

Water is *Not* H₂O[†]

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1. Introduction

In defending semantic externalism, philosophers of language have often assumed that there is a straightforward connection between scientific kinds and the natural kinds recognized by ordinary language users.¹ For example, the claim that water is H₂O assumes that the ordinary language kind water corresponds to a chemical kind, which contains all the molecules with molecular formula H₂O as its members. This assumption about the coordination between ordinary language kinds and scientific kinds is important for the externalist program, because it is what allows us to discover empirically the extensions of ordinary language kind terms.

While I am sympathetic to the semantic externalist project, I think that the discussion of chemical kinds by philosophers of language has been rather badly oversimplified, hiding difficulties that arise when we try to coordinate scientific kinds with the natural kinds recognized by ordinary language users.² In this paper, I will examine these difficulties by looking more closely at the chemist's notion of water.

To help with this examination, I will begin by making explicit a principle on which I believe semantic externalists rely. The *coordination principle* is the thesis that scientific kinds and the natural kinds recognized by natural language users line up or can be mapped onto one another one-to-one. A brief examination of an externalist picture of kind reference will show how the coordination principle is relied on.

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¹ There is, of course, a good deal of variation among semantic externalists. In this paper, I will primarily be discussing the views of Putnam (1975) and Kripke (1980).

² One philosopher who has appreciated the problems with this view for biological kinds is John Dupré (1993).

At some point in human history, when in causal contact with water, someone baptized water with the word “water.” This person need not have had any correct beliefs about the kind of thing water was, she merely needed to attach the kind term “water” to the token of water that was in front of her. Whether subsequent samples of liquid are actually water or not depends on whether they are of the same natural kind and hence share the same micro-structure or essence as the original sample of water. The reference of the term “water” is fixed for the community of language users in virtue of their causal connections to the baptizer. By being causally connected to the baptizer, the community of language users is connected to the original baptism event. In virtue of this, they needn’t have any true beliefs about water to refer to water. All that is required is that they are part of a linguistic community that has the right kind of causal links through time.

While the ordinary language user and even the baptizer need not have true beliefs about water in order to refer to it, someone in the community eventually will need to have these beliefs if the meaning of “water” is to be made explicit. The obvious people to ask about the nature of water are chemists, and semantic externalists have often assumed that this is where we must turn. Putnam and Kripke aren’t very explicit about the details of the role chemists play in semantics, but this is where I believe the coordination principle is implicitly relied upon. Chemists discover the natural kinds of the material world, which I will call “chemical kinds.” The coordination principle presumes that the very same kinds that chemists discover are the ones relevant to ordinary language. If this is the case, then when you describe a chemical kind in detail, you will have nailed down the semantics of the ordinary kind term associated with that chemical kind. Putnam and Kripke seem to believe that in the case of water, chemists describe a chemical kind whose members include all and only the molecules with molecular formula H_2O . Appealing to this fact and to the coordination principle, they conclude that water is H_2O .

Closer examination of what water really is, I believe, shows that for chemists, water isn’t just the set of all molecules with molecular formula H_2O . There are multiple chemical kinds that might reasonably be coordinated with the ordinary language kind water. Because chemistry provides us with many different types of natural kinds, and because it doesn’t provide us with rules favoring one set of kinds over another, deference to the findings of chemistry will not unambiguously allow us to discover the extensions of natural kind terms in ordinary language. A more nuanced version of the coordination principle, which has specific rules for picking out the appropriate chemical kind in particular

circumstances, will be needed to carry forward the semantic externalist project.

2. Individuation Criterion

Linus Pauling famously told us that chemistry is “the science of substances—their structure, their properties, and the reactions that change them into other substances.” (Pauling, 1947) Using slightly more contemporary language, we can say that chemistry studies the *structure* and *reactivity* of substances. Structure is studied at three compositional levels. Molar structure consists of the macroscopic or bulk properties of a substance. Molecular structure is the spatial configuration of atoms connected by chemical bonds. Atomic structure, from the chemical point of view, includes both the kinds of atoms from which a substance is composed and their quantum mechanical state. “Reactivity” is a general term referring to the transformations of substances. This involves both the intrinsic properties of a substance to transform itself over time and the ways in which it is transformed when brought in contact with other substances.

This description of chemistry’s subject matter leads us to a criterion for the individuation of chemical kinds. In deciding whether two samples of a substance are of the same kind, a chemist examines their structure and reactivity at all three compositional levels. For example, the two alcohols methanol and ethanol are distinct chemical kinds in virtue of their different molecular structures. Drawing on Pauling’s description, we can give a simple criterion for chemical individuation:

I: Chemical kinds are to be individuated with respect to structure and reactivity at the molar, molecular, and atomic levels.

In this paper, I will appeal to this individuation criterion in order to determine which groupings are legitimate chemical kinds and which are not. For example, all the solvents in a laboratory manufactured by the Aldrich chemical company do not constitute a chemical kind. They might be a legitimate grouping if we wanted to determine how much money was owed to Aldrich; however, given that they were not individuated by similarities in structure or reactivity, they do not constitute a chemical kind.

When we apply the individuation criteria to water, it is clear that we ought to investigate all three structural levels as well as water’s reactivity in order to have a complete picture of how water should be individuated. In this paper, I will confine myself to discussing atomic level structure as well the related properties of reactivity. A full treat-

ment of what exactly water is, however, would require far more detail about the higher structural levels than I will give in this paper.³

3. Isotopic Isomers

Both hydrogen and oxygen are found in a variety of isotopes in nature, giving rise to the phenomenon of isotopic isomerism. After describing how this phenomenon applies to water, I will discuss the implications of isotopic isomerism for the coordination principle. Although the presentation of the scientific and philosophical issues here is my own, I am indebted to the insights found in Mellor (1974), Stroll (1998), and Needham's (2000) discussions of these issues.

Isotopes are sets of atoms with the same numbers of protons and electrons, but different numbers of neutrons. In most cases a hydrogen atom has one proton and one electron. Chemists generally just call this "hydrogen" and symbolize it as "H". When it is necessary to distinguish between isotopes chemists call it "hydrogen-1" or symbolize it as "¹H". A second isotope of hydrogen called "deuterium" was discovered by Harold Urey in 1931. Deuterium, which is symbolized as "D", has one neutron, one proton, and one electron. Subsequent research also discovered a third isotope of hydrogen called "tritium" (symbolized as "T") which has two neutrons, one proton and one electron. Naturally occurring samples of hydrogen contain a mixture of hydrogen-1 and deuterium. Tritium does not occur naturally but can be found in samples of hydrogen for many different reasons, such as being generated as decay products of other isotopes, by cosmic rays, or even by nuclear fallout. Oxygen also has three isotopes—¹⁶O, ¹⁷O, and ¹⁸O. All three of these stable isotopes have 8 protons and 8 electrons. They have 8, 9, and 10 neutrons respectively.

Since isotopes have very similar chemical and thermodynamic behavior, the naturally-occurring chemical reactions that produce molecules like water cannot, for the most part, distinguish between the isotopes.⁴

³ Many discussions of natural kinds in the philosophical literature treat the macroscopic as the domain of common sense and the microscopic as the domain of science. Mark Johnson (1997), for example, makes this claim in his distinction between chemical kinds and manifest kinds. Although I will not be saying much about chemical treatments of the macroscopic properties of water, these are very important. While there may be such a thing as a manifest kind, it is important to see that chemical kinds can also be individuated at the macroscopic level in virtue of the ensemble structures of substances.

⁴ A more formal way of making this point is to say that the chemical behavior of the two isotopic isomers is the same to a first approximation. Roughly speaking this is because the chemical behavior of the different isotopes is proportional to

Because of this fact and because all samples of hydrogen in nature contain a mixture of the isotopes, an elemental analysis of natural water would reveal a certain fraction of deuterium mixed with hydrogen-1. The ratio would most likely mirror the natural or “background” ratio of hydrogen-1 to deuterium, 99.985:0.015. Similarly, many samples of terrestrial water will contain trace amounts of tritium because of the trace amounts of tritium found on Earth. If we look at enough samples of enough water, we will find H₂¹⁷O, H₂¹⁸O, HD¹⁶O, D₂¹⁷O, T₂¹⁸O, etc., in addition to H₂¹⁶O. In fact, natural samples of water almost always contain a mixture of these other isomers. In figuring out how to individuate the kind water, then, we need to ask several questions: Is pure H₂¹⁶O a chemical kind? How about pure D₂¹⁶O? In normal, terrestrial samples that are mostly H₂¹⁶O, how much tolerance of isotopic variation is allowed? If the substances described in all these other questions are chemical kinds, how do we decide which one corresponds to the ordinary language kind water?

Pure H₂¹⁶O is a chemical kind because it can be individuated with respect to structure at both the molecular and the atomic levels. Similarly, pure H₂¹⁷O is a chemical kind and so is pure D₂¹⁶O. This is a problem because the coordination principle requires that chemistry generate a single kind that can be associated with the ordinary language kind. Although this looks like it might merely be a manifestation of the “qua problem,”⁵ I will argue that it is actually a symptom of a deeper problem. Before turning to this, let us consider what would happen if we just picked one of these kinds to coordinate with our ordinary language kind. One principled way to do this is to pick the major component of samples of naturally occurring water. Following this rule, we would pick the kind that consisted of all and only the molecules with molecular formula H₂¹⁶O.

This solution, however, is problematic because there are *always* isomers present in natural samples. One of these isomers (HD¹⁶O)

\sqrt{m} , where m is the reduced mass of the molecule. This is exemplified in molecular velocity, the vibrational frequencies of IR spectra, and other chemically important properties of molecules. Isotopic differences typically only change the reduced mass slightly. The different isotopes of hydrogen, however, are significantly different in mass, enough to give rise to significant chemical differences between isomers.

⁵ The “qua problem” has to do with the multiplicity of kinds associated with any particular object. Sterelny imagines that on a mission to Mars, he spots a catlike animal and calls it a “schmat.” He writes: “. . . the schmat will be a member of many kinds. A non-exhaustive list would include: physical object, animate object, animate object with certain structural properites, . . .” (Sterelny, 1983, 120) The problem is how to determine what kind was baptized as a schmat on Sterelny’s visit to Mars. Semantic externalists writing today are sensitive to this issue and take seriously the need to address this problem. See, for example, (Devitt & Sterelny, 1999, 90).

constitutes about 0.03% of Earth's natural water. This may seem insignificantly small, but it means that in one sip of water (about 18 mL) there are about 1.8×10^{22} molecules of HD^{16}O . That is ten million billion molecules of HD^{16}O per sip. For this reason, it seems wrong to ignore outright the contributions of other isotopes.

Perhaps one way to save the claim that water should be identified with all and only molecules with molecular formula H_2^{16}O is to insist that the other isomers are impurities. This suggestion seems initially plausible, for we have no trouble regarding sea water, dirty water, acid rain and the like as water, at least in the every day sense, although they are not homogenous at the molecular level.

Attractive as this possibility may seem, I believe that we cannot regard isomers as impurities. To regard some substance token as an impurity or containing impurities, we have to begin with a conception of a pure substance type. If isomers like D_2^{16}O are impurities, then this suggests that a sample completely made up of H_2^{16}O molecules is the pure substance. Are there good reasons to conclude this?

I believe that there are not. In fact, if purity means something like "without changes or additions," then there is a sense in which isotopically *homogenous* samples are impure. Standard isotopic ratios have been measured for all stable isotopes and built into the elemental masses reported on the periodic table. These values reflect the outcome of a set of geological, biological, chemical and nuclear fractionation processes that have taken place through the history of our planet. The reason these values allow us to make accurate calculations is because all the natural samples that we have measured have undergone the same fractionation processes throughout their histories. Deviations from this background distribution of abundances must be explained as the intervention of some *further* geological, biological, chemical, or nuclear fractionation process.

If the notion of a pure substance is to be useful, it cannot merely be a measure of homogeneity. Rather, our notion of a pure substance must take natural isotopic variation into account. This is important if we want to discover the extension of the ordinary language natural kind term "water." A homogeneous sample of H_2^{16}O molecules is a chemical kind, but when we are trying to find a chemical kind that is close to the kind recognized by ordinary speakers, there is no justification that I can see for simply ignoring the standard isotopic ratios.

It is clear that we cannot just ignore isomers in individuating chemical kinds. We also have learned that we cannot just claim that isomers are impurities. A more plausible possibility is to claim that " H_2O " is actually a higher-order term, a genus which includes as its constituent species all of the isomers of H_2O . We then could preserve the claim

that water is H₂O, but with a slightly different understanding of what “H₂O” means. Something seems right about this suggestion, for we are starting to see how our kind terms in ordinary language may not map neatly onto chemical kinds. The genus/species solution, however, will not work well in this case.

The main problem with the H₂O-as-genus solution is that it makes no mention of the relative abundances of the isomeric species and such differences can have large impacts on the properties of substances. If we treat “H₂O” as a genus term and preserve the claim that “water is H₂O,” then we have to conclude that a sample consisting solely of D₂¹⁶O is water. No doubt pure D₂¹⁶O is a chemical kind. In fact, it is usually called “heavy water” and is used in some nuclear reactors. Pure D₂¹⁶O, however, is saliently different from ordinary water. Although D₂¹⁶O can undergo similar reactions to H₂¹⁶O, the reaction rate is different enough to make ingestion of D₂¹⁶O lethal. The D from D₂¹⁶O exchanges with hydrogen-1 atoms in our body, disrupting critical metabolic processes. In addition, some of the molar structural properties, such as freezing point and viscosity, are quite different among samples with different mixtures of isotopic isomers. The freezing point of pure D₂¹⁶O, for example, is about 2 °C as opposed to 0 °C for a sample of ordinary terrestrial water. This is also a salient difference according to our individuation criteria. Our proposal to treat “H₂O” as a higher-order term, picking out all of its isomers, however, treats pure D₂¹⁶O and pure H₂¹⁶O as the same kind of thing. And while they are species of a common genus, they are clearly distinguished both in chemistry and in everyday contexts.

Neither treating isomers as impurities nor treating “H₂O” as a higher order term picking out all its isomers seems to be an acceptable way to find the single chemical kind demanded by the coordination principle. It is clear that the system of kinds recognized within chemistry is very complex and multi-faceted, which is at odds with the coordination principle’s demand for a single chemical kind to be associated with the ordinary language kind water. Perhaps a closer look at how chemists themselves deal with the complex system of kinds will help to resolve the tension.

Chemists deal with the multiplicity of chemical kinds in two different ways. Most often, they deal with it by using context-sensitive kind terms. These terms pick out different chemical kinds in different explanatory and conversational contexts. “Water,” as uttered by a chemist, will sometime refer to the isomers of H₂O in their natural abundances, sometimes to any isomer of H₂O, and sometimes, perhaps, to a homogenous sample of H₂¹⁶O depending on the circumstances of the utterance.

When forced to be explicit, chemists use a set of very specific kind terms corresponding to very specific chemical kinds. The results of chemists being forced to be explicit can be found in the extremely precise and often very complex nomenclature established by the International Union of Pure and Applied Chemistry. In this nomenclature, even the different phases of water, a concept which I haven't discussed, are given their own designations like water (I), water (VI), etc. The vast majority of chemists and the chemical literature, however, refers to substances in a more straightforward manner—using terms like “water,” or “ethanol,” or “tetrahydrofuran,” which are clear in context.

4. Revising the Coordination Principle

The discussion of isotopic isomerism is just one source of chemical complexity that poses problems for the coordination principle. Many other fascinating and complicating factors arise when we consider the macroscopic properties of water.⁶ These are especially important as chemists usually think of water as a macroscopic substance with macroscopic properties, not merely as a collection of water molecules. While it would be fascinating to explore these complexities further, I believe we already have enough information to reexamine the coordination principle.

Our very brief examination of the nature of water has revealed that there is no single kind for water that is useful in all chemical contexts. In particular, we have seen that the set of substances with molecular formula H_2O is often not a very useful chemical kind. It fails to make distinctions among substances that both chemists and ordinary language users would want to make. Even if the coordination principle is acceptable without revision, we should choose a kind with more carefully determined membership conditions. Perhaps we could choose a kind that takes into account standard isotopic distributions. I am skeptical that this will be an adequate solution, however, because the problems with the coordination principle run deeper than this solution addresses.

Two results of our investigation put pressure on the coordination principle in its current form. The first result is that chemistry cannot just hand us a single kind with which we can associate the ordinary language kind water, because in chemistry there is a more complex system of kinds. The second result is that chemists often deal with these issues by using kind terms in context sensitive ways. I believe that each of these holds a key to refining the coordination principle.

⁶ See (Needham, 2000) for a thorough discussion of these issues.

The first result suggests that the one-to-one match between kind terms in natural language and kind terms in the natural sciences required by the coordination principle may not be possible. Unlike some critics, I haven't been arguing that ordinary language and the natural sciences use terms with different extensions. An externalist can evade this kind of criticism by defending an attitude of deference to experts, ignoring our folk conception of the extensions of natural kind terms. My argument is that even if we defer to experts about cases like water, they cannot give us a *single* natural kind to associate with the kind used in everyday contexts by ordinary language users. The system of kinds recognized within chemistry is much more complex than the system of kinds recognized by users of natural language. There are many more types of kinds in chemistry, useful for different theoretical purposes.

The second result suggests a way that an externalist philosopher of language might refine the coordination principle to take into account the first result. Chemists' ordinary use of natural kind terms are highly context sensitive. When they need to be more precise so as to make fine distinctions between subtly different phenomena, they use a more robust set of kind terms corresponding more closely to the multiplicity of kinds recognized within chemistry. In many situations, however, context sensitive terms are sufficient. Say a chemist needs to use a warm water bath to keep a reaction at a particular temperature. Her request for more warm water from an associate will be taken to mean that she wants a substance that is composed primarily of H₂O molecules with an isotopic abundance somewhere in the normal background range. On the other hand, if she is doing a very isotopically sensitive kinetic study, her request for water would be interpreted in a different way, perhaps requiring additional distinctions.

These considerations suggest that the coordination principle should include a mechanism for picking out the right chemical kind to be coordinated with ordinary language kinds in different contexts. Like chemistry itself, and perhaps more so, ordinary language admits of a lot of tolerance for things like isotopic distributions in many contexts. Watering the lawn, filling a swimming pool, and even bathing don't put very strenuous requirements on such things as isotopic ratios. However in some cases, like when we want to prepare pharmaceuticals, protect an ecosystem, or even just have a drink, our tolerance for variation is limited. In contexts where extreme variation is acceptable, the coordination principle can be fairly relaxed, associating the kind term in an utterance with a set of chemical kinds or a higher level genus kind. In contexts where such variation is not acceptable, the coordination principle must have a mechanism for picking out the most appropriate chemical kind for that context.

While an externalist could simply pick some chemical kind to coordinate with the ordinary language kind in all contexts, ignoring the complexity of the system of chemical kinds, I believe that this strategy is short-sighted. Since the externalist strategy I have been discussing contains an attitude of deference to the natural sciences, I believe that our closer look at the types of kinds actually recognized in chemistry is relevant. The complexity of material substances demands that chemists, the people who interact with them at the greatest level of detail, use a multi-faceted and often context sensitive set of kind terms. We would do well to mirror this practice in our discussions of ordinary language.

5. Conclusions

In this essay I have discussed an assumption of semantic externalist theories which I called the coordination principle. This is the idea that natural language kinds and scientific kinds line up or can be mapped onto one another one-to-one. A closer look at water shows that there is not this type of simple one-to-one match between chemical and ordinary language kinds. In fact, the use of kind terms in chemistry is often context sensitive and in cases where chemists want to ensure no ambiguity, they use a very complex and nuanced set of kind terms, none of which could be reasonably associated with the ordinary language kind term “water” alone. Since we cannot just turn to chemistry to find a *single* chemical kind that can be used to determine the extension of “water,” there isn’t any strict sense in which water is H₂O, because exactly what water is depends on the context in which “water” is uttered.

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