*Forthcoming in Nous.* 23 Sept 2008

# Microessentialism: What is the Argument?

Paul Needham

*Department of Philosophy, University of Stockholm, SE-106 91 Stockholm, Sweden*

**Keywords**

Microessentialism, water, stereotypical property, Kripke, Putnam

**Abstract**

According to microessentialism, it is necessary to resort to microstructure in order to adequately characterise chemical substances such as water. But the thesis has never been properly supported by argument. Kripke and Putnam, who originally proposed the thesis, suggest that a so-called stereotypical characterisation is not possible, whereas one in terms of microstructure is. However, the sketchy outlines given of stereotypical descriptions hardly support the impossibility claim. On the other hand, what naturally stands in contrast to microscopic description is description in macroscopic terms, and macroscopic characterisations of water are certainly possible. This suffices to counter the claim that microdescriptions are necessary. Whether it counters the impossibility claim depends on whether all macroscopic descriptions are stereotypical (stereotypical descriptions presumably being macroscopic). In so far as systematic import of "stereotypical" can be determined, it would seem not. But some macroscopic characterisations have definite affinity with everyday knowledge, which presumably stands in conflict with the spirit of the impossibility claim. Since what is characterised are properties expressed by predicates like "is water", the necessity of identity has no bearing here, and matters of interpretation pose problems for claims to the effect that science fixes the extension of "water" as ordinarily understood.

## Introduction

The Kripke-Putnam thesis has it that the extension of the term "water" is not fixed by descriptions of water in terms of manifest properties, but by a description of the microstructure of water. They render the latter by saying "Water is $H_2O$", the expression "$H_2O$" standing proxy for a description of the microstructure of water. The example of water is taken to illustrate a general feature of terms called natural kinds, which the argument's proponents take to include chemical substances and biological species. Criticism of the application of this line of thought to biological species came quickly (Dupré 1981) and was soon absorbed into the literature. But an early critique of the application of this line of thought to chemical substances (van Brakel 1986) has not been similarly acknowledged, and later efforts in the same general direction (van Brakel 2000a and b, Needham 2000 and 2002) seem to have made little impression on philosophers writing on natural kinds. Nevertheless, the fact remains that there are serious weaknesses in what Kripke and Putnam have to say about chemical substances, and water in particular, which are discussed here.[1]

The description of water as a colourless, transparent, tasteless, thirst-quenching, etc. liquid (Putnam 1975, p. 269) in terms of manifest or superficial properties is what Putnam calls a stereotypical characterisation. The "etc." poses a serious problem. Is the claim that the list of properties can be qualified and completed to provide a necessary and sufficient condition for being water or not? Surely, leaving the list incomplete suggest that, well, it is incomplete. It is not necessary to adduce further considerations to show that it stands in need of complementation. But both authors do go on to adduce further considerations, yet without attempting to complete the list. Kripke seems to think that something not falling under this kind of description could be water and something that is not water could fall under this description when he argues

> We identified water originally by its characteristic feel, appearance and perhaps taste, (though the taste may usually be due to impurities). If there were a substance, even actually, which had a completely different atomic structure from that of water, but resembled water in these respects, would we say that some water wasn't $H_2O$? I think not. We would say instead that just as there is a fool's gold there could be a fool's water; a substance which, though having the properties by which we originally identified water, would not in fact be water. And this, I think, applies not only to the actual world but even when we talk about counterfactual

---

1 For a parallel discussion of the temperature-is-average-kinetic-energy claim and a critique of Kim's rejection of emergentism, see Needham (2009).

> situations. If there had been a substance, which was a fool's water, it would then be fool's water and not water. On the other hand if this substance can take another form—such as the polywater allegedly discovered in the Soviet Union, with very different identifying marks from that of what we now call water—it is a form of water because it is the same substance, even though it doesn't have the appearances by which we originally identified water. (Kripke 1980, pp. 128-9)

Nothing amounting to an argument for the conclusion that a complete stereotypical description can't be produced from manifest properties is to be found in this passage, however.

The term "fool's gold" merely arose from the fact that prospectors in the wild west were not equipped to adequately separate the gold-coloured substance from the rock in which it is ingrained, and colour was the only accessible feature conceivably of relevance. But simple observable properties such as density (feeling the difference in weight of samples of equal volume, one held in each hand), or a straightforward chemical test by reaction with nitric acid, would nevertheless suffice to distinguish gold from fool's gold. Kripke may have had in mind Kant's claim that "Gold is a yellow metal" is an analytic truth (which he wished to dispute in connection with his thesis that there are necessary a posteriori truths). Pyrite (iron pyrites, $FeS_2$, or fool's gold) is harder and more brittle than gold, however, and whereas gold is quite soft and easily worked, pyrite cannot be worked like a metal. So fool's gold doesn't clearly show that Kant's conditions (or some very simple variant) are not sufficient to distinguish gold. But suppose some particular list of properties is shown not to give a sufficient characterisation of a substance. That would only demonstrate the inadequacy of that particular list. If a point of principle is to be established, the specific list would have to be particularly interesting, for example as the best possible attempt to produce a characterisation drawing from a certain source. As we will see, the items in Putnam's list hold out little hope for a successful completion if they are indicative of how he would carry on filling out the "etc.". Putnam gives no reason for thinking that his list is the best possible, and it quite certainly is not. On the contrary, it is largely irrelevant given the ease with which a sufficient condition can be specified. There is, however, an uncertainty about what the source of properties is from which a stereotypical description can be drawn. This is a serious defect in the conception of stereotypical property which calls for further comment. For the moment, suffice it to say that an argument is required to show that the kind of stereotypical description that Kripke or Putnam has in mind is necessarily insufficient, or defeasible, and the strategy of arguing by producing counterexamples to uninteresting candidates hardly motivates the general charge of inadequacy.[2]

Kripke is right to point out that the *same* substance may appear in different guises. Mercuric oxide prepared by treating a mercuric salt with potassium hydroxide appears as a yellow precipitate, but as a red powder when produced by heating mercury in oxygen. A similar point can be made about water, which is not always liquid, but appears in the vapour state and in the solid state as ice. The putative characterisation of water is therefore simply wrong. As with putative sufficient conditions, however, if a point of principle is to be made about the impossibility of specifying necessary conditions by drawing properties from a particular source, then a general argument is required and not just counterexamples to a particular candidate characterisation. Any such general argument would have to appeal to a clear general criterion of what would be allowed as a stereotypical property. Lack of a clear criterion presents a problem for the development of such a general argument, which reflects on the general thesis.

Kripke goes on to suggest that in order to obtain an adequate characterisation of a chemical substance, we have to look at the microstructure of water at the atomic level, and the microstructure of gold as specified by its atomic number. Putting the question of isotopes aside, atomic number is a specification of a sufficient condition for being gold. Proponents of the Kripke-Putnam view never give a specific account of “the microstructure of water”, however. The expression “$H_2O$” isn’t a specification of microstructure, and these proponents really need to allay the suspicion that they just mean “whatever would do the trick of establishing their conclusion” and simply assume

---

[2] A referee comments that Kripke might argue that a general argument cannot be provided because the properties are a posteriori and thus require testing on a case-by-case basis. This would support my contention that no argument has been provided to show the inadequacy of stereotypical characterisations, and raises the question of what motivates the microessentialist thesis. Certainly, a posteriori considerations are at issue, but as we will see, these do provide general principles for determining when a quantity of matter comprises just one substance (is pure something), and indicate determinables whose specific features distinguish one substance from another, without resorting to microscopic properties.

that there is some such thing. But the main point I want to make at the moment is that no argument has been given for the *microessentialist* claim that we must turn to microscopic features to obtain an adequate characterisation of a substance. Even if an adequate characterisation is to be had by drawing on microscopic features, no argument has been given to show that this is the only way to obtain such a characterisation. Whether such an alternative would necessarily be a stereotypical characterisation depends on what, exactly, is meant by a stereotypical characterisation.

**2. What is a Stereotypical Characterisation of a Substance?**

Kripke opens the passage quoted above by alluding to the historical circumstances in which matter was identified as being water, and both he and Putnam indicate that quantities of watery matter encountered in ordinary life are mixtures with varying properties of taste and smell. The ancient Greeks were aware that the stuff they valued as a thirst-quencher was to be distinguished from olive oil, and that it was more similar to but still had to be distinguished from sea water, which isn't thirst quenching. But they had no need to distinguish it from glycol. Salt obtained from sea water by evaporation could be dissolved in water to yield something just like sea water, so they could understand that sea water is a mixture, and reasonably conclude that other watery substances could likewise be considered mixtures of water with other substances. This gave rise to theorising about the notions of substance and mixture, leading Aristotle in particular to the view that genuine (homogeneous) mixtures are the result of mixing several substances, but not themselves actual mixtures in the sense of actually comprising distinct substances as distinct parts. We can imagine a historical process in which the description of water is successively elaborated to distinguish it from newly discovered substances while recognising its similarity to watery stuff taken to be mixtures understood on the basis of some theoretical model, either as actually containing a part which is water or in terms of the Aristotelian conception.

Incompleteness of the stereotypical characterisation of water might be understood in historical terms, as a continually evolving description, subject to modification by addition and qualification as experience calls for greater precision and finer distinctions. But Kripke and Putnam seem to have something else in mind. The historical development might well be thought to eventually incorporate systematic scientific considerations and come to an end when an adequate characterisation is achieved. Kripke and Putnam seem to think that there are systematic reasons why, on their understanding of a stereotypical characterisation, it cannot be complete. At any rate, their reliance on microscopic features for an adequate characterisation apparently presupposes that a stereotypical characterisation cannot be complete, for otherwise it wouldn't be necessary, as they seem to think it is, to resort to microscopic features. But this is to beg the question, and doesn't provide the argument required.

Let us consider Putnam's everyday stereotypical description of water as a "liquid which is colourless, transparent, tasteless, thirst quenching, …". Is water really colourless? Leaving the question of mixtures aside for the moment, in sufficiently large amounts water is not colourless but blue-green, as can be seen in sea water (which is not coloured by the salt). What about very small amounts? Surely, a quantity too small to see cannot be colourless. It certainly isn't thirst quenching. A gram-molecule (approx. 0.2 dl.) of water contains of the order of $10^{23}$ water molecules. A millionth part of this is hardly visible, but nevertheless contains of the order of $10^{17}$ molecules, and is appropriately considered a macroscopic quantity bearing macroscopic properties. So being colourless is not a feature of all water, but of water in amounts falling within certain limits. The items explicitly mentioned in Putnam's list all have this failing, that they are not the kind of thing that holds of all of whatever they hold of. In the terminology of mass predication, they are not distributive: they don't apply to all the parts of what they apply to. In the terminology of thermodynamics, they are not intensive properties, applying throughout whatever they apply to and contrasted with extensive properties, which depend on the mass of whatever they apply to. Substance predicates are mass predicates, and if Putnam's "etc." signifies an attempt at elaborating his stereotypical characterisation of water by resorting to additional predicates that, like those already given, aren't mass predicates, the project is doomed to failure. But this only shows that that particular approach to the problem is a dead end.

Quine (1960, p. 98) suggests that the distributive condition is limited, the predicate "is water" holding down to single molecules but not atoms. In fact, it is limited in other ways, raising the question of the interpretation of mixtures (Needham 2007, pp. 31ff.). But it applies to all spatial parts of whatever it applies to that are of macroscopic dimensions, which, as just noted takes us well below the limits of visibility.

The general feature of Putnam's stereotypical properties of not applying to all water can be elaborated in a different way by giving some consideration to the issue of mixtures. On the Aristotelian conception, mixtures can be disregarded because a substance like water is not to be found in a mixture like sea water resulting from mixing it with some other substance, and the characterisation given of water is necessarily in terms of properties exhibited in isolation. But a more natural interpretation, it may well be thought, is that, contrary to the Aristotelian conception, mixtures contain the original ingredients somehow in intimate contact but otherwise intact. On this conception, aqueous solutions are homogeneous mixtures of the sort resulting from dissolving a salt in water without chemical reaction and have a proper part which is water. What does this mean for Putnam's stereotypical properties? No discernible part of a discernible quantity of copper sulphate solution is colourless, and even if drinking it would give an initial experience of being thirst quenching, this is not advisable since it is poisonous. Whether the everyday feature of water not being poisonous is implied by being thirst quenching I don't know. But notoriously, sea water (a solution of common salt) is definitely not thirst quenching, and this applies to every discernible part of anything that is sea water. It would seem that the water in a copper sulphate solution is blue. By the same count, however, the water in a cobalt chloride solution is red, and in a potassium permanganate solution it is deep purple and, except for the thinnest strips, not transparent. The properties in Putnam's list are not, in general, applicable to water in solution, and so again, they don't, at least on a natural interpretation of mixtures, apply to all water. On either view of mixtures, then, they are at best applicable to water only when in isolation.

It is standard procedure to specify properties of substances in this way. A glance at a standard textbook in inorganic chemistry shows that characteristic data for each of the elements frequently specifies properties displayed in isolation, such as thermal conductivity and heat of vaporisation. (Some properties, such as the specification of oxygen's abundance in the earth's crust as 461000 parts per million, do not refer solely to substances in isolation.) These properties are usually dispositional, specifying, for example, the heat per mole that, if it were transferred to the substance, would induce a phase change from liquid to gas. It might be suggested that the feature displayed by the substance in isolation should likewise be construed as applicable to mixtures dispositionally, to the effect that were the substance in question separated out, then it would display, for example, a heat of vaporisation of the specified value. But that would be misleading since properties are described by specifying numerical values of measurable magnitudes for both the isolated substance and when mixed at specified concentrations with specified substances. The melting point of an aqueous salt solution, for example, is lower than that of water in the isolated state (which is why salt is spread on icy roads). Understanding the notion of a stereotypical description of water to apply to the substance in isolation (not mixed with other substances), a characterisation of water which would seem to be a stereotypical one is easily given by specifying its melting point.

Further properties, such as the boiling point, density of the liquid at specified temperature and pressure, inversion of density at 4°C, and so forth, could be added, or they might be thought of as distinct characterising conditions. But if precisely specified (i.e. narrow limits of tolerable experimental error specified), the melting (or boiling) point is adequate to distinguish the pure substance from others. Like Putnam's stereotypical properties, it doesn't apply to quantities of matter comprising water mixed with other substances, but with this restriction, it does apply to all quantities of water of macroscopic dimensions.

It is not necessary, then, to resort to microscopic features in order to obtain an adequate characterisation of water, distinguishing it from other substances. But it might be retorted that melting point is not really a stereotypical property in Kripke and Putnam's sense. We can imagine a historical process whereby the everyday idea of water is tightened as the need arises, and comes to include simple measurements—for example, melting and boiling points. For many everyday purposes, these can be quite vague (i.e. used with no conception of what specification of limits of experimental error would involve or how variation of circumstances is relevant, judged by feeling or observation of simultaneous changes in the surroundings, etc.). But they are successively sharpened as, for example, the need to specify pressure becomes apparent. Nevertheless, once appeal is made to measurement, however crude, Kripke and Putnam might say, we've stepped beyond stereotypical properties and entered into the realm of science.

Such a reply hardly advances the microessentialist's case. If such familiar properties are counted non-stereotypical because scientific, then this shows to everyone's satisfaction that it is not necessary to resort to microscopic features in order to obtain necessary and sufficient conditions characterising water. A scientific characterisation needn't be a microscopic characterisation. Whether there is any real value in stereotypical features negatively characterised in this way as not remotely scientific looks all the more unlikely. But any assessment would have to more carefully delineate the degree of ignorance a person would have to have in order to count as employing purely stereotypical properties.

Another, more interesting, systematic contrast that proponents of the necessity of resorting to microscopic properties to characterise substances might have in mind is that between macroscopic and microscopic properties. Judging by the examples Kripke and Putnam give, an essential feature of stereotypical properties is that they are macroscopic. But is being macroscopic sufficient for being a stereotypical property? Some macroscopic properties are quite sophisticated, finessed on the basis of organised experimental practice and systematic theory. Although Kripke's and Putnam's texts don't provide an answer this question, microessentialists give the distinct impression that in their view, macroscopic theory is an anathema, a contradiction in terms. They certainly seem not to accord it any significance. Thus, when Putnam (1992, p. 434) retouches his position, allowing that "low-level" laws are to be included in the stereotypical characterisation, he moves towards the position outlined in the previous paragraph. But this is not yet to allow for systematic macroscopic theory. So even if it is granted (as it would be a mistake not to), that macroscopic properties afford a characterisation of water and classical chemical substances, and that it is not necessary to resort to microfeatures for this purpose, still the microessentialists might think that only by appeal to microfeatures is a theoretically grounded, systematic, characterisation of chemical substance to be had. Again, however, there's no argument for this in Kripke's and Putnam's writings, and I'm not aware that any of their followers have filled in the details. All we have are counterexamples to a straw man's attempted stereotypical characterisation and the bare claim that it is necessary to resort to microfeatures to obtain a necessary and sufficient characterisation, but no general account of what stereotypical properties are beyond the necessary condition that they are macroscopic.

### 3. Providing a Systematic Characterisation of Substances

It is not true that we have to turn to microdescriptions for a theoretically grounded, systematic characterisation of chemical substances. Many macroscopic properties are systematically related by general theory. Thermodynamics, as I have explained elsewhere (Needham 2000 and 2002), is a macroscopic theory (traditionally described as neutral with respect to microscopic interpretation) which provides grounds for systematic criteria for characterising and distinguishing substances. The Gibbs phase rule provides clear criteria, derived from the general theory, for determining whether a quantity of matter contains just one or several substances. Where there is just one substance, thermodynamics clearly delimits several general patterns of behaviour under varying circumstances which are characteristic of matter containing a single substance, i.e. the occurrence of a substance in isolation. The specific quantitative features of this behaviour provide ample resources for sets of necessary and sufficient conditions characteristic of particular substances. Triple points, for example, at which three phases are at equilibrium, obtain at a specific temperature and pressure, and are constants of nature. These require a more exacting experimental procedure than determining points on a line separating two phases, such as the melting point line, along which the temperature of the phase change varies with pressure, or even more simply, the melting point—i.e. a point on this line at a certain pressure—also a constant of nature.

The application of thermodynamics is not limited to providing the theoretical grounds for ascribing characteristic properties of substances in isolation. Gibbs' phase law also provides systematic criteria for addressing the question of how many substances are present in mixtures. This has been discussed elsewhere (Needham 2000, 2002, 2007) and the details will not be pursued here. There should be no doubt that the thesis that it is necessary to resort to microscopic theory in order to provide systematic criteria for the characterisation of chemical substances is irredeemable.

What are the microdescriptions characterising chemical substances that microessentialists have in mind? It was allowed above that atomic number for gold might provide such a characterisation. But this is not generalisable beyond the elements. Compounds like water don't have atomic numbers. What we are offered by the microessentialists is "$H_2O$" in the case of water, which isn't a microdescription. "$H_2O$" is a compositional formula, containing the information that the compound is composed of hydrogen and oxygen in the fixed gravimetric *proportions* of 1 : 8, converted into a scale of equivalents. Equivalents give a chemical measure of amount, expressing that water, with compositional formula $H_2O$, contains just as much hydrogen as iron pyrites, with compositional formula $FeS_2$, contains sulphur, and contains just as much oxygen as iron pyrites contains iron. But again, if the object is to uniquely characterise water, then "being a compound of hydrogen and oxygen in the proportions 2 moles to 1", which is the entirely macroscopic information that "$H_2O$" conveys, does the trick. Attempting to similarly characterise alcohol (ethyl alcohol) and many other substances by composition fails, however, because alcohol has an isomer, dimethyl ether, which is a distinct substance with the same compositional formula, $C_2H_6O$, as alcohol. Isomers (distinct substances with the same composition) are usually represented with distinct *structural formulas*. Thus, dimethyl ether is represented by $(CH_3)_2O$, and ethyl alcohol by $C_2H_5OH$. It is arguable that, as with compositional formulas, it is not necessary to resort to microstructure to explain the workings of structural formulas; but it will not be necessary to insist on the point here. The expression "$H_2O$" provides a characterisation of water without resorting to microstructure, and anyone wanting to give a microdescription of water who simply offers "$H_2O$" fails miserably.

The way microessentialists talk about the microstructure of water is actually worse than alluding in circular fashion to whatever their argument would require in order to stand up. The definite article suggests there is a single structure. But water in the form of ice has a very different microstructure from water in the form of a liquid, and again a very different microstructure from water in the gas phase. Here it might be said that what Putnam, and perhaps Kripke, talked about was just the stuff that is the same *liquid* as a particular liquid sample (at a certain time—there's no guarantee that the very same quantity always has been and always will be liquid). In that case, he (they) are not talking about the stuff that schoolchildren are taught has a melting point of 0°C and condenses at 100°C under normal pressure (so that lakes comprise the same substance in winter as in summer). Or again, it is not the stuff that schoolchildren are taught is composed of hydrogen and oxygen in the ratio represented by "$H_2O$". For schoolchildren know that hydrogen and oxygen are each gases at normal temperatures and pressures when water is solid or liquid, and it just doesn't make sense to say that water is composed of hydrogen and oxygen when any of the three substances is supposed to be restricted to some specific phase (gas, liquid, solid). A variant on the same point is to say that schoolchildren know that ice (steam) is $H_2O$, that $H_2O$ is water, and accordingly that ice (steam) is water. Perhaps the "ordinary speakers" whose usage is sometimes said to determine stereotypical descriptions don't include people for whom elementary school education has made any impression.

As we have seen, macroscopic properties afford characterisations of water, but it is uncertain whether these count as stereotypical because the philosophers who appeal to this notion have not been sufficiently clear about how they understand it. At all events, it seems that Putnam (1992) came to realise that macroscopic properties of substances do not float free of microstructure and the assumption of his twin earth fantasy of a substance twater satisfying all the same macroscopic properties as water but having a different microstructure from water's (whatever water's might be) is untenable. (It is trivially true, of course, that some substances share some macroscopic properties; but in order to narrow the issue to the possibility of having the same stereotypical description—in the sense of a characterisation—we would have to know what a stereotypical description is.) In fact, the macroscopic properties of water are systematically used in inferring the microscopic structure of water under varying conditions. For example, a substance of comparable molecular weight like methane, with formula $CH_4$, has a very much lower melting and boiling point (–183°C and –161°C, respectively) than water, which doesn't even melt until 0°C. The fact that it doesn't even melt until 0°C calls for a microstructure amounting to more than a simple pile of molecular particles. Substances like methane satisfy the 19th century paradigm of molecular structure—the molecular view of substance—according to which the substance is just a collection of particles of a single kind represented by the chemical formula. To call these molecules particles is to say that the forces of interaction between the molecules are considerably weaker than the internal forces of cohesion holding each molecule together as a unit. Water's relatively high melting point suggests that the solid does not consist of a collection of molecular particles like this, but of an interconnected structure extending over the entire extent of the macroscopic lump of ice. Further, water's relatively low latent heat of fusion (only 15% of the latent heat of evaporation) suggests that much of the intermolecular structure of the solid state is retained in the liquid too, and is only destroyed on boiling. This inference is borne out by the large heat capacity of the liquid (nearly twice that of ice at the melting point, and more than twice that of steam at the boiling point). Increasing the motion of the molecules accounts for only half of the liquid's heat capacity; there must be a structure in the liquid which the rest is utilised in deforming.

This indicates how characteristic macroscopic properties like melting and boiling points, latent heats and specific heats are related to the microstructure. It doesn't rule out the possibility of having some macroscopic feature in common with another substance with different microscopic properties. There are many substances which are, like water, more or less colourless in the liquid phase, for example, or translucent in the solid phase. Indeed, there are many pairs of very similar substances—adjacent pairs in series of homologous hydrocarbons such as pentane and hexane, isotopic variants such as protium oxide and deuterium oxide, ortho- and parahydrogen which differ in whether nuclear spins in the same molecule are parallel, etc. What could Putnam's twin earth fantasy show beyond the triviality that sufficiently ignorant people might not be able to distinguish similar substances? If it assumes that two substances are distinct at the microlevel and yet share all their macroproperties, so that they can't be distinguished in terms of macroproperties, then the scenario is wildly implausible. Assuming that it is in some sense possible doesn't show it to be possible. The ploy certainly can't show that it is necessary to resort to microfeatures in order to characterise a substance. That would require an argument. Back in 1750, perhaps no one was in a position to adequately characterise water (because descriptions then on offer fail to distinguish between water and some other substance we know today). So what? Distinctions are revealed with the growth of knowledge. Atomic weight was once thought to characterise elements. But that was discovered not to be constant for a given set of chemical properties defining a place in the periodic table. Then came atomic number, which was uniquely associated with a same place in the periodic table despite varying atomic weights. But more precise measurements and associated theory since 1923 when the IUPAC made its ruling on atomic number as the defining feature of elements have raised the question whether isotopes, such as the isotopes protium, deuterium and tritium of hydrogen, shouldn't be considered, in principle at least, as distinct substances (van der Vet 1979, Needham 2008). The finer details are controversial, but taking a position on whether the systematic criteria determining sameness of substance are purely microscopic is not helped by Putnam's fantastic thought experiment.

## 4. Necessity and Predication

Whatever water's microstructure is, it is very complicated. The particles of which it consists are of many and varying kinds. Yet it is a single substance. This is not a matter of convenience of convention but of the laws determining the behaviour of material comprising a single substance derived from thermodynamics and outlined at the beginning of the last section. Water is composed of hydrogen and oxygen, but in such a way as to distinguish it from a homogeneous mixture (solution) of the two elements in the same proportions. This difference is marked by different properties, such as the different volumes of equal masses in the gas phase at the same temperature and pressure. Again, thermodynamics accounts for the greater stability of the compound over the mixture, which is an explanation of the distinctive state of combination of the elements in water. The theory also gives an account of the systematic import of water's characteristic macroscopic properties such as melting point 0°C, inversion of density at 4°C, forming an azeotropic mixture with 96% by weight of alcohol (ethyl) boiling at 78°C, etc. Laws incorporated in other theories also bear on water's characteristic properties, which are thus necessary because law governed. Were the laws different, there would be no water; perhaps something similar if some of the deviations were small, but I see no point in speculating.

The necessities don't follow from the necessity of identity which Quine (1976, pp. 174-5) showed follows from the laws of identity and necessitation. Expressions like "water" and "$H_2O$" describing chemical substances are predicates, and arguments about the rigidity of reference deriving from the necessity of identity are not applicable. A term referring to an abstract entity waterhood might be considered to flank the identity sign if some point could be given to the introduction of such a term. The substance predicates of interest here are not terms referring to any such things, of course, and the issue won't trouble us further. Another suggestion allowing "water" to meaningfully flank the identity sign is that "water" refers to something like the world's water—all the water that there is. Presumably, this means that "water" refers to a mereological sum. Then it must be recognised that a mereological sum is determined by a predicate; it is the sum of all those quantities of matter satisfying a certain predicate. So on this interpretation, any water said to be identical with something would be what the predicate "water" applies to. A predicate "water" is presupposed, and there is no question of this flanking an identity.

But as noted in Needham (2000), it is not yet clear what all the world's water is. Water is continually being consumed in chemical reactions and created in others. It is combined with carbon dioxide in the photosynthesis of carbohydrates, for example, and produced in the neutralisation of acids by hydroxides and alcohols. Accordingly, some of what is water at one time is not so at another, and some of what isn't is. This is naturally accommodated by treating substance predicates, or at least those like "water" expressing a property of being a compound substance, as dyadic, expressing a relation between a quantity of matter and a time.[3] Such an approach presupposes that the

[3] As indicated earlier, they are also mass predicates, and some features of dyadic mass substance predicates are developed in Needham (2007). This contradicts a suggestion in Bird and Tobin (2008, p. 11) that kinds are not relational.

quantities of matter that bear substance properties are permanent existents, persisting through chemical change as they cease to bear some substance properties and acquire others. It forms the basis of a natural interpretation of the principle of the conservation of mass in chemical reactions formulated by Lavoisier, who, as Poincaré (1913, p. 65) puts it, “has demonstrated the indestructibility of matter by demonstrating the invariability of mass”. On this view, a well-defined mereological sum over what is water would require the specification of a time. In the absence of further qualification, the tense of the verb in “all the water that there is” might be understood to refer to the present time, and some further appeal to context might settle whether this is the present minute, the present hour, the present day or whatever. However it is determined, the time will be an interval, and since water will be continually created and destroyed during the course of this interval by chemical reactions which take time, it is still not clear what a sum over water during this time amounts to. One way of making it definite would be to count anything as part of the sum which is water for any subinterval of the time in question. That is to say, the sum would then be the mereological sum of all those quantities which for some subinterval of the time in question are water. An alternative way of making the sum definite would be to define it as the mereological sum of all those quantities which are water for the entire duration of the time in question. The longer the time, the smaller will this sum be, entailing a certain risk that, for extremely long times, no quantity is water for the whole period when the prerequisite for the existence of a sum, that something satisfies its defining condition, is not met. One way or another, “the world’s water” can be clearly interpreted as a term which can meaningfully flank an identity sign provided the corresponding existence condition is fulfilled.

A different approach might be taken, however, which seeks to interpret the talk of creation and destruction of substances in chemical reactions literally. This view would treat the subjects of chemical substance predicates more like individuals such as biological organisms, which come into and go out of existence, and it would have to be investigated whether an operation of sum can be defined. It would contrast with the scientifically moderately well-informed view just outlined. Perhaps some such conception underlies ordinary speaker’s notions of the metaphysics of chemical substances. I leave it to others who might be interested in this conception to develop it in detail. But it should be clear that it represents a very different interpretation of substance predicates such as “is water” from the dyadic predicates envisaged in the previous paragraph. What is meant by the extension of the water predicate will accordingly differ on the two interpretations. In that case, it makes little sense to argue that the extension of the water predicate as ordinarily used is the same as the water predicate as used by chemists. And in the same vein, it might be said that speakers towards the end of the eighteenth century understood "is water" along the lines of this second interpretation, whereas most modern speakers with English as their first language have learnt of Lavoisier's principle in school and understand that matter is not created or destroyed in chemical reactions. So again, there's little sense in saying that the extension of the predicate remains unchanged.

A further difference of interpretation can be broached in another way. As I understand Aristotle's conception of water, it is defined as cold and wet, these properties being essentially what, on his view, underlies being liquid. This and other considerations from Aristotle's texts which could be brought to bear support the claim that for Aristotle, water is essentially liquid. Ice and steam (water vapour) are different substances because they are what chemists would now describe as different phases of water, and what chemists now describe as a change of phase, say from liquid to vapour, Aristotle conceived as a transmutation. This Aristotelian conception held sway for some considerable time. When Joseph Black made what contemporary scientists describe as his discovery of the latent heat of fusion of water in 1761, he understood it in terms of a chemical reaction between ice and caloric resulting in the production of a new substance, water. Although Lavoisier began to move away from this conception, he was still in its grips when he distinguished between base of oxygen and oxygen gas, which he thought was a compound between base of oxygen and caloric. The conception was finally dropped by chemists in the nineteenth century. But perhaps it lingers on in ordinary speakers' usage, as witnessed by suggestions that establishing that some quantity is the same substance as water is a matter of establishing that it is the same liquid. This Aristotelian conception of tying substance to phase properties might be combined with either of the two preceding views to give distinctive extensions of "water".

The twin earth fantasy has given rise to a claim to the general effect that different extensions correspond to the same description. But a more concise statement of the claim apparently defies articulation. The relevant sense of "same description" eluded us in the previous section. Reasons have been adduced for ascribing the term "water" different extensions in this section, although reflecting different understandings of "water" on the basis of what might be called different general conceptions of chemical substance rather than what the proponents of the claim seem to have in mind with different descriptions. Presumably, the proponents are not thinking of such differences of extension, but of different descriptions on the basis of the same general conception of substance. At all events, on the modern scientific conception of substance, there are whole ranges of more of less similar substances, and there are conceptions of substance differing from the modern scientific conception. An adequate formulation of whatever claim proponents of the twin earth fantasy want to make must take this into account.

### 5. Can Water be Characterised by a Purely Microscopic Description?

The argument for the necessity of resorting to microscopic descriptions in order to characterise substances has been found wanting. What about the weaker and more plausible thesis that there is a microscopic description characterising any substance? It would seem that microessentialists are committed to some such thesis, although it is not easy to assess exactly what the claim is given the sparsity of detail actually offered. But introducing a place-holder for a microscopic description to be supplied by someone else does carry with it an assumption, perhaps of uniqueness but certainly of existence, which should be justified. It has been clear since Perrin's and Einstein's investigations of Brownian motion put the existence of the micro-realm beyond doubt, however, that a macroscopic quantity of matter has some microstructure. The interesting question is whether there is a *purely* microscopic description, or just one which is still dependent in some way on macroscopic features. And if a claim of the former kind were to be justified, we would have to know what the microscopic description is.

Kripke's reflections on gold led him to suggest that atomic number provides an appropriate microscopic description. This criterion collects isotopes under the same substance in conformity with the IUPAC ruling of 1923. Although the atomic number criterion has been defended by Hendry (2006), questions can, as suggested above, be raised about this in view of developments since then. But at best, the IUPAC criterion could only apply to elements. On the molecular view, this might have yielded a criterion for characterising compounds if, as was believed in the first decades of the 19th century after Proust was taken to have established the law of constant proportions, compounds are distinguished by their fixed elemental composition. There would still be the question of what, exactly, the microdescription is supposed to be—exactly which thing in a quantity of a compound is a particular element (Needham 2006). But leaving this aside, composition is not, as we saw above, in general sufficient. Berzelius coined the term "isomerism" for the phenomenon first recognised in the 1820s, that elemental composition could be common to several substances. This was illustrated above with dimethyl ether, with structural formula $(CH_3)_2O$, and ethyl alcohol, with structural formula $C_2H_5OH$, which are isomers with the same compositional formula, $C_2H_6O$. The real testing ground is the microscopic characterisation of compounds.

The microessentialist might respond by claiming that the full structural formulas depict the 3-dimensional spatial structure of the corresponding molecules, including the symmetry features distinguishing stereoisomers. Even if this counts as giving a microstructural description for organic isomers, however, it doesn't have the makings of a general recipe. In this connection it is apposite to note the warning given by an inorganic chemist of the dangers of "a slavish devotion to the cult of the molecule and a naive faith in the general applicability of Dalton's laws of chemical combination," who goes on to say

> … organic chemistry … [has] tended to warp the balanced development of chemical theory, since two of the main characteristics of organic compounds are (a) they are molecular, and (b) carbon has a constant valency of four … [and] many (inorganic) compounds could not be satisfactorily described in these terms. An indication of how the constant quadrivalency of carbon led to the basic structural elements of organic molecules can be gained by considering the formulae of a few simple hydrocarbons:
>
> $CH_4$, $C_2H_6$, $C_3H_8$—concept of chains (rather than valencies of 4, 3, 2.67 for carbon);
> $C_2H_6$, $C_2H_4$, $C_2H_2$—concept of single, double, and triple bonds;
> $C_3H_6$, $C_5H_6$, $C_6H_6$—concept of rings, unsaturated rings and aromaticity.
>
> [But] this … simple theory is completely inadequate to interpret the structure and stoichiometry of the boranes: $B_2H_6$, $B_4H_8$, $B_5H_9$, $B_5H_{11}$, etc. (Greenwood 1968, p. 5)

Water in particular is an inorganic substance which, as mentioned in section 3, is not molecular, except under certain conditions in the gas phase. It comprises so many different kinds of entities of varying longevities in the liquid phase that if distinctness of kinds of microparticles were the guide to distinctness of substances, water would be a mixture. But as outlined at the beginning of section 3 (and described in more detail in

Needham 2000 and 2002), this is not the guide. Rather, macroscopic criteria determine that a quantity of matter whose microstructure scientists investigate is in fact water. Hendry (2006, p. 872), in a much weakened and better informed version of the microstructuralist thesis along the lines of that at issue in this section, claims that "water is the substance formed by bringing together $H_2O$ molecules and allowing them to interact spontaneously". But this is just to say that the molecular character of the gas phase at low pressure disappears on condensation; it doesn't actually give the microstructure of liquid water.

Greenwood goes on after the passage quoted above to discuss berthollides—compounds with non-stoichiometric formulas. "[I]f a compound consists not of molecules but of an infinite array of ions," he says,

> then valency and composition can often vary continuously. For example ferrous oxide does not have the composition FeO; such a composition is unstable under all conditions of temperature and pressure. The phase varies in composition between about $Fe_{0.94}O$ and $Fe_{0.86}O$ by leaving some $Fe^{2+}$ sites vacant and raising the charge on twice this number of the remaining cations from $Fe^{2+}$ to $Fe^{3+}$. Such behaviour clearly requires revision of the classical ideas of 'valency', 'compound' and the simple laws of chemical combination. It should be emphasised that, at the atomic level, the changes in oxidation state of an individual ion are integral but that, because of the effectively infinite array of ions, variations in the overall stoichiometry of the phase appear continuous. (Greenwood 1968, p. 6)

The stability he speaks of is thermodynamic stability. How the macroscopic conditions of temperature and pressure affect the composition and allow the entropy gained by lattice defects to compensate the energy required for conversion of ions to the higher oxidation state is governed by the thermodynamic potential appropriate to the macroscopic constraints.

Prospects for a purely microscopic description vary, then, from one group of substances to another. The relative ease with which this can be done for the molecular substances of organic chemistry is not a guide to substances in general. This is not to deny, of course, that even in the more recalcitrant cases, there is a microstructure. As I say, so much has been clear since Perrin and Einstein's investigations into Brownian motion. What doesn't follow from this is that the details of the microstructure of any particular substance are reasonably well known, and certainly not that they are independent of macroscopic constraints or somehow determine the macroscopic features of substances or that substances are in some clear sense "nothing but" their microconstituents. The issues of reduction are not settled by mere acknowledgement of microstructure but raise additional questions, which can't be pursued here in any detail beyond some brief remarks.[4]

One might hope to find a more unified account of the microscopic realm underlying the rather disparate picture painted here by looking to quantum mechanics. The classic molecular structures of organic substances involve the binding together and spatially orienting of atomic constituents by bonds. The formation of bonds by the pairing of electrons suggested by G. N Lewis in 1916 was every bit as unintelligible as the stability of Bohr's 1913 atom on the basis of the classical laws of physics. Two negative charges should repel, not form a connected unity. This latter kind of problem was overcome in general terms with the replacement of classical laws governing atomic structure by quantum mechanics and the introduction of the exchange energy corresponding to the interchange of electrons in the wave function. But whether quantum mechanics recognises bonds after Mullikan's molecular orbital theory is a vexed question (Weisberg 2008). And to cite the title of a paper by R. G. Woolley (1985), "The Molecular Structure Conundrum" remains.[5] The Schrödinger equation is set up by considering just the Coulomb forces between all the charged particles (protons and electrons) in a molecule. But in the case of isomers such as dimethyl ether and ethyl alcohol, the charged particles are precisely the same, so distinct molecular structures are not forthcoming from fundamental quantum mechanics. Molecular properties are in fact calculated on the basis of the Born-Oppenheimer approximation, which in effect imposes molecular structure on the system by taking the atomic nuclei to form a framework around which the electronic motions are calculated. As Woolley puts it, molecular structure "as a universal attribute in molecular science is … not securely founded in quantum theory" (1978, p. 1077), but is introduced "by hand" (1988, p. 56) in the course of simplifying and making more tractable the original exact quantum mechanical equations. The problem is not just one affecting isomers. Substances like water with no isomers have molecules which are not symmetric, but the set-up in the Schrödinger equation taking into consideration only the Coulomb forces between the

[4] For a discussion of reduction in chemistry, see Hendry and Needham (2007).

[5] See also Weininger (1984).

charged particles doesn't give any indication of this asymmetry. The characteristic structure of the water molecule with an average H–O–H bond angle of 104.5° and associated polarity is discerned from spectroscopic studies and imposed on the solution of the Schrödinger equation by the Born-Oppenheimer approximation. Molecular structure becomes important, it seems, in the condensed phases of matter where molecules can't be realistically treated as standing in isolation, but are subject to environmental influences. The question is whether an adequate account can be given which doesn't appeal at some point to the macroscopic theory of chemical substance.

## 6. Concluding Remarks

The main purpose of this paper has been critical. Microessentialist claims are unclear, but in so far as their gist can be understood, they involve assumptions which have not been adequately justified. The central claim is that it is necessary to resort to microscopic descriptions to characterise substances because so-called stereotypical descriptions are inadequate. But a reasonably general account of what a stereotypical description is of which this is true has not even been given. All we are offered is considerations showing the inadequacy of a specific list of properties. This is not very difficult to arrange, and leaves the impossibility thesis entirely unmotivated. A much clearer notion, standing in contrast to being microscopic, is that of being macroscopic. But there is no problem about giving a characterisation of classical chemical substances like water in terms of macroscopic properties.

This suffices to counter the thesis that it is necessary to resort to microdescriptions to characterise a substance such as water. It would seem, then, that whatever "stereotypical" means, there are non-microscopic descriptions which aren't stereotypical. Stereotypical properties are clearly macroscopic, but what of the converse? Two reasons were detailed suggesting it doesn't hold: (i) some macroscopic properties can be numerically more or less precise, and so broadly scientific, and (ii) some are quite abstract and many are systematically connected by very abstract and general theory, and so quite definitely scientific. But it is uncertain how those who use the term understand it, and whether these conditions can be further elaborated to delimit a useful notion of stereotypical property I leave to those who might be interested in the project.

Why have defenders of the microessentialist view made no noticeable effort to arrive at adequate stereotypical descriptions of chemical substances? It is tempting to speculate that the reason water figures so prominently as the example around which discussions are built is because it is tacitly presupposed that readers know what it is, and any serious effort at describing it is conveniently taken to be superfluous. Butane couldn't be treated so nonchalantly. An impression is given of a great schism separating ordinary mortals from members of the scientific community, who are presumed to deal exclusively in microstructure. But this is assumed rather than systematically motivated. Against this, it can be said that amongst the many suitable characterisations of water in terms of macroscopic properties, several can fairly be taken to be understood by reasonably observant non-scientists sufficiently precisely even if not to the point of specifying numerical values, or at least not to the degree of precision (within the recognised limits of error) with which numerical values are quoted in the standard scientific reference literature. Although many people with only a secondary-school education would be able to quote 4°C as the temperature when the density of water is locally maximum, many who can't are nevertheless aware that water freezes from the top down, that ice floats and fish are able to survive by following the denser water to the bottom of lakes. This is characteristic of water. Similar tales can be told about water's melting point, its boiling point and its facility for dissolving a wide range of other substances. But most people may only be able to distinguish butane from propane by the features that the one comes in cylinders marked "butane" whereas the other comes in cylinders marked "propane". They may be aware that both are colourless inflammable gases under normal conditions, and not be able to distinguish them in the wild, as it were. A person may well not know which properties characterise particular substances.

The choice of water as the paradigm example also conveniently suggests that chemists distinguish a substance which is essentially what is at issue in everyday uses of the term in question, so that chemists can be said to determine the extension of the same predicate. It is, perhaps, evident to many people that chemists do discuss water and mean the same stuff when using the term in the lab as they do when at home. This correlation is assumed to be to some significant extent generalisable. But typically, what in everyday terms counts as a substance doesn't for a chemist. Butter and margarine are mixtures of many substances in a colloidal state (several phases). The various things falling under the term "jade" wouldn't ordinarily be so counted under conditions when these materials are all liquid, whereas mere changing of phase doesn't imply changing substance kind for the chemist. Perhaps even ice and steam are not water in the everyday sense, if some philosophers are to be believed. This alone would imply that much that falls within the extension of "water" as the scientist understands it doesn't on the everyday understanding. Further sharp discrepancies arise because, as discussed in section 4, various conceptions of water might lead to extensions quite different from one another as well as from that corresponding to the chemist's use of the term.

This discussion is also taken to sanction talk of things called natural kinds somehow more narrowly construed than properties featuring in laws to exclude such things as being negatively charged, having mass and undergoing displacement (Bird and Tobin 2008, pp. 5, 11). Is air a natural kind, or did it cease to be thought one when it was discovered to be a mixture? Is mortar a natural kind, despite the fact that it is a mixture which undergoes chemical reaction in the hardening process? Are ice and steam natural kinds and are they the same kind as water? Is diamond, which, unlike the chemical substance carbon comprising it, looses its characteristic features on melting, a natural kind? Are plastics, which chemists first synthesised in the 1930s but are now to be found widely distributed in the Pacific Ocean, natural kinds? How do you tell? Is any useful purpose served by the term "natural kind" which improves on the use of "substance" and other more clearly delimited general terms from chemistry?

Another hopelessly underdescribed aspect of the twin earth scenario standing in the way of formulating passably general claims is the notion of microstructure. Although it may be convenient for the purposes that the microessentialist has in view to speak of *the* microstructure of water, the uniqueness implied by the definite article is again an unjustified assumption. Apart from the statistical variations under fixed macroscopic conditions, there is a variation needed to accommodate the variations in phase from solid to liquid to gas. Variation still occurs over the range of conditions a substance sustains a given phase, accommodating variation in density, acidity, etc. When a variation in microstructure exceeds that for which microessentialists use the term "$H_2O$" as proxy and becomes a case of XYZ is totally unclear. Not only is the idea of two substances which are macroscopically indistinguishable pure fantasy; no coherent notion of microscopic distinguishability has been provided to substantiate that aspect of the twin earth case as a possible scenario either.

Finally, it has been emphasised that the general concept of a chemical substance is tied down by laws and not governed by matters of convention. It is therefore necessary that what is water is a single substance with the characteristic features it in fact has. What is water is, of course, what the "water" predicate applies to, and as with any singular term, whatever identities it is involved in are necessary. Water’s having its characteristic features necessarily is nothing to do with this.

## References


Bird, Alexander and Emma Tobin (2008), "Natural Kinds", *The Stanford Encyclopedia of Philosophy*, (Fall 2008 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/fall2008/entries/natural-kinds/>.

Dupré, John (1981), "Natural Kinds and Biological Taxa", *Philosophical Review*, 90, 66-90.

Greenwood, N. N. (1968), *Ionic crystals, Lattice Defects and Nonstoichiometry*, Butterworths, London.

Hendry, Robin Findlay (2006), "Elements, Compounds and Other Chemical Kinds", *Philosophy of Science*, 73, 864–75.

Hendry, Robin Findlay and Paul Needham (2007), "Le Poidevin on the Reduction of Chemistry", *British Journal for the Philosophy of Science*, 58, 339-53.

Kripke, Saul (1980), *Naming and Necessity*, Blackwell, Oxford.

Needham, Paul (2000), "What is Water?", *Analysis*, 60, 13-21.

_____ (2002), "The Discovery that Water is $H_2O$", *International Studies in the Philosophy of Science*, 16, 205-226.

_____ (2006), "Substance and Modality", *Philosophy of Science*, 73, 829-40.

_____ (2007), "Macroscopic Mixtures", *Journal of Philosophy*, 104, 26-52.

_____ (2008), "Is Water a Mixure? Bridging the Distinction Between Physical and Chemical Properties", *Studies in History and Philosophy of Science*, 39, 66-77.

_____ (2009) "Reduction and Emergence: A Critique of Kim", *Philosophical Studies*, 146, 93-116.

Poincaré, Henri (1913), "Les conceptions nouvelles de la matière", in Henri Bergson, et al., *Le matérialisme actuel*, Flammarion, Paris; pp. 49-67.

Putnam, Hilary (1975), *Philosophical Papers*, Vol. 2, Cambridge University Press, Cambridge.

_____ (1992), "Is It Necessary That Water Is $H_2O$?" in Lewis Edwin Hahn, ed., *The Philosophy of A. J. Ayer*, Open Court, La Salle, Illinois; pp. 429-54.

Quine, W. V. (1976), "Three Grades of Modal Involvement", Proceedings of the XIth International Congress of Philosophy, Brussels, 1953, Vol. 14, Amsterdam: North-Holland; reprinted in *The Ways of Paradox*, 2nd. ed., Harvard University Press, Cambridge, Mass.

_____ (1960), *Word and Object*, Cambridge, Mass.: MIT Press.

van Brakel, Jaap (1986), "The Chemistry of Substances and the Philosophy of Mass Terms", *Synthese*, 69, 291-324.

_____ (2000a), “The Nature of Chemical Substances”, in N. Bhushan and S. Rosenfeld, eds., *Of Minds and Molecules*, Oxford University Press, Oxford, pp. 162-84.

_____ (2000b), *Philosophy of Chemistry: Between the Manifest and the Scientific Image*, Leuven University Press, Leuven.

van der Vet, Paul (1979), “The Debate Between F. A. Paneth, G. von Hevesy and K. Fajans on the Concept of Chemical Identity”, *Janus*, 66, 285-303.

Weininger, Steven (1984), “The Molecular Structure Conundrum: Can Classical Chemistry Be Reduced to Quantum Chemistry?” *Journal of Chemical Education*, 61, 939-44.[6]

Weisberg, Michael (2008), “Challenges to the Structural Conception of Bonding”, *Philosophy of Science*, 75, 932-46.

Woolley, R. G. (1978), “Must a Molecule Have a Shape?”, *Journal of the American Chemical Society*, 100, 1073-8.

_____ (1985), “The Molecular Structure Conundrum”, *Journal of Chemical Education*, 62, 1082-4.

_____ (1988), “Must a Molecule Have a Shape?”, *New Scientist*, 120 (22 Oct.), 53-7.