at the standard pressure $p = p^o$. For a solute in solution it is the (hypothetical) state of solute at the standard molality m^o, standard pressure p^o or standard concentration c^o and exhibiting infinitely dilute solution behaviour. For a pure substance the concept of standard state applies to the substance in a well defined state of aggregation at a well defined but arbitrarily chosen standard pressure." (IUPAC, 2014, p. 1438)

examined and thus admitted as a substance. To put it crudely, for nature, one set of conditions (as determined by pressure, concentration or molality) is no different or better than any other.

All in all, substances that are regarded as stable under some set of thermodynamic conditions, may not be so under other conditions. In fact, the example of liquid acrylonitrile above shows that it is possible for entities to be admitted as substances even if they are stable under different conditions from those that chemists regard as normal. Indeed, scientists more often than not admit as substances chemical entities which are stable under vastly different set of conditions. On the other hand, this also implies that there are chemical entities which are not identified as substances (yet) even though they could in principle be stable under some set of conditions that scientists do not wish or cannot consider (because for example, these conditions are too extreme to be experimentally reproducible).

In sum, whether a chemical entity is stable is determined by the choice of conditions under which it is examined which in turn implies that its admittance as a substance (or not) is also dependent on the particular choices of scientists. This undermines a natural realist reading of substance-kinds because it challenges criterion (I), namely that a kind's unifying properties are not artificial.

One way to resist this challenge is by pointing out that as long as there are some set of conditions in which a substance is stable, this suffices for stability to be regarded a natural property. That is, one could argue that as long as there is at least one set of thermodynamic conditions under which an entity is stable then this suffices to admit it as a substance-kind. On this view, the naturalness of stability is retained because whether an entity achieves stability (under any conditions) does not hinge on scientists' choice of specific conditions (they are not, that is, intentionally dependent). This is because, after having set specific thermodynamic conditions under which a substance is considered (either theoretically or empirically), scientists have no control over whether said substance reaches energetic stability or not. That is, scientists' interference is restricted to the choice of conditions in which a substance is studied. It is only in this sense that stability can be said to be context-dependent. But whether an entity achieves stability under those conditions remains a mind-independent matter of fact.

Nevertheless, there are two consequences to this response that can be problematic. The first is that a much wider range of chemical entities are admitted as candidate kinds, including entities which may not be identified by scientists as substances. This would include entities that reach stability under conditions that are far from the normal ones or that may not even be practically possible to experimentally reproduce. In the following section, I discuss realist views on kindhood that are willing to bite the bullet on this. Nevertheless, it is still worth keeping in mind that by doing so we are lead to admit as substance-kinds categories that go far beyond those that scientists posit or work on.

The second problem has to do with criterion (VI) of the list offered by Bird and Tobin, namely that natural kinds are categorically distinct. This is not an uncontroversial criterion and not everyone accepts it as a necessary requirement for natural kinds (even under the natural realist reading of kinds). However, following Bird and Tobin, I assume that this is something that natural kinds fulfil under the standard realist reading of kinds. Bird and Tobin explicate nicely the content of this criterion by invoking an example from chemistry (see also Ellis, 2001):

> There cannot be a smooth transition from one kind to another. For then the borderline between them could not be one drawn by nature but is one that is somehow or other drawn by us. In which case the kinds would not be genuinely natural. This is exhibited by the chemical elements. Chlorine and argon are neighbours in the periodic table. There are no atoms that are intermediate between chlorine atoms and argon atoms, for the nucleus of an atom cannot have a number of protons between seventeen (chlorine) and eighteen (argon) (Bird & Tobin, 2024).

So, it seems that chemical elements satisfy this requirement. However, substances do not. Once again, this is because of stability and the fact that this property is determined within a continuous range of thermodynamic conditions. To spell out this argument, I return to the definition of substances formulated by IUPAC: "(m)atter of constant composition best characterized by the entities (molecules, formula units, atoms) it is composed of." (IUPAC, 2014, p. 265). Note that this definition does not require that substances are composed by electrically neutral atoms or molecules. As long as a chunk of matter of constant composition is thermodynamically stable, this suffices for it to count as a substance. By allowing substances to be stable under any range of thermodynamic conditions, one would have to admit substance-kinds that are composed of ions, namely by atoms or molecules that are electrically charged. Indeed, there are thermodynamic conditions in which ions can be stable.

If one accepts this situation then —to the extent that criterion VI is admitted as a valid prerequisite for kinds— they would have to abandon the natural realist interpretation of kinds.[18] This is because criterion VI is

[18] Admittedly this is a weak objection against the natural realist interpretation of

overturned: there is no clear cut distinction between one substance-kind and the next, but rather a smooth transition that includes intermediate substance-kinds composed of all the possible configurations of its ionised states. One way to circumvent this problem is by excluding non-neutral chemical configurations as candidate kinds and only admitting neutral ones. However, this would go against chemical practice which already admits acids and bases as kinds despite the fact that not all of them are electrically neutral. The latter in fact reinforces the idea that what is admitted as a substance-kind (and what not) depends very much on the particular intentions of the scientists, thus undermining a natural realist view of substance-kinds.

This section argued that chemical stability is not a natural, but an artificial, property of substance-kinds because it is determined by the choices of the scientists. This undermines the first criterion for the natural realist interpretation of kinds. A possible way to circumvent it is by distinguishing stability's mind-independence from its dependence on thermodynamic conditions, and argue that the latter does not imply the former. But in this case, one would have to reject criterion (VI), namely that kinds are categorically distinct. In any case, the standard natural realist view of kinds is undermined when applied to substances. The next section maps the possible ways to respond to this situation.

4. Implications and Possible Responses

There are different ways one can respond to the aforementioned analysis that range from rejecting substances as natural kinds, to amending one's view of natural kinds or even rejecting this idea altogether. I present each alternative and discuss how each one could be supported by scientific evidence and practice. I do not defend a specific view as the purpose here is to only map the plausible ways of response in light of stability's role in identifying substances.[19]

4.1 Against substance-kinds or against kinds altogether

One option is to simply reject that substances are good candidates for natural kinds. That is, one could believe that science posits classifications

kinds because one could just drop this criterion altogether without compromising their realism about natural kinds.

[19] I take that the positions I present in this section to cover a wide range of plausible responses though I do leave open that there might be other positions I have not presently considered.

that carve nature at its joints and that there are scientific categories which have metaphysical import, but deny that substances are such an example. This is a coherent option about substances but one which to my knowledge has not been defended in the literature so far.

Another option is to deny that there are natural kinds altogether and defend an antirealist or conventionalist view of natural kinds. Naturalism about kinds is contrasted to conventionalism which in turn takes classifications into kinds to be mind-dependent. As J.S. Mill explicated the distinction:

> In so far as a natural classification is grounded on real kinds, its groups are certainly not conventional; it is perfectly true that they do not depend upon an arbitrary choice of the naturalist (Mill, 1884, bk. IV, ch. II)

Indeed, one could claim that the artificial character of chemical stability (as explicated above) is suggestive of an arbitrariness inherent in the choice of thermodynamic conditions (following Mill) which in turn undermines the naturalness of the relevant classifications. In this context, substance-kinds can be viewed as conventional classifications that are posited by scientists in order to serve certain epistemological aims, such as explanation, prediction, and so on. There is no metaphysical import assigned to these classifications; they are merely useful tools in chemical practice.

It is not the first time substance-kinds (specifically, a subset of them) are viewed as conventional kinds. A view along these lines has been defended by Hasok Chang (2012) who believes that acids are not natural kinds (as per the realist) because there is no unifying property to its members. His view is based on different grounds from those presented here, namely on the conceptual unclarity and 'messiness' (as he calls it) in defining acids. Regardless of whether his claim holds, his criticism shows that an antirealist position for substance-kinds is not new in the literature. In fact, his criticism is indicative of a more general problem with defending the traditional realist interpretation of natural kindhood for chemical substances.

4.2 Promiscuous realism

However, all is not lost for the realist about kinds. One way to circumvent an antirealist reading of substance-kinds is by defending a different form of realism about them. An example is John Dupré's promiscuous realism about natural kinds. According to Dupré (1993), nature may not be carved at its joints but scientists do succeed in discovering kinds with metaphysical import. The key difference to the naturalist interpretation of kinds is that promiscuous realism allows the crosscutting of kinds and denies the need for them to be categorically distinct. It is a pluralist reading of natural kinds: science discovers many different classifications which are not hierarchical, may overlap one another, yet all possess metaphysical import.

This is a plausible position given the challenges raised in the previous section. Specifically, one could maintain that stability is an arbitrarily defined yet natural property, allowing for much more classes of substances to be admitted as kinds and accepting that these kinds transition smoothly from one to the other. Given that Dupré denies criterion (VI), the challenge posed against it in the previous section is not a problem for the promiscuous realist. And, regarding criterion I, the problem raised above reinforces the plurality of kinds purported by Dupré, rather than undermines its account.

Nevertheless, the key challenge for this account is that it would have to admit as natural kinds, classifications which are not posited or invoked by chemists thus distancing itself considerably from chemical nomenclature and practice. If one wishes to maintain a naturalistic stance towards her metaphysics, in the sense that she wishes to adopt metaphysical views that conform to our best scientific knowledge and practice, then this is not a favourable position.[20]

4.3 Functional view of substance-kinds

That chemists only identify as substances those chunks of matter that can be manageable, reproducible and analysable under some conditions prompts us to think of these classifications in functional terms. Doing so cannot only circumvent the worries raised in the previous section; it can also incorporate in our understanding of natural kinds how substances are in practice identified.

Very briefly, a functional kind is one whose unifying properties correspond to specific functions. To put it crudely, what unifies members of a functional kind is a common function they all share. For example, objects that belong in the class of knives are grouped together because they all share the specific function of acting as knives: they are used in order to cut and serve food.

[20] There is extensive literature on naturalistic (or naturalised) metaphysics (e.g. Ladyman & Ross, 2007; Morganti & Tahko, 2017; Soto, 2015). This should not be conflated with the naturalised view of kindhood that is discussed throughout this paper.

A functional view of natural kinds has been prominent with respect to biological classifications and has been spelled out extensively for biological and biochemical kinds. In this context, proteins are a paradigmatic example of purported functional kinds. Proteins are macromolecules which —instead of being grouped together in terms of their microstructure (as would be typical of chemical entities; see section 2)— they are unified in terms of their specific functions in biophysical processes (e.g. Bartol, 2016; Bellazzi, 2022; Tahko, 2020; Tobin, 2010). In chemistry too, functional kinds are not a new idea. Goodwin discusses how organic molecules are classified in terms of their functional groups.[21] He states:

> Organic molecules are also classified by functional group because this is really useful in understanding and projecting the chemical reactions in which they might participate. Many organic molecules contain more than one functional group, and so they might be classified into different groups for different purposes or in different situations (2011, p. 538).[22]

In a similar manner, substance-kinds can be viewed as an example of functional kinds. Because stability —which is one of substances' necessary properties— is functionally determined by the interests of scientists, it follows that substances are functional kinds. That is, given that one of their unifying properties is a functional property, substance-kinds are functional kinds.

To establish this position, one needs to offer an account of why and in what sense chemical stability is a functional property. Briefly, there are good reasons to think of stability in functional terms. Given that there is no principled difference between one set of thermodynamic conditions and any other, one could argue that the choice of particular conditions under which scientists consider an entity (and thus its stability) is solely based on their goals and experimental means. This is corroborated by the fact that there is no single, unique set of conditions in which all substances are considered stable, but also by the fact that the appropriate conditions for stability can change over time depending on the goals and technological

[21] A functional groups is "an atom, or a group of atoms that has similar chemical properties whenever it occurs in different compounds. It defines the characteristic physical and chemical properties of families of organic compounds" (IUPAC 2014, p. 605). While the term 'functional' is used both with reference to functional groups in chemistry and with respect to functional kinds in philosophy, the two are not identical in meaning and should not be conflated.

[22] However, Goodwin's view is that microstructure is still the fundamental characteristic of both organic molecules and of proteins.

means available to scientists. This is how I view the general argument to unfold, though I admit that more should be said to establish it in full.

Nevertheless, there is a worry that also needs to be addressed in order to establish a functional view of substance-kinds. Specifically, one needs to establish that the functional aspect of stability is not reducible to some other non-functional property (or causal power). The need to address this stems from a general worry about functional kinds. For example, Tahko has argued that —following a proper subset view of powers— the causal powers of a function corresponds to the proper subset of the powers of the microstructure of the protein which realises that function (2020, p. 806). This leads to the reduction of the functional character of kinds to their microstructural properties (see section 2). A similar but distinct example is Goodwin who argues for the 'fundamental role' of structure in purported functional kinds. Looking at organic molecules, he claims that molecular structure is fundamental because it explains why a functional group classification is appropriate at a particular instance (Goodwin, 2011, pp. 538-540).

I do not explore how one can respond to this worry; I take this to warrant a detailed analysis elsewhere. The goal here is to map different ways in which to circumvent the issues raised against the natural realist interpretation of kinds. I take that a functional view of substance-kinds is a promising and interesting way to do so.

4.4 Natural kinds as real patterns

The last option I consider is based on Ladyman and Ross's (2007) analysis of kinds in terms of real patterns. To spell out this account, we need to first point out an important —yet overlooked— feature of substance-kinds. This feature is revealed through the analysis of their stability: substance-kinds are scale relative classes (or, put differently, context-sensitive classes).[23] The scale-relativity of substances has been pointed out before. First, Hendry, in support of his emergentist view, has stated that a substance's existence and structure are both "scale-dependent" (2021, p. 44). More recently, Ladyman and Seifert (forthcoming) claimed that stability illustrates the scale-relativity of substances and that this in turn affects our views on their kindhood (without however going into further detail).

[23] An alternative but equivalent way to put this is in terms of context-sensitivity. I use the term 'scale-relativity' instead because scale has a precise definition which applies perfectly in this particular instance. Scale refers to the particular time, length and/or energy scale at which posited entities, etc. are found.

Interestingly, invoking chemical stability is not required to establish the scale-relativity of substances. By definition, all chemical species are scale-relative, as IUPAC illustrates through its definition of them:

> An ensemble of chemically identical molecular entities that can explore the same set of molecular energy levels on the time scale of the experiment. The term is applied equally to a set of chemically identical atomic or molecular structural units in a solid array. For example, two conformational isomers may be interconverted sufficiently slowly to be detectable by separate NMR spectra and hence to be considered to be separate chemical species on a time scale governed by the radiofrequency of the spectrometer used. On the other hand, in a slow chemical reaction the same mixture of conformers may behave as a single chemical species, i.e. there is virtually complete equilibrium population of the total set of molecular energy levels belonging to the two conformers. Except where the context requires otherwise, the term is taken to refer to a set of molecular entities containing isotopes in their natural abundance. The wording of the definition given in the first paragraph is intended to embrace both cases such as graphite, sodium chloride or a surface oxide, where the basic structural units may not be capable of isolated existence, as well as those cases where they are. In common chemical usage generic and specific chemical names (such as radical or hydroxide ion) or chemical formulae refer either to a chemical species or to a molecular entity (IUPAC, 2014, p. 264).

In light of this, a convincing view on the kindhood of substances should accommodate the empirically well-supported fact that substances are scale-relative classifications.[24] The role of scale-relativity in scientific classifications is something that is overlooked within the literature on natural kinds. Ladyman and Ross have pointed this out, being quite judgmental of the absence of such an acknowledgement:

> But they (philosophers on natural kinds) have us imagine that giant pandas could (in some extra-physical sense) be a type regardless of the context, just as long as the properties essential to their kind were glued together in the appropriate way. This is beguiling because, after all, some cohesive objects in our notional world are so effective at resisting entropy that we can transport them to radically new environments in

[24] This is especially pressing if one wishes to maintain a naturalistic stance towards her metaphysical views.

> space and time and yet relocate them. But for a naturalist it is beguiling *nonsense*. Nothing in contemporary science motivates this picture (2007, p. 294).

In response to this attitude, Ladyman and Ross propose to view natural kinds from the perspective of structural realism and, more precisely, in terms of real patterns. They state:

> We contend that everything a naturalist could legitimately want from the concept of a natural kind can be had simply by reference to real patterns (2007, p. 296).

In particular, they propose that natural kinds should be understood as referring to real patterns of high indexical redundancy. As Crețu explicates this requirement:

> Indexical redundancy concerns the relative distribution and measurability of real patterns in the universe. The more real patterns of a certain kind there are, the more measurements we can take. The more measurements we can take, the more objective real patterns are. What this means for natural kinds is that by being of high-indexical redundancy, they are objective. That real patterns are scale-relative means that what real patterns exist on a particular scale may not exist on a different scale (2020, p. 15).

Interestingly, while Crețu helps us unpack how Ladyman and Ross understand natural kinds, she diverges from their view because she takes it to fall short in terms of the ontological commitments we standardly assign to kinds. For this reason she proposes an amendment to their understanding by endorsing "a dual commitment to real patterns (qua relations) and objects (qua relata)" (Crețu, 2020, p. 14).

As with the case of a functional view of substance-kinds (subsection 4.3), I take this account to warrant a much more detailed analysis elsewhere. Among other things, for one to endorse such a view they would have to address the general worries that have been raised against Ontic Structural Realism (as spelled out against Ladyman and Ross's original account (2007) or against its amended forms). In any case, I take the main advantage of such a view on substance-kinds to be that it explicitly takes into account the scale-relative character of substances. All in all, I believe this is a promising and exciting new way of understanding their kindhood in light of the issues that are raised about their stability.

5. Conclusion

It is far from uncontroversial that even the most paradigmatic cases of chemical kinds are in fact natural kinds as per the standard realist view. In particular, I discuss the case of chemical substances and show that their chemical stability undermines a natural realist interpretation of their kindhood. I then explore different ways in which one can view substance-kinds in light of this analysis, including an antirealist and conventionalist interpretation of kindhood but also alternative realist readings of it.

Whichever avenue one choses to endorse, it is clear that we need to look beyond microstructure when discussing the kindhood of chemical entities, and turn our attention to each and every requirement that has been set in the general literature for natural kinds. This is because, as I showed, we cannot take for granted that they are straightforwardly met. Hopefully this paper motivates further research into this topic.

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